Submission to the Independent Review of the Aquaculture Licencing Process and associated Legal Framework

February 2017

I wish to make the following submission to the Independent Review of the Aquaculture Licencing Process and associated Legal Framework. I would like to state from the outset that my position has been influenced by the travesty which is being inflicted on Linsfort Beach and Stragill Strand near Buncrana, Co Donegal due to a seriously flawed decision taken by the Minister for the Marine. The process for awarding a 10 year licence (ref T12/462) for an Oyster Farm covering 42 acres of unspoilt sandy beaches has completely disregarded the severe impact that such an enterprise will have on Lough Swilly, an area of outstanding natural beauty which rivals the best that this Country has to offer. The licences were granted without the knowledge of those most affected, both locally and in the wider community, who have been visiting and enjoying these beaches for years. The entire Licencing Process from application to award of the licence must be called into question in that it has lacked transparency and seems to have been conducted in such a manner as to deliberately avoid public scrutiny.

The Department of the Marine has confirmed that the licence application and screening process complied with regulations. It certainly can't be denied that a notice was published in a newspaper and that the notice did state the location and type of activity being applied for. However, the newspaper in which the notice was published sells approximately 100 copies in a huge peninsular area which has a population of almost 40,000 people according to the last census. That's hardly a public notice. In fact, the newspaper's circulation in the area is so small that Donegal County Council specifically excludes it from its list of approved publications for planning permission notices in Inishowen. Secondly, the notice stated that the location is an 'area of foreshore in Lough Swilly'. Considering the length of the shoreline on both sides of the Lough is over 80km long, that description is not exactly dropping a pin on a specific location for the purpose of encouraging public consultation. It's hardly surprising that no-one engaged with the process when it was published in such an evasive manner. I don't see why applications for Aquaculture and Foreshore Licences can't adhere to similar notice requirements for planning applications submitted to Local Authorities i.e. published notices in approved publications and notices placed at the site of the proposed licence.

Finally, the notice stated that it is for cultivation of oysters. What it failed to say was that the licence is for cultivation of a non-native species known as the Pacific Oyster which is extremely invasive and has the potential to wipe out the existing native wild oyster stock in the Lough. Studies carried out in Lough Swilly as recently as 2013 have reported declining stocks of the native wild oyster and emphasised the importance of managing the current stock by controlling the introduction of the Pacific Oyster. At least two of these reports were published by the Marine Institute, the same organisation which carried out a pre-screening assessment for the licence and came to the conclusion that an Environmental Impact Statement wasn't required. This allowed the Minister to waive the requirement for an EIS to be submitted with the application. It is important for the sake of accuracy to point out that the aforementioned studies were carried out within a designated Natura 2000 Special Area of Conservation and the licence granted for the oyster farm is for an area 1km to the north of the SAC. However, given that Lough Swilly is an estuary with substantial tidal movements and currents running at up to 6 knots, it is difficult to comprehend how the biodiversity of the SAC could not be directly impacted by the introduction of an invasive non-native species in such close proximity. Surely, the prudent advice would have been to thoroughly assess the risk through public and scientific consultation rather than dismiss it. Significantly, had an EIS been recommended, a public consultation process would have been legally required under EU regulations.

The State will get an annual fee of €63.49 in return for surrendering 42 acres of one of the most scenic areas in Ireland. That is the equivalent of 21 football pitches filled with rusting steel cages strewn across a valuable public amenity, turning it into a no-go area for locals and tourists. Does this justify destroying our coastline for the benefit of one business owner. The price that is being paid for a short term gain is simply too high. I would call into question whether this enterprise has created the number of full time jobs as was promised in the original application form and would request that this should be followed up on by the review committee.

If the above is the standard that has to be met to justify important Government decisions, then it is yet another indictment on a political and bureaucratic system that has been taking ordinary people for granted for far too long.

It is ironic that The Draft National Strategic Plan for Sustainable Aquaculture Development Plan endorses six high-level principles, promoted by the Department of the Marine and recommended by the Marine Institute, which "are intended to provide a broad direction to guide the ongoing development of sustainable aquaculture in Ireland and instil confidence in all stakeholders in the commitment to appropriate development of the industry." Based on the above and my research on other licence applications, I would seriously question whether these principles are being followed in the current licencing process

These Principles are as follows:

Principle 1 - Responsible Planning

"Responsible planning ensures that the overall development of aquaculture and the siting of individual farms are compatible with other uses and the responsible management of the marine environment. Such an approach, within a wider marine spatial planning framework, ensures a comprehensive consideration of constraints and synergies, and appropriate siting of fish farms, and reduces the uncertainty and administrative burden for developers."

Principle 2 - Ecosystem Protection

"Licensing and ongoing regulation of aquaculture operations ensures compatibility with the goal of maintaining healthy, productive and resilient marine ecosystems. This ensures that we maintain good water quality and healthy populations of wild species, prevent escapes and accidental discharges into the environment, and avoid harmful interactions with wild fish stocks, protected habitats and species."

Principle 3 - Science-based Approach

"Planning, licensing and regulation of the sector are founded on the best available, impartial and objective science, as delivered by the national and international science community. This provides the highest level of confidence in the decision-making process and allows for the adoption of a risk and evidence-based approach to determining monitoring requirements that are subject to continuous improvement."

Principle 4 - Compliance

"Planning, licensing and regulation of the sector ensures full compliance with relevant European and National legislation, including SEA and EIA legislation, nature conservation legislation (Birds and Habitats Directives), and legislation seeking to achieve and maintain good environmental status of coastal and marine waters (Water Framework Directive, Marine Strategy Framework Directive)."

Principle 5 - Openness, Transparency and Accountability

"Openness, transparency and accountability are core considerations in the licensing and regulatory framework for aquaculture. Seeking public and local knowledge inputs during the process increases confidence in the decision-making process. Likewise, accountability and openness on the part of the industry will help to educate stakeholders on the social and economic benefits of the industry and ensure an accurate understanding of its potential environmental interactions."

Principle 6 - Industry Best Practice

"Aquaculture operators should strive to adopt, maintain and improve best practice in all aspects of farm operations, including fish health and welfare, feed utilisation and sustainability, use of medication, abstraction of water, and cage design and maintenance. Additionally, industry should be supported / encouraged to implement Codes of Best Practice and independent certification schemes."

The objections to the Linsfort Beach licence described above and also set out below are testament to the perception that the above principles are merely aspirational and are not being followed by the Department or the Minister.

Breach in Foreshore Licensing regulations (1933)

Technically the Linsfort Beach licence has not fulfilled the licence criteria specifically sections 8.1, 9.1 and 19 of S.I. No. 236/1998 - Aquaculture (Licence Application) Regulations, 1998 and has also contravened the Aarhus Convention by denying:

- The right to participate in environmental decision-making. And the right to review procedures to challenge public decisions that have been made.
- The correct notification was not followed due to the use of an incorrect public outlet for public notification. The Thursday edition of Donegal Democrat, in which the notice appeared sells 80-100 copies in Inishowen. This compares to Derry Journal Friday edition's 2,500-3,000 and similar sales figures for both The Inish Times and The Inishowen Independent. The Thursday Donegal Democrat is only approved for planning notices for the DED of Manorcunningham in Inishowen. This Foreshore Licence area is not in the DED of Manorcunningham. By publishing the notice in a newspaper that has such a small circulation in the area the right of the general public to be involved was denied.
- It is not a legal requirement to erect site notices, so locals did not have the opportunity to learn about the proposed development in that way.

Donegal County Council have publicly stated that they were not consulted in relation to the oyster farm development at Linsfort Beach by the Licencee. A result they could not make a submission and were unaware of the planned development. It has since transpired under a Freedom of Information request for Linsfort Beach that the Department of the Marine forwarded an email calling for public body consultation to info@donegalcoco.ie rather than a named individual in the Council. No response is considered as an implied statement of approval by the Dept. This is NOT transparent consultation!

All of the above contravenes proper planning as currently carried out by Local Authorities and the Department of Housing, Planning, Community and Local Government in that it goes against the procedures that have to be followed for any structures or business activities that take place on the land. Why should the Department of the Marine be exempt from such procedures, particularly, given their aspirations on transparency and openness.

In the Linsfort Beach Licence application, there are also a number of anomalies to the Public Notice under the Second schedule of S.I. No. 236/1998 - Aquaculture (Licence Application) Regulations, 1998, as follows:

a. The address of the applicant was not published in the public notification.
b. The location of aquaculture site proposed was not published correctly. The notice read "an area of foreshore in Lough Swilly". Lough Swilly covers an area of 150km2, and is over 40km long and 8km wide. No one reading the notice would have any idea where the proposed development would be located.
c. The species for cultivation was not published. This is significant because the Pacific Oyster species being cultivated is highly invasive. (See Appendix II)
d. The wrong address for making submissions/observations was put on the notice, eg Dept. of the Marine and Natural Resources (Coastal Zone Administration Division), Leeson Lane, Dublin 2 instead of Foreshore Coordination Unit, Aquaculture and Foreshore Management Division, Dept. of Agriculture, Food and the Marine, National Seafood Centre, Clonakilty, Co. Cork. Therefore, if a member of the public did make a written submission, it would go to the wrong address. With only a short period left for observations, this correspondence may not reach the correct address on time.
e. Ref: Public Notice under the Fourth Schedule of S.I. No. 236/1998 – Aquaculture (Licence Application) Regulations, 1998. The location of proposed aquaculture was not published, only vague information, in contravention of point 4 of the second schedule. How could the public make an observation about such a large area without a specific location?
f. Under S.I. No. 236/1998 - Aquaculture (Licence Application) Regulations, 1998 4. (c) Developments on the foreshore require planning permission in addition to a Foreshore Lease/Licence/Permission. Donegal county Council have confirmed that no permission has been sought or granted for the material change of use from a private residence pedestrian access to a commercial access including use of fill to provide a roadway and destruction of existing sand dunes. And also no permission has been granted for use of the foreshore and beach as an egress route. Thus, the planning conditions as set out by Donegal County Council, the Department of the Environment and Local Government were not met and the granting of the application is thus deemed to be void and illegal under current legislation. A clear breach in planning law is evident.

Access and Planning

The access point to the site as outlined in Figure 2 of the licence is through the grounds of a private dwelling. Planning was not obtained for the creation of a roadway onto the foreshore and a change of use for the lands in question from dwelling to commercial access. According to the criteria for the granting of licences as stated by the Minister:

> "3.10. The Licensee shall ensure that tractors (or other vehicles) accessing and leaving the site adhere strictly to approved access and egress routes as specified in Schedule 1 attached."

In addition:

> "9.4. The Licensee shall at all times hold all necessary licences, consents, permissions, permits or authorisations associated with any activities of the Licensee in connection with the licensed area."

No Environmental Impact Study

Section 6 of the Fisheries (Amendment) Act, 1997- states that Aquaculture licence applications may be subject to environmental assessments under the Natural Habitats Regulations if located within or close to Natura 2000 conservation sites.

This site at Linsfort is within 500ft of the Natura 2000 area but the public notice just stated that only an EIA. Given the proximity of the Nature 2000 site, this application should have required a full EIS due to its likely significant effects directly and indirectly on the environment with impact on the following:

> (i) human beings;(ii) flora;(iii) fauna;(iv) soil;(v) water;(vii) air;(viii) climate;(ix) the landscape;(x) the interaction between the beings and things listed in subparagraphs (i) to (ix);(xi) material assets;(xii) the cultural heritage;

There are a multitude of implications on all of the above caused by this aquaculture licence and, under the Aarhus Convention, the general public and interested parties should have been notified if, as required, a complete EIS had been carried out.

The main issue with transparency is that Foreshore Act 1933 (2009 Amendment) specifically states that the Minister can only waive the requirement for an EIS in exceptional circumstances. However, my research into Aquaculture Licence applications for Shellfish in County Donegal over the past 4 years has discovered that over 44 licences have been granted by the Minister in Lough Swilly, Donegal Bay, Dungloe Bay, McSwynes Bay – Inver and Trawenagh Bay. In every instance, the Minister has waived the requirement for an Environmental Impact Statement under identical grounds. There has only been one Screening matrix done and that was for Lough Swilly. All of the remaining Ministerial Determinations were based on Appropriate Assessments done by the Marine Institute. The result of this is that for 100% of the licences granted, no public consultation process was required because the requirements of the Aarhus Convention weren't activated. This does not promote a perception of transparency and openness. It seems that secrecy is systematic in the Department and this is just based on my research for Donegal. What about the rest of the country?

Further to the above, I would like to make the following additional points based on criteria for granting of licences as stated by the Minister.

- **The limited magnitude and extent of the direct impacts arising from the proposed aquaculture activity**
    - What are the criteria and decision matrix which determines the magnitude and impact of licences?
      The level of public support for 'Save Linsfort Beach' would indicate that the magnitude and impact of that development is significant (over 2,500 people have signed a petition against this Licence). The scale of disruption is felt throughout the whole West Inishowen coast community and, also importantly, by the sizeable number of tourists who frequent the beach during summer months. With limited other amenities in the area beaches such as Linsfort Beach/Stragill Strand are key products in the regional tourism offering. This stretch of coast is also located along both the Wild Atlantic Way and the Inishowen 100 Tourism Routes which have experienced a significant increase in tourist numbers last year.

    - It is also of particular significance because the species being cultivated at Linsfort Beach is the Pacific Oyster which is known to be invasive and displaces the native Oyster. The native Oyster is already in decline in Lough Swilly and introducing more Pacific Oysters to the Lough will have a direct impact and accelerate the decline. The Marine Institute has published a research paper (Tully & Clarke, Irish Fisheries Investigations, No 24 2012) which, inter alia, states: "Management of threats to native oyster beds will also be important in optimising recovery potential. These include freshwater drainage which may increase freshwater volume flow through estuaries, urban development and associated changes in microbiological and viral status of water and introduction or management of non-native species, which pose a threat to oyster, such as the Slipper limpet (Crepidula fornicata) and Pacific oyster. Competition with introduced species, such as Pacific oyster, is a realised threat to the maintenance of native oyster beds as shown here in L. Swilly. The surveys showed that large areas of previous native oyster bed had high densities of Pacific oyster in some areas to the exclusion of native oyster. An intensive commercial fishery for Pacific oysters was sustained in 2010 and 2011 in areas of the Lough showing that, locally, biomass of this species was high. This is a recent development stimulated by higher market prices for Pacific oysters but also because high catches are possible. O'Sullivan (2001) did not report Pacific oysters in L. Swilly suggesting that Pacific oyster has, recently, expanded in the Lough. Successful control of that expansion will be important for the recovery and maintenance of native oyster."

The Department of Marine environmental screening document refers to the adjoining Natura 2000 site and makes reference to the invasive nature of the pacific oyster and recommends the use of sterile triploid oysters yet there is no stipulation anywhere that these must be grown to help protect the native oyster population.

It is worth noting that in all of the 44 Licences granted in Donegal over the past 4 years, I haven't been able to find any recommendations for Triploid Oysters I n any licences with the exception of Lough Swilly. Does that mean that the State has no enforcement powers and the Licensee can't be prosecuted if the invasive Diploid Oyster Species is introduced?

There are several reports on the results of introducing the invasive Pacific Oyster in Strangford Lough and Holland which have shown that there has been a detrimental effect on the native since their introduction. Are these reports taken into consideration when recommendations are being made by the Marine Institute? If so, it is amazing that in no recent application has an EIS been requested.

- **The low population density of the surrounding area.**
  - The Linsfort Beach site is one of five beaches/public bathing areas used by the residents of Buncrana and west Inishowen (pop. Approx.. 10000) and visitors from Derry (pop. 250,000) and tourists from around the world.
    The Licence has resulted in an immediate negative impact on the marine/coastal tourism offering of the Buncrana and West Inishowen area by restricting and monopolising the use of one the key and most valuable natural resources of the area, to a single private individual.

- **The low visual impact of the proposed aquaculture activity**
    - 42 acres of metal cages is a huge visual impact on a beautiful unspoilt beach. The negative industrial appearance and disruptive visual impact of the site during periods of low tide is difficult to reconcile with the above statement. Introducing dangerous industrial structures into a pristine natural vista immediately reduces the value and role of vistas in the area for use as a resource for tourism and, in particular, the 'Wild Atlantic Way' product.

- **The minimal impact on recreational use of the adjoining foreshore**
    - The Linsfort Beach site encompasses five beaches/bathing areas used by the residents of Buncrana and West Inishowen (pop. circa 10,000) and Co. Derry. In this area of Inishowen the only amenities families and the general public can use are local beaches, generations of families have been using this beach. "Bathing Waters are an important amenity, valuable for both their tourism and recreational potential. It is important that they are afforded the appropriate protections in accordance with legislation, including the European Union's Bathing Waters Directive (2006/7/EC)"
      The Licence has resulted in an immediate restriction for coastal recreation and, in effect, monopolises the use of one of the key, and most valuable natural resources of the area, to a single private individual. The beach is part of a coastal walkway from Buncrana and is featured in books and TV productions that have focused on the value of the sites' natural beauty, aesthetic qualities and history including Mount Peter the ancient site of a promontory fort. Kayakers and swimmers based at Ned's Point also frequent the entire area up as far as Curragh Hole. (See Appendix IV)

- **Consultation with Public Bodies and External Stakeholders**
    - How are Local Authorities, Fáilte Ireland, An Taisce and other agencies informed of Licance applications and do they make submissions to the Department of the Marine before Licences are granted.

Implementation of Licence Conditions
For all Aquaculture Licences, there is an accompanying Foreshore Licence. The standard wording of the Insurance Condition in all Foreshore Licences is as follows:

> ***Infrastructure and Site Management***
> *Indemnity*
> *3.1. The Licensee shall indemnify and keep indemnified the State, the Minister, his officers, servants or agents against all actions, loss, damage, costs, expenses and any demands or claims howsoever arising in connection with the construction, maintenance or use of any structures, apparatus, equipment or any other thing used in connection with the licensed operation in the licensed area or in the exercise of the rights granted under the licence and the Licensee shall take such steps as the Minister may specify in order to ensure compliance with this condition.*

The Insurance Condition is therefore a condition of a legally binding Contract between the State and the Licensee. Furthermore, the wording of this Condition is explicit in its requirement for the Licensee to indemnify the State, the Minister etc. This is a condition precedent for the licence to be lawful. If an indemnity isn't in place, the Licensee is technically in breach of the conditions of the licence. This should have been requested before the Licensee was allowed to commence any works, as is the norm under public works contracts. More importantly, it would appear that, by not demanding the relevant indemnity insurance documentation, the State may not been fully protected from potential 3rd party claims arising from the Licensee's activities. If the Licensee hasn't got sufficient cover in place, the state could be held liable for any shortfall on a potential claim. It would be remiss of the Department not to demand proof that the relevant documentation and level of cover (normally €13m) is in place. Failure to provide such proof would be grounds to revoke the licence under Condition 9 of the Foreshore Licence.

It is standard procedure for a Local Authority and the Office of Public Works, amongst others, to seek an indemnity from Contractors carrying out Works on Public Lands. The Foreshore is Public Lands also so it stands to reason that the Department of the Marine would also ensure that an indemnity is in place before any works commence under an Aquaculture Licence.

I have raised this issue with the Department of the Marine on a number of occasions and sought a copy of the indemnity provided to the Department by the Licensee on the Linsfort Beach Site but have received the same response as follows:

> *"It should be noted that condition 4 is a general condition included in all Foreshore Licences. The documents associated with this condition, namely the Licensee's relevant indemnity insurance documentation and tax clearance certificate, is only*

required to be submitted to the Department on demand of same. As this has not been requested, the Department is not in a position to confirm the level of indemnity cover provided."

It therefore needs to be clarified from a Legal perspective if the State has any potential liability by a failure to

a) Specify the level of indemnity required in the wording of the licence condition and
b) Obtain proof of Insurance cover and renewal on an annual basis.

In addition to the Insurance Condition, there is a condition relating to maintenance and responsibility for the upkeep of the site which is not being adequately enforced by the Department: The condition is as follows:

3.2. The duty of maintenance and responsibility for the upkeep and safety of the site rests with the Licensee.

There is significant photographic evidence that the operator at Linsfort Beach is not adequately maintaining the site and this was raised by local residents with the Department of the Marine on several occasions with no satisfactory response or improvement.

The debris that is constantly strewn across the foreshore contradicts the responsibility of the Licensee under the above condition and is testament to the lack of adequate management of the site by the Operator and the Department (the Licencing Authority), both of whom have a duty of care to the Public who continue to use the beach and adjacent beaches. Whilst it is unfortunate that the Operator has suffered damage to his operation as a result of storms and weather events, it calls into question the suitability of such an exposed site for this type of aquaculture and the long term sustainability of such a venture. It also calls into question the level of expertise within by the Screening Group and the extent of due diligence carried out in making the recommendations referred to in the Minister's Determination in relation to EIS requirements, in particular under the following headings cited in the Determination:

b) the limited magnitude and extent of the direct impacts arising from the proposed aquaculture activity

e) the low visual impact of the proposed aquaculture activity

g) the minor risk of accidents occurring as result of the proposed aquaculture activity

h) the low risk of impacts on navigational safety

i) the minimal impact on recreational use of the adjoining foreshore

j) Screening matrix for T12/462 Oyster Culture in Lough Swilly.

'Boom and Bust' Planning

During the 'boom', Ireland used light touch regulation in the building sector to pursue development goals to the detriment of strategic long term planning.

In the case of the Linsfort Beach Licence, it is in an inappropriate site. It is not a question of jobs or aquaculture but a question of siting the development in an appropriate place. Lessons should be learnt from past mistakes in other developing industries and, although it is acknowledged that national aquaculture targets must be met, it is important that they be met in an appropriate manner, ie a manner which does not negatively affect a community's ability to develop and sustain sustainable jobs through tourism. Meeting short term goals in aquaculture because of short term issues in the French market, and national job creation targets, does not enable a community to provide its citizens with a viable and/or sustainable future.

Conclusion

A report titled "The Dynamics of Environmental Sustainability and Local Development: Aquaculture" was carried out for the National Social and Economic Counsel by Dr Patrick Bresnihan and published in April 2016. It refers in Chapter 4 to the issues for all parties affected by the decision making process and gives good examples of the outcome of decisions that lack transparency.

The people of Donegal are entitled to be involved in decisions that have a direct impact on their local amenities. It's time to stop talking about transparency and openness and replace the talk with action and evidence that these principles are being fully implemented.

Noel McGann

[redacted]

Dublin 15

[redacted]

Refer also to appendices attached.

Appendix 1

<u>Notice from Donegal Democrat for Linsfort Bay Licence</u>

APPLICATION FOR AQUACULTURE LICENCES UNDER THE FISHERIES (AMENDMENT) ACT, 1997 (NO. 23)

APPLICATION FOR FORESHORE LICENCES UNDER THE FORESHORE ACT, 1933 (NO.12)

<u>NOTICE IS HEREBY GIVEN</u> that the Derek Diver has applied to the Minister for Agriculture, Food and the Marine for Aquaculture Licences to cultivate oysters using bag and trestles on an area of Foreshore in Lough Swilly, Co. Donegal.

<u>NOTICE IS ALSO GIVEN</u> that the applicants have applied to the Minister for Foreshore Licences for an area of foreshore to be used for these aquaculture activites.

Any person may, during the period of 4 weeks from the date of publication of this notice, make written submissions or observations to the Minister for Agriculture, Food and the Marine, (quoting the appropriate Reference: T12/462A in relation to a) the Aquaculture Licence applications and b) the foreshore Licence applications. Any such submissions or observations should be furnished to the Department of Agriculture, Food and the Marine (Aquaculture and Foreshore Management Division), National Seafood Centre, Clonakility, Co. Cork, within the period.

All submissions or observations received on foot of public notice procedures may be made available to the applicant for comment.

Details of the Aquaculture and Foreshore Licence applications, which include a site plan of the area, drawings of the proposed works and structures, AA pre-screening matrix and EIA pre-screening assessment maybe inspected at Buncrana Garda Station and Letterkenny Garda Station (open 24 Hours).

Date of Publication
12th of June 2014

Appendix 2

List of Aquaculture Licences awarded in County Donegal

Donegal Bay

- AQ806 T12-92A - Seabreeze Ltd - Pacific Oysters - 2.1 Hectares - 2015.03.31
- AQ807 T12-92B - Seabreeze Ltd - Pacific Oysters - 1.3 Hectares - 2015.03.31
- AQ808 T12-92C - Seabreeze Ltd - Pacific Oysters - 0.2 Hectares - 2015.03.31
- AQ809 T12-374 - Seabreeze Ltd - Pacific Oysters - 1.4 Hectares - 2015.03.31
- AQ810 T12-401A - Eugene & Conor & Greg - Pacific Oysters - 2.4 Hectares - 2015.03.31
- AQ811 T12-401B - Eugene & Conor & Greg - Pacific Oysters - 5.4 Hectares - 2015.03.31
- AQ812 T12-401C - Eugene & Conor & Greg - Pacific Oysters - 2.0 Hectares - 2015.03.31
- AQ813 T12-402B - Seabreeze Ltd - Pacific Oysters - 2.8 Hectares - 2015.03.31
- AQ814 T12-402C - Seabreeze Ltd - Pacific Oysters - 0.6 Hectares - 2015.03.31
- AQ815 T12-402D - Seabreeze Ltd - Pacific Oysters - 0.3 Hectares - 2015.03.31
- AQ816 T12-443 - Rory McHugh - Pacific Oysters - 5.2 Hectares - 2015.03.31
- AQ817 T12-463A - Paul McHugh - Pacific Oysters - 0.2 Hectares - 2015.03.31
- AQ818 T12-463B - Paul McHugh - Pacific Oysters - 0.4 Hectares - 2015.03.31
- AQ819 T12-465 - Paul McHugh - Pacific Oysters - 0.3 Hectares - 2015.03.31
- AQ820 T12-467A - Seabreeze Ltd - Pacific Oysters - 4.3 Hectares - 2015.03.31
- AQ821 T12-467B - Seabreeze Ltd - Pacific Oysters - 1.8 Hectares - 2015.03.31
- AQ822 T12-467C - Seabreeze Ltd - Pacific Oysters - 1.5 Hectares - 2015.03.31
- AQ823 T12-467D - Seabreeze Ltd - Pacific Oysters - 0.9 Hectares - 2015.03.31
- Donegal Bay - Article 6 Assessment - Annex 1 - May 2014
- Donegal Bay - Article 6 Assessment - Annex 2 - July 2013
- Donegal Bay - Article 6 Assessment - May 2014
- Donegal Bay AA Conclusion Statement 190215
- EIS Determinations - Donegal Bay

Lough Swilly

- AAScreeningMatrixT12462060614
- AQ799 T12-462 - Derek Diver - Pacific Oysters - 16.1 Hectares - 2014.10.16
- MinisterialDeterminationEISShellfishAquacultureLoughSwilly050614

Dungloe Bay

- AQ581 T12-287 - James Gallagher - Pacific Oysters - 2 Hectares - 2012.06.06
- AQ582 T12-287A - James Gallagher - Pacific Oysters - 2.5 Hectares - 2012.06.06
- AQ583 T12-302A - SeamusHunter - Pacific Oysters - 2 Hectares - 2012.06.06
- AQ584 T12-302B - SeamusHunter - Pacific Oysters - 2 Hectares - 2012.06.06
- AQ585 T12-303A - Conal Hunter - Pacific Oysters - 2012.06.06
- AQ586 T12-304A - Charlie Doherty - Pacific Oysters - 2.3 Hectares - 2012.06.06
- AQ587 T12-399A - Charlie Hunter - Pacific Oysters - 2 Hectares - 2012.06.06
- AQ588 T12-399B - Charlie Hunter - Pacific Oysters - 6 Hectares - 2012.06.06
- AQ700 T12-422A - Ostrean Ltd - Gigas Oysters - 1.4 Hectares - 2013.09.16
- AQ701 T12-423A - Ostrean Ltd - Pacific Oysters - 0.6 Hectares - 2013.09.16
- AQ702 T12-424A - Ostrean Ltd - Pacific Oysters - 20.8 Hectares - 2013.09.16
- EIS Determination - Dungloe Bay

McSwynes Bay

- AQ762 T12-64- Gerard McMenamin - Pacific Oysters & Mussels - 3 Hectares - 2015.02.05
- AQ796 T12-62 - Ballyloughan Shellfish Ltd - Pacific Oysters - 3.5 Hectares - 2015.07.16
- AQ804 T12-425A - Natura Mussels Ltd - Pacific Oysters & Mussels - 6.1 Hectares - 2015.01.16
- AQ805 T12-425B - Natura Mussels Ltd - Pacific Oysters & Mussels - 2.5 Hectares - 2015.01.16
- AQ824 T12-456 Ballyloughan Shellfish Ltd - Pacific Oysters - 15.8 Hectares - 2015.05.15
- EIS Determination - McSwynes & Trawenagh Bays
- EIS Determination - McSwynes Bay - Ballyloughan Shellfish Ref 456
- EIS Determination - McSwynes Bay

Trawenagh Bay

- AQ580 T12-299 - Charlie ODonnell - Pacific Oysters - 2.7 Hectares - 2012.06.06
- AQ754 T12-448A - Sliogeisc Na Rossan - Pacific Oysters - 5.7 Hectares - 2014.02.05
- AQ755 T12-449A - Sliogeisc Na Rossan - Pacific Oysters - 6.4 Hectares - 2014.02.05
- AQ758 T12-128 - Sliogeisc Na Rossan Teoranta - Pacific Oysters - 2.3 Hectares - 2014.02.05
- AQ759 T12-128C - Sliogeisc Na Rossan Teoranta - Pacific Oysters - 1.3 Hectares - 2014.02.05
- AQ760 T12-128D - Sliogeisc Na Rossan Teoranta - Pacific Oysters - 4.1 Hectares - 2014.02.05
- AQ761 T12-128E - Sliogeisc Na Rossan Teoranta - Pacific Oysters - 0.5 Hectares - 2014.02.05
- AQ787 T12-389A - David Gallagher - Pacific Oysters - 2 Hectares - 2014.03.26
- AQ788 T12-389B - David Gallagher - Pacific Oysters - 0.6 Hectares - 2014.03.26
- EIS Determination - McSwynes & Trawenagh Bays
- EIS Determination - Trawenagh Bay - Martin Brennan
- EIS Determination - Trawenagh Bay - Sliogeisc Ne Rossan Teo
- EIS Determination - Trawenagh Bay - TRABAY Ltd

Appendix 3

List of Ministerial Determinations for Aquaculture Licences in County Donegal

1) Dungloe Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of each of 3 individual aquaculture licence applications in Dungloe Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for Shellfish Aquaculture Licensing in Dungloe Bay

2) McSwynes Bay and Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of each of 3 individual aquaculture licence applications in McSwynesBay and Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for Shellfish Aquaculture Licensing in McSwynes Bay and Trawenagh Bay

3) Trawenagh Bay, Co Donegal
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of each of 3 individual aquaculture licence applications in Trawenagh Bay, Co Donegal. Ministerial Determination in relation to EIS requirements for Shellfish Aquaculture Licensing in Trawenagh Bay, Co Donegal

4) Trawenagh Bay, Co. Donegal
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for Shellfish Aquaculture Licensing in Trawenagh Bay, Co. Donegal

5) Mc Swynes Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of each of 2 individual aquaculture licence applications in McSwynes Bay Co. Donegal. Ministerial Determination in relation to EIA requirements for Shellfish Aquaculture Licensing in McSwynes Bay

6) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for Shellfish Aquaculture Licensing in Lough Swilly, Co. Donegal

7) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of 12 individual aquaculture licence applications in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIA requirements for Shellfish Aquaculture Licensing in Donegal Bay, Co. Donegal

8) Mc Swynes Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in McSwynes Bay Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Ballyloughan Shellfish Ltd.(T12/456) in McSwynes Bay, Co Donegal

9) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Martin Brennan (T12/380) in Trawenagh Bay, Co Donegal

10) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Sliogeisc BáTraigheanna Teoranta (T12/412) in Trawenagh Bay, Co. Donegal

11) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Sliogeisc Na Rossan Teoranta (T12/477) in Trawenagh Bay, Co. Donegal

12) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Jago Moulton (T12/479) in Trawenagh Bay, Co. Donegal

13) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Lee Hunter (T12/480) in Trawenagh Bay, Co. Donegal

14) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Lough Swilly Shellfish Growers CoOperative Society Ltd (T12/37) in Lough Swilly, Co. Donegal

15) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Ronan O'Doherty and Andrew Ward (T12/293/1) in Lough Swilly, Co. Donegal

16) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Patrick Shovelin (T12/297) in Lough Swilly, Co. Donegal

17) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Hannigan Fish Trading Ltd (T12/311) in Lough Swilly, Co. Donegal

18) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Steven Brown (T12/328) in Lough Swilly, Co. Donegal

19) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Fresco Seafoods Ltd. (T12/330) in Lough Swilly, Co. Donegal

20) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Alan O¿Sullivan (T12/343) in Lough Swilly, Co. Donegal

21) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Iasc Sliogach Uisce Leathan Teoranta (T12/340) in Lough Swilly, Co Donegal

22) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Lough Swilly Wild Oysters Society Ltd (T12/339) in Lough Swilly, Co Donegal

23) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Iasc Sliogach Uisce Leathan Teoranta (T12/284) in Lough Swilly, Co Donegal

24) Lough Swilly
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Lough Swilly, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Conor Blake (T12/251/1) in Lough Swilly, Co. Donegal

25) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Donegal Oceandeep Oysters Ltd (T12/145) in Donegal Bay, Co. Donegal

26) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Donegal Oysters Ltd (T12/243) in Donegal Bay, Co. Donegal

27) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Donegal Oysters Ltd (T12/346) in Donegal Bay, Co. Donegal

28) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Racoo Shellfish Ltd and Bells Isle Seafoods Ltd (T12/347) in Donegal Bay, Co. Donegal

29) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Donegal Oceandeep Oysters Ltd (T12/349) in Donegal Bay, Co. Donegal

30) Donegal Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Donegal Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Paul Mc Hugh and George Mc Hugh (T12/350) in Donegal Bay, Co. Donegal.

31) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by Oisiri Min An Chairn Teoranta (T12/489) in Trawenagh Bay, Co. Donegal.

32) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by by Oisiri Min An Chairn Teoranta (T12/490) in Trawenagh Bay, Co. Donegal.

33) Trawenagh Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Trawenagh Bay, Co. Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of Shellfish by by Oisiri Min An Chairn Teoranta (T12/491) in Trawenagh Bay, Co. Donegal.

34) Gweedore Bay (Bunbeg area)
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Gweedore Bay (Bunbeg area), Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence application for the cultivation of shellfish by Seamus Corbett & Eamonn Sweeney (T12/193) in Gweedore Bay (Bunbeg area), Co.Donegal

35) Gweedore Bay (Carrickfin area)
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Gweedore Bay (Carrickfin area).Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by James Bonner (T12/305) in Gweedore Bay (Carrickfin area), Co.Donegal

36) Gweedore Bay (Carrickfin area)
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Gweedore Bay (Carrickfin area), Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by John Boyle (T12/326) in Gweedore Bay (Carrickfin area), Co.Donegal

37) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by John Boyle (T12/364) in Braade Strand, Gweedore Bay, Co.Donegal

38) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Celtic Kerber Ltd. (T12/365) in Braade Strand, Gweedore Bay, Co.Donegal

39) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Thierry Gillardeau & Desmond Moore (T12/410) in Braade Strand, Gweedore Bay, Co.Donegal

40) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal.Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Celtic Kerber Ltd. (T12/419) in Braade Strand, Gweedore Bay, Co.Donegal

41) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by John Boyle (T12/430) in Braade Strand, Gweedore Bay, Co.Donegal

42) Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Gary Boyle (T12/438) in Gweedore Bay, Co.Donegal

43) Braade Strand, Gweedore Bay
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Braade Strand Gweedore Bay,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Brendan Boyle (T12/461) in Braade Strand, Gweedore Bay, Co.Donegal

44) Kincasslagh Bay, Gweedore
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Kincasslagh Bay, Gweedore,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Paul McHugh & John Paul Baska(T12/432) in Kincasslagh Bay, Gweedore, Co.Donegal

45) Cruit Strand, Kincasslagh Bay, Gweedore
The Minister has considered and determined that an Environmental Impact Statement is not required in respect of an individual aquaculture licence application in Cruit Strand, Kincasslagh Bay, Gweedore,Co.Donegal. Ministerial Determination in relation to EIS requirements for an Aquaculture Licence for the cultivation of shellfish by Benedetta Cazzamali (T12/458) in Cruit Strand, Kincasslagh Bay, Gweedore, Co.Donegal

Appendix 4

Submissions to National Strategic Plan for Sustainable Aquaculture Development on behalf of Save Linsfort Beach and Save the Swilly

<u>Save Linsfort Beach</u>

NATIONAL STRATEGIC PLAN FOR SUSTAINABLE AQUACULTURE DEVELOPMENT

Draft for Public Consultation, June 2015

We wish to make the following submission as part of the consultation process for the National Strategic Plan for Sustainable Aquaculture Development to avoid a repeat of the travesty which is being inflicted on Linsfort Beach and Stragill Strand near Buncrana, Co Donegal due to a seriously flawed decision taken by the Minister for the Marine. The process for awarding 10 year licences (ref T12/462) for an Oyster Farm covering 42 acres of unspoilt sandy beaches has completely disregarded the severe impact that such an enterprise will have on Lough Swilly, an area of outstanding natural beauty which rivals the best that this Country has to offer. The licences were granted without the knowledge of those most affected, both locally and in the wider community, who have been visiting and enjoying these beaches for years.

The Department of the Marine has confirmed that the licence application and screening process complied with regulations. It certainly can't be denied that a notice was published in a newspaper and that the notice did state the location and type of activity being applied for. However, the newspaper in which the notice was published sells approximately 100 copies in a huge peninsular area which has a population of almost 40,000 people according to the last census. That's hardly a public notice. In fact, the newspaper's circulation in the area is so small that Donegal County Council specifically excludes it from its list of approved publications for planning permission notices in Inishowen. Secondly, the notice stated that the location is an 'area of foreshore in Lough Swilly'. Considering the length of the shoreline on both sides of the Lough is over 80km long, that description is not exactly dropping a pin on a specific location for the purpose of encouraging public consultation. It's hardly surprising that no-one engaged with the process when it was published in such an evasive manner. We recommend that applications for Aquaculture and Foreshore Licences should strictly adhere to the requirements of the Local Authority for both published notices in approved publications and notices to be placed at the site of the proposed licence.

Finally, the notice stated that it is for cultivation of oysters. What it failed to say was that the licence is for cultivation of a non-native species known as the Pacific Oyster which is extremely invasive and has the potential to wipe out the existing native wild oyster stock in the Lough. Studies carried out in Lough Swilly as recently as 2013 have reported declining stocks of the native wild oyster and emphasised the importance of managing the current stock by controlling the introduction of the Pacific Oyster. At least two of these reports were published by the Marine Institute, the same organisation which carried out a pre-screening assessment for the licence and came to the conclusion that an Environmental Impact Statement wasn't required. This allowed the Minister to waive the requirement for an EIS to be submitted with the application. It is important for the sake of accuracy to point out that the aforementioned studies were carried out within a designated Natura 2000 Special Area of Conservation and the licence granted for the oyster farm is for an area 1km to the north of the SAC. However, given that Lough Swilly is an estuary with substantial tidal movements and currents running at up to 6 knots, it is difficult to comprehend how the biodiversity of the SAC could not be directly impacted by the introduction of an invasive non-native species in such close proximity. Surely, the prudent advice would have been to thoroughly assess the risk through public and scientific consultation rather than dismiss it. Significantly, had an EIS been recommended, a public consultation process would have been legally required under EU regulations.

The State will get an annual fee of €63.49 in return for surrendering 42 acres of one of the most scenic areas in Ireland. That is the equivalent of 21 football pitches filled with rusting steel cages strewn across a valuable public amenity, turning it into a no-go area for locals and tourists. At best, this enterprise will create 2 or 3 jobs, but does this justify destroying our coastline for the benefit of one business owner. The price that is being paid for a short term gain is simply too high.

If this is the standard that has to be met to justify important Government decisions, then it is yet another indictment on a political and bureaucratic system that has been taking ordinary people for granted for far too long. What's to stop this from happening somewhere else? Where is the transparency? We believe that it is unacceptable and ask the Minister to reconsider his decision and either revoke the foreshore licence with immediate effect as allowed under condition 6 of the licence or, suspend both licences to allow a proper public consultation process to take place.

It is ironic that the Minister is currently promoting public consultation by inviting submissions as part of the National Strategic Plan for Sustainable Aquaculture Development. The Plan endorses six high-level principles, recommended by the Marine Institute, which “are intended to provide a broad direction to guide the ongoing development of sustainable aquaculture in Ireland and instil confidence in all stakeholders in the commitment to appropriate development of the industry.”

Two of these principles are as follows:

> Principle 1 – “Responsible planning ensures that the overall development of aquaculture and the siting of individual farms are compatible with other uses and the responsible management of the marine environment.”
>
> Principle 5 – “Openness, transparency and accountability are core considerations in the licensing and regulatory framework for aquaculture. Seeking public and local knowledge inputs during the process increases confidence in the decision-making process.”

Do the people of Inishowen not deserve the same courtesy?

Save the Swilly

21 July 2015

NATIONAL STRATEGIC PLAN FOR SUSTAINABLE AQUACULTURE DEVELOPMENT
Draft for Public Consultation, June 2015

SUBMISSIONS and COMMENTS – SAVE THE SWILLY

This document is one in a series of attempts over many years to substitute aquaculture in Ireland's marine strategy for traditional pursuits. Those who have observed Ireland's aquaculture sector over the decades have noted the policy shift among Ireland's primary state agencies engaged in the marine sector to favour aquaculture at the expense of fishing, tourism, and generally, any competing interests. It is our contention that the apparent conclusion among European and Irish marine policymakers and State agencies that aquaculture is the only, or the major, mitigating solution to the world's diminishing natural protein sources is both dangerous and self-serving.

The decline in pelagic and demersal fishing in recent decades is partly a function of over-fishing, climate change and global population growth. However, there are also more micro and regional factors, not least the treatment of Ireland in the European Common Fisheries Policy, the failure to regulate the fishing sector adequately, and to implement regulations effectively. The notion that the same process and the same marine governance structure which presided over the loss of sovereignty over Irish fishing rights will protect all stakeholders in the proposed official endeavour to more than double aquaculture output in less than a decade requires, at the very least, independent scrutiny.

Save The Swilly is not simply criticising any and all forms of aquaculture, and our starting point is to respect the good faith of the Irish government in embarking on this consultation process. Our concern is that aquaculture sites are appropriately sized and located, their cumulative environmental effects taken into honest consideration, and that verifiable attention to, and equitable sharing with, other legitimate stakeholders are taking place.

The concerns we have are the historic conduct of marine policy in Ireland, where State agencies have by their actions demonstrated compliance with a central theme that aquaculture is the future, and that any contradiction of this core principle should be swept away or silenced. Along with the aims of "openness, transparency and accountability" (page 75), the NSPSAD also says it endorses Vision for 2020's policy of "equitable" (NSPSAD, page 84). Some might question this latest inclusion.

There has been denial or obfuscation of research into the impacts of aquaculture over the years. The impact of invasive species such as Pacific oysters (*crassostrea gigas)* on native species; the impact of salmon farming and associated proliferation of sea-lice on both wild salmon (*salmo salar*) and sea trout (*salmo trutta*) populations throughout Ireland; the decline in migrating wild salmon – all of these have attracted credible domestic and international research at various times, which in turn has been deliberately undermined by State agencies and/or suppressed.

While the breadth and depth of the NSPSAD document is welcomed, Save The Swilly believes a preliminary stage is required – restructuring the administration of Ireland's marine sector to remove the conflicts of interest where the same Minister and the same chain of command is responsible for promotion, licensing, regulation and compliance within the industry. There is little evidence of "Chinese walls" between the State agency responsible for promotion and development, Bord Iaschaigh Mhara (BIM), the research agency the Marine Institute, and the Department of the Marine's Coastal Administration and Seafood Divisions.

For one department to be responsible for promoting aquaculture (and presumably incentivised for growing the output) while also responsible for regulating it (presumably by ensuring compliance with regulations) is self-evidently unsustainable, and requires reorganisation to separate these conflicting objectives.

REALISTIC PROJECTIONS?

We are very concerned about the apparently linear extrapolation of production targets, arriving at a figure of 81,700 tonnes by 2023, or 122.6% higher than the baseline output in 2012, of 36,700 tonnes. We believe the level of governance and compliance over the Irish aquaculture sector already leaves much to be desired, and projections to double output without reference to the upscaling of administration and effective management processes is a serious concern. The scale and pace of expansion is unrealistic and likely to produce negative consequences through rapid licensing and inadequate regulation/governance.

Increasing production by 45,000 tonnes (more than double current output) in eight years, and the suggested scenario "where all [licensees] achieve production levels at or near previous historic maxima simultaneously" (page 52) is excessive and not grounded in a balanced approach between the ambitions of the industry, regulators and promoters *vis a vis* the impact on the environment and other stakeholders. Such an increase in production will also increase any existing impacts from aquaculture, such as pesticides, feed ratio, escapees, eutrophication.

This seems to be a quantitative and linear projection of production possible based on the assumed "capacity", without acknowledging that the "capacity" is Ireland's own marine area, owned by its people, and not by Europe or by the multinational companies which dominate Ireland's finfish and shellfish aquaculture industries.

On the finfish segment, the pressure on wild fish resources to support the aquaculture sector is already an issue. We refer to the document Future Brief: Sustainable Aquaculture, issue 11, published by European Commission Science for Environment Policy, June 2015 [http://ec.europa.eu/science-environment-policy], wherein various sources are cited:

- "...with the expected expansion of aquaculture, there is an urgent need to further reduce the percentage of wild fish in feed and, most importantly, the total amount of wild fish consumed (should demand for feed rise significantly under aquaculture expansion)." (Welch, et al. (2012). They estimate that the amount of fish used in feed to produce one unit of output would have to be reduced by at least 50% from current levels for aquaculture to be sustainable in 2050.

- Tacon, Hasan & Metian (2011) write that the global supply of nutrients and feed will have to grow at a rate of around 8–10% per year to 2025, to match the aquaculture sector's growth rate. "Increased aquaculture production could help to contribute to increased food security and local production as a means of securing future supply in a way which is carbon efficient and fits local economies. "

While the NSPSAD argues in favour of aquaculture meeting the protein needs of the population, it is important to note that the vast majority of Ireland's aquaculture output, by volume and value, is exported, so the argument supporting rapid expansion is an economic one. It is not based on Ireland's own food security requirements. We believe it is disingenuous to argue that the desired expansion of Ireland's aquaculture industry is based on altruistic motives.

With regards to employment, the dismissal of tourism in favour of sweeping expanses of aquaculture in remote coastal areas, has been exposed as flawed by the hugely successful Wild Atlantic Way initiative. This program has attracted large numbers of tourists to the natural scenery in areas such as County Donegal.

Aquaculture, a comparatively small contributor to Ireland's economy, should not be allowed to threaten tourism, which contributed more than EUR6.5 billion to the economy in 2014, by comparison with an estimated EUR200m for all aquaculture.

Tourism employment also dwarfs aquaculture, with around 180,000 people directly employed in tourism, or 100x that of aquaculture. It is clear which is the more important sector, viz. tourism, and the idea presented in the document, that aquaculture sites can be a tourist attraction, is not deserving of serious attention. The association of aquaculture development with the Wild Atlantic Way tourism initiative is a crass and unrealistic attempt to suggest tourism and aquaculture are complementary.

AIMING FOR GROWTH – ENVIRONMENTAL COSTS

The premise (page 9) that Europe (and Ireland) must "catch up" as aquaculture production has "stagnated" is flawed. There is no pre-eminent obligation to achieve growth for its own sake. Ireland has competing demands for the resources required to produce farmed seafood, and the objective should be to achieve balance in resources, not tonnage for its own sake. "Ireland and other Member States through EU institutions have recognised the unsustainable position that the EU finds itself in with regard to seafood supply and has targeted resurgence in growth in output from aquaculture as a major priority over the remainder of this decade." Why is this a natural conclusion?

We refer to the EU document, Future Brief: Sustainable Aquaculture, which states that "in its expansion, aquaculture must continue to respect environmental legislation" and refers specifically to a series of important European directives and initiatives:

- The **Marine Strategy Framework Directive (MSFD)** requires EU Member States to achieve 'Good Environmental Status' for their marine waters by 2020, as judged against a range of 11 so-called 'descriptors'. Thus, national aquaculture strategies must ensure that aquaculture does not have negative impacts in terms of non-indigenous species, eutrophication, seafloor integrity, concentrations of contaminants (both in the water generally and in seafood specifically), populations of commercial fish or marine litter.

- **The Water Framework Directive (WFD)** addresses pollution and biodiversity concerns in inland, coastal and transitional waters (e.g. estuaries and fjords). It requires Member States to attain 'good ecological status' and 'good chemical status' in these waters. Pollution by 'priority' chemical substances, some of which are used in aquaculture, must be progressively reduced and, in some cases, phased out completely.

- Aquaculture operations must respect wildlife protection requirements under the **Birds** and **Habitats Directives**. In particular, they must comply with the conservation objectives of sites included in **Natura 2000**, the EU network of protected areas, and be subject to an Appropriate Assessment prior to authorisation in line with Article 6 of the Habitats Directive.

- The **Regulation on the use of alien and locally absent species in aquaculture** addresses the movement of alien species for aquaculture purposes. Operators must conduct prior risk assessments and obtain permits to transfer alien aquatic species. The newly adopted **EU Regulation on the prevention and management of the introduction and spread of invasive alien species** will also apply to aquaculture.

- Planning and development of new aquaculture sites fall under the **Environmental Impact Assessment (EIA)** and **Strategic Environmental Assessment (SEA)** directives. These allow environmental concerns to be taken into account very early on in planning processes, thus avoiding or minimising negative impacts. In addition, the recently-agreed **Directive on Maritime Spatial Planning (MSP)** aims to promote sustainable development and use of marine resources, including for aquaculture, through Maritime Spatial Plans to be established in each Member State by 2021.

The premise for the National Strategic Plan for Sustainable Aquaculture seems to be that "sustainable" applies exclusively to economic sustainability. In fact, the suite of applicable European policies is more far-reaching than this, and the requirement for compliance with the five areas listed above is at least as important as the economic sustainability objective.

These EU requirements are NOT optional, but obligatory, and the tone of the NSPSAD, suggesting Ireland's responsibilities to the environment under European directives are non-binding or voluntary, is incorrect. The failure to comply adequately with the requirements under NATURA 2000 are not indicative of problems with NATURA 2000, but refer to the inherent resistance of Ireland's marine management to observe environmental obligations. It is of extreme concern to us that measures such as NATURA 2000 should be designated as a "threat" under the SWOT analysis on page 23: "Spatial restrictions on aquaculture activities to protect NATURA 2000 designated species and habitats." We do not accept that these are "threats" to aquaculture, but essential pre-conditions to its operations. In our view, this demonstrates the presumption that any obstacle to aquaculture, even protected habitats, are "threats" to be removed. After all, the aquaculture industry is the only industry we specifically allow to pollute our waters.

KNOWLEDGE, INNOVATION, TECHNOLOGY – AND TRANSPARENCY?

It is curious that Chapter 5 seems to overlook the impact of invasive species on indigenous species -- for example, Pacific oyster (*crassostrea gigas*) proliferation on native oysters – as well as the cumulative impact of treatments for disease and parasites in finfish on other species, and the impact of these diseases and parasites themselves.

Research by the former Central Fisheries Board into the impact of sea lice on migratory wild salmon, for example, has been intentionally suppressed, although Description of the Licensing Process, a 13-step programme (page 94-96) includes Step 4 " . . . with particular reference to ensuring scientific agreement…". And NSPSAD claims 'impartial and objective science' in "Principle 3 of Sustainable Development: Science-based approach . . . best available, impartial and objective science …" (page 75).

A National Sea Lice Monitoring Plan has been introduced, which requires fish farms to "treat", i.e. apply anti-sea lice pesticides, when the sea lice reach a particular concentration. This is clearly aimed at supporting the fish farms in dealing with their own problems, but gives no reference to the impact of the sea lice or of the treatments beyond their own cages. This is NOT a control plan, but merely a monitoring plan, and experience over many years leads us to conclude that the regulators and the industry are determined to deny the environmental impact of sea lice – and pesticides - on the wider marine environment, and on wild salmonids especially.

At the 'Sea Lice 2014' conference held in Maine (USA) in early September 2014, the Marine Institute admitted to "persistent difficulties in achieving sea lice control targets at certain locations" but claimed "a downward trend of mean sea lice levels on Irish farms". There were, however, 39 reported incidents of sea-lice in the first 10 months of 2014, versus 19 in the previous year.

There is not only fudging of statistics, but a secrecy around the monitoring results, data which should be available to the public. This concern is reinforced by the extraordinary decision to close the investigation into sea lice management and control in Ireland due to "lack of evidence". The "lack of evidence" is almost entirely due to the fact that the data held by the Marine Institute is inaccessible to the general public.

The Marine Institute publishes annual reports but monthly data is marked private and confidential - with the following warning attached to reports:

> *This data is supplied for the information of the recipient only and is not to be used, cited, or conveyed to third parties without the prior permission of the Marine Institute.*
> **Published data for 2013 is available at** http://hdl.handle.net/10793/955
> **Marine Institute, Rinville, Oranmore, Co. Galway, Ireland. Tel:+353 91387200** www.marine.ie

ENSURING SUSTAINABILITY

"Vision for 2020: 'An aquaculture industry that develops in harmony with nature, and with the confidence of stakeholders.'" (NSPSAD, page 74)

While the language is to be applauded, we are skeptical that, without extensive reorganisation, Ireland's marine management structure is capable of achieving the headline objectives in a way that any reasonable and neutral observer would describe as compliant. The "Guiding Principles for the Sustainable Development of Aquaculture" are all admirable, but there is little or no evidence that Ireland has paid considered attention to these principles in the past:

- Responsible Planning
- Ecosystem Protection
- Science-based approach
- Compliance
- Openness, Transparency and Accountability
- Industry Best Practice

For us, there is ample evidence from our own experience that in Ireland none of these principles has been well-observed, with perhaps the most egregious being "Openness, Transparency and Accountability". Advertising of license applications in newspapers distant from those directly affected by licenses; control of information on operations of aquaculture operations; sub-leasing of licenses from indigenous operators to multinationals, all with no evident accountability, are some of the experiences in the operation of aquaculture in Ireland.

In this segment, an area worthy of consideration is the principle of appropriate siting of salmon farms, i.e. offshore. However, in a point which is typical of the aquaculture sector, definitions seem to be pliable, and "offshore" seems to mean what the regulator decides it should mean. In response to a written parliamentary question in June 2015, Minister Simon Coveney replied, *"My Department has been advised by the Marine Institute that offshore*

aquaculture as referred to in the National Strategic Plan for Sustainable Aquaculture Development is considered to mean the execution of activities in sites that are subject to ocean conditions, with significant exposure to wind and wave action. This includes fully open ocean sites and sites that, although close to the open ocean, and subject to ocean waves, benefit from some shelter provided by local topographical features (e.g. headlands and islands)."
https://www.kildarestreet.com/wrans/?id=2015-06-25a.268

A key risk of offshore farming, as pointed out in the EU Future Brief document: "It is difficult to predict the exact environmental impacts of this, as scientific knowledge is lacking." Also, "Troell et al (2009) caution that offshore farms are likely to be much larger than today's coastal farms, and produce more waste. Even in the open ocean, assimilative capacities can still be exceeded by nutrient pollution, they warn."

It should be noted that while control of invasive species is regarded as a high priority, it is also a problem created by aquaculture.

- "Control of invasive species is a major challenge, and involves cross-sectoral and cross-border co-operation by a range of responsible bodies and sectoral interests." (page 78)
- (quoting Article 19 report): "The majority of the known initial introductions of NIS to Irish waters have occurred via shipping (commercial and recreational) or through aquaculture." (page 79)

Does this not suggest that a quick solution to the problem may be to stop growing non-indigenous species and importing broodstock/seeds? However, the Minister for the Marine continues to grant licenses for breeding non-indigenous oysters. How is this inconsistency reconciled?

For more than 10 years, wild oystermen in Lough Swilly have been told by the Marine Institute that the gigas oyster was not worth their concern as it was 'sterile.' The NSPSAD (pages 26, 31ff, 56) however, gives a slightly different version:

". . .since 2010 Irish [oyster] operators have been building up a source of certified disease free sterile oysters. The first of these sterile stocks will be produced in spring 2015. Currently, one hatchery is carrying out this work, funded jointly by BIM and MI, and this stock will be made available to other Irish hatcheries. To exploit this properly, it is vital to invest in a full scale breeding programme run collaboratively with all Irish hatcheries. There is an opportunity to use fertile stocks from different disease free sources around the coast to maintain genetic diversity, while selectively breeding for resilience and other characteristics in an Irish produced sterile oyster."

Once again, aquaculture is favoured over the traditional resource, supported by suppressed and/or incorrect information, to the detriment of the native species.

COORDINATED SPATIAL PLANNING

The idea of coordinated spatial planning cannot be faulted, and provided it is accomplished with comprehensive and appropriate consultation and genuine transparency concerning implications of the operations being planned, we would have no objection.

Spatial planning implies consultation with local communities. The launch of the Coordinated Local Aquaculture Management Systems (CLAMS) was a cynical attempt to present an aquaculture industry networking system as an objective consultation body. CLAMS is an aquaculture sector organisation, whose main objective is to advance the interests of the industry. From CLAMS' own handbook introduction: "Though CLAMS is integrated with these [marine] plans and the viewpoints of all interest groups are documented, the process is driven by the aquaculture producers." CLAMS is not an objective source or conduit of information, and the idea that the CLAMS network will provide unbiased bottom-up data on appropriate planning is ludicrous.

A second point of concern in the assessment of this element is the suggestion that effective planning is required to work around environmental obstacles such as NATURA 2000. This was expressed in Sunday Times, 5 July 2015: Department of Agriculture [Food and the Marine] . . . "called on the commission to take a flexible approach to enforcement because 'the complexity involved in achieving compliance generally in the marine environment appears to have been greatly underestimated.'"

It is our view that the European environmental policies have evolved from comprehensive investigation, research and debate, and are not trivial hurdles to be overcome. They set the bar for industrial and other activities, and any industry unable to comply must (a) adapt so that they do comply; or (b) cease their activities.

AQUACULTURE LICENSING

The implication in the statement on aquaculture licensing "…to progressively remove the current aquaculture licensing backlog" is perhaps the most disturbing aspect of this report. There is no doubt that the aquaculture licensing process has been slowed in recent years, but the reasons for this lie at the door of the Minister and the Department, rather than some technical anomaly which can be resolved by hurry-up diktat. The main reason for licensing delays has been Ireland's failure to observe European environmental directives.

If anything, this failure to have followed the regulations from the beginning should lead to a tightening of the licensing regime rather than some form of "blanket amnesty" which seems to be the Irish government's intention. Throughout the NSPSAD, there are frequent references to "overhaul" and "revision" of the regulatory/legislative framework.

The recent issuing of 70 mussel licences in Roaring Water Bay, and 120 mussel licences in Cronane, Co. Kerry alone, would suggest that cumulative effect is of little concern to those in charge of marine management. Each licence was signed off by the Minister with a document stating that "this application would not in itself have a significant impact on the environment."

There is some contradiction about the number of new licences expected: " . . . a limited number of new licences" (page 52), and ". . . the expected outturn for 2015 in respect of licence determinations is in the order of 150" (page 96) -- but given there have been 190 mussel licences issued alone this year, the tallying seems a bit fluid. Meanwhile, the ratio of aquaculture licences approved vs those refused (page 94) stands at a startling 244 : 4.

The establishment of a "Data management and information system, with online aquaculture licence application and tracking functionality, and spatial mapping of aquaculture sites" (pages 90,94,97 – and notably, without an ETA), seems to suggest a fast-track licensing approach. While we do not object to improved efficiency, if the intention is to circumvent or in any way diminish the public right to consider and object to license applications, it cannot be condoned. Public access to the network of aquaculture licenses through the 'Public Viewer' would appear to be after, not prior to, licences being granted. Where is the "openness, transparency and accountability" for the public in this?

Finally, fish farms license their sites. The marine resource belongs to the people of Ireland. The proposal (page 59) " [optimisation of existing licensed capacity] could be a case of an unused or underutilised licensed site being sold or sub-let to a better resourced or more ambitious operator" is, at best, questionable.

CONSERVATION

" Planning, licensing and regulation of the sector ensures full compliance with relevant European and National legislation, including SEA and EIA legislation, nature conservation legislation (Birds and Habitats Directives), and legislation seeking to achieve and maintain good environmental status of coastal and marine waters (Water Framework Directive,

Marine Strategy Framework Directive)." – Principle 4 of the six Guiding Principles for the Sustainable Development of Aquaculture recommended by the Marine Institute.

Save the Swilly applauds this principle, but seriously doubts whether this is also recognised as an obligation by the promoters/developers of aquaculture, let alone as a positive principle to embrace. Inclusion of NATURA 2000 compliance as a 'threat' in the SWOT analysis of the proposed industry expansion was surprising. More recently, there was the Sunday Times plea by the Department that it was just too hard to be compliant, and they were in need of a work-around.

This is most disappointing in that it reinforces our long-held view that the aquaculture industry, supported by policy-makers, sees environmental protection and Ireland's unique marine habitats as hindrances to industrial development. We believe the integrity of Ireland's habitats is a national treasure to be protected and enhanced, and not to be eroded by a global aquaculture industry colluding with politicians and civil servants intent on expanding an industry for sectoral interests, rather than for the greater national good.

Finally, it is almost inconceivable that Ireland has not implemented a policy of Marine Conservation Areas, given its location and the importance of its marine habitat, both to this generation and the next. We believe that certain areas should be designated free of aquaculture and commercial fishing for sustained periods to enable wild fish stocks to be replenished. This should be part of any 'strategic policy'.

According to the Marine Strategy Framework Directive, enacted into Irish law in 2011, Ireland is required to achieve "good environmental status" for its coastal zone by 2021. The logical way to do this is to establish a network of Marine Protected Areas, which are common or under active development elsewhere in Europe and in other regions of the world. The fact that this concept is not even mentioned in this document is a serious shortcoming.

Appendix 5

<u>Photographs (more available on Save Linsfort Beach Facebook Page)</u>

Appendix 6

Reports on Native Oyster vs Invasive Species

- Appropriate Assessment of Fisheries and Aquaculture in Lough Swilly - Marine Institute
- Can the spread of Non-Native Oysters at early stages be managed
- Cause & Affect of a Highly Successful Marine Invasion
- Exploitation of natural food sources by two sympatric invasive suspension feeders
- Fishery Natura Plan for Native Oysters in Lough Swilly 2012-2017
- Invasive Species Ireland
- National Strategic Plan for Sustainable Aquaculture Development - draftconsult100615
- The Dynamics of Environmental Sustainability and Local Development - Aquaculture
- The Native Oyster - Article by Karen Dubsky
- The Status and Management of Native Oyster - Tully & Clarke 2012

ANNEX 1:

Appropriate Assessment of Fisheries and Aquaculture in Lough Swilly (SAC 002287)

Marine Institute

Rinville

Oranmore, Co. Galway

Version: May 2013

Contents

1 Introduction

This document assesses the potential ecological impacts of aquaculture activities within Lough Swilly (site code 002287) Special Area of Conservation (SAC) on the Conservation Objectives of the site (COs).

The information upon which this assessment is based is a definitive list of applications and extant licences for aquaculture received by the Department of Agriculture Food and Marine (DAMF) and forwarded to the Marine Institute as of end of April 2012; and also the 5 year Fishery Nature Plan (FNP) for Native oysters in Lough Swilly (LSWOSL, 2012). The activities include bottom culture of mussels and the bottom and suspended culture (BST long lines, bags & trestles) of oysters (native & pacific).

2 Conservation Objectives for Lough Swilly (SAC 002287)

The appropriate assessment of aquaculture in relation to the Conservation Objectives for Lough Swilly is based on version 1.0 of the objectives as produced by NPWS (2011a).

The SAC extent

Lough Swilly is a long sea inlet situated on the west side of the Inishowen Peninsula in north Co. Donegal, it extends from below Letterkenny to just north of Buncrana. The site is estuarine in character, with shallow water and intertidal sand and mud flats being the dominant habitats. The main rivers flowing into the site are the Swilly, Lennan and Crana. At low tide, extensive sand and mud flats are exposed, especially at the mouths of the Swilly and Lennan rivers. The boundary of the SAC is shown in Figure 1 below.

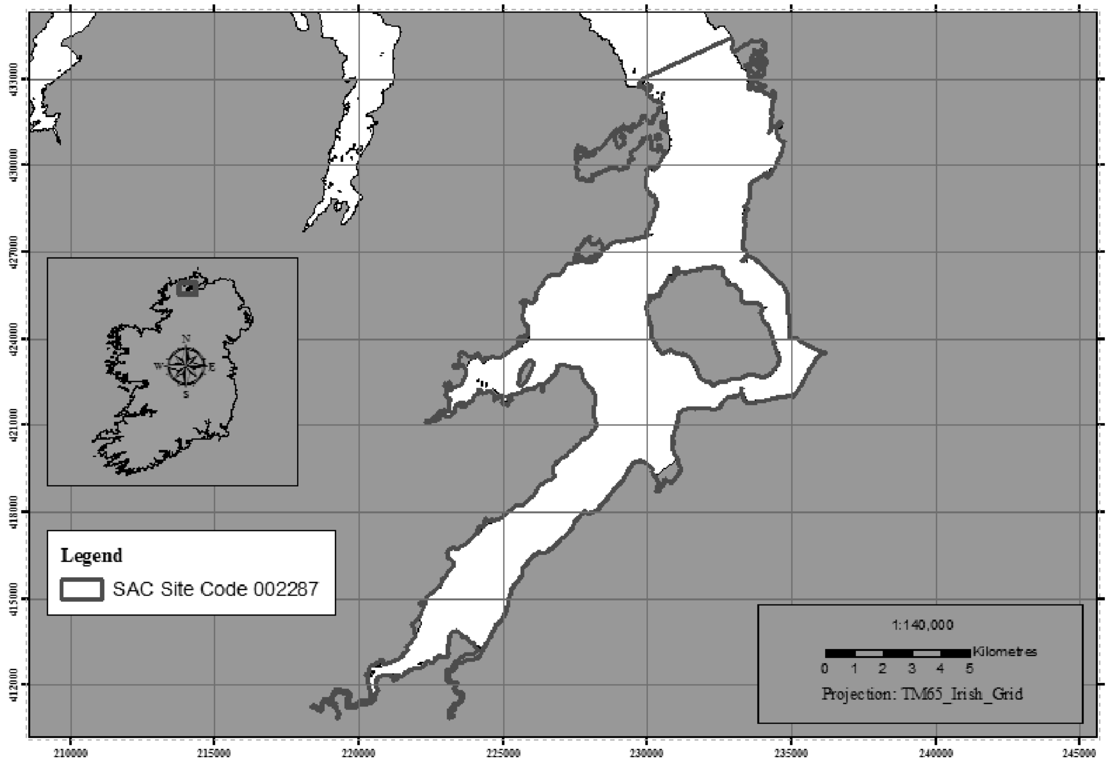


Figure 1: The extent of Lough Swilly SAC (site code 002287).

Qualifying interests (SAC)

The SAC is designated for the following habitats and species, as listed in Annex I and II of the Habitats Directive:

- 1130 Estuaries
- 1150 Coastal lagoons (priority habitat under Habitat Directive)
- 1330 Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
- 1355 Otter (*Lutra lutra*)
- 91A0 Old sessile oak woods with Ilex and Blechnum in the British Isles

Constituent communities and community complexes recorded within the qualifying interest Estuaries (1130) are listed in NPWS (2011a) and illustrated in Figure 2:

1130 Estuaries

- Fine sand community complex
- Intertidal mixed sediment with polychaetes
- Subtidal mixed sediment with polychaetes and bivalves
- Muddy fine sand with *Thyasira flexuosa*
- Mud community complex
- *Ostrea edulis* dominated community

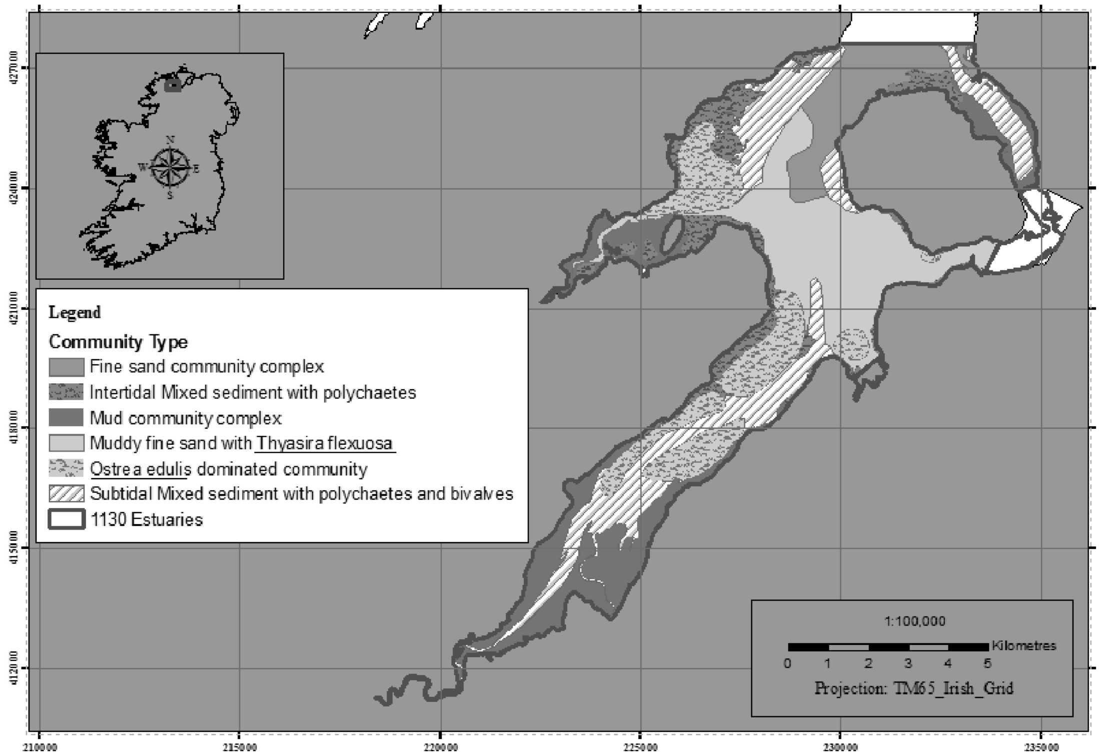


Figure 2: Principal benthic communities recorded within the qualifying interest Estuaries within Lough Swilly SAC (site code 002287) (NPWS 2011a).

Conservation objectives for Lough Swilly SAC

The conservation objectives for the qualifying interests (SAC) were identified by NPWS (2011a). The natural condition of the designated features should be preserved with respect to their area, distribution, extent and community distribution. Habitat availability should be maintained for designated species and human disturbance should not adversely affect such species. The features, objectives and targets of each of the qualifying interests within the SAC are listed in Table 1. Specifically, for marine habitats and species, the attributes listed in Tables 1 should be conserved.

Table 1: Conservation objectives and targets for marine habitats and species in Lough Swilly SAC (site code 002287) (NPWS 2011Apr.Ver. 1)

FEATURE	OBJECTIVE	TARGET
Estuaries	Maintain favourable conservation condition	6118ha, permanent habitat is stable or increasing, subject to natural processes
Fine sand community complex	Maintain favourable conservation condition	583ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Intertidal mixed sediment with polychaetes	Maintain favourable conservation condition	655ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Subtidal mixed sediment with polychaetes and bivalves	Maintain favourable conservation condition	1314ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Muddy fine sand with *Thyasira flexuosa*	Maintain favourable conservation condition	1320ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Mud community complex	Maintain favourable conservation condition	1127ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Ostrea edulis dominated community	Maintain favourable conservation condition	906ha, Conserved in a natural condition, persistent disturbance to ecology <15% of area
Otter (*Lutra lutra*)	Restore the favourable conservation condition	Maintain distribution, 88% positive survey sites
		839ha, No significant decline in extent of marine habitat
		Couching sites and holts, No significant decline and minimise disturbance
		Fish biomass, No significant decline in marine fish species in otter diet
		Barriers to connectivity, No significant increase

3 Details of the proposed plans and projects

Aquaculture

Aquaculture activities are widespread in Lough Swilly and comprises of shellfish (mussel and oyster) and finfish (salmon) culture. Mussel (*Mytilus edulis*) & oyster (*Crassostrea gigas* & *Ostrea edulis*) production is carried out within the SAC & SPA boundaries. However, no aquaculture occurs in Blanket Nook Lough or Inch Lough. This assessment focuses on aquaculture activities which fall within the qualifying interest of Estuary (1130) for which the site is designated. methods of shellfish cultivation carried out within the feature Estuary include bottom culture, longlines, BST longlines and bags & trestles. The aquaculture activities considered in this assessment can be broadly divided according to species cultured and method of culture as well as licence status (licensed or application). Within the boundary of the qualifying interest (Estuary 6118ha) the total area currently licensed for shellfish production is 1771.4ha; this comprises of oyster cultivation (86.1ha), mussel cultivation (511.6ha) and dual mussel and oyster cultivation (1173.8ha). Currently (May 2012) applications are submitted for another 861.2ha, comprising bottom culture of mussels (549ha), bottom culture of oysters (280.3ha) and suspended culture of oysters employing BST Longlines (17.9ha) and Bags & Trestles (14ha).

3.1.1 Mussel Culture

Mussel (*Mytilus edulis*) culture occurs throughout the Lough Swilly SAC, but the majority occurs in inner Lough Swilly south of Rathmullan. Bottom culture is the sole method of cultivation employed within this area covered by this assessment (i.e. Estuary); other culture methods (Longlines) are employed outside of the extent of the qualifying interest and the SAC boundary. Within the qualifying interest (Estuary) of Lough Swilly SAC there are currently 7 sites licensed for bottom culture of mussels and 13 applications pending (Figure 3). There are also three sites licensed for the bottom culture of mussels and oysters together. Currently the total area, within the boundary of the qualifying interest, under licensed mussel cultivation is 511.6ha with a further 549ha being subject to application. There are also three sites (1173.8ha) licensed for the bottom culture of oysters and mussels together (Figure 4).

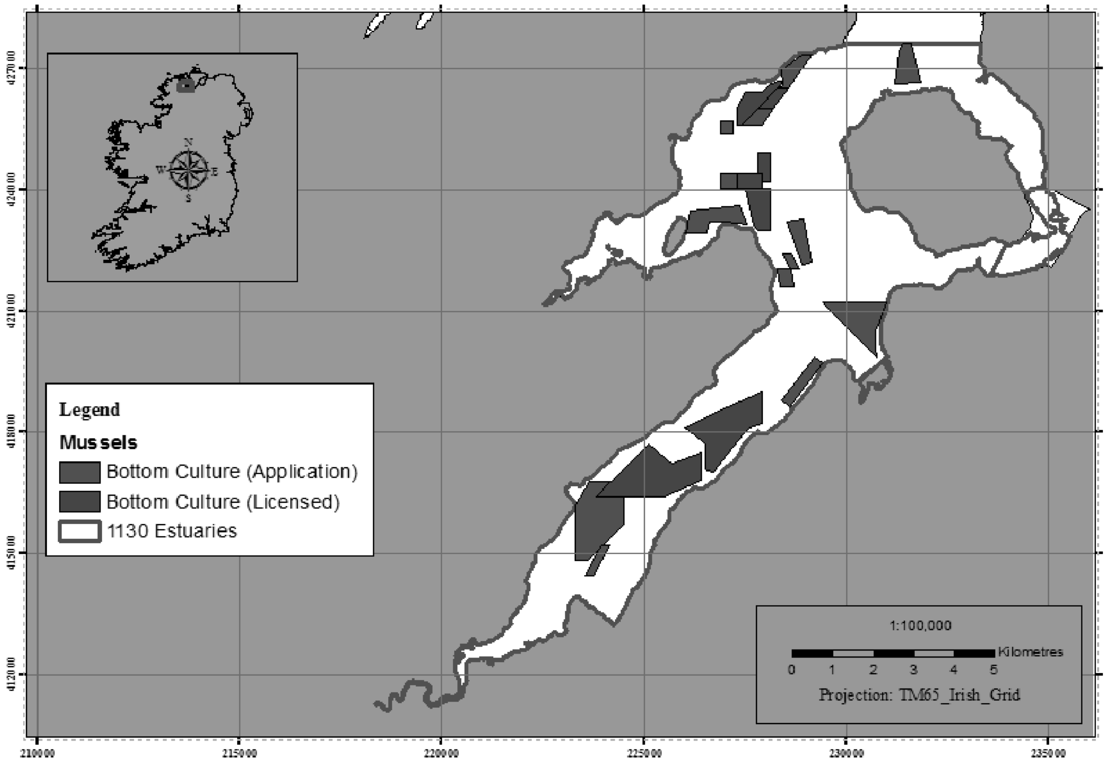


Figure 3: Proposed and existing bottom mussel culture activity within the qualifying interest Estuaries of Lough Swilly SAC.

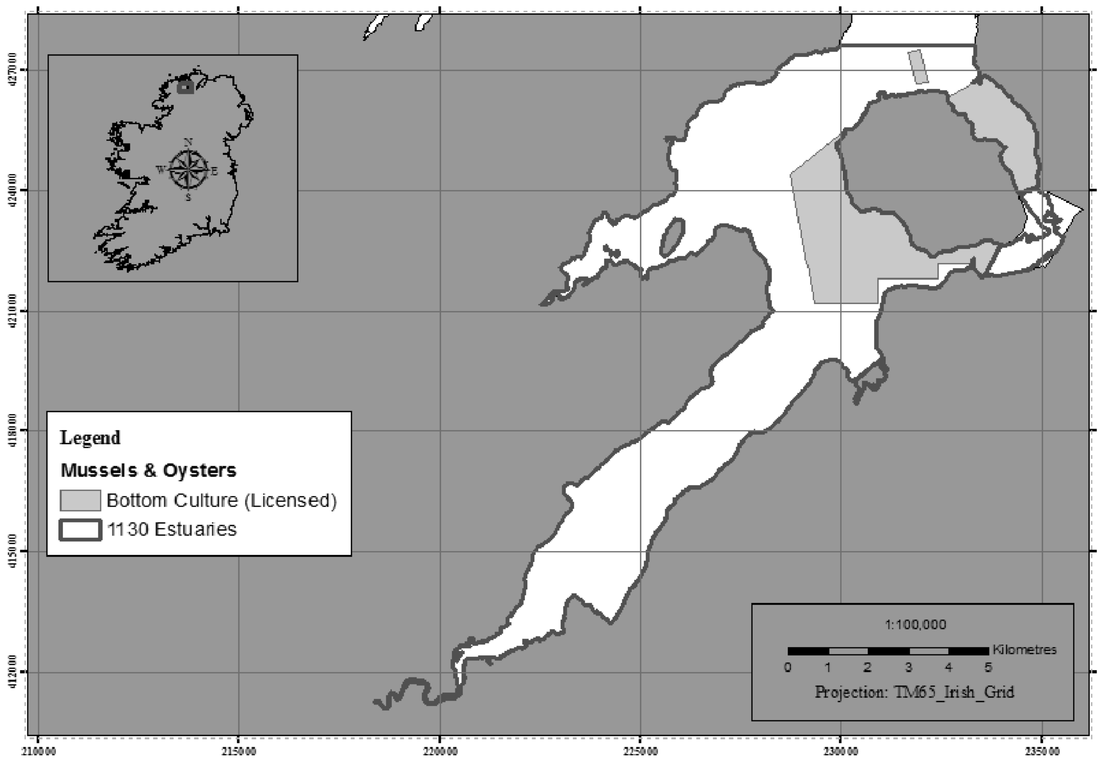


Figure 4: Existing bottom mussel and oyster culture activity within the qualifying interest Estuaries of Lough Swilly SAC.

Bottom Mussel Culture

With bottom mussel culture, seed is transplanted to licensed areas where the mussels are placed directly onto the seafloor. No structures are used for the culture of mussels on the seafloor, mussels are placed in an uncontained fashion on the seabed; most of the beds are sub-tidal. In Lough Swilly, techniques vary among producers from simply transferring seed to licensed sites, where they remain until they reach harvest size to very mobile stocks which can be moved 3-4 times from nursery to ongrowing sites during their life cycle. When the mussels reach commercial size 9-18 months later, they are harvested using dredges. Mussel vessels operating in Lough Swilly use between 2 and 4 dredges depending on vessel size. The types of dredge used on all vessels are 2m mussel dredges with a flat bar that are designed to skim the surface of the sea bed and separate mussels from the underlying sediment of the substrate.

Seed Source and Collection

Mussel see is sourced from both within the Lough and as part of the National Seed Allocations. Mussel seed sources for Lough Swilly come both from within the bay and from the managed Irish Sea Fishery. The main local seed area is to the west of Inch Island stretching from Drum Point to Hawke's Nest. When first introduced into the Lough from other areas (in accordance with seed allocations) mussel seed is placed in the deeper water of the licensed areas for a short time to become accustomed to the environment. Depending on the robustness of this seed, it may remain here (deeper water) for the remainder of the on-growing period. During this time the stock is carefully monitored and if necessary (i.e. poor growth, high mortality) may be transplanted to shallower waters.

Nursery Areas

When native seed is collected it is immediately transferred to nursery areas, usually in the intertidal. The co-op's nursery areas are in the Farland Creek and Fahan Creek. For other licensed sites, the nursery area may comprise the shallower parts of the site. Stocks remain in the nursery areas for 12-18 months, at which stage they have reached a size of approximately 35mm, the stock is then transplanted to deeper ongrowing sites.

Ongrowing Stage

Stock is moved using dredges from the nursery areas to deeper waters within the licensed site, and remains here for 6-9 months until harvest. In many bottom culture regimes the mussels would remain on the same plot until harvest, however, as a result of predation by starfish and local hydrodynamic conditions, mussels grown in Lough Swilly can be moved 3-4 more times prior to harvest (Table 2). This is especially true for the co-op licensed area (one large licensed site adjacent to Inch Island) as the management regime allows for greater flexibility for movement between the individually allocated ongrowing plots within the licensed area.

Table 2: Frequency of activity associated with the bottom culture of mussels within Lough Swilly, BIM.

				Year 1												Year 2												Year 3											
	High Tide	**Low Tide**	**Day**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Mussel Spawning								X																															
Seed Mussel Fishery	X		X								L	L	H																										
Nursery	X		X										H	L	L	L	L	L	L	L	L	L	L	H	X	X	X	X	X	X									
Starfish Control	X Mop	X Hand Picking	X										H	L	L																								
Ongrowing																								H	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Stock Movements																														X	X	X							
Harvesting			X																											X	X	X	X	X	X	X	X	X	X

Harvesting

Harvest is generally conducted 18-27 months after initial seeding, from February through to December.

3.1.2 Oyster Culture

Oyster culture, native (*Ostrea edulis*) and pacific (*Crassostrea gigas*), within Lough Swilly is concentrated to the west and south of Inch Island (Figure 5). Oyster farming within Lough Swilly is a form of intensive culture which has been taking place since the early 1990s. Culture methods employed are both intertidal and subtidal in bags & trestles and BST longlines for *Crassostrea gigas* and bottom culture for *Crassostrea gigas and Ostrea edulis*. Within the extent of the qualifying interest, there are currently 3 sites licensed for the sole culture of oysters (2-Bags & Trestles, 1-Bags & Trestles and BST Longlines) and 7 applications pending (3-Bags & Trestles, 2-BST Longlines, 2-Bottom Culture). Currently the total area, within the boundary of the qualifying interest, under licensed oyster culture is 86.1ha with a further 312.2ha being subject to application. The licensed area comprises of Bag & Trestle (26.3ha) and Bags & Trestles and BST longline (59.8ha) culture. In applications pending bottom culture (280.3ha) is the predominant method of culture, with BST Longlines (17.9ha) and Bags & Trestles (14ha) also. It should be noted that there are two instances of overlap where areas already licensed for mussel bottom culture (T12/293; T12/298) are also subject to an application for oyster bottom culture (T12/339a; T12/339B), this overlap comprises an area of 175.180477ha (Figure 6 Area of overlap).

There are three sites, covering an extensive area (1173.8ha), that are licensed for the bottom culture of oysters and mussels together (Figure 4).

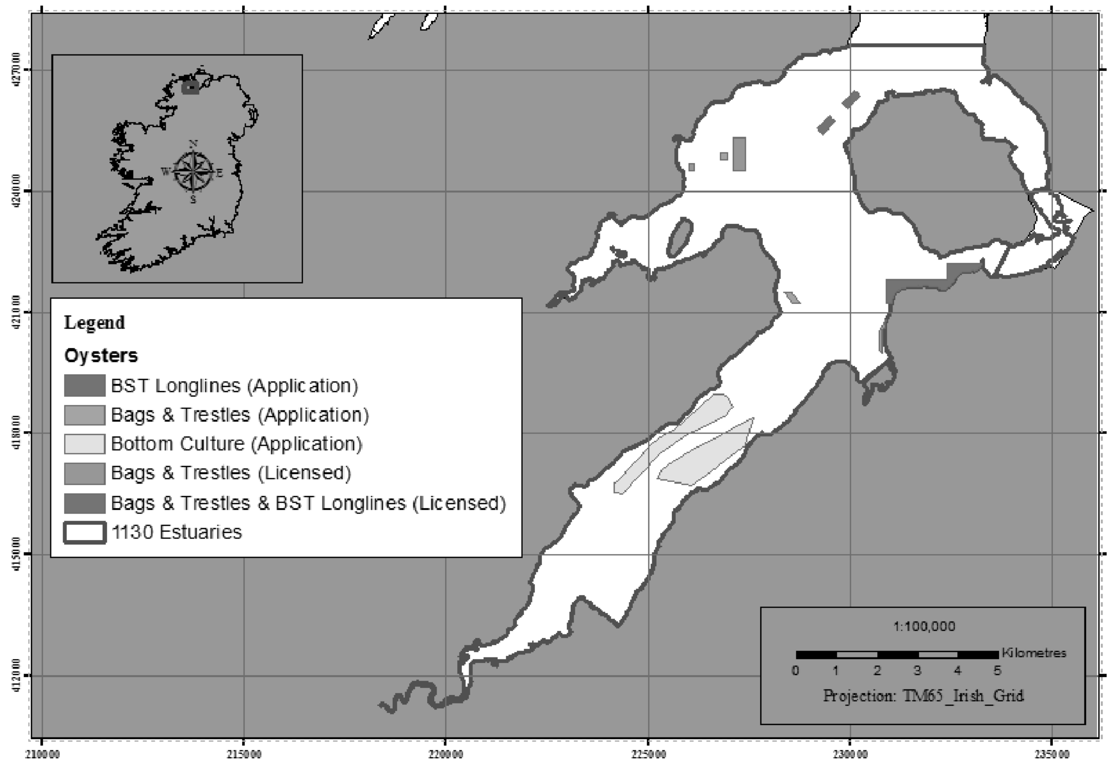


Figure 5: Proposed and existing oyster culture activity within the qualifying interest Estuaries of Lough Swilly SAC.

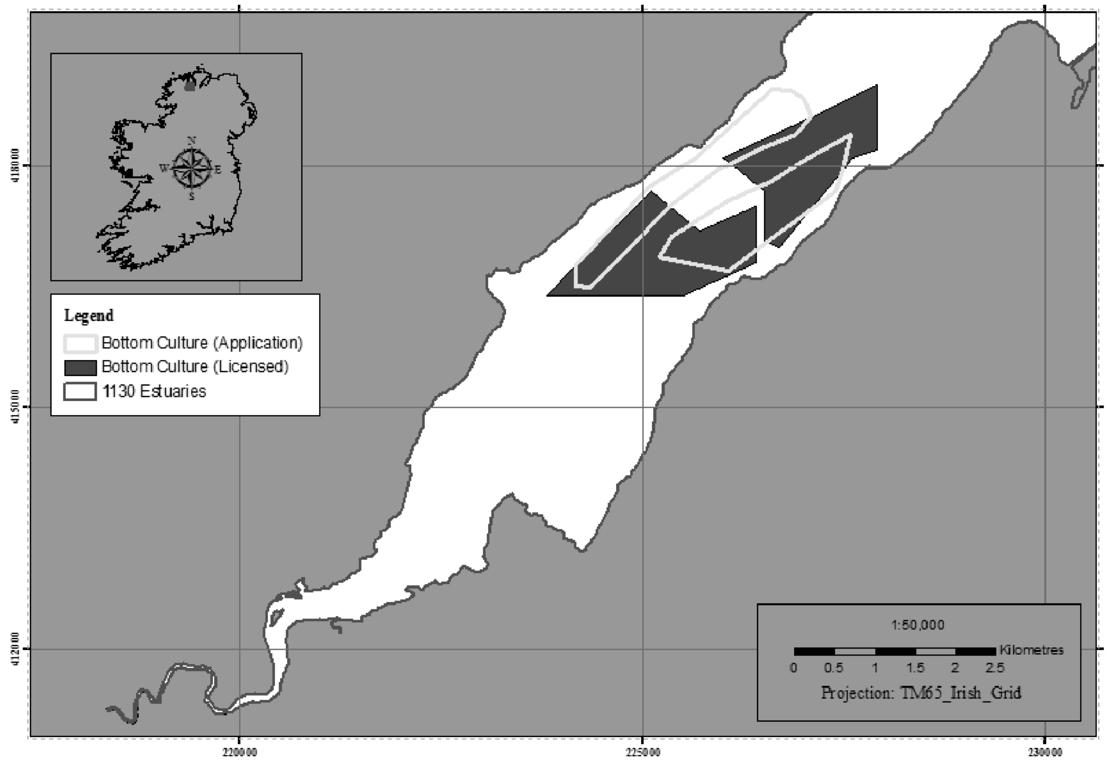


Figure 6: Area of overlap, two areas already licensed for mussel bottom culture (red) are also subject to applications for oyster bottom culture (yellow). This overlap comprises an area of 175.180477ha.

Suspended Oyster Culture (Bags & Trestles, BST Longlines)

Oysters cultured in the intertidal areas of Lough Swilly are grown in plastic mesh bags secured to metal trestles predominantly on sedimentary habitat. Bags are made of a plastic mesh and are fastened to trestles using rubber straps and hooks. Bags vary in mesh size depending on oyster stock grade (6mm, 9mm and 14mm).

Oyster culture also takes place on the BST longline system at one site (T12/37D). This method of culture appears to be more effective for oysters in the lower inter-tidal environments. Cylindrical baskets (6mm, 12mm and 16mm mesh size) are suspended from longlines rigged to the seabed by poles at either end.

Intertidal sites within Lough Swilly are positioned between Mean Low Water Spring and Mean Low Water Neap, allowing 2.5 to 3.5 hours exposure each day depending on prevailing weather conditions. This translates to approximately 15% visual exposure during day light hours over a typical month. (In total there is 0.15% of the Lough licensed to oyster farming, of which only an estimated 18% is currently being utilised).

Seed source

Seed or 'spat' oysters are purchased from hatcheries. They are available in a variety of size grades, usually from 4mm – 30 mm shell length. Seeding is generally carried out in spring-time when seed (>5g) becomes available from hatcheries. In Lough Swilly the production cycle begins in the spring when seed (8-10 mm) is introduced from UK (Seasalter) and French (Naisain) hatcheries. More recently the majority of oyster seed introduced into the lough is triploid which has the commercial advantage of generally maintaing higher condition throughout he year a consequence of reduced reproductive output.

Access

Sites are accessed at low tide using a tractor and trailer and more recently by the use of purpose built flat bottom barges. The farms on the east shore are accessed by tractor and by foot from a dedicated access point with associated work areas and land storage. The oyster farms on the west shore are accessed by barge and only occasionally by tractor. A larger barge has a crane and grading equipment onboard. The smaller barges serve only to access sites and operate as work platforms. Outboard engines on these only operate when entering and leaving the site once daily.

Bottom Culture of Oysters

This culture method involves the placement of oysters (Native and Pacific) in an uncontained fashion on the seabed after a nursery phase in the intertidal zone. In the area around Inch Island the Lough Swilly Shellfish Growers Co-op society is licensed to bottom culture both mussels and oysters in this fashion.

It is proposed that suitably sized oysters (> 15g) are spread within the licensed area. Oysters are checked periodically when the progress (growth and mortality) of the oysters are monitored and intervention will be necessary if anomalies are discovered. For example, oysters may need turning-over if excessive fouling or siltation is noted on the animals. Such intervention, as well as harvesting (when oysters are approximately 100g), is carried out using oyster dredges deployed from boats. The dredges are typically 1.5m wide and have contact with the substrate via a flat blade.

Harvesting

Harvesting is carried out between October and April, 12-18 months after initial seeding. The stock is harvested when they attain suitable size and condition. This can be from 75g (>85mm) upwards. It can take 2.5–3 years to first harvest.

Fisheries

3.2.1 History of the native oyster fishery -

The following information and fishery data is taken from the Fishery Natura Plan for oysters (LSWOSL, 2012: Appendix I) which details the fishery plan for the native oyster in Lough Swilly from 2012 to 2017. Wild oyster (*Ostrea edulis*) was first documented in Lough Swilly in 1604 when the British Admiralty report identified that oysters existed in commercial quantities in the bay. There has been a traditional native oyster fishery in the bay ever since. In 1904 the first comprehensive survey was conducted and documented in the "Brown Report" which stated that "there are two natural oyster beds in Lough Swilly one on the north side between Ballygreen Point and Ardrummon, in the Letterkenny Rural District and the other on the south side of the Lough between Drumbiy and Ballyaghan". A private bed on the north shore adjoining the public bed at Ardrummon has also been recorded. In the mussel survey carried out by E. Edwards in 1969 there was no mention of oysters but naturally occurring mussel beds were observed at the locations of the oyster beds noted by Brown. In July of 1991 a dredge survey was carried out in Lough Swilly by M. O'Toole (BIM). Eight dredges were taken in the area of Farland Creek, south of Inch Island (now part of the co-op licence) and no oysters were found. Once again mussels were found in the area between Ballygreen Point and Ardrummon.

3.2.2 Current status of native oyster stocks and fisheries in Lough Swilly

In 2011, two surveys of the oyster populations within Lough Swilly were undertaken by the Marine Institute and BIM. The first survey (March 2011), excluded sites already licensed for aquaculture, indicated that the wild oyster population was at a low level and that previous fishing may have removed a high proportion of larger oysters (>76mm). The survey also indicated that a naturalised Pacific oyster (*Crassostrea gigas*) population was established and occurred in the native oyster bed at various densities and was of multiple year classes. The second survey (November 2011), included both wild Oyster beds and aquaculture sites, confirmed and extended the conclusions of the initial survey that generally stocks were low and that Pacific oysters were widespread. The surveys also showed however that some annual recruitment was occurring and growth rates appear to be strong. The findings of these surveys and also the survey carried out by O'Sullivan and Dennis (2001) provide updated information on the distribution of native oyster beds within Lough Swilly, while local knowledge also suggests that there are additional beds not included in these surveys (Figure 7).

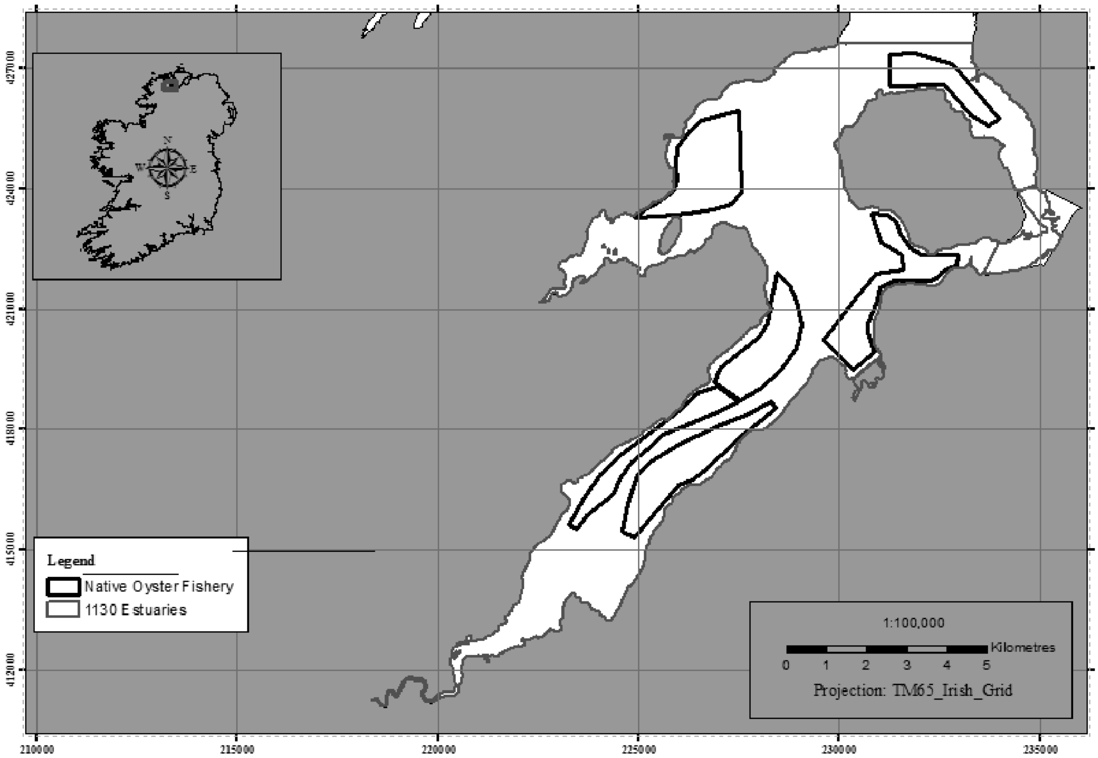


Figure 7: Distribution of native oyster beds within the qualifying interest Estuaries of Lough Swilly SAC (source: LSWOSL, 2012).

3.2.3 Current governance and regulation of oyster fisheries in L. Swilly

The Lough Swilly Wild Oyster Development Association was formed in 2000 to represent the interests of fishermen licensed to gather wild oysters on the Swilly beds. Subsequently the Lough Swilly Wild Oyster Society Limited (LSWOSL) was formed as a friendly Society registered with the Irish Co-operative Organisation Society Limited. It has 29 members from the wild oyster (*Ostrea edulis*) fishing community. The Society currently has no legal authority to manage the fishery but has been active in promoting the conservation and management of wild oyster in Lough Swilly since 2000.All oyster fishermen are required to hold dredge licences issued by Inland Fisheries Ireland (IFI) which specifies the season during which the dredge can be used. In addition the oyster fishing vessel should be registered on the National Sea Fishing Register administered by The Department of Agriculture, Food and Marine (DAFM) and hold the requisite bivalve or polyvalent capacity. In 2012, 24 oyster dredge licences were issued to inshore fishermen in the locality to dredge for oysters. The fishery is regulated

(IFI) by minimum landing size of 76mm and by a closed season from June 1st to August 30th. There is no legal mechanism currently in place that could limit the number of vessels fishing for oysters, the total fishing effort or the annual outtake. Other oyster fisheries in the country have either a fishery order which authorises the local co-op to manage the fishery or they have an aquaculture licence which gives them this same authority

Data in LSWOSL (2012) shows that output from the fishery varies annually depending on stock availability, fishing effort and market price. Annual output in recent years has varied from 40-55 tonnes. The really significant development in the fishery has been the landing of 300 tonnes of naturalised Pacific oyster in 2010, this fishery continued in 2011.

3.2.4 Proposed activity as described in the FNP (LSWOSL 2012)

The proposed plan will operate over an area of 1771ha. However the following annual restrictions and modifications are described in the plan

1. No fishing will occur in an area of 54ha which will be used as a spawning reserve
2. No fishing will occur, for years 1-3 of the plan, in an area which is to be cultched to promote spat settlement. This area is 50.5 ha. Cultching will involve spreading of clean mussel or oyster shell on the seabed to improve settlement conditions for oyster.
3. No fishing will occur where density of oysters is less than 0.25 oysters m^{-2} **and** where the proportion of Pacific oysters is <50%, as determined by a 2012 survey. This area is 257ha and applies for the first year of the plan. The area will be reviewed annually following annual surveys.
4. Areas where >80% of oysters are <55mm will not be fished. Data from the 2011 survey indicate a cluster of stations at Fahan creek where this condition applies.
5. In combination and accounting for spatial overlaps between 1-4, and for the first year of the plan, the measures in 1-4 above sum to an area of approximately **350ha** which will be **closed** to fishing in 2012 ()
6. The area **open** to the fishery in 2012 will be **1421 ha.** In much of the open area *O. edulis* densities are less than the cut off for closure (<$0.25m^{-2}$) but the percentage of oysters that are *C. gigas* in these areas is >50% and therefore these areas come under the control programme for *C. gigas* described in the management plan. Otherwise these areas would also be closed.
7. Undersized oysters (<76mm) captured in areas where the control programme for *C. gigas* operates will be transplanted to the spawning reserve so they are not subject to repeat contact with dredges.
8. The fishery will occur annually for the period Sept 19th to March 31st in the areas that are open in any given year
9. The plan aspires to limiting the number of vessels in the fishery and indicates the number of permits that have been annually since 2006. Other input controls include restrictions on dredge design and a limited fishing season as described above. As indicated in the plan neither the proposers nor the existing legislation for this fishery allows for the number of licences to be limited.
10. Outtake will be limited by restricting the exploitation to 33% of the spawning stock biomass in the areas open to the fishery and including any landings of native oyster originating from the control programme for *C. gigas*.

Spatial Extent of Aquaculture and Fishery Activities.

Spatial extents of existing and proposed activities within the qualifying interest (Estuaries) of Lough Swilly were calculated using coordinates of activity areas in a GIS. The spatial extent of the various aquaculture activities (current and proposed) is presented in Table 3.

Table 3: Spatial extent (ha) of aquaculture and fisheries activities within the qualifying interest (Estuaries) of Lough Swilly, presented according to species, method of cultivation or fishing and license status.

Species	Culture/Fishing Methods	Licence Status	Spatial Extent (ha)
Mussels	Bottom Culture	Licensed	511.60
Mussels	Bottom Culture	Application	548.97
Oyster	Bags & Trestles	Licensed	26.25
Oyster	BST Longlines & Bags & Trestles	Licensed	59.82
Oyster	BST Longlines	Application	17.92
Oyster	Bags & Trestles	Application	14
Oyster	Bottom Culture	Application	280.27*
Oyster & Mussel	Bottom Culture	Licensed	1173.75
Native Oyster Fishery	Dredging	Licensed†	1771**

*There are two instances of overlap where areas licensed for mussel bottom culture (T12/293; T12/298) are also subject to an application for oyster bottom culture (T12/339a; T12/339B), this overlap comprises an area of 175.18ha (Refer Figure 6).

† Dredges Licensed by Inland Fisheries Ireland (IFI) and vessels licenced by DAFM.

**Total area over which the proposed oyster fisheries plan will operate.

4 Natura Impact Statement for the proposed activities

Potential Ecological Effects of aquaculture

The potential ecological effects on the conservation objectives for the site relate to the physical and biological effects of aquaculture structures, fishing activity and associated human activities on designated species, intertidal and subtidal habitats and invertebrate communities and biotopes of those habitats. The potential ecological effects of aquaculture and fisheries on the qualifying interests of the site depend primarily on the type of species being cultured or fished the system of culture and fishing and the properties of the receiving habitat. Both extensive and intense aquaculture and fishing practices can alter the surrounding environment, both physically and biologically, not only due to the presence of the culture organisms (e.g. increased deposition, disease, shading, fouling, alien species) but also due to the activities associated with the culture mechanisms (e.g. structures resulting in current alteration, dredging, sediment compaction), the extraction of commercial natural populations and the physical effects of fishing.

Within the qualifying interest of Lough Swilly, the species cultured are bivalve mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas*, *Ostrea edulis*) and the main culture methods are bottom culture (uncontained on seafloor) and suspended culture (contained in bags & trestles and/or BST longlines) and fishing with dredges. Details of the potential biological and physical effects of these aquaculture and fishing activities, their sources and the mechanism by which the impact may occur are discussed below and summarised in Table 4 below. The impact summaries below are extracted from a variety of review documents (and references contained therein) that have specifically focused upon the environmental interactions of shellfish culture (e.g. McKindsey et al. 2007; NRC 2010; O'Beirn et al 2012; Cranford et al 2012).

Biological Effects of Aquaculture

4.1.1 Deposition/Organic enrichment- All culture methods

Mussels and oysters, being suspension feeding bivalve molluscs, feed at the lowest trophic level feeding largely as herbivores, relying primarily on ingestion of phytoplankton. Therefore, the culture process does not rely on the input of feedstuffs into the aquatic environment. Suspension feeding bivalves filter suspended matter from the water column and the resulting faeces and pseudofaeces (non-ingested material) are then deposited onto the seafloor, this is known as biodeposition and is a component of a greater process called benthic-pelagic coupling. This deposition can accumulate on the seafloor beneath aquaculture installations (suspended and intertidal culture) and can alter the local sedimentary habitat type in terms of organic content and particle size which has the potential to alter the infaunal community therein; in the case of bottom culture this deposition results in the formation of 'mussel mud' directly beneath the mussels themselves.

Moderate enrichment due to deposition can lead to increased diversity due to increased food availability; however further enrichment can lead to a change in sediment biogeochemistry (e.g. oxygen levels decrease and sulphide levels increase) which can result in a reduction in species richness and abundance resulting in a community dominated by specialist species. In extreme cases of protracted organic enrichment anoxic conditions may occur where no fauna survives and the sediment may become blanketed by a bacterial mat. Changes to the sedimentary habitat due to deposition are indicated by a decrease in oxygen levels, increased sulphide reduction, decrease in REDOX depth and particle size changes.

Several factors can affect the rate of deposition onto the seafloor; these include structure and culture density, site hydrography and site history. Oysters and mussels have a 'plastic response' to increased levels of suspended matter in the water column and can modify their filtration rate accordingly and thus increase the production of pseudofaeces which results in an increase in transfer of particles to the seafloor. The degree to which the material disperses away from the footprint of the culture system (e.g. Longlines, BST Longlines, floats, trestles & bags etc.) is governed by the density of mussels/oysters on the system, the depth of water and the water currents in the vicinity. It is likely that some overlap in effect will be realised. The duration and extent to which culture has been conducted on site may lead to cumulative impacts on the seabed, especially in areas where assimilation or dispersion of faeces/pseudofaeces is not rapid. A number of features of the site and culture practices will govern the speed at which faeces/pseudofaeces are assimilated or dispersed by the site. These relate to:

Hydrography-(residence time, tidal range, residual flow) govern how quickly the wastes disperse from the culture location and the density at which they will accumulate on the seafloor i.e. the greater the tidal range and residual flow then the greater the rate of dispersion and therefore the risk of accumulation is reduced.

Turbidity in the water-the higher the water turbidity the greater the production of pseudo-faeces/faeces by the suspension feeding animal ('plastic response') and therefore greater the risk of accumulation on the seafloor.

Density of structures-high density of culture structures (e.g. Longlines, BST Longlines, floats, trestles & bags etc.) can result in the slowing of water currents/impediment of water flow (baffling effect), slow it down and cause localised deposition of material on the seafloor.

Density of culture-the greater the density organisms the greater the risk of accumulations of material, suspended culture is considered a dense culture method with high densities of culture organisms over a small area. The density of culture organisms is a function of:

a. depth of the site (shallow sites have shorter droppers and hence fewer culture organisms),
b. husbandry practices – proper maintenance will result in optimum densities on the lines as well as ensuring a reduced risk of drop-off of culture animals to the seafloor as well as ensuring a sufficient distance among the longlines to reduce the risk of cumulative impacts in depositional areas.

4.1.2 Seston filtration-All culture methods

Suspension feeding bivalves such as mussels and oysters have a large filtration capacity and in confined areas have been shown to alter the phytoplankton and zooplankton community abundance and structure and therefore potentially impact on the production of an area. This method of feeding may reduce water turbidity hence increasing light penetration, which may increase phytoplankton production and therefore food availability. This increase in light penetration can have positive effects on light sensitive species such as maerl, seagrass and macroalgae.

4.1.3 Shading-Subtidal-Suspended culture

The structures associated with suspended culture (e.g. Longlines, BST Longlines, floats, trestles & bags etc.) can prevent light penetration to the seabed and therefore potentially impact on light sensitive species such as maerl, seagrass and macroalgae.

4.1.4 Fouling/Habitat creation-All culture methods

The structures associated with aquaculture, and the culture organisms themselves provide increased habitat for fouling species to colonise and therefore increase diversity; results in increased secondary production and increased nekton production.

4.1.5 Introduction of Non-native species- All culture methods

Movement and introduction of bivalve shellfish can be a vector for the introduction and spread of non-native/alien species. In some instances the introduced species may proliferate rapidly and compete with and in some cases replace the native species. A recent survey of Lough Swilly (2011) has documented that the pacific oyster (*C. gigas*), introduced for culture purposes, is now established within the native oyster beds and is widespread throughout the Lough (Kochmann, 2012; Kochman et al., in press).

Another means is the unintentional introduction of non-native species/diseases which are associated with the imported target culture species, and their subsequent spread and establishment. These associated species are referred to as 'hitch-hikers' and include animals and plants and/or parasites and diseases that potentially could cause outbreaks within the culture species or spread to other local species.

The introduction and establishment of non-native species can result in loss of native biodiversity due to increased competition for food and habitat and also predation and/or disease.

4.1.6 Disease risk-All culture methods

Due to the nature of the culture methods the risk of transmission of disease from cultured to wild stocks is high, e.g. the introduction of the parasitic protozoan *Bonamia ostreae*, which has caused the mass mortality within Irish native Oyster Beds. This risk can be limited by compiling a bio security plan, screening all introduced stock prior to transferring to on growing site and also good animal husbandry. Disease risk associated with movement of shellfish is governed by Fish health legislation on the movement of shellfish stocks into and out of culture areas and will not be considered further in this assessment.

4.1.7 Monoculture-Bottom culture

The relaying of mussels on the seabed also alters the infaunal community in terms of number of individuals and number of species present. As the habitat is dominated by single species this may lead to the transformation of an infaunal dominated community to an epifaunal dominated community and also cause alteration of sediment type and chemistry due to the production of mussel 'mud' (see 6.2.9 below).

4.1.8 By-catch mortality-Bottom culture

Mortality of organisms captured or disturbed during the harvest and damage to structural fauna or reefs.

4.1.9 Nutrient Exchange - All culture methods

By their suspension feeding nature, removing particulate matter from the water column and releasing nutrients in solid and dissolved forms, bivalves influence benthic-pelagic coupling of organic matter and nutrients. Intensive bivalve culture can cause changes in ammonium and dissolved inorganic nitrogen resulting in increased primary production. The removal of Nitrogen from the system is caused by both removal via harvest or denitrification at sediment surface.

Physical effects of aquaculture

4.1.10 Current alteration-Suspended culture

The structures used in aquaculture (e.g. Longlines, BST Longlines, floats, trestles & bags etc.) can alter the hydrodynamics of an area i.e. increase/decrease water flow, this is known as the 'Baffling effect'. An increase in water flow will result in scouring of the seafloor leading to an increase in coarse sediment while a decrease in current flow will result in an increase in the amount of fine particles being deposited. Both result in a change in the sedimentary habitat structure and therefore can lead to change in the composition of the benthic infaunal community.

4.1.11 Surface disturbance-All culture methods

All aquaculture activities physically alter the receiving habitat, but the level of this disturbance depends on the culture method employed. The culture of bivalves on the seabed (on-bottom) in an uncontained fashion involves the dredging of the seafloor at various stages in the culture process i.e. the collection of seed mussels and relaying of spat, routine maintenance, removal of predators ('mopping'), stock movements and finally harvesting. The frequency of dredging activity depends site management and how often stock is moved to new ongrowing areas to maximise growth and minimise predation prior to harvest. This dredging activity physically disturbs the seafloor and the organisms therein, and has been demonstrated to cause habitat and community changes.

The intertidal culture of bivalves (e.g. BST Longlines, Bags & trestles) does not require dredging and therefore is less damaging (physically) to the seafloor than the bottom culture method. However, the intertidal habitat can be affected by ancillary activities on-site i.e. servicing, vehicles on shore; human traffic and boat access lanes, causing an increased risk of sediment compaction resulting in sediment changes and associated community (infaunal and epifaunal) changes. Such activities can result in shallow and/or deep physical disturbance causing burrows to collapse, deeply burrowed organisms to die due to smothering and/or preventing siphon connection to the sediment surface or by directly crushing the animal.

4.1.12 Shading-Suspended culture

The structure associated with suspended culture (e.g. Longlines, BST Longlines, floats, trestles & bags etc.) have the potential to prevent light penetration to the seabed and therefore potentially impact on light sensitive species such as maerl, seagrass and macroalgae.

Potential Effects of fisheries

4.1.13 Biological effect of the oyster FNP

The objectives of the FNP are to increase the standing stock (density and biomass) of native oyster in native oyster beds. As such certain biological effects, namely increased deposition of organic material, seston filtration, nutrient exchange, extraction of the target species (native oyster) and by-catch mortality may be expected. Physical effects of dredging involves seabed surface and sub-surface disturbance summarized above and below in Table 4..

Table 4: Potential indicative environmental pressures of aquaculture and fishery activities within the qualifying interest (Estuary) of Lough Swilly.

CULTURE METHOD	PRESSURE CATEGORY	PRESSURE	POTENTIAL EFFECTS	EQUIPMENT	DURATION (DAYS)	TIME OF YEAR	FACTORS CONSTRAINING THE ACTIVITY/EFFECTS
Suspended - Bags & trestles; BST longlines (Oysters)	**Biological**	Deposition	Faecal and pseudofaecal deposition on seabed potentially altering sediment and community composition		365	All year	Hydrography, Turbidity, Culture/structure density
		Seston filtration	Alteration of phyto/zooplankton communities and potential impact on carrying capacity		365	All year	Culture density, Turbidity
		Shading	Prevention of light penetration to seabed potentially impacting light sensitive species		365	All year	Culture/structure density
		Fouling	Increased secondary production on structures and culture species. Increased nekton production		365	All year	Culture/structure density
		Introduction of non-native species	Potential for non-native culture and 'hitchhiker' species become naturalized				Screening/ Culture method/ Introduce biosecurity plan
		Disease risk	Potential for disease introduction and uncontrolled spread				Screening/ Introduce biosecurity plan
		Monoculture	Habitat dominated by single species; Potential transformation of infaunal dominated community to epifaunal dominated community.				
		Nutrient exchange	Changes in ammonium and dissolved inorganic nitrogen				Culture density

CULTURE METHOD	PRESSURE CATEGORY	PRESSURE	POTENTIAL EFFECTS	EQUIPMENT	DURATION (DAYS)	TIME OF YEAR	FACTORS CONSTRAINING THE ACTIVITY/EFFECTS
			resulting in increased primary production. N_2 removal at harvest or denitrification at sediment surface.				
	Physical	Current alteration	Structures may alter the current regime resulting in increased deposition of fines or scouring therefore changing sedimentary composition	Long lines, Baskets, Bags, Trestles, Floats etc	365	All year	Culture/structure density
		Surface disturbance	Ancillary activities at sites increase the risk of sediment compaction resulting in sediment changes and associated community changes.	Site services, human & vehicular traffic			
		Shading	Structures prevent light penetration to the seabed and therefore potentially impact on light sensitive species	Long lines, Baskets, Bags, Trestles, Floats etc	365	All year	Culture/structure density
Bottom (Mussels, Oysters)	**Biological**	Deposition	Faecal and pseudofaecal deposition on seabed potentially altering sediment and community composition		365	All year	Hydrography, Turbidity, Culture/structure density
		Seston filtration	Alteration of phyto/zooplankton communities and potential impact on carrying capacity		365	All year	Culture density, Turbidity
		Fouling	Increased secondary production on culture species. Increased nekton production		365	All year	Culture density

CULTURE METHOD	PRESSURE CATEGORY	PRESSURE	POTENTIAL EFFECTS	EQUIPMENT	DURATION (DAYS)	TIME OF YEAR	FACTORS CONSTRAINING THE ACTIVITY/EFFECTS
		Introduction of non-native species	Potential for non-native culture and 'hitchhiker' species become naturalized				Screening, Culture method
		Disease risk	Potential for disease introduction and uncontrolled spread				Screening
		Nutrient exchange	Changes in ammonium and dissolved inorganic nitrogen resulting in increased primary production. N_2 removal at harvest or denitrification at sediment surface.		365	All year	Culture density
	Physical	Surface disturbance	Ancillary activities at sites increase the risk of sediment compaction resulting in sediment changes and associated community changes.	Site services, human & vehicular traffic	365?	All year	Good Site practices
		Surface disturbance	Abrasion at the sediment surface and redistribution of sediment	Dredge 'Mop'	Variable depends on predator numbers	Mar-May; Sept-Nov	Predation control Refer to Table 2
		Sub-surface disturbance	Shallow and deep disturbance, Epifaunal and infaunal community disturbance	Dredge	Seed collection, relaying spat, acclimatisation, stock movements and harvesting	Aug-Oct; Oct-Sept;	Refer to Table 2
Oyster fishery plan	Biological	Deposition, Seston filtration and nutrient exchange as described above		Oyster dredges		Sept to March	Conditions in the FNP

CULTURE METHOD	PRESSURE CATEGORY	PRESSURE	POTENTIAL EFFECTS	EQUIPMENT	DURATION (DAYS)	TIME OF YEAR	FACTORS CONSTRAINING THE ACTIVITY/EFFECTS
		Extraction	Removal of target species	Oyster dredges		Sept to March	Conditions in the FNP
	Physical	Surface and sub-surface disturbance	Surface and shallow sub-surface disturbance of epifauna and infauna	Oyster dredges		Sept to March	Conditions in the FNP

5 Appropriate Assessment Screening

An appropriate assessment screening is an initial evaluation of the possible impacts that activities may have on the qualifying interests. The screening, is a filter, which may lead to exclusion of certain activities from appropriate assessment proper, thereby simplifying the assessments, if this can be justified unambiguously using limited and clear cut criteria. Screening is a conservative filter that minimises the risk of false negatives.

In this assessment screening of the qualifying interests against the proposed activities is based solely on spatial overlap i.e. if the qualifying interests overlap spatially with the proposed activities then significant impacts due to these activities on the conservation objectives for the qualifying interests is not discounted (not screened out) except where there is absolute and clear rationale for doing so. Where there is relevant spatial overlap appropriate assessment proper is warranted. Likewise if there is no spatial overlap then the possibility of significant impact is discounted and further assessment of possible effects is deemed not to be necessary. Table 5 provides spatial overlap extent between designated habitats and aquaculture activities within the qualifying interests of Lough Swilly SAC.

Aquaculture Activity Screening

- Table 5 provides an overview of overlap of aquaculture activities and habitat features (identified from Conservation Objectives).
- None of the aquaculture activities overlap with 1150 (Coastal Lagoons-Blanket Nook Lough and Inch Lough), 1330 (Atlantic salt meadows), 91AO (Old sessile oak woods with Ilex and Blechnum in the British Isles).
- Where the overlap between an aquaculture activity and a feature is zero it is screened out and not considered further.
- Table 6 lists the percentage overlap of aquaculture activity (species, by status and location) and habitat/community. Each shaded cell (aquaculture activity – benthic community/designated species combination) in Table 6 is assessed separately and in combination in Section 6.

Table 5: Habitat utilisation (spatial overlap by ha) by Aquaculture and fishing activities within the qualifying interest of Lough Swilly based on licence database provided by DAFM and the FNP (Appendix I).

		Aquaculture or fishing activity								
Code	**Designation**	*Mussel Culture- Bottom Culture (licensed)*	*Mussel Culture- Bottom Culture (application)*	*Oyster Culture Bags & Trestles (licensed)*	*Oyster Culture Bags & Trestles (application)*	*Oyster Culture Bags & Trestles; BST Longlines (licensed)*	*Oyster Culture BST Longlines (application)*	*Oyster Culture Bottom Culture (application)*	*Oyster/Mussel Culture- Bottom Culture (licensed)*	*Native Oyster fishery*
1130	**Estuaries**									
	Fine sand community complex	0	40.93	0	0	0	16.36	0	111.49	71.74
	Intertidal Mixed sediment with polychaetes	24.94	46.13	18.19	4.71	13.48		3.15	53.89	167.1
	Mud community complex	6.00	68.75						136.02	71.86
	Muddy fine sand with *Thyasira flexuosa*	48.10	164.40		4.34	46.35	1.56		628.87	263.4
	Ostrea edulis dominated community	200.56	40.05	5.70	4.95			244.64	5.90	877.9
	Subtidal Mixed sediment with polychaetes and bivalves	232.01	188.72	2.36				32.48	237.54	218.5
1150	**Coastal Lagoons**	0	0	0	0	0	0	0	0	0
1330	**Atlantic salt meadows**	0	0	0	0	0	0	0	0	0
1355	**Otter *(Lutra lutra)***	All activities potentially overlap with all designated species but the spatial overlap is not fixed and therefore cannot be calculated								
91AO	**Old sessile oak woods with Ilex and Blechnum in the British Isles**	0	0	0	0	0	0	0	0	0

Table 6: Aquaculture activity (species, by status and location) and habitat overlap. Shaded cells are those taken further in appropriate assessment. Numbers in <u>italics</u> represent the percentage overlap of activity with relevant habitat.

Species	Culture / fishing Method	Licence Status	Fine sand community complex	Intertidal mixed sediment with polychaetes	Mud community complex	Muddy fine sand with *Thyasira flexuosa*	*Ostrea edulis* dominated community	Subtidal Mixed sediment with polychaetes and bivalves
Extent (ha) of marine habitat within qualifying interest (Estuary):			**582.6261**	**655.3023**	**1126.9168**	**1320.4796**	**905.9781**	**1314.0290**
Mussels	**Bottom Culture**	**Licensed**	0	24.94	6.00	48.09	200.56	232.01
				3.81	*0.53*	*3.64*	*22.14*	*17.66*
Mussels	**Bottom Culture**	**Application**	40.93	46.13	68.75	164.40	40.05	188.72
			7.02	*7.04*	*6.10*	*12.45*	*4.42*	*14.36*
Oysters	**Bags & Trestles**	**Licensed**	0	18.2	0	0	5.70	2.36
				2.78			*0.63*	*0.18*
Oysters	**Bags & Trestles**	**Application**	0	4.71	0	4.34	4.95	0
				0.72		*0.33*	*0.55*	
Oysters	**Bags & Trestles; BST Longlines**	**Licensed**	0	13.48	0	46.35	0	0
				2.06		*3.51*		
Oysters	**BST Longlines**	**Application**	16.36	0	0	1.56	0	0
			2.81			*0.12*		
Oysters	**Bottom Culture**	**Application**	0	3.15	0	0	244.64	32.48
				0.48			*27.00*	*2.47*
Oysters/Mussels	**Bottom Culture**	**Licensed**	111.49	53.90	136.02	628.87	5.90	237.54
			19.14	*8.22*	*12.07*	*47.62*	*0.65*	*18.08*
Native oyster fishery	**<u>Dredging</u>**	**Licensed**	71.74	167.1	71.8	263.4	877.9	218.5
			12.31	*25.50*	*6.37*	*19.95*	*96.90*	*16.63*

6 Assessment

Determining significance

The significance of the possible effects of the proposed activities on habitats, as outlined in the Natura Impact statement, is determined here in the appropriate assessment. The significance of effects is determined on the basis of Conservation Objective guidance for constituent habitats (NPWS 2011b) (Figure 8).

Habitats that are key contributors to biodiversity and which are sensitive to disturbance should be afforded a high degree of protection i.e. thresholds for impact on these habitats is low and any significant anthropogenic disturbance should be avoided. Within the Lough Swilly SAC the qualifying habitats are

1. Estuaries (1130)
2. Coastal Lagoons (1150)
3. Atlantic salt meadows (1330)
4. Old sessile oak woods with Ilex and Blechnum in the British Isles (91AO)

Significant disturbance is interpreted in this assessment as indicated in Figure 8. For broad sedimentary communities significance of impact is determined in relation to spatial overlap, disturbance and the persistence of disturbance as follows:

1. The degree to which the activity will disturb the qualifying interest. By disturb is meant change in the characterising species, as listed in the Conservation Objective guidance (NPWS 2011b) for constituent communities. The likelihood of change depends on the sensitivity of the characterising species to the aquaculture activities. Sensitivity results from a combination of intolerance to the activity and recoverability from the effects of the activity (see section 8.1.3 below).
2. The persistence of the disturbance in relation to the intolerance of the community. If the activities are persistent (high frequency, high intensity) and the receiving community has a high intolerance to the activity (i.e. the characterising species of the communities are sensitive and consequently impacted) then such communities could be said to be persistently disturbed
3. The area of communities or proportion of populations disturbed. In the case of community disturbance (continuous or ongoing) of more than 15% of the community area it is deemed to be significant.

In relation to designated species the capacity of the population to maintain itself in the face of anthropogenic induced disturbance or mortality at the site will need to be taken into account in relation to the Conservation Objectives (CO's) on a case by case basis.

Effects will be deemed to be significant when cumulatively they lead to long term change in communities in greater than 15% of the area of any constituent community listed.

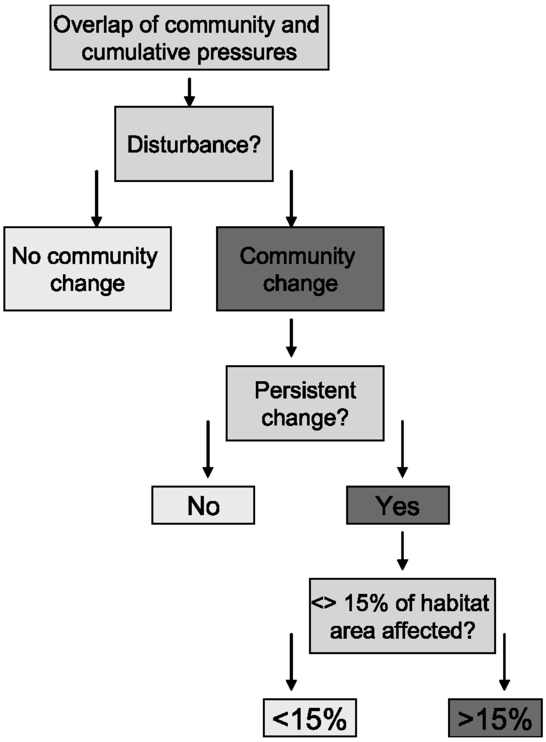


Figure 8: Determination of significant effects on community distribution, structure and function (following NPWS 2011b).

6.1.1 Supporting evidence and confidence in conclusions

There are various levels of supporting evidence and therefore confidence for conclusions on the effects of activities on the conservation objectives for each qualifying interest. The degree of confidence with respect to findings of significant or no significant effects is categorised as high, medium or low (Table 7).

Table 7: Level of confidence, based on supporting evidence, in relation to significance of effects and the implication for management decisions.

Level of confidence	**Supporting evidence**	**Implication in relation to significance**	
		Where effects are found to be **significant** (>15% of any community type is persistently disturbed)	Where effects are found to be **insignificant** (<15% of any community type is persistently disturbed or where the activity occurs on >15% of the area but is not persistent or activity that is persistent in >15% of the area but is not considered disturbing)
High	Direct measurement of effects at the site	The impacting activity is unlikely to be allowed until the effects can be mitigated (i.e. brought below agreed thresholds).	The activities can proceed without mitigation
Moderate	Effects deduced from similar activities at similar sites		The activities can proceed but precautionary mitigation may be introduced.
Low	Expert judgement, ecological theory and expectation	The impacting activity may not be allowed until direct measurements of effects at the site shows evidence of non-significant effects	The activities can proceed but only with significant precautionary mitigation and agreement to provide direct evidence of non-significant effects within an agreed time scale

6.1.2 Sensitivity assessment rationale

This assessment primarily employed two sources of information in assessing the sensitivity of the characterising species of each community recorded within the Estuarine habitat of Lough Swilly - the MarLIN Sensitivity Assessment (Marlin.ac.uk) and the AMBI Sensitivity Scale (Borja *et al.*, 2000). The former assessment lists the sensitivity of species/habitat/community to a range of pressures while the latter lists the sensitivity of a species to the pressure of organic enrichment predominantly. Sensitivity of a species to a given pressure is the product of the intolerance (the susceptibility of the species to damage, or death, from an external factor) of the species to the particular pressure and the time taken for its subsequent recovery (recoverability-the ability to return to a state close to that which existed before the activity or event caused change). Life history and biological traits are important determinants of sensitivity of species to pressures from aquaculture.

The separate components of sensitivity (intolerance, recoverability) are relevant in relation to the persistence of the pressure

- For persistent pressures i.e. activities that occur frequently and throughout the year recovery capacity may be of little relevance except for species/habitats that may have extremely rapid (days/weeks) recovery capacity or whose populations can reproduce and recruit in balance with population damage caused by aquaculture. In all but these cases and if intolerance is moderate or high then the species may be negatively affected and will exist in a modified state. Such interactions between aquaculture and species/habitat/community represent persistent disturbance. They become significantly disturbing if more than 15% of the community is thus exposed (NPWS 2011b).
- In the case of episodic pressures i.e. activities that are seasonal or discrete in time both the intolerance and recovery components of sensitivity are relevant. If intolerance is high but recoverability is also high relative to the frequency of application of the pressure then the species/habitat/community will be in favourable conservation status for at least a proportion of time.

The sensitivities of species which are characteristic (as listed in the COs) of benthic communities to pressures similar to those caused by aquaculture (e.g. smothering, organic enrichment and physical disturbance) are listed, where available, in Tables 8, 9 and 10. In cases where the sensitivity of a characterising species (NPWS 2011b) has not been reported this appropriate assessment adopts the following guidelines

- Intolerance of certain taxonomic groups such as emergent sessile epifauna to physical pressures is expected to be generally high or moderate because of their form and structure (Roberts *et al.* 2010). Also high for those with large bodies and with fragile shells/structures, but low for those with smaller body size. Body size (Bergman and van Santbrink 2000) and fragility are regarded as indicative of a high intolerance to physical abrasion caused by fishing gears (i.e. dredges). However, even species with a high intolerance may not be sensitive to the disturbance if their recovery is rapid once the pressure has ceased.
- Intolerance of certain taxonomic groups to increased sedimentation is expected to be low for species which live within the sediment, deposit and suspension feeders; and high for those sensitive to clogging of respiratory or feeding apparatus by silt or fine material.
- Recoverability of species depends on biological traits (Tillin *et al.* 2006) such as reproductive capacity, recruitment rates and generation times. Species with high reproductive capacity, short generation times, high mobility or dispersal capacity may maintain their populations even when faced with persistent pressures; but such environments may become dominated by these (r-selected) species. Slow recovery

is correlated with slow growth rates, low fecundity, low and/or irregular recruitment, limited dispersal capacity and long generation times. Recoverability, as listed by MarLIN, assumes that the impacting factor has been removed or stopped and the habitat returned to a state capable of supporting the species or community in question. The recovery process is complex and therefore the recovery of one species does not signify that the associated biomass and functioning of the full ecosystem has recovered (Anand & Desrocher, 2004) cited in Hall *et al.*, 2008).

Sensitivity of benthic species and communities in relation to potential disturbance by individual aquaculture activities

Aquaculture pressures on a given habitat are related to vulnerability (spatial overlap or exposure of the habitat to the equipment/culture organism combined with the sensitivity of the habitat) to the pressures induced by culture activities. To this end the location and orientation of structures associated with the culture organism, the density of culture organisms, the duration of the culture activity and the type of activity are all important considerations when considering risk of disturbance to habitats.

NPWS (2011b) provide lists of species characteristic of benthic communities that are defined in the Conservation Objectives. Different species and habitats will have different tolerance to the pressures associated with shellfish aquaculture activities (pressures as discussed in Chapter 6).

6.2.1 Mussel Bottom Culture

Mussel Bottom Culture (licensed) covers 511.6ha of the qualifying interest (Estuary) within the Lough Swilly SAC (Figure 9).

Mussel Bottom Culture (applications) covers 549ha of the qualifying interest (Estuary) within the SAC in (Figure 9).

This aquaculture type overlaps all of the six different community types found within the qualifying interest of Lough Swilly SAC.

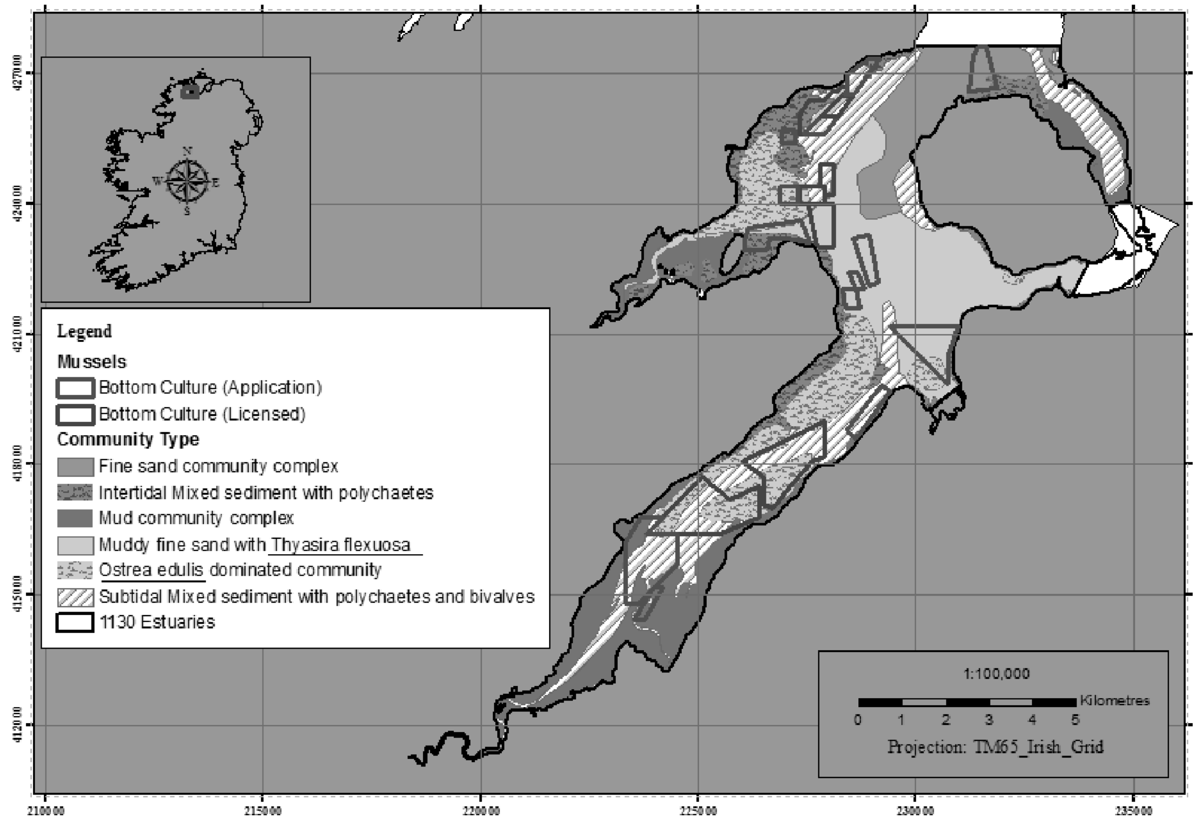


Figure 9: Spatial overlap between bottom mussel culture sites (Applications-blue; Licensed red) and habitats within the qualifying interest of Lough Swilly SAC.

The potential impacts of the bottom mussel culture on the sedimentary communities of Lough Swilly are:

- **Biodeposition** on the seabed of mussel faeces and pseudofaeces can lead to organic enrichment and smothering. The bottom culture of mussels on the seafloor alters the sedimentary habitat and leads to the development of 'mussel mud' beneath the mussel bed as the filtration and feeding activities of the mussels increase sedimentation rates. These deposits are composed of dead shells, silt and pseudofaeces, which can persist in excess of 18mths after the mussels have been removed (Kaiser and Beadman, 2002). Deposition can therefore result in a change in sediment type which in turn can result in changes to the biological communities within. The production of biodeposits by mussels is a function of, (1) The level of seston in the water column (Tenore and Dunstan 1973; Kautsky and Evans 1987; Navarro and Thompson 1997) and, (2) the size of the mussel, such that larger mussels will produce greater quantities of bio-deposits in absolute terms (Callier *et al.* 2006). The duration of the activity is year-round resulting in a risk of chronic organic enrichment of the seafloor. Benthic responses to organic enrichment have been described by Pearson & Rosenberg (1978) and Gray (1981). Moderate enrichment can lead to increased diversity however as enrichment increases diversity will decline and the community will become dominated by fewer species tolerant of organic enrichment.
- **Physical disturbance:** The dredging activities (seed relaying, stock movements, predator control and harvesting) associated with this culture practice are deemed to be disturbing to the physical habitat and to the resident faunal community. Such physical disturbance can lead to the removal and/or destruction of infaunal species and changes to sediment composition. Although some individual species are deemed to have a high recoverability from this pressure (based on biological traits) this assumes the pressure has

ceased and is not ongoing. In Lough Swilly dredging occurs on a number of occasions throughout the year (refer Table 1) and may be classed as a persistent disturbance. A study carried out by Dernie *et al.* (2003) demonstrated a strong relationship between the rate at which the physical structure of soft sediment habitats was restored and the rate at which the biological components of the system recover. Recovery was shown to be most rapid for clean sand habitats, intermediate for mud habitats and longest for muddy-sand habitats.

- **Monoculture:** The location of large numbers of a single epifaunal species onto sedimentary habitats characterised by infaunal communities can smother existing fauna and/or result in a change to the habitat and thereby the biological community contained therein. Sessile epifaunal species would also be affected, and some would not survive such smothering. The duration of the activity is year-round resulting in continuous disturbing impact upon the resident community from this pressure.
- **Disease risk:** Due to the uncontained fashion by which the culture organisms are relayed on the seafloor, complete removal may not be possible if required in the event of disease outbreak.
- **Introduction of non-native species:** There is a risk associated with the introduction seed from outside Ireland although the risk of introduction of listed diseases in the target organism are monitored and mitigated under legislation (Council Directive 2006/88/EC which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases). However, this practice presents the risk of establishment and spread of species that are associated with the introduced bivalves (Carlton 1989, 1999). These species may include both "hitchhiking" species i.e., animals and plants that grow associated with the bivalves and both listed and potentially non-listed diseases or parasites that may cause outbreaks in the same or other species (Barber 1996). If non-native species become established habitat structure and function may change.

Community Type: Fine Sand Community Complex

- Applications for the bottom culture of mussels overlap with 40.92ha of the Fine sand community complex; this overlap constitutes 7.02% of the habitat area for this community type within the qualifying interest.
- This community complex is characterized by a range of infaunal species-the polychaetes *Spiophanes bombyx*, *Lumbrineris latreilli*, *Pygospio elegans*, *Nemertea* spp., *Nephtys hombergii*, *Scoloplos armiger*; the oligochaete *Tubificoides benedii*; the bivalves *Angulus tenuis, Donax vittatus, Thracia papyracea* and *Phaxas pellucidus* and the amphipods *Bathyporeia pilosa* and *B. elegans*. There are three variants of this community recorded within Lough Swilly, however only Variant 3 is present within the boundary of the Annex 1 habitat. This variant is characterised by the polychaetes *Spiophanes bombyx*, *Lumbrineris latreilli*, *Nephtys hombergii*, and the bivalves *Thracia papyracea* and *Phaxas pellucidus*.
- The species characterising this community complex (variant 3) are typically infaunal polychaetes and bivalves. The latter are deemed sensitive to organic enrichment (Table 8), but none of the characterising species are considered sensitive to smothering (≤5cm sedimentation) as they are mobile and can migrate up through any additional sediment (Table 9).
- These characteristic infaunal species would likely be extirpated from the footprint of the area covered by the culture organism and would only recover if the culture organism was removed and settlement occurred from adjacent communities.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e.

dredging). However their recoverability (based on biological traits) is classed as high to very high therefore their sensitivity to the pressure is low (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is continuous and ongoing and therefore recoverability may be affected.

- **The percentage of the community that will be thus affected is 7.02%.**

Conclusion: Considering the range of impacts identified above and the persistent nature of the pressure, this activity is considered disturbing on Fine Sand Community Complex.

<u>Community Type: Intertidal Mixed Sediment with Polychaetes</u>

- Sites licensed for the bottom culture of mussels overlap with 24.9ha of the Intertidal Mixed Sediment with Polychaetes community; this overlap constitutes 3.8% of the habitat area for this community type within the qualifying interest. Applications for this culture method also overlap this community type by 46.1ha which is a 7% overlap. In total, therefore, this culture method (applications & licensed) overlaps 71ha (10.8%) of the Intertidal Mixed Sediment with Polychaetes community.
- This community is characterized by a range of infaunal polychaetes *Pygospio elegans* (tube dwelling) *Eteone* sp., *Scoloplos armiger*, *Glycera tridactyla*, *Anaitides mucosa*, *Euclymene oerstedii*, the oligochaete *Tubificoides benedii* and the bivalve *Cerastoderma edule*.
- These characteristic infaunal species would likely be extirpated from the footprint of the area covered by the culture organism and would only recover if the culture organism was removed and settlement occurred from adjacent communities.
- The species characterising this community are typically infaunal polychaetes and bivalves tolerant/indifferent of organic enrichment, with the exception of *Euclymene oerstedii* which is sensitive (Table 4.1). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments. Species present have no/low sensitivity to smothering by sedimentation (Table 9)
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *C. edule* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is continuous and ongoing and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 10.8%.**

Conclusion: Considering the range of impacts identified above and the persistent nature of the pressure, this activity is considered disturbing on Intertidal Mixed Sediment with Polychaetes community.

AMBI Classification/	Sensitive (I)	Indifferent (II)	Tolerant (III)	Second-order opportunistic (IV)	First-order opportunistic (V)
Community	**Characterising species**				
Fine Sand Community Complex (Variant 3)	*Thracia papyracea* *Phaxas pellucidus*	*Lumbrineris latreilli* *Nephtys hombergii*	*Spiophanes bombyx*		
Intertidal Mixed Sediment with Polychaetes	*Euclymene oerstedii*	*Glycera tridactyla*	*Pygospio elegans* *Scoloplos armiger* *Eteone* sp. *Cerastoderma edule*		*Tubificoides benedii*
Subtidal Mixed Sediment with Polychaetes and Bivalves	*Timoclea ovata* *Venerupis senegalensis* *Parvicardium exiguum* *Ampharete lindstroemi* *Diplocirrus glaucus* *Leptochiton cancellatus*	*Lumbrineris latreilli* *Pomatoceros triqueter*	*Abra alba* *Scoloplos armiger*		*Capitomastus minima*
Muddy Fine Sand with *Thyasira flexuosa*	*Euclymene oerstedii* *Ampelisca brevicornis* *Phaxas pellucidus* *Thracia papyracea* *Nucula nitidosa*	*Nephtys hombergii* *Ophiodromus flexuosus*	*Scoloplos armiger* *Notomastus latericeus* *Scalibregma inflatum* *Abra nitida* *Thyasira flexuosa* *Abra alba*	*Prionospio fallax*	
Mud Community Complex		*Nephtys hombergii*	*Corophium volutator* *Pygospio elegans* *Etone sp.* *Hediste diversicolor* *Macoma balthica* *Scrobicularia plana* Nematoda sp.		*Tubificoides benedii* *Tubificoides pseudogaster*
Ostrea edulis Dominated Community	Refer to communities 2 and 3 above *Ostrea edulis*				

Table 8: Sensitivities to organic enrichment (based on the AMBI classification) of species characteristic of communities which have spatial overlap with aquaculture activities within the Annex 1 Habitats of Lough Swilly SAC.

Table 9: Sensitivity assessment to increased smothering (≤5cm; permeable material) (as reported in www.marlin.ac.uk) of characterising species (numerically dominant) of communities which have spatial overlap with aquaculture activities within the Annex 1 Habitats of Lough Swilly SAC.

	Characterising species						**Dominant taxonomic groups**			
Community	1	2	3	4	5	6	1	2	3	4
Fine Sand Community Complex (Variant 3)	***Spiophanes bombyx***	***Thracia papyracea***	***Phaxas pellucidus***	***Nephtys hombergii***	***Lumbrineris latreilli***		Polychaetes	Bivalves		
Intertidal Mixed Sediment with Polychaetes	***Pygospio elegans***	***Eteone* sp.**	***Scoloplos armiger***	***Glycera tridactyla***	***Tubificoides benedii***	***Cerastoderma edule***	Polychaetes	Oligochaetes	Bivalves	
Subtidal Mixed Sediment with Polychaetes and Bivalves	***Pomatoceros triqueter***	***Lumbrineris latreilli***	***Capitomastus minima***	***Scoloplos armiger***	***Abra alba***	***Timoclea ovata***	Polychaetes	Bivalves		
Muddy Fine Sand with *Thyasira flexuosa*	***Thyasira flexuosa*** *****	***Scoloplos armiger***	***Nephtys hombergii***	***Euclymene oerstedii***	***Ampelisca brevicornis***	***Phaxas pellucidus***	Bivalves	Polychaetes	Amphipods	
Mud Community Complex	***Tubificoides benedii***	***Macoma balthica***	***Scrobicularia plana***	***Corophium volutator***	***Hediste diversicolor***	***Nephtys hombergii***	Oligochaetes	Bivalves	Amphipods	Polychaete
Ostrea edulis Dominated Community	**Refer to communities2 and 3 above**	*Ostrea edulis*								

Sensitivity code :

Low = Low/Intermediate intolerance, High recoverability	**Not sensitive=Tolerant/Low intolerance, Not relevant/Immediate recoverability**
Very High = High Intolerance, Very low recoverability	**Moderate = High intolerance/High recoverability**

Table 10: Sensitivity assessment to **physical disturbance** (as reported in www.marlin.ac.uk) of characterising species (numerically dominant) of communities which have spatial overlap with aquaculture activities within the Annex 1 Habitats of Lough Swilly SAC.

	Characterising species						**Dominant taxonomic groups**			
Community	1	2	3	4	5	6	1	2	3	4
Fine Sand Community Complex (Variant 3)	***Spiophanes bombyx***	***Thracia papyracea***	***Phaxas pellucidus***	***Nephtys hombergii***	***Lumbrineris latreilli***		Polychaetes	Bivalves		
Intertidal Mixed Sediment with Polychaetes	***Pygospio elegans***	***Eteone sp***	***Scoloplos armiger***	***Glycera tridactyla***	***Tubificoides benedii***	***Cerastoderma edule***	Polychaetes	Oligochaetes	Bivalves	
Subtidal Mixed Sediment with Polychaetes and Bivalves	***Pomatoceros triqueter***	***Lumbrineris latreilli***	***Capitomastus minima***	***Scoloplos armiger***	***Abra alba***	***Timoclea ovata***	Polychaetes	Bivalves		
Muddy Fine Sand with *Thyasira flexuosa*	***Thyasira flexuosa***	***Scoloplos armiger***	***Nephtys hombergii***	***Euclymene oerstedii***	***Ampelisca brevicornis***	***Phaxas pellucidus***	Bivalves	Polychaetes	Amphipods	
Mud Community Complex	***Tubificoides benedii***	***Macoma balthica***	***Scrobicularia plana***	***Corophium volutator***	***Hediste diversicolor***	***Nephtys hombergii***	Oligochaetes	Bivalves	Amphipods	Polychaetes
Ostrea edulis Dominated Community	***Refer to communities 2 and 3 above***	*Ostrea edulis*								

Sensitivity to code :

Low = Low/Intermediate intolerance, Very/High recoverability	**Not Sensitive= Tolerant/Low intolerance, Not relevant/Immediate recoverability**
Moderate = High intolerance, High recoverability	**High = Intermediate intolerance, Low recoverabilty**

Community Type: Subtidal Mixed Sediment with Polychaetes and Bivalves

- Sites licensed for the bottom culture of mussels overlap with 232ha of the Subtidal Mixed Sediment with Polychaetes and Bivalves; this overlap constitutes 17.7% of the habitat area for this community type within the qualifying interest. Applications for this culture method also overlap this community type by 188.7ha which is a 14.4% overlap. In total, therefore, this culture method (applications & licensed) overlaps 420.7ha (32.1%) of the Subtidal Mixed Sediment with Polychaetes and Bivalves community.
- A high number of distinguishing species were recorded for this community; the following were present in medium to high abundance: the polychaetes *Pomatoceros triqueter, Lumbrineris latreilli, Capitomastus minima* and *Scoloplos armiger* and bivalves *Abra alba* and *Timoclea ovata.*
- The bivalves *Timoclea ovata*, *Venerupis senegalensis* and *Parvicardium exiguum* recorded within this community are deemed sensitive to organic enrichment (Table 8); *C. minima* is an opportunistic (first order) species which proliferates in reduced environments. The tube worm *P. triqueter* is deemed sensitive to smothering (Table 9).
- These characteristic infaunal species would likely be extirpated from the footprint of the area covered by the culture organism and would only recover if the culture organism was removed and settlement occurred from adjacent communities.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *A. alba* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure (mussel bottom culture) is continuous and ongoing and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 32.1%.**

Conclusion: Considering the range of impacts identified above and the persistent nature of the pressure, this activity is considered disturbing on Subtidal Mixed Sediment with Polychaetes and Bivalves community.

Community Type: Muddy Fine Sand with *Thyasira flexuosa*

- Sites licensed for the bottom culture of mussels overlaps with 48.1ha of the Muddy Fine Sand with *Thyasira flexuosa* community; this overlap constitutes 3.6% of the area for this community type within the qualifying interest. Applications for this culture method also overlap this community type by 164.4ha which is a 12.5% overlap. In total, therefore, this culture method (applications & licensed) overlaps 212.5ha (16.1%) of the Muddy Fine Sand with *Thyasira flexuosa* community.
- This community is characterized by the infaunal bivalve *Thyasira flexuosa*. The polychaetes *Scoloplos armiger*, *Nephtys hombergii* and *Euclymene oerstedii,* the amphipod *Ampelisca brevicornis* and the bivalve *Phaxas pellucidus* are also commonly present.
- Three of these distinguishing species (*Euclymene oerstedii, Ampelisca brevicornis, Phaxas pellucidus*) and the bivalves *Thracia papyracea* and *Nucula nitidosa* are sensitive to organic enrichment (Table 8); Species present are not deemed sensitive to smothering (Table 9).

- These characteristic infaunal species would likely be extirpated from the footprint of the area covered by the culture organism and would only recover if the culture organism was removed and settlement occurred from adjacent communities.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However, depending on their recoverability their sensitivity to it varies. The bivalve *T. flexuosa* is deemed to have intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is continuous and ongoing and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 16.1%.**

Conclusion: Considering the range of impacts identified above and the persistent nature of the pressure, this activity is considered disturbing on Muddy Fine Sand with *Thyasira flexuosa* community.

Community Type: Mud Community Complex

- Sites licensed for the bottom culture of mussels overlaps with 6ha of the Mud Community Complex; this overlap constitutes 0.5% of the area for this community type within the qualifying interest. Applications for this culture method also overlap this community type by 68.7ha which is a 6.1% overlap. In total, therefore, this culture method (applications & licensed) overlaps 74.7ha (6.6%) of the Mud Community Complex.
- This community is characterized by the oligochaete *Tubificoides benedii*, the bivalves *Macoma balthica* and *Scrobicularia plana*, the amphipod *Corophium volutator* and the polychaetes *Pygospio elegans, Eteone* sp., *Nephtys hombergii* and *Hediste diversicolor.*
- The characterizing species is an opportunistic species (1^{st} order) indicative of an environment under stress/ which proliferates in reduced environments; all other characterising species are tolerant/indifferent to organic enrichment (Table 8). Species present are deemed to have a low sensitivity to smothering (Table 9).
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However, depending on their recoverability their sensitivity to it varies. The bivalve *Macoma balthica* is deemed to have intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 4.3). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is continuous and ongoing and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 6.6%.**

Conclusion: Considering the range of impacts identified above and the persistent nature of the pressure, this activity is considered disturbing on Mud Community Complex.

Community Type: *Ostrea edulis* dominated community

- Sites licensed for the bottom culture of mussels overlaps with 201ha of the *Ostrea edulis* dominated community; this overlap constitutes 22.1% of the area for this community type within the qualifying interest. Applications for this culture method also overlap this community type by 40ha which is a 4.4% overlap. In total, therefore, this culture method (applications & licensed) overlaps 241ha (26.5%) of the *Ostrea edulis* dominated community.
- This community occurs in those areas described as an Intertidal mixed sediment with polychaetes and a Subtidal mixed sediment with polychaetes and bivalves and therefore its distinguishing fauna is a combination of both. This community is therefore characterized by a wide range of species, those present in moderate to high numbers include the polychaetes *Capitomastus minima, Eteone* sp., *Euclymene oerstedii*, *Glycera tridactyla*, *Lumbrineris latreilli, Pygospio elegans, Scoloplos armiger*, *Pomatoceros triqueter,* the oligochaete *Tubificoides benedii* and the bivalves *Abra alba, Cerastoderma edule* and *Timoclea ovata.*
- The species characterising this community are typically infaunal polychaetes and bivalves tolerant/indifferent of organic enrichment, with the exception of *E. oerstedii* and *T. ovata* which are sensitive (Table 8). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments. Species listed have no/low sensitivity to smothering (Table 9). However continuous deposition would be detrimental to sessile fixed epifauna such as *Ostrea edulis* which has a very high sensitivity to the pressure.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalves *C. edule* and *A. Alba* are deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is continuous and ongoing and therefore recoverability may be affected. The native oyster *Ostrea edulis* has a high sensitivity to the physical disturbance.
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes; and also may result in the smothering of resident epifaunal species i.e. *O. edulis.*
- The introduction of diseases and non-native species associated with bivalve culture has been known to severely impact the native oyster (Sewell & Hiscock, 2005). The non-native copepod parasite *Myticola intestinalis*, a parasite initially of mussels, which now infects oysters, is a threat to the native oyster beds. According to MarLIN this community has a very high sensitivity to the introduction of non-native species and to the introduction of parasites/pathogens.
- **The percentage of the community that will be thus affected is 26.5%.**

Conclusion: Considering the range of impacts and habitat and species sensitivities identified above and the persistent nature of the pressure, this activity is considered disturbing on *Ostrea edulis* dominated community.

6.2.2 Oyster Bottom Culture

There are no licenses granted to date solely for the bottom culture of oysters (*Ostrea edulis* and *Crassostrea gigas* combined) within Lough Swilly.

Oyster Bottom Culture (applications) covers 280.3ha* of the qualifying interest (Estuary) within the SAC in (Figure 10). (*It should be noted that 175ha of these applications occur in an area that is already licensed for the bottom culture of mussels (considered above). Given these overlaps, the viability of these applications should be but has not been fully addressed. Therefore the real cover of featured habitat is 105ha (see Figure 10).

This aquaculture type overlaps three of the six different community types found within the qualifying interest of Lough SAC.

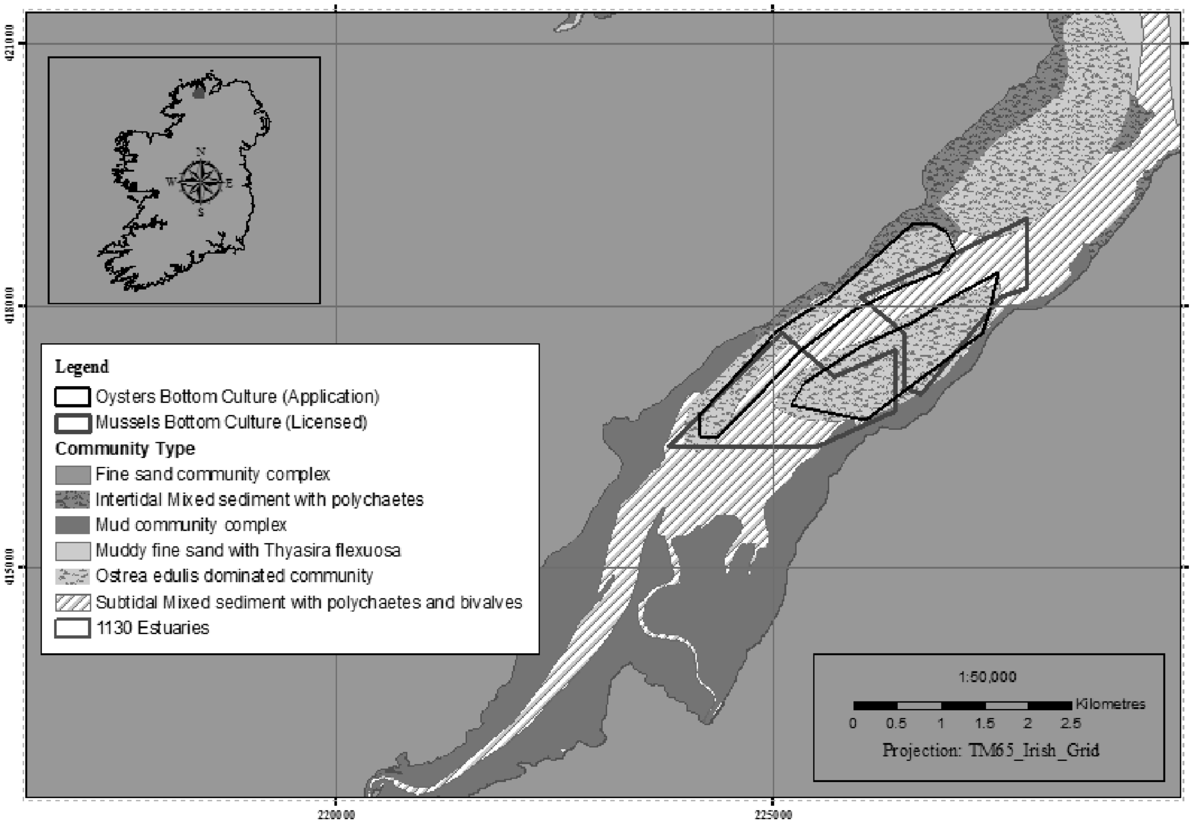


Figure 10: Spatial overlap between bottom oyster culture sites (applications) and habitats within the qualifying interest of Lough Swilly SAC. (Area of overlap with licensed bottom mussel culture (red) is highlighted).

The potential impacts of the operation on the sedimentary communities of Lough Swilly are:

- **Organic** and **sediment deposition**, **physical disturbance** and **monoculture** - these are discussed in detail above (8.2.1)
- **Introduction of non-native species** Oyster culture poses a significant risk in terms of the introduction of non-native species and diseases as the widely cultivated species pacific oyster (*Crassostrea gigas*) is a non-native species. Lough Swilly contains a number of native oyster beds which are considered scarce throughout Ireland and the UK, and are deemed at risk from disease and competition from non-native species. The introduction of non-native species is a serious cause for concern for native oyster beds, as there is the risk that the widely cultivated introduced species (*C. gigas*) may become naturalised (i.e. establishment of a breeding population) and compete with the native species for space and food. The use of triploid stock (non-reproducing) is

the main method employed to eliminate this problem. However, it has being reported that the pacific oyster (*C. gigas*) has become established as a self-seeding population in Lough Swilly and their distribution suggests that they are already a threat to wild oyster stocks and habitat (MI 2012).

- **Disease:** Due to the nature of the culture methods the risk of transmission of disease from cultured to wild/native stocks is high.

<u>Community type: Intertidal Mixed Sediment with Polychaetes</u>

- Applications for this culture method also overlap this community type by 3.2 ha which is a 0.5% overlap.
- This community is characterized by a range of infaunal polychaetes, oligochaetes and bivalves that are tolerant/indifferent of organic enrichment, with the exception of *Euclymene oerstedii* which is sensitive (Table 8). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments. Species present have no/low sensitivity to smothering (Table 9)
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *C. edule* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (bottom oyster culture) the pressure is episodic and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 0.5%.**

Conclusion: Considering the range of impacts and habitat and species sensitivities identified above and the persistent nature of the pressure, this activity is considered disturbing on Intertidal Mixed Sediment with Polychaetes.

<u>Community Type: Subtidal Mixed Sediment with Polychaetes and Bivalves</u>

- Applications for this culture method overlap this community type by 32.5ha* (-22ha) which is a 2.5%* (-1.7%) overlap. (*It should be noted that 1.7% (22ha) of these applications occur in an area that is already licensed for the bottom culture of mussels and therefore one would assume these applications are not viable. Therefore the real potential overlap is 0.8% and 10.5ha)
- A high number of distinguishing species were recorded for this community; the following were present in medium to high abundance: the polychaetes *Pomatoceros triqueter, Lumbrineris latreilli, Capitomastus minima* and *Scoloplos armiger* and bivalves *Abra alba* and *Timoclea ovata.*
- The bivalves *Timoclea ovata*, *Venerupis senegalensis* and *Parvicardium exiguum* recorded within this community are deemed sensitive to organic enrichment (Table 8); *C. minima* is an opportunistic (first order) species which proliferates in reduced environments. The tube worm *P. triqueter* is deemed sensitive to smothering (Table 9).
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *A. alba* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes

the pressure has ceased, however due to the nature of the activity (oyster bottom culture) the pressure is episodic and therefore recoverability may be affected.

- **The percentage of the community that will be thus affected is 0.8%.**

Conclusion: Considering the range of impacts and habitat and species sensitivities identified above and the persistent nature of the pressure, this activity is considered disturbing on Subtidal Mixed Sediment with Polychaetes.

Community Type: *Ostrea edulis* dominated community

- Applications for this culture method overlap with 245ha*(-153ha see below) of the *Ostrea edulis* dominated community; this overlap constitutes 27%* of the area for this community type within the qualifying interest. (*It should be noted that 17% (153ha) of these applications occur in an area that is already licensed for the bottom culture of mussels and therefore one would assume these applications are not viable. Therefore the real potential overlap is 10% and 92ha)
- This community occurs in those areas described as an Intertidal mixed sediment with polychaetes and a Subtidal mixed sediment with polychaetes and bivalves and therefore its distinguishing fauna is a combination of both. This community is therefore characterized by a wide range of species, those present in moderate to high numbers include the polychaetes *Capitomastus minima, Eteone* sp., *Euclymene oerstedii*, *Glycera tridactyla*, *Lumbrineris latreilli, Pygospio elegans, Scoloplos armiger*, *Pomatoceros triqueter,* the oligochaete *Tubificoides benedii* and the bivalves *Abra alba, Cerastoderma edule* and *Timoclea ovata.*
- The epifaunal native oyster *Ostrea edulis* and the polychaete *E. oerstedii* and the bivalve *T. ovata* are sensitive to organic enrichment (Table 8). Other species characterising this community, typically infaunal polychaetes and bivalves, are tolerant/indifferent of organic enrichment, with the exception of T*. benedii* is an opportunistic (first order) species which proliferates in reduced environments.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalves *C. edule* and *A. Alba* are deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (bottom culture) the pressure is episodic/repeated and therefore recoverability may be affected. The native oyster *O. edulis* has an intermediate intolerance and a low recoverability and therefore is highly sensitive to physical disturbance.
- Non-native species introduced within the oyster farming industry (as the culture organism and along with the culture organism) that have caused major mortalities to native oyster beds include the slipper limpet *Crepidula fornicata* and the parasitic protozoan *Bonamia ostreae.* According to MarLIN this community has a very high sensitivity to the introduction of non-native species and to the introduction of parasites/pathogens.
- **The percentage of the community that will be thus affected is 10%*.**

Conclusion: Considering the range of impacts and habitat and species sensitivities identified above ,the persistent nature of the pressure, this activity (i.e. culture of native and non-native oyster species) is considered disturbing on *Ostrea edulis* dominated community.

6.2.3 Suspended Oyster Culture

Suspended Oyster Culture within Lough Swilly includes the use of Bags and trestles and also BST Longlines; at some sites both methods of culture are employed.

Suspended oyster culture using bags & trestles (licensed) covers 26.3ha and applications for same covers 14ha of the qualifying interest (Estuary) within the Lough Swilly SAC (Figure 11).

An area of 59.8 ha is under the dual culture methods of bags & trestles and BST longlines (licensed) while applications for BST Longlines covers 17.9ha of the qualifying interest (Estuary) within the SAC in (Figure 11).

This aquaculture type overlaps five of the six different community types found within the qualifying interest of Lough SAC (see below).

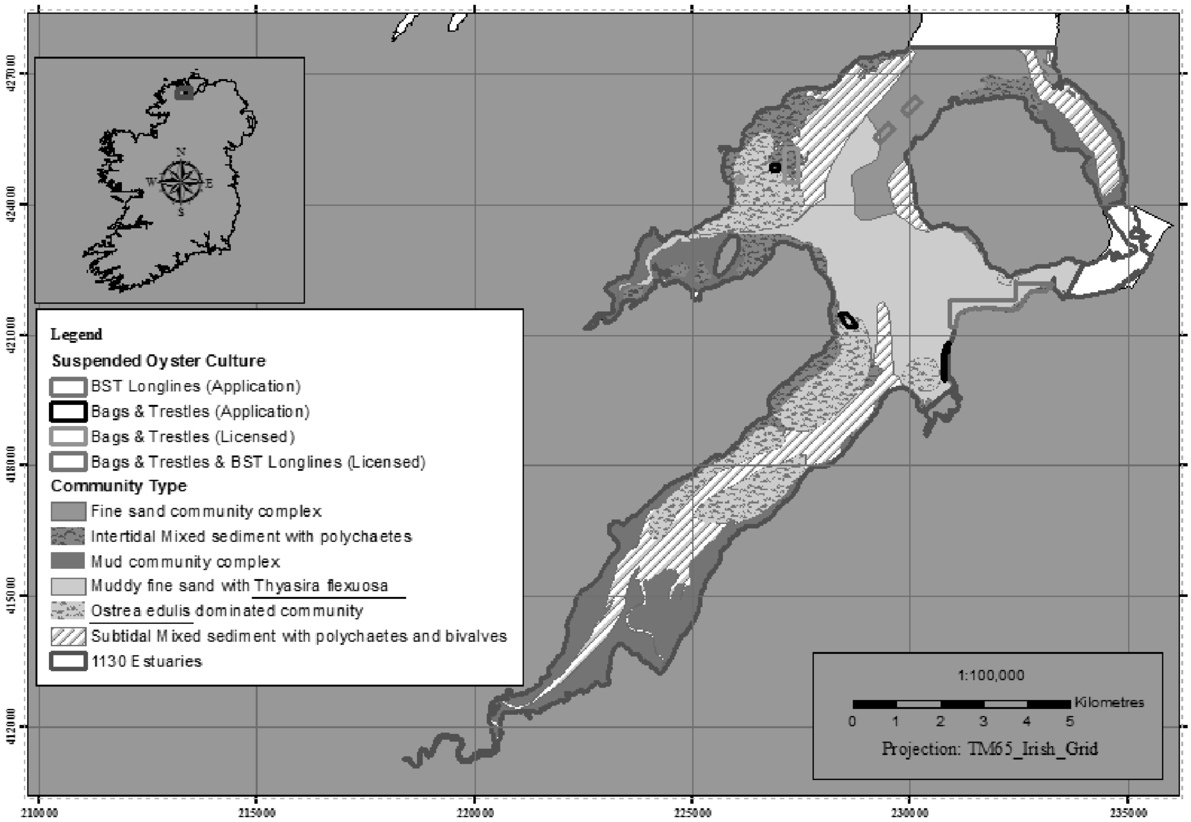


Figure 11: Spatial overlap between suspended oyster culture sites and habitats within the qualifying interest of Lough Swilly SAC.

The potential impacts of the operation on the sedimentary communities of Lough Swilly are:

- **Deposition** on the seabed of oyster faeces and pseudofaeces can lead to organic enrichment and can result in a change in sediment type which in turn can result in changes to the biological communities within. The degree of deposition depends on the culture density, the baffling effect caused by the culture structures, exposure of the site. The physical presence of the trestles and bags are responsible for reducing water flow and allowing suspended material (silt, clay as well as faeces and pseudo-faeces) to fall out of suspension to the seafloor. The build-up of material will typically occur directly beneath the trestle structures and can result in accumulation of fine, organically rich sediments. These sediments may result in the development of infaunal communities distinct from the surrounding areas. However, suspended oyster culture typically has a moderate and localised (usually under the footprint of the culture activity) effect on inter-tidal benthos (Bouchet and Sauriau 2008; Forrest *et al.* 2009).

- **Physical disturbance:** Dredging is not involved in this culture method but sedimentary habitats may be subject to varying degrees of surface disturbance due to human traffic and vehicular movements. In Lough Swilly, suspended cultivation sites are accessed by flat bottom barges and by tractor and trailers on low tide. The latter activity would be result in the risk of compaction on the sedimentary habitats of the area.
- **Introduction of non-native species** Oyster culture poses a significant risk in terms of the introduction of non-native species and diseases as the widely cultivated species pacific oyster (*Crassostrea gigas*) is a non-native species. The introduction of diseases and non-native species associated with bivalve culture has been known to severely impact the native oyster (Sewell & Hiscock, 2005). Lough Swilly contains a number of native oyster beds which are considered scarce throughout Ireland and the UK, and are deemed at risk from disease and competition from non-native species. The introduction of non-native species is a cause for concern for the native oyster fishing industry, as *C. gigas* has become naturalised (i.e. establishment of a breeding population) in the bay and may compete with the native species for space and food. The use of triploid stock (non-reproducing) is the main method employed to mange this issue.
- **Disease:** Due to the nature of the culture methods (high density) there is a risk of transmission of disease from cultured to wild/native stocks.

Community Type: Fine Sand Community Complex

- Applications for the suspended culture of oysters (BST Longlines) overlap with 16.4ha of the Fine sand community complex; this overlap constitutes 2.8% of the habitat area for this community type within the qualifying interest.
- This community complex is characterized by a range of infaunal species (refer above). There are three variants of this community recorded within Lough Swilly, however only Variant 3 is present within the boundary of the Annex 1 habitat. This variant is characterised by the polychaetes *Spiophanes bombyx*, *Lumbrineris latreilli*, *Nephtys hombergii*, and the bivalves *Thracia papyracea* and *Phaxas pellucidus*
- The bivalves characterising this community complex (variant 3) are deemed sensitive to organic enrichment (Table 8), but none of the characterising species are considered sensitive to smothering (≤5cm sediment) as they are mobile and can migrate up through any additional sediment (Table 9).
- The percentage of the community that will be thus affected is 2.8%.

Conclusion: Impact of suspended culture of oysters on Fine Sand Community Complex can be discounted for the following reasons:

- Stock is contained and therefore complete removal of can be achieved in the event of a disease outbreak
- The characterising species are not particularly sensitive to sedimentation.

- The activity occurs on less than 15% of the Fine Sand Community Complex which is below the threshold for significant effects.

Community Type: Intertidal Mixed Sediment with Polychaetes

- Sites licensed for suspended oyster culture overlaps with 31.7ha of Intertidal Mixed Sediment with Polychaetes community; this overlap constitutes 4.8% of the habitat area for this community type within the qualifying interest. This includes the following culture methods Bags & trestles (18.2ha; 2.8%) and Bags & trestles and BST longlines (13.5ha; 2%)
- Applications for suspended oyster culture (Bags & trestles) overlap with 4.7ha of Intertidal Mixed Sediment with Polychaetes community; this overlap constitutes 0.7% of the habitat area for this community type within the qualifying interest.
- The total overlap of suspended oyster culture with this habitat type is therefore 36.4ha (5.5%).
- This community is characterized by a range of infaunal polychaetes and bivalves (refer above) which are deemed tolerant/indifferent to organic enrichment, with the exception of *Euclymene oerstedii* which is sensitive (Table 8).
- The mixed sediment nature of the site would suggest that superficial fines (as a consequence of sedimentation) will likely not persist and will be dispersed easily.

Conclusion: Impact of suspended culture of oysters on the Intertidal Mixed Sediment with Polychaetes community can be discounted for the following reasons:

- Stock is contained and therefore complete removal of can be achieved in the event of a disease outbreak
- The characterising species are not likely exposed to or are tolerant of the primary impacts
- The activity occurs on less than 15% of the Intertidal Mixed Sediment with Polychaetes community which is below the threshold for significant effects.

Community Type: Subtidal Mixed Sediment with Polychaetes and Bivalves

- Sites licensed for suspended oyster culture (Bags & trestles) overlap with 2.4ha of Subtidal Mixed Sediment with Polychaetes and Bivalves community; this overlap constitutes 0.18% of the habitat area for this community type within the qualifying interest
- A high number of distinguishing species were recorded for this community (refer above).
- The bivalves *Timoclea ovata*, *Venerupis senegalensis* and *Parvicardium exiguum* recorded within this community are deemed sensitive to organic enrichment (Table 8); *C. minima* is an opportunistic (first order) species which proliferates in reduced environments. The tube worm *P. triqueter* is deemed sensitive to smothering (Table 9).
- The mixed sediment nature of the site would suggest that superficial fines (as a consequence of sedimentation) will likely not persist and will be dispersed easily.
- The percentage of the community that will be thus affected is 0.18%.

Conclusion: Impact of suspended oyster culture on the Subtidal Mixed Sediment with Polychaetes and Bivalves community can be discounted for the following reasons:

- The activity occurs on less than 15% of the community which is below the threshold for significant effects.

- Stock is contained and therefore complete removal of can be achieved in the event of a disease outbreak.
- The characterising species are not likely exposed to or are tolerant of the primary impacts

Community Type: Muddy Fine Sand with *Thyasira flexuosa*

- Sites licensed for suspended oyster culture (Bags & trestles and BST longlines) overlaps with 46.3ha of Muddy Fine Sand with *Thyasira flexuosa* community; this overlap constitutes 3.5% of the habitat area for this community type within the qualifying interest.
- Applications for suspended oyster culture (Bags & trestles; BST longlines) overlap with 5.9ha of Muddy Fine Sand with *Thyasira flexuosa* community; this overlap constitutes 0.45%.
- The total overlap of suspended oyster culture with this habitat type is 52.2ha (4%).
- This community is characterized by the infaunal bivalve *Thyasira flexuosa*, polychaetes, amphipods and bivalves (refer above).
- A number of distinguishing species (*Euclymene oerstedii, Ampelisca brevicornis, Phaxas pellucidus, Thracia papyracea* and *Nucula nitidosa*) are sensitive to organic enrichment (Table 8); Species present are not deemed sensitive to smothering (Table 9).

Conclusion: Impact of suspended culture of oysters on the Muddy Fine Sand with *Thyasira flexuosa* Community can be discounted for the following reasons:

- The activity occurs on less than 15% of the community which is below the threshold for significant effects.
- Stock is contained and therefore complete removal of can be achieved in the event of a disease outbreak.

Community Type: *Ostrea edulis* dominated community

- Sites licensed for suspended oyster culture (Bags & trestles) overlaps with 5.7ha of *Ostrea edulis* dominated community; this overlap constitutes 0.63% of the habitat area for this community type within the qualifying interest. Applications for same overlap with 5ha of the community; this overlap constitutes 0.5%.
- This community occurs in those areas described as an Intertidal mixed sediment with polychaetes and a Subtidal mixed sediment with polychaetes and bivalves and therefore its distinguishing fauna is a combination of both. This community is therefore characterized by a wide range of species (refer above) and dominated by the native oyster *Ostrea edulis*.
- The species characterising this community are typically infaunal polychaetes and bivalves tolerant/indifferent of organic enrichment, with the exception of *O. edulis*, *E. oerstedii* and *T. ovata* which are sensitive (Table 8). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments.
- Most species present have no/low sensitivity to smothering (Table 9). However the native oyster due to its sessile habit has a high intolerance to smothering and its recoverability is deemed very low.
- Due to its epifaunal habit *O. edulis* would be sensitive to physical damage due vehicular and human traffic.

- The introduction of diseases and non-native species associated with bivalve culture has been known to severely impact the native oyster (Sewell & Hiscock, 2005). Non-native species introduced within the oyster farming industry that have caused major mortalities to native oyster beds include the slipper limpet *Crepidula fornicata* and the parasitic protozoan *Bonamia ostreae.* According to MarLIN this community has a very high sensitivity to the introduction of non-native species and to the introduction of parasites/pathogens.
- The total overlap of suspended oyster culture with this habitat type is 10.7ha (1.1%).

Conclusion: Impact of suspended oyster culture on the *Ostrea edulis* dominated community is considered disturbing and cannotbe discounted for the following reasons:

- The dominant species *O. edulis* is highly sensitive to smothering and sensitive to organic enrichment and to activities associate with suspended culture (e.g. compaction).
- Native oyster beds (*O.edulis*) beds are considered scarce
- The community is highly sensitive to the introduction of non-native species and also parasites/pathogens.

6.2.4 Bottom culture of oysters and mussels

The Bottom Culture of oysters and mussels (licensed) covers 1173.8ha of the qualifying interest (Estuary) within the Lough Swilly SAC (Figure 12).

This aquaculture type overlaps all of the six different community types found within the qualifying interest of Lough SAC.

The potential impacts of the operation on the sedimentary communities of Lough Swilly are listed in sections 8.2.1 and 8.2.2 above.

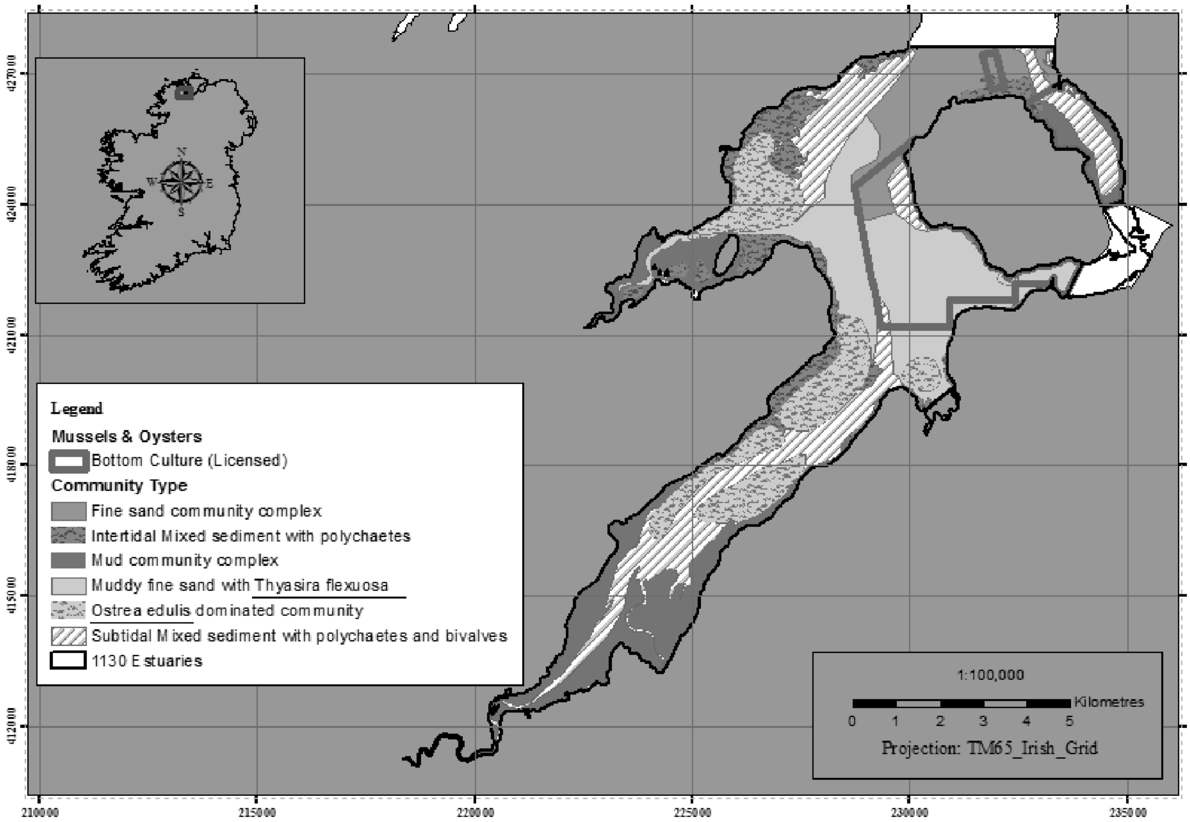


Figure 12: Spatial overlap between bottom oyster & mussel culture sites and habitats within the qualifying interest of Lough Swilly SAC.

Community type: Fine sand community complex

- Sites licensed for the bottom culture of oysters and mussels overlap with 112ha of the Fine sand community complex; this overlap constitutes 19% of the habitat area for this community type within the qualifying interest.
- The species characterising this community complex (variant 3) are typically infaunal polychaetes and bivalves (refer above).
- The characterising bivalves are deemed sensitive to organic enrichment (Table 8), but none of the characterising species are considered sensitive to smothering (≤5cm sedimentation) as they are mobile and can migrate up through any additional sediment (Table 9).
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However their recoverability (based on biological traits) is classed as high to very high therefore their sensitivity to the pressure is low (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is episodic and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 19%.**

Conclusion: Impact of bottom culture of mussels and oysters on Fine Sand Community Complex is considered disturbing and CANNOT be discounted for the following reasons:

- The overlap of the activity and community exceeds the threshold area of 15%.
- Activity is continuous and ongoing.
- Some species present are sensitive to biological changes to sediments type due to deposition i.e. organic enrichment.
- Physical disturbance (dredging) of the seabed is deemed significantly disturbing (≥15%).
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes.

Community Type: Intertidal Mixed Sediment with Polychaetes

- Sites licensed for the bottom culture of oysters and mussels overlap with 54ha of the Intertidal Mixed Sediment with Polychaetes; this overlap constitutes 8.2% of the habitat area for this community type within the qualifying interest.
- This community is characterized by a range of infaunal polychaetes, oligochaetes and bivalves that are tolerant/indifferent of organic enrichment, with the exception of *Euclymene oerstedii* which is sensitive (Table 8). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments. Species present have no/low sensitivity to smothering (Table 9)
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *C. edule* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (bottom oyster culture) the pressure is episodic and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 8.2%.**

Conclusion: Impact of bottom culture of mussels and oysters on Intertidal Mixed Sediment with Polychaetes is considered disturbing and CANNOT be discounted for the following reasons:

- Activity is continuous and ongoing.
- Some species present are sensitive to biological changes to sediments type due to deposition i.e. organic enrichment.
- Physical disturbance (dredging) of the seabed is deemed significantly disturbing.
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes.

Community type: Subtidal Mixed Sediment with Polychaetes and Bivalves

- Sites licensed for the bottom culture of mussels and oysters overlap with 238ha of the Subtidal Mixed Sediment with Polychaetes and Bivalves; this overlap constitutes 18.1% of the habitat area for this community type within the qualifying interest.
- A high number of distinguishing species were recorded for this community; the following were present in medium to high abundance: the polychaetes *Pomatoceros triqueter, Lumbrineris latreilli, Capitomastus minima* and *Scoloplos armiger* and bivalves *Abra alba* and *Timoclea ovata*. .
- The bivalves *Timoclea ovata*, *Venerupis senegalensis* and *Parvicardium exiguum* recorded within this community are deemed sensitive to organic enrichment (Table 8); *C. minima* is an

opportunistic (first order) species which proliferates in reduced environments. The tube worm *P. triqueter* is deemed sensitive to smothering (Table 9).

- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalve *A. alba* is deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (bottom culture) the pressure is episodic and therefore recoverability may not be possible.
- **The percentage of the community that will be thus affected is 18.1%.**

Conclusion: Impact of bottom culture of mussels and oysters on the Subtidal Mixed Sediment with Polychaetes and Bivalves community is considered disturbing and CANNOT be discounted for the following reasons:

- The overlap of the activity and community exceeds the threshold area of 15%.
- Activity is continuous and ongoing.
- Some species present are sensitive to biological changes to sediments type due to deposition i.e. organic enrichment.
- Physical disturbance (dredging) of the seabed is deemed disturbing
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes.

<u>Community Type: Muddy Fine Sand with *Thyasira flexuosa*</u>

- Sites licensed for the bottom culture of oysters and mussels overlap with 629ha of the Muddy Fine Sand with *Thyasira flexuosa* community; this overlap constitutes 48% of the habitat area for this community type within the qualifying interest.
- This community is characterized by the infaunal bivalve *Thyasira flexuosa* and polychaetes, amphipods and other bivalves (refer above).
- Three of these distinguishing species (*Euclymene oerstedii, Ampelisca brevicornis, Phaxas pellucidus*) and the bivalves *Thracia papyracea* and *Nucula nitidosa* are sensitive to organic enrichment (Table 8); Species present are not deemed sensitive to smothering (Table 9).
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies. The bivalve *T. flexuosa* is deemed to have intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is episodic and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 48%.**

Conclusion: Impact of bottom culture of mussels and oysters on the Muddy Fine Sand with *Thyasira flexuosa* community is considered disturbing and CANNOT be discounted for the following reasons:

- The overlap of the activity and community at 48% significantly exceeds the threshold area of 15%.

- Activity is continuous and ongoing.
- Some species present are sensitive to biological changes to sediments type due to deposition i.e. organic enrichment.
- Physical disturbance (dredging) of the seabed is deemed significantly disturbing
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes.

Community Type: Mud Community Complex

- Sites licensed for the bottom culture of oysters and mussels overlap with 136ha of the Mud Community Complex; this overlap constitutes 12% of the habitat area for this community type within the qualifying interest.
- This community is characterized by oligochaetes, bivalves, amphipods and polychaetes (refer above).
- The characterizing species (*Tubificoides benedii*) is an opportunistic species (1st order) indicative of an environment under stress/ which proliferates in reduced environments; all other characterising species are tolerant/indifferent to organic enrichment (Table 8). Species present are deemed to have a low sensitivity to smothering (Table 9).
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies. The bivalve *Macoma balthica* is deemed to have intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is episodic and therefore recoverability may be affected.
- **The percentage of the community that will be thus affected is 12%.**

Conclusion: Impact of bottom culture of mussels and oysters on Mud Complex community is considered disturbing and CANNOT be discounted for the following reasons:

- Activity is continuous and ongoing.
- Some species present are sensitive to biological changes to sediments type due to deposition i.e. organic enrichment.
- Physical disturbance (dredging) of the seabed is deemed significantly disturbing
- Monoculture may lead to changes to the infaunal community which is characterized by bivalves and polychaetes.

Community Type: *Ostrea edulis* dominated community

- Sites licensed for the bottom culture of oysters and mussels overlap with 5.9ha of the *Ostrea edulis* dominated community; this overlap constitutes 0.65% of the habitat area for this community type within the qualifying interest.
- This community occurs in those areas described as an Intertidal mixed sediment with polychaetes and a Subtidal mixed sediment with polychaetes and bivalves and therefore its distinguishing fauna

is a combination of both. This community is therefore characterized by a wide range of species (refer above).

- The species characterising this community are typically infaunal polychaetes and bivalves tolerant/indifferent of organic enrichment, with the exception of *E. oerstedii* and *T. ovata* which are sensitive (Table 8). *T. benedii* is an opportunistic (first order) species which proliferates in reduced environments. Species listed have no/low sensitivity to smothering (Table 9). However continuous deposition would be detrimental to sessile fixed epifauna such as *Ostrea edulis* which has a very high sensitivity to the pressure.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and are therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However depending on their recoverability their sensitivity to it varies, the bivalves *C. edule* and *A. Alba* are deemed to have an intermediate intolerance but high recoverability and therefore a low sensitivity to physical disturbance (Table 10). This high recoverability assessment assumes the pressure has ceased, however due to the nature of the activity (mussel bottom culture) the pressure is episodic and therefore recoverability may be affected. The native oyster *Ostrea edulis* has a high sensitivity to physical disturbance.
- The introduction of diseases and non-native species associated with bivalve culture has been known to severely impact the native oyster (Sewell & Hiscock, 2005). The non-native copepod parasite *Myticola intestinalis*, a parasite initially of mussels, which now infects oysters, is a threat to the native oyster beds. This community has a very high sensitivity to the introduction of non-native species and to the introduction of parasites/pathogens (MarLIN).
- **The percentage of the community that will be thus affected is 0.65%.**

Conclusion: Impact of bottom culture of mussels and oysters on the *Ostrea edulis* dominated community is considered disturbing and CANNOT be discounted for the following reasons:

- The dominant species *O. edulis* is highly sensitive to smothering and sensitive to organic enrichment
- Native oyster beds (*Ostrea edulis*) beds are considered scarce
- The community is highly sensitive to the introduction of non-native species and also parasites/pathogens.

6.2.5 The Fishery Natura Plan for native oyster

The proposed FNP for native oysters in L. Swilly (Annex I) includes a number of separate activities that may have effects on benthic communities. These are:

1. Fishing native oysters with dredges
   Oysters will be fished by bottom oyster dredge fitted with a blade but no teeth. Dredge width will be limited to 150cm. Dredges will be towed by vessels 7-12m in length typical of the Irish inshore fleet. The conditions (including oyster densities) under which fishing will occur are described in the FNP and involve avoiding areas of low oyster density ($<0.25m^{-2}$) as indicated by annual oyster surveys.
2. Fishing for Pacific oysters.

Using dredges similar to that described above. This unrestricted activity will occur in areas where Pacific oysters comprise more than 50% of all oysters. It is expected that the areas involved will decrease annually during the lifetime of the plan due to this control programme.

3. Establishing a spawning reserve

   This will involve transplanting oysters caught in the fishery to an area of 54ha and therefore the establishment of higher density of oysters on the seabed than currently exists.

4. Spreading cultch

   This involves relaying of dead shell, originating from L. Swilly or elsewhere, onto an area of 50 ha to increase the shelliness of the benthic habitat and improve conditions for settlement of oyster

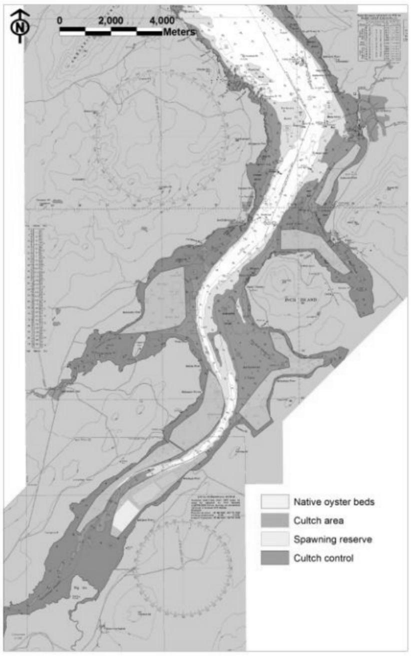


Figure 13. Overall distribution of the proposed fishery natura plan for native oysters in L. Swilly.

6.2.6 Effects of fishing for *O. edulis* and *C. gigas* (activities 1 and 2 above)

Community type: Fine sand community complex

- The oyster FNP overlaps with 71ha (12.1%) of the fine sand community complex (total area 582ha) in the qualifying interest Estuary (Fig. 14). Within this 71ha , in 2011, the area where density of *O. edulis* is >0.25m^{-2} is approximately 12ha and the area where the proportion of *P. gigas* is >0.5 is approximately 3.7ha. There are only minor overlaps between these areas. The effective overlap of the proposed fishery in the first year of the FNP is therefore (12+3.7)/582 or 2.7% of the intertidal mixed sediment community.
- Dredging for oysters represents a physical surface and sub-surface pressure on the fine sand community._Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). However, their recoverability (based on biological traits) is classed as high to very high therefore their sensitivity to the pressure is low (Table 10). This high recoverability assessment assumes the pressure is intermittent rather than persistent. The oyster fishing season is proposed from Sept 19th to March 31st. Recoverability of species is

highest during spring and summer due to recruitment processes. This period is closed to fishing. Although not explicit in the FNP fishing will not be persistent during the fishing season and will cease when oyster densities are <0.25m^{-2} or when exploitation rate reaches 33%.

Conclusion

- As the % overlap between the proposed fishery and the fine sand community is below the threshold of 15%, as physical disturbance caused by dredging will be intermittent, as recoverability of characterising species is high and as limits on the exploitation of oyster are included in the FNP significant impacts of the activity on the fine sand community **can** be discounted.

Community Type: Intertidal Mixed Sediment with Polychaetes

- The oyster FNP overlaps with 167ha (25.5%) of the Intertidal mixed sediments with polychaetes community (total area 655ha) in the qualifying interest Estuary (Fig. 14). Within this 167ha, in 2011, the area where density of *O. edulis* is >0.25m^{-2} is approximately 40ha and the area where the proportion of *P. gigas* is >0.5 is approximately 70ha. Both of these areas overlap completely. The effective overlap of the proposed fishery in the first year of the FNP is therefore 75/655 or 11% of the intertidal mixed sediment community.
- Dredging for oysters represents a physical surface and sub-surface pressure on the fine sand community. Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). Recoverability of these species is generally moderate or high (Table 10) to pressures that are intermittent such as seasonal fisheries and their sensitivity therefore is low or moderate.

Conclusion

- As the % overlap between the proposed fishery and the fine sand community is below the threshold of 15%, as physical disturbance caused by dredging will be intermittent, as recoverability of characterising species is high and as limits on the exploitation of oyster are included in the FNP significant impacts of the activity to the intertidal mixed sediment community **can** be discounted.

Community type: Subtidal Mixed Sediment with Polychaetes and Bivalves

- The oyster FNP overlaps with 218ha (16.6%) of the sub-tidal mixed sediments with polychaetes and bivalves community (total area 1314ha) in the qualifying interest Estuary (Fig. 14). Within 218ha the area where density of *O. edulis* is >0.25m^{-2} is approximately 40ha and the area where the proportion of *P. gigas* is >0.5 is approximately 75ha. These areas do not overlap substantially. The effective overlap of the proposed fishery in the first year of the FNP is therefore (40+75)/1314 or 8.7% of the sub-tidal mixed sediment with polychaetes and bivalves community.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). Recoverability of these species is generally moderate or high (Table 10) to pressures that are intermittent such as seasonal fisheries and their sensitivity is therefore low or moderate

Conclusion

- As the % overlap between the proposed fishery and the sub-tidal mixed sediment community is below the threshold of 15%, as physical disturbance caused by dredging will be intermittent, as recoverability of characterising species is moderate or high and as limits on the exploitation of oyster are included in the FNP significant impacts of the activity to the intertidal mixed sediment community **can** be discounted.

Community Type: Muddy Fine Sand with *Thyasira flexuosa*

- The oyster FNP overlaps with 263ha (20%) of the muddy fine sand with *Thyasira flexuosa* community (total area 1320ha) in the qualifying interest Estuary (Fig. 14). Within this 263ha, in 2011, the area where density of *O. edulis* is >0.25m^{-2} is approximately 45ha and the area where the proportion of *P. gigas* is >0.5 is approximately 2ha. These latter areas overlap. The effective overlap of the proposed fishery in the first year of the FNP is therefore 45/1320 or 3.4% of the muddy fine sand with *T. flexuosa* community.
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). Recoverability of these species is generally moderate or high (Table 10) to pressures that are intermittent, such as seasonal fisheries, and their sensitivity is therefore low or moderate.

Conclusion

- As the % overlap between the proposed fishery and the sub-tidal mixed sediment community is below the threshold of 15%, as physical disturbance caused by dredging will be intermittent, as recoverability of characterising species is moderate or high and as limits on the exploitation of oyster are included in the FNP significant impacts of the activity to the intertidal mixed sediment community **can** be discounted.

Community Type: Mud Community Complex

- The oyster FNP overlaps with 72ha (6.4%) of the mud community complex (total area 1127ha) in the qualifying interest Estuary. Within this 72ha, in 2011. the area where density of *O. edulis* is >0.25m^{-2} is approximately 21ha and the area where the proportion of *P. gigas* is >0.5 is approximately 1.6ha. These latter areas overlap. The effective overlap of the proposed fishery in the first year of the FNP is therefore 21/1127 or 1.8% of the mud community complex
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). Recoverability of these species is generally moderate or high (Table 10) to pressures that are intermittent such as seasonal fisheries, and their sensitivity is therefore low or moderate.

Conclusion

- As the % overlap between the proposed fishery and the sub-tidal mixed sediment community is below the threshold of 15%, as physical disturbance caused by dredging will be intermittent, as recoverability of characterising species is moderate or high and as limits on the exploitation of oyster are included in the FNP significant impacts of the activity to the intertidal mixed sediment community **can** be discounted.

Community Type: *Ostrea edulis* dominated community

- Fishing activity in the oyster FNP overlaps with 878ha (97%) of the *O. edulis* dominated community (total area 906ha) in the qualifying interest Estuary (Fig. 14). Within this 878ha, in 2011, the area where density of *O. edulis* is >0.25m^{-2} is approximately 371ha and the area where the proportion of *P. gigas* is >0.5 is approximately 270ha. These latter areas overlap by 115ha. Activities 3 and 4 (closed area and cultch area) will not be fished and involve 104ha.The effective overlap of the proposed fishery in the first year of the FNP is therefore (371+270-115-104)/906 or 46% of the *O. edulis* dominated community
- Characterising species of this complex are deemed fragile (i.e. soft bodied organism/fragile shell) and therefore have a degree of intolerance to physical disturbance that would penetrate the sediment (i.e. dredging). Recoverability of these species is generally moderate or high (Table 10) to pressures that are intermittent such as seasonal fisheries.
- *O. edulis* is sensitive to physical disturbance. Regular contact with dredges can cause mortality of oysters that are actively growing and can stunt growth in surviving oysters (Waugh 1972). Commercial dredging activity leads to shell breakage and gradual homogenisation of habitat and loss of small scale structural relief (Sewell *et al.*. 2007, Thrush *et al.*. 1998, 2001, Collie *et al.*. 1996, Kaiser *et al.*. 2000, Langton and Robinson 1990). These changes may be contrary to the physical and topographic conditions required for larval settlement. Although unsilted substrate is important the angle of presentation of the substrate and small scale 3D relief on the seabed may be important in providing suitable hydrodynamic conditions at very local scale that stimulate larvae to settle (Cranfield 1968). Increasing and maintaining habitat complexity, shelliness and relief is therefore important. The impact of dredging on these habitat characteristics depends on the intensity and frequency of the activity.
- Currently, as evidenced by oyster survey data (MI 2011), O. edulis is not a dominant characterising species in '*O. edulis* habitat' in L. Swilly. As such, and also given the high(er) densities of the introduced species *C. gigas* in the habitat and the description of the COs for this habitat as '*O. edulis* dominated' , the current conservation condition of this habitat must be regarded as unfavourable. The removal and control of *C. gigas* is a necessary first step for the restoration of the COs for this habitat. This will involve intensive dredging in some areas followed by habitat restoration involving provision of shell for *O. edulis* settlement if necessary.
- Dredging and removal of *O. edulis* in areas where densities are >0.25m^{-2} is proposed in the FNP. Limits are imposed on exploitation in this area; only oysters greater than 76mm will be taken, the exploitation rate on oysters above 76mm will be limited. The proportion of the oyster population removed, therefore, will and considering 2011 data, generally be less than 20% in the initial years of this plan.
- Fishing is proposed in areas where oyster density is >0.25m^{-2}. Considering that the twin objectives of the FNP are to maintain a commercial fishery and in parallel to build the biomass and density of *O. edulis*, the 0.25m^{-2} harvest control rule in the FNP must be considered to be a limit (to be avoided) rather than a target to be achieved i.e. fishing down to densities of 0.25m^{-2} is not the

objective. Considering the collective conservation measures in the FNP and the stated objectives and if the FNP is implemented then it is expected that oyster density will increase as a result of the plan. This is consistent with the COs for oyster habitat.

- Annual monitoring and evaluation of how the objectives, as laid out in the FNP, are being achieved will be necessary and some annual adaptation of the plan, based on monitoring results, and to ensure that the continued development of the fishery remains consistent with the COs, could be envisaged.

Conclusion

- o Although the proposed fishery overlaps with >15% of *Ostrea* habitat, given that the activity is intermittent, that a number of conservation or control measures are included in the FNP that limits exploitation and that the stated objectives of the FNP are to rebuild Ostrea stocks the FNP will progress this habitat towards favourable conservation status. Significant negative impact of the FNP on this habitat **can** be discounted.

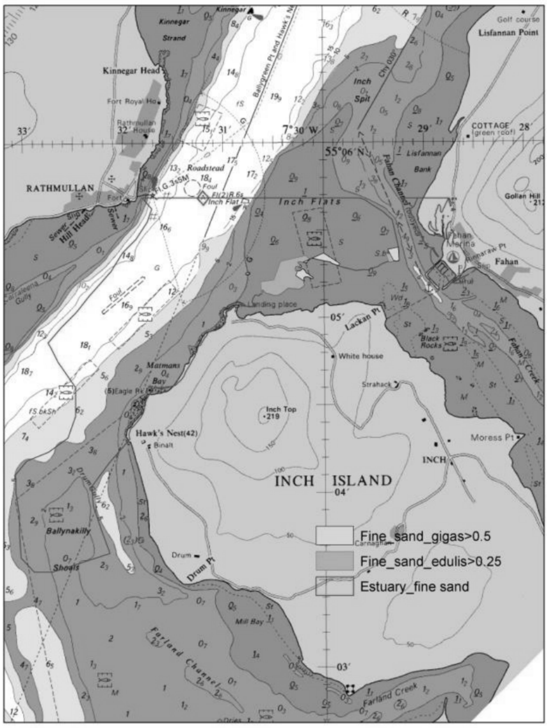
6.2.7 Effects of re-stocking closed areas and relaying cultch (activities 3 and 4 above)

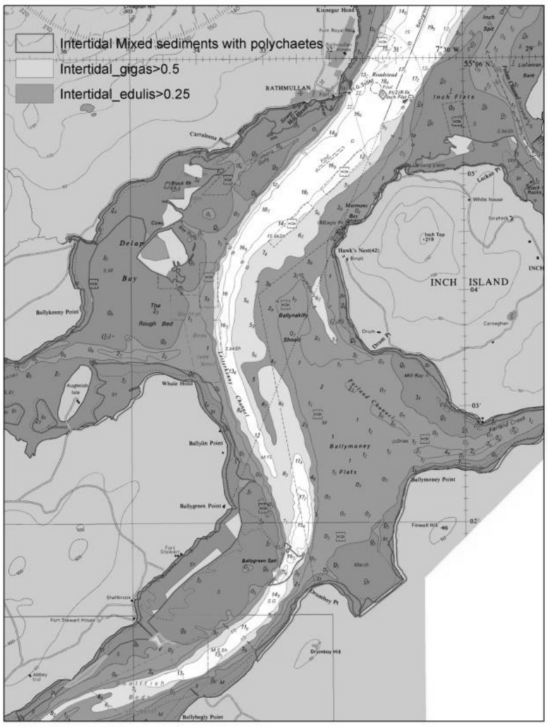
- The objective of these activities is to increase oyster density in the closed area and oyster settlement (and ultimately density) in the cultch area. As such they are consistent with recovering this habitat to favourable conservation status (*Ostrea* dominated) and could be deemed to be positive and necessary management measures for the conservation of the habitat
- Two separate areas (Fig. 13) are described in the FNP one which will be closed to fishing and restocked with native oysters and a second where cultch (shell) will be relayed in a trial to determine if it increases the settlement of native oysters to the seabed.
- The cultch relay area (50ha) effectively overlaps with *O. edulis* habitat only. The total overlap is approximately 50ha of 906ha or 5.5% of *O. edulis* habitat (Fig 13 and Figs in Annex I).
- Part of the spawning reserve (37.8ha) overlaps with 3.7% of the sub-tidal mixed sediments with polychaetes biotope and 16.2ha overlaps represents 1.4% intertidal mud community complex
- The main effect of both activities initially is to increase the shell content and cover on the seabed. In the case of the closed area this will be through transplanting live native oysters into the area and in the cultch area through the spreading of dried shell of mussels, pacific oysters or native oysters. In the spawn reserve there is expected to be some increase in organic enrichment due to increased density of oysters.
- Increasing shell content in the cultch area followed by increased settlement and oyster density may lead to smothering of infauna depending on the density of cultch achieved. Increase in density of live oyster in the spawn reserve area may lead to changes in fauna due to enrichment.

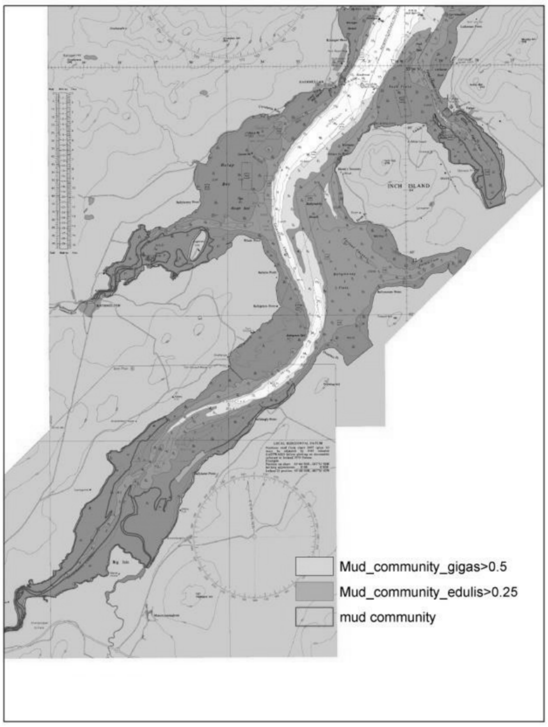
Conclusion

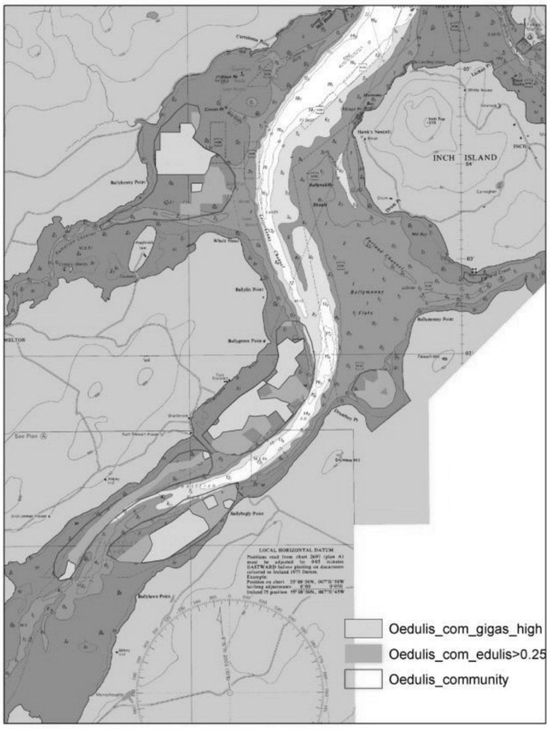
- o In *O. edulis* habitat cultching can be deemed necessary for the conservation of *Ostrea* in that it promotes spawning activity and habitat restoration. However, increasing shell content and restoring oyster from very low density to higher densities is expected to lead to some change in existing infauna.
- o Overlap of the spawning area with intertidal mud and sub-tidal mixed sediment habitats is <15%. Nevertheless increasing oyster density within these areas may have persistent and significant effects on existing infauna

- The proposed activities represent an experiment to see if it is viable to increase oyster recruitment in oyster habitat and with some overlap with other intertidal and subtidal habitats and as such are important in determining how native oyster habitat can be conserved and managed at the site.


Fine_sand_gigas>0.5
Fine_sand_edulis>0.25
Estuary_fine sand
INCH ISLAND
RATHMULLAN
Kinnegar Head
Lisfannan Point
Inch Flats
Hawk's Nest(42)
Ballynakilly
Farland Channel
Mill Bay
Farland Creek
White house
Inch Top


Intertidal Mixed sediments with polychaetes
Intertidal_gigas>0.5
Intertidal_edulis>0.25
RATHMULLAN
INCH ISLAND
Inch Flats
Hawk's Nest(42)


Mud_community_gigas>0.5
Mud_community_edulis>0.25
mud community
INCH ISLAND


Oedulis_com_gigas_high
Oedulis_com_edulis>0.25
Oedulis_community
INCH ISLAND
Hawk's Nest(42)
LOCAL HORIZONTAL DATUM

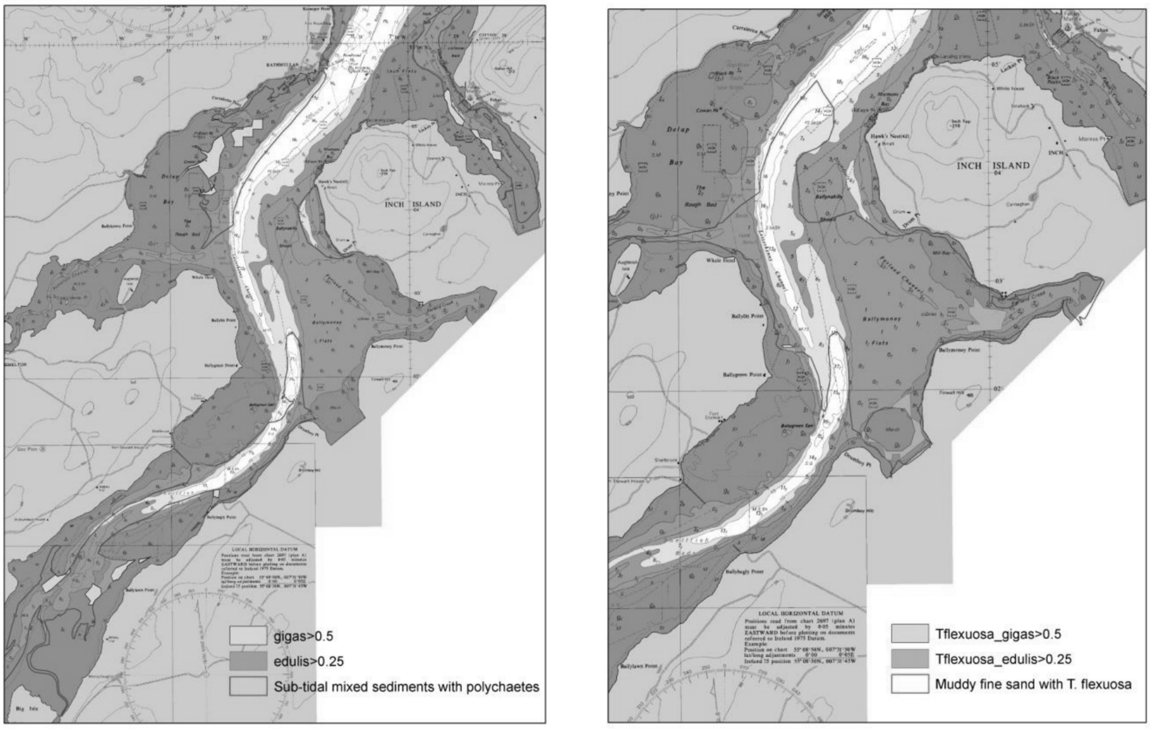


Fig. 14. Overlap of individual benthic communities and fishing for native and pacific oyster in L. Swilly.

In-combination effects of activities on individual community types.

Section 6.2 details the likely impact aquaculture activities have on the qualifying feature Estuaries and more specifically, the likely interaction between the activities and the constituent benthic community type that are found within the SAC. Each activity and community type combination was considered and a conclusion as to whether the activity presented a disturbance risk to the community type was proffered. While the cumulative effects (spatial extent) of each activity were considered and presented in Section 6.2, the in-combination (different activities combined together) effects were not.

This section considers in-combination effects among different aquaculture activities and other activities on the features and communities of the SAC.

6.3.1 Aquaculture in-combination effects

Table 11 details the combination of activities considered disturbing on individual community types and provides a combined estimate of the spatial extent of each community type that will likely be impacted. These values represent the in-combination effects on each of the community types.

These combined values range from 18.7% to 63.72% overlap between activities and individual community types. All values exceed the 15% threshold identified (NPWS 2011) as the spatial extent to which conduct of activities must be examined more closely and a cautious approach to licencing adopted. Table 12 partitions the combined spatial overlap of activities based upon the status of licencing. It is apparent that existing activities (19.14%-51.26%) exceed the threshold value (15%) for precaution in 4 of the 6 community types and for the other two types the spatial overlap (approx. 12%) approaches the 15% threshold (Table 12).

The assessment considers the impacts of aquaculture activities with the boundary of the feature of conservation interest (Estuary)

6.3.2 Aquaculture and fisheries in-combination effects

The proposed activities associated with the management and exploitation of the native oyster in the Lough (Annex I) while having some compatibility with conservation objectives for oyster habitat in the SAC will likely be antagonistic to existing and proposed aquaculture activities in the Lough. In "Ostrea edulis dominated community' which describes the majority of native oyster habitat in Lough Swilly SAC, the objective of the FNP is to increase the density of native oyster. The objective of bottom mussel and Pacific oyster culture is to increase the density of Pacific oyster and mussels. These objectives cannot be simultaneously achieved in the same area. It would be irrational therefore to evaluate the ecological in-combination effects of these activities as economically and operationally they are incompatible and antagonistic with each other. This part of the assessment is therefore incomplete as it has not taken the full set of fishery and aquaculture proposals at face value in providing an assessment of in-combination effects.

Other Aquaculture activities outside the conservation feature area (Estuary)

Given the total area of the Lough Swilly SAC extends beyond the boundary for the designated feature Estuary, there is other aquaculture activities licensed (or proposed) within the SAC that should be considered in terms of cumulative and in-combination effects. Within this area there are four aquaculture activities considered, three areas are licenced for the production of mussels using longlines and are 24, 22 and 12 ha in spatial extent, respectively. There is currently one application (30ha) pending for the extensive (on-bottom) production of mussels.

In short, these activities have no spatial overlap with community types described for the feature of conservation interest and while they may have some impact on the seafloor, the effect is likely to be localised and will not extend into the qualifying interest. Therefore there are no in-combination impacts to assess.

Table 11: Extent (ha) of aquaculture (species, culture method and licence status) in Lough Swilly SAC. Shaded cells are those activities considered disturbing (from Section 6.2). Values in italics represent the percentage overlap of activity with relevant habitat. In-combination values represent the total extent of activities considered disturbing on the six community type found within the SAC.

			Community Type					
Species	**Culture method**	**Licence Status**	**Fine sand community complex**	**Intertidal mixed sediment with polychaetes**	**Mud community complex**	**Muddy fine sand with *Thyasira flexuosa***	***Ostrea edulis* dominated community**	**Subtidal Mixed sediment with polychaetes and bivalves**
Extent (ha) of communities within qualifying interest (Estuary)			**582.63**	**655.30**	**1126.92**	**1320.48**	**905.98**	**1314.03**
Mussels	**Bottom Culture**	**Licensed**	0.00	24.94	6.00	48.09	200.56*	232.01*
				3.81	*0.53*	*3.64*	*22.14*	*17.66*
Mussels	**Bottom Culture**	**Application**	40.93	46.13	68.75	164.40	40.05	188.72
			7.02	*7.04*	*6.10*	*12.45*	*4.42*	*14.36*
Oysters	**Bags & Trestles**	**Licensed**	0.00	18.19	0.00	0.00	5.70	2.36
							0.63	
Oysters	**Bags & Trestles**	**Application**	0.00	4.71	0.00	4.34	4.95	0.00
							0.5	
Oysters	**Bags & Trestles/BST**	**Licensed**	0.00	13.48	0.00	46.34	0.00	0.00
Oysters	**BST Longlines**	**Application**	16.36	0.00	0.00	1.56	0.00	0.00
Oysters	**Bottom Culture**	**Application**	0.00	3.15	0.00	0.00	244.64**	32.48**
				0.48			*27.00*	*2.47*
Oysters/Mussel	**Bottom Culture**	**Licensed**	111.49	53.89	136.02	628.87	5.90	237.54
			19.14	*8.22*	*12.07*	*47.62*	*0.65*	*18.08*
In-combination (%) overlap of disturbing aquaculture activities on communities:			***26.16***	***19.55***	***18.70***	***63.72***	***38.41***	***50.91***

Note: Two aquaculture applications (**) overlap two licensed areas (*) which represent 153.44ha (16.9360%) and 21.74ha (1.6547%) of ***Ostrea edulis* dominated community** and **Subtidal Mixed sediment with polychaetes and bivalves community,** respectively. A correction has been introduced to the in-combination totals presented in the table (i.e. reduction in percentage overlap) under the assumption that only one of the disturbing activities (licensed activity) is likely to occur on the community types.

Table 12: Summary of spatial overlap of potentially disturbing activities on six community types according to activity type and licence status.

	Community Type					
Licence Status	**Fine sand community complex**	**Intertidal mixed sediment with polychaetes**	**Mud community complex**	**Muddy fine sand with *Thyasira flexuosa***	***Ostrea edulis* dominated community**	**Subtidal Mixed sediment with polychaetes and bivalves**
Aquaculture - Licenced (% Overlap)	**19.14**	**12.03**	**12.6**	**51.26**	**23.42**	**35.74**
Aquaculture - Application (% Overlap)	**7.02**	**7.52**	**6.10**	**12.45**	**14.98***	**15.16***
Cumulative Aquaculture (% overlap)	**26.16**	**19.55**	**18.70**	**63.72**	**38.41**	**50.91**

Note: Two aquaculture applications (**) overlap two licensed areas (*) which represent 153.44ha (16.9360%) and 21.74ha (1.6547%) of ***Ostrea edulis* dominated community** and **Subtidal Mixed sediment with polychaetes and bivalves community,** respectively. A correction has been introduced to the in-combination totals presented in the table (i.e. reduction in percentage overlap) under the assumption that only one of the disturbing activities (licensed activity) is likely to occur on the community types.

Assessment of the effects of shellfish production and in combination effects on the Conservation Objectives for Otter and Salmon Statement for AA

As the shellfish production activities within the SAC spatially overlap with Otter (*Lutra lutra*), and Salmon (*Salmo salar*) these activities may have negative effects on the abundance and distribution of populations of these species.

Otter (*Lutra lutra*)

Lough Swilly is designated for the Otter (*Lutra lutra*); the conservation objectives for such are listed in Chapter 4. The risk of negative interactions between aquaculture operations and aquatic mammal species is a function of:

1. The location and type of structures used in the culture operations- is there a risk of entanglement or physical harm to the animals from the structures?

2. The schedule of operations on the site – is the frequency such that they can cause disturbance to the animals?

Bottom Culture, harvesting and fishing

Given that this culture type does not entail any structures and operations are likely to be carried out in daylight hours, while the otter foraging is primarily crepuscular, the interaction with bottom culture operators/operations with the otter is likely to be minimal. It is unlikely that this culture type poses a risk to otter populations in Lough Swilly. Impacts can be discounted.

Oyster culture (suspended)

Given the intertidal location of the structures and activities associated this form of oyster culture it is unlikely that the marine mammals will have any negative interaction with this culture method. Impacts can be discounted.

The proposed activities will not lead to any modification of the following attributes for otter:

- Extent of terrestrial habitat,
- Extent of marine habitat or
- Extent of freshwater habitat.
- The activity involves net input rather than extraction of fish biomass so that no negative impact on the essential food base (fish biomass) is expected
- The number of couching sites and holts or, therefore, the distribution, will not be directly affected by aquaculture and fisheries activities.
- National surveys of otter in Ireland in 2006 found that 65% of sites surveyed in the north-west of Ireland showed signs of otter occupancy. There are no specific data on otter population size in Lough Swilly although they are present throughout the area.
- Shellfish production activities are unlikely to pose any risk to otter populations through entrapment or direct physical injury.
- Disturbance associated with vessel and foot traffic could potentially affect the distribution of otters at the site. However, the level of disturbance is likely to be very low given the likely encounter rates will be low dictated primarily by tidal regime .

Salmon (*Salmo salar*)

Salmon populations run into the River Leannan which flows into Lough Swilly. Current estimates have the numbers of adult salmon returning to the River Leannan at 28% of the conservation limits based upon 2009 returns (SSCWSS 2010). Consequently there is no estimated surplus. Based upon an extensive review the status of the stocks in the river and the supporting habitats it has been concluded that a number of issues present in relation to water and habitat quality in the broader catchment and in particular tributaries (Inland Fisheries Ireland, 2011).

Notwithstanding the issues highlighted above which appear to be confined the freshwater portion of the catchment, it is concluded that shellfish production and fisheries activities in the Lough Swilly SAC do not pose any risk to the following salmon attributes:

- Distribution (in freshwater)
- Fry abundance (freshwater)
- Population size of spawners (fish will not be impeded or captured by the proposed activity)
- Smolt abundance (out migrating smolts will not be impeded or captured by the proposed activity)
- Water quality (freshwater)

The appropriate assessment in relation to effects on otter and salmon is summarised in Table 13.

Table 13. Concluding Appropriate Assessment in relation to effects of all activities on salmon and otter.

Activity	Relevant ecological effects (from statement of AA)	Species affected	Attributes	Attribute following proposed activity	Significance of impact	Rationale	Supporting evidence	Confidence
All activities	Activities may affect the abundance and distribution of the species concerned	Salmon, Otter	All	No change	None	No spatial overlap with attributes or no direct or indirect impact envisaged	GIS	High

7 SAC Appropriate Assessment Concluding Statement and Recommendations

Some aquaculture (mussel and oyster culture) activities that are carried out in the Lough Swilly SAC have been considered as disturbing on habitats. The extent of existing and proposed aquaculture activities are presented in Table 12 above, wherein existing licenced activities account for greater than the 15% threshold of interaction in four of the six habitat types found in the feature of conservation interest (i.e. Estuary). When applications are considered, in-combination with licenced activities, threshold values are exceeded in all communities identified (Table 12). As indicated previously, oyster fishery activities/plans within the bay are not compatible with aquaculture activities by virtue of the species targeted i.e., oysters as opposed to mussels for on-bottom culture methods, as well as the risk of interference with structures used for aquaculture (e.g. float and ropes and bags and trestles). The oyster fishery proposal as reflected in the Fishery Natura Plan (Annex1), however, is broadly compatible with the conservation of *'Ostrea edulis dominated community'* that constitutes approx 906ha of the conservation feature of the SAC (i.e. 15% of Estuary). While the ultimate goal of the plan is to increase the standing stock of native oysters in the Lough, to a level which can sustain fishery activity, this is considered a beneficial management proposal to the overall status of the native oyster, and native oyster habitat, in the Lough.

Given the findings identified in Chapter 6 it is concluded that the *status-quo* relating to aquaculture activities (i.e. existing licences) presents a risk of not achieving of good conservation status for habitats within the SAC. This is manifest in two ways; (1) the threshold value for considering disturbing activity of 15% is exceeded for a number of different habitat types and also constitutes 28.6% of Estuary, the overall feature of conservation interest. When considering the cumulative values of current licences and applications, the threshold values are exceeded in all habitat types and constitute 39.7% of the feature Estuary and, (2) the incompatibility of native oyster fishing and shellfish culture. As indicated previously and specifically in relation to oyster habitat, the objective of the Fishery plan for native oysters is to increase the density of native oyster, whereas the objective of bottom mussel and Pacific oyster culture is to increase the density of Pacific oyster and mussels, both of which are considered disturbing activities. These objectives cannot be simultaneously achieved in the same area; operationally these activities are incompatible. Therefore, as the oyster fishing plan is considered more compatible with the COs for '*Ostrea edulis* dominated community' than aquaculture activities oyster fishing would have precedence over aquaculture activities in this habitat on this basis alone. Following are a number of recommendations relating to Aquaculture and Fisheries activities that might ensure sustainable levels of both activities within the bays while allowing the Natura site to attain good conservation status.

Aquaculture

In relation to aquaculture licencing, a goal of achieving no greater than 15% disturbing activities in habitats must be achieved. To achieve this 'goal' aquaculture activities may be managed in a number of different ways, some mechanisms are suggested below that might be considered in isolation or in-combination:

1. Revoke inactive licences as per the Fisheries (Aquaculture) Act 1997 (Section 69-Subsections 1 and/or 2) wherein licenced areas unused for a period greater than 2 years can be revoked by the Minister).
2. No new licences should be issued in Lough Swilly unless the type of activity proposed is considered non-disturbing to habitats of conservation interest.
3. No aquaculture activities should be carried out in 'Ostrea edulis dominated community', as they are all considered disturbing to this habitat type.

4. A *pro-rata* reduction of licenced areas be applied in order to reduce the spatial overlap between individual habitats and aquaculture activities to 15% or lower, which is consistent with that identified in the conservation objectives. To this end, Table 14 (below) identifies the specific overlap between licenced (as well applied for) areas and individual habitat types. These data may aid in the selection of specific areas where reductions in aquacultures activities might be targeted.

Fisheries

1. Rationalizing aquaculture licenced areas down to 15% overlap with individual habitat will represent significant reduction in extent of such activities. Some of the proposed activities in the oyster fishing plan also occurs in non-oyster habitat thereby making it more difficult for aquaculture to reduce to the 15% in-combination threshold. As the existing extent of habitat defined as oyster habitat includes areas where oyster is at very low density and given that only a proportion of it is fished and given the uncertainty regarding how feasible it is to restore oyster stocks the activities associated with the oyster fishery plan should only occur in *'Ostrea edulis dominated community'* and not in other habitats. The main activity affected will be the location of the spawning reserve for oyster which should be moved into the '*Ostrea edulis dominated community'* This may be a reasonable compromise, considering the very significant reductions in aquaculture activity required to bring aquaculture activity below the 15% overlap threshold with habitats.
2. It will be necessary to implement all of the measures outlined in the oyster fishery plan and where necessary to give these measures legislative support, if it is to achieve its objective and therefore be compatible with the conservation objectives for *'Ostrea edulis dominated community* .
3. An implementation plan for the oyster fishery proposal should be developed with the relevant stakeholder groups

Table 14. Spatial information on individual aquaculture licences considered potentially disturbing and overlap (ha and proportion in italics) with each habitat in L. Swilly.

License ID	Status	Species	Total License Area (ha)	Fine sand community complex		Intertidal mixed sediment with polychaetes		Mud community complex		Muddy fine sand with *Thyasira flexuosa*		*Ostrea edulis* dominated community		Subtidal mixed sediment with polychaetes and bivalves	
Extent (ha) of marine habitat within qualifying interest (Estuary):				**582.63**		**655.30**		**1126.92**		**1320.48**		**905.98**		**1314.03**	
				Area	***% habitat***	**Area**	***% habitat***	**Area**	***% habitat***	**Area**	***% habitat***	**Area**	***% habitat***	**Area**	***% habitat***
T12/251A	Licensed	Mussels	24.00							0.34	*0.03*	8.33	*0.92*	15.32	*1.17*
T12/251B	Licensed	Mussels	43.50			24.88	*3.80*							18.62	*1.42*
T12/273A	Licensed	Mussels	48.05							45.23	*3.42*			2.76	*0.21*
T12/278A	Licensed	Mussels	19.00							2.52	*0.19*			16.48	*1.25*
	Licensed	Mussels	16.25											16.25	*1.24*
T12/293	Licensed	Mussels	196.00					5.86	*0.52*			110.12	*12.15*	80.02	*6.09*
T12/298	Licensed	Mussels	164.80					0.14	*0.01*			82.11	*9.06*	82.55	*6.28*
T12/037A	Licensed	Oysters & Mussels	304.26	0.10	*0.02*	12.07	*1.84*	136.02	*12.07*					156.07	*11.88*
T12/037B	Licensed	Oysters & Mussels	844.03	94.09	*16.15*	33.71	*5.14*			628.87	*47.62*	5.90	*0.65*	81.47	*6.20*
T12/037C	Licensed	Oysters & Mussels	25.42	17.30	*2.97*	8.12	*1.24*								
T12/297	Licensed	Oysters	2.25									2.25	*0.25*		
T12/311A[1]	Licensed	Oysters	24.00									3.45	*0.38*		
Total area (or proportion) of habitat occupied by potentially disturbing licenced aquaculture (ha)				**111.49**	***19.14***	**78.77**	***12.02***	**142.02**	***12.60***	**676.96**	***51.27***	**212.16**	***23.42***	**469.55**	***35.73***

				Area	*% habitat*	Area	*% habitat*	Area	*% habitat*	Area	*% habitat*	Area	*% habitat*	Area	*% habitat*
T12/328A	Application	Mussels	44.50	40.93	*7.02*	3.57	*0.55*								
T12/328B	Application	Mussels	34.53			1.29	*0.20*	0.56	*0.05*					32.68	*2.49*
T12/328C	Application	Mussels	166.93					52.95	*4.70*			2.30	*0.25*	111.68	*8.50*
T12/328D	Application	Mussels	13.96							13.96	*1.06*				
T12/330A	Application	Mussels	17.99											17.99	*1.37*
T12/330B	Application	Mussels	60.64			26.84	*4.10*	1.99	*0.18*	22.56	*1.71*	9.25	*1.02*		
T12/330C	Application	Mussels	35.04							35.04	*2.65*				
T12/341A	Application	Mussels	9.00			8.08	*1.23*							0.92	*0.07*
T12/341B	Application	Mussels	27.88			6.32	*0.96*							21.55	*1.64*
T12/341C	Application	Mussels	16.62									16.62	*1.83*		
T12/344/1A	Application	Mussels	7.94							7.94	*0.60*				
T12/379A	Application	Mussels	97.83			0.03	*0.00*			84.91	*6.43*	11.88	*1.31*	1.01	*0.08*
T12/398B	Application	Mussels	16.32					13.42	*1.19*					2.91	*0.22*
T12/339A[2]	Application	Oysters	135.24			3.15	*0.48*					65.50	*7.23*	10.74	*0.82*
T12/339B[2]	Application	Oysters	145.03									25.71	*2.84*		*0.00*
Suspended Culture (Bags & Trestles)															
T12/317A[1]	Application	Oysters	2.25									1.04	*0.11*		
T12/343A[1]	Application	Oysters	6.00									3.91	*0.43*		
Total area *(or proportion)* of habitat occupied by potentially disturbing aquaculture (ha)				**152.41**	***26.16***	**128.05**	***19.54***	**210.94**	***18.72***	**841.36**	***63.72***	**348.37**	***38.45***	**669.02**	***50.91***

NOTES: **1:** The sites considered here are intertidal culture of oysters using bag and trestles. This activity is considered non-disturbing to all bar one ('Ostrea' dominated) community type. The values in the table reflect the interaction with this community type only.

2: These sites overlap with exisiting licenced areas for a portion of the area applied; the values presented in table represent that area that does not overlap with existing licenced areas.

8 References

Barber, B.J. 1996. Impacts of Shellfish introductions on local communities. In Exotic species workshop: issues relating to aquaculture and biodiversity. Edited by J. Pedersen. MIT Sea Grant College Program (MITSG 96-15), Cambridge. pp. 18- 21.

Bergman, M.J.N. and vanSantbrink, J.W. 2000. Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea 1994. ICES Journal of Marine Science 57(5), 1321-1331.

Borja, A., Franco, J. & Pérez, V. 2000. A marine biotic index of establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar. Pollut. Bull. 40: 1100 – 1114.

Bouchet VMP, Sauriau P-G. 2008. Influence of oyster culture practices and environmental conditions on the ecological status of intertidal mudflats in the Pertuis Charentais (SW France): a multi-index approach. *Marine Pollution Bulletin* 56: 1898-1912

Callier, M.D.,Weise, A.M., McKindsey, C.W., Desrosiers, G. 2006. Sedimentation rates in a suspended mussel farm (Great-Entry Lagoon, Canada): biodeposit production and dispersion. Mar. Ecol. Prog. Ser. 322, 129–141.

Carlton, J.T. 1989. Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conserv. Biol. 3: 265-273.

Carlton, J.T. 1999. Molluscan invasions in marine and estuarine communities. Malacologia 41: 439-454.

Collie, J.S., Escanero, G.A. and Hunke, L. (1996). Scallop dredging on Georges Bank: photographic evaluation of effects on benthic fauna. ICES CM 1996/Mini:9

Cranfield, H. 1968. An unexploited population of oysters, *Ostrea lutaria* Hutton, from Foveaux Strait. New Zealand Journal of Marine and Freshwater Research, 2, 183-203.

Cranford, Peter J., Pauline Kamermans, Gesche Krause, Alain Bodoy, Joseph Mazurié, Bela Buck, Per Dolmer, David Fraser, Kris Van Nieuwenhove, Francis X. O'Beirn, Adoración Sanchez-Mata, Gudrun G. Thorarinsdóttir, and Øivind Strand. 2012. An Ecosystem-Based Framework for the Integrated Evaluation and Management of Bivalve Aquaculture Impacts. Aquaculture Environment Interactions. 2:193-213

Dernie, K.M., Kaiser, M.J. and Warwick, R.M. 2003.Recovery rates of benthic communities following physical disturbance. Journal of Animal Ecology, 72, 1043-1056.

Forrest, B.M., Keeley, N.B., Hopkins, G.H. 2009. Synthesis of the Ecological Effects of Intertidal Oyster Aquaculture. Cawthron Report No. 1476.

Gray. J. S. 1981. Detecting pollution induced changes in communities using the log-normal distribution of individuals among species. Mar. Pollut. Bull. 12: 173-176.

Hall, K., Paramor, O.A.L., Robinson L.A., Winrow-Giffin, A., Frid C.L.J., Eno, N.C., Dernie, K.M., Sharp, R.A.M., Wyn, G.C.& Ramsay, K. 2008. Mapping the sensitivity of benthic habitats to fishing in Welsh waters- development of a protocol. CCW [Policy Research] Report No: [8/12], 85pp.

Inland Fisheries Ireland. 2011. Status report on key salmon rivers in the Northern Regional Fisheries Board with management recommendations. Inland Fisheries Ireland - Version 1.2. 277pp (http://www.fisheriesireland.ie/Salmon-management/salmon-management.html)

Kaiser, M.J., Beadman, H.A. 2002. Scoping study of the carrying capacity for bivalve cultivation in the coastal waters of Great Britain. The Crown Estate. Interim Report: 39 pp.

Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. and Brand, A.E. (2000).Chronic fishing disturbance has changed shelf sea benthic community structure. Journal of Animal Ecology, 69, 494-503.

Kautsky N, Evans S. 1987. Role of biodeposition by Mytilus edulis in the circulation of matter and nutrients in a Baltic coastal ecosystem. Mar Ecol Prog Ser 38:201–212.

Kochmann, J. 2012. Documenting and predicting the spread of Pacific oysters (*Crassostrea gigas*) in Ireland. PhD Thesis, University College, Dublin.

Kochmann, J, F O'Beirn, J. Yearsley, T. Crowe. *In press*. Environmental factors associated with invasion: modelling occurrence data from a coordinated sampling programme for Pacific oysters. Biological Invasions.

National Research Council, 2010. Ecosystems Concepts for Sustainable Bivalve Culture. National Academy Press, Washington, DC.

Navarro, J.M. & Thompson, R.J. 1997. Biodeposition by the horse mussel *Modiolus modiolus* (Dillwyn) during the spring diatom bloom. *Journal of Experimental Marine Biology and Ecology,* 209, 1-13.

NPWS 2011a Conservation Objectives for Lough Swilly SAC (002287) and Lough Swilly SPA (0004075).Version 1.0. Department of the Environment Heritage & Local Government.

NPWS 2011b Conservation objectives supporting document coastal habitats. Version 1.0. Department of the Environment Heritage & Local Government.

NPWS 2011c Lough Swilly SAC (Site Code 2287) Conservation Objectives and supporting document - marine habitats. Version 1. Department of the Environment Heritage & Local Government.

NPWS 2011d Lough Swilly Special Protection Area (Site Code 4075) Conservation Objectives and supporting document. Version 1. Department of the Environment Heritage & Local Government..

Lough Swilly Wild Oyster Society Limited (LSWOSL). 2012. Fishery Natura Plan for Native oysters in Lough Swilly 2012-2017.

McKindsey, CW, Landry, T, O'Beirn, FX & Davies, IM. 2007. Bivalve aquaculture and exotic species: A review of ecological considerations and management issues. Journal of Shellfish Research 26:281-294.

O'Beirn, F.X., C. W. McKindsey, T. Landry, B. Costa-Pierce. 2012. Methods for Sustainable Shellfish Culture. In: Costa-Pierce, B.A. (ed.), *Ocean Farming and Sustainable Aquaculture Science and Technology. Encyclopedia of Sustainability Science and Technology. Springer Science, N.Y.*

Pearson, T., Rosenberg, R. (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology. An Annual Review 16: 229-311.

Roberts, C., Smith, C., Tillin, H., Tyler-Walters, H. 2010. Evidence. Review of existing approaches to evaluate marine habitat vulnerability to commercial fishing activities. Report SC080016/R3. Environment Agency,UK. ISBN 978-1-84911-208-6.

Sewell, J. & Hiscock, K., 2005. Effects of fishing within UK European Marine Sites: guidance for nature conservation agencies. *Report to the Countryside Council for Wales, English Nature and Scottish Natural Heritage from the Marine Biological Association.* Plymouth: Marine Biological Association. CCW Contract FC 73-03-214A. 195 pp.

Sewell, J., Harris, R., Hinz, H., Votier, S., Hiscock, K. (2007). An assessment of the impact of selected fishing activities on European marine sites and a review of mitigation measures. The MBA and University of Plymouth, report SR591, ISBN 0903941694

Standing Scientific Committee for Salmon. 2011. The Status of Irish Salmon Stocks in 2010 and Precautionary Catch Advice for 2011. 71pp + appendices. (http://www.fisheriesireland.ie/Salmon-management/salmon-management.html)

Tenore, K. R., Dunstan, W. M. (1973a). Comparison of feeding and biodeposition of three bivalves at different food levels. Mar Biol. 21: 190-195

Thrush, S.F. et al. (1998). Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. Ecological Applications 8, 866-879.

Thrush, S.F. et al. (2001). Fishing disturbance and marine biodiversity: role of sediment structure in simple soft bottom sediments. Marine Ecology Progress Series, 221, 255-264.

Tillin, H.M., Hiddink, J.G., Jennings, S and Kaiser, M.J. 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea basin scale. Marine Ecology progress Series, 318, 31-45.

Waugh, G.D. (1972). Settlement of *Ostrea edulis* (L.) in relation to the cultivation of oyster grounds. Fishery Investigations London, Series II, 27, 2, 33pp.

Marine Pollution Bulletin 60 (2010) 1059–1064

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Can the spread of non-native oysters (*Crassostrea gigas*) at the early stages of population expansion be managed?

Claire Guy *, Dai Roberts

School of Biological Sciences, Queen's University Belfast, BT9 7BL, UK

ARTICLE INFO

Keywords:
Crassostrea gigas
Non-native species
Introductions
Eradication

ABSTRACT

The Pacific oyster (*Crassostrea gigas*) was introduced into Strangford Lough, Northern Ireland in the 1970s. It was assumed that local environmental conditions would not facilitate successful reproduction. However, in the 1990s there were reports of *C. gigas* outside licensed aquaculture sites and this investigation set out to ascertain the current distribution, years of likely recruitment and population structure of the species. *C. gigas* were found distributed widely throughout the northern basin during surveys; the frequency distribution suggesting *C. gigas* is not recruiting every year. Establishment of feral populations of *C. gigas* elsewhere have linked to habitat change. A pilot cull was initiated to assess the success rate of early intervention. This paper demonstrates the potential benefits of responding rapidly to initial reports of non-native species in a way that may curtail establishment and expansion. The method advocated in simple and can be recommended to the appropriate regulatory authorities.

1. Introduction

The spread and establishment of non-native species is thought to be one of the greatest threats to the conservation of biodiversity (Diamond, 1989; Mack et al., 2000). Numerous accounts document profound changes in recipient ecosystems caused by the establishment of non-native, invasive species (see for example Grosholz and Ruiz, 1996; Kideys, 2002; Olden et al., 2004; Simberloff, 2005). The Pacific oyster, *Crassostrea gigas*, has been widely translocated for aquaculture due to its high growth rates and resilience to disease and now accounts for over 80% of world oyster aquaculture production (Ayers, 1991). This widespread global translocation was to provide a commercial alternative to fisheries for several native oyster species which collapsed during the 19th and 20th centuries due to unsustainable harvesting, disease and habitat deterioration.

There is a great deal of variation in the recorded spawning temperatures of *C. gigas* ranging from 18 °C (Mann, 1979; Detertre et al., 2009) to 27 °C (Kobayashi et al., 1997). In addition, water temperatures must remain above 15 °C during the larval phase to ensure development and subsequent settlement (Child and Laing, 1998; Ruesink et al., 2005). The accepted wisdom in the late 1960s and early 1970s was that water temperatures in northern Europe would not be high enough for successful breeding and settlement of *C. gigas* (see, for example Spencer et al., 1994); this was the rationale for its widespread introduction to revitalise oyster production in the UK and elsewhere in Europe. However, by the late 1990s spawning in *C. gigas* as a result of unusually elevated temperatures in Dungarvan, Ireland was reported by Steele and Mulcahy (1999). Feral populations of *C. gigas* have since been reported widely along the northern European coastline (Cardoso et al., 2006; Cognie et al., 2006) where its spread has probably been accelerated by warm summers (Diederich, 2005); the species is also spreading in the south Atlantic (Orensanz et al., 2002).

The spread of feral *C. gigas* populations has had detrimental ecological and economic impacts. For example in the Wadden Sea, *C. gigas* was introduced in 1964 for commercial exploitation to replace *Ostrea edulis* which had collapsed during the 1940s due to overexploitation (Nehring, 2003). However, natural spatfall of *C. gigas* during warm summers had negative impacts on the productivity of commercially important beds of the blue mussel, *Mytilus edulis* (Wolff and Reise, 2002). Similarly, in Australia *C. gigas* was introduced to provide an alternative to the faltering *Saccostrea glomerata* stocks which had suffered population declines during the 20th century. The first reported attempt to introduce Pacific oysters was in the 1940s but it wasnot until the 1980s that the species was introduced on a large-scale for aquaculture (Nell, 1993). It is now thought that this large-scale introduction and the subsequent establishment of *C. gigas* in Australia led to further declines in *S. glomerata* (Bayne, 1999).

Favourable growth of both *C. gigas* and *O. edulis* provided the incentive for the development of oyster culture in Strangford Lough in the 1970s (Kennedy and Roberts, 1999). Currently, most oyster cultivation in the lough is focused on *C. gigas* although commercial stocks of *O. edulis* are still maintained. As with other

* Corresponding author. Address: School of Biological Sciences, Queen's University Belfast, MBC, 97 Lisburn Road, Belfast BT9 7BL, UK. Tel.: +44 289097206.
E-mail address: cguy04@qub.ac.uk (C. Guy).

0025-326X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.01.020

introductions in the UK and Ireland, it was presumed that *C. gigas* would not spread outside licensed cultivation sites because temperatures were thought to be too low for successful spawning and settlement. Recently, however, *C. gigas* has been reported in several locations around the Lough outside licensed aquaculture sites (Smyth, 2007).

This is the first report that documents the initial spread of *C. gigas* outside licensed aquaculture sites in Strangford Lough, Northern Ireland. The spread of *C. gigas* is of particular concern in Strangford Lough because it is a designated Special Area of Conservation (SAC) under the Habitats Directive. Many cases of the spread of non-native species are documented when their spread is very advanced and unlikely to be reverted.

The main objective of this research was to ascertain the extent to which *C. gigas* has spread throughout Strangford Lough outside licensed aquaculture areas. In addition, preliminary trials were initiated during the present study to test the efficacy of culling *C. gigas* while densities remain low because the chances of removing a non-native species are likely to be more successful during the early stages of its expansion (Simberloff, 2003).

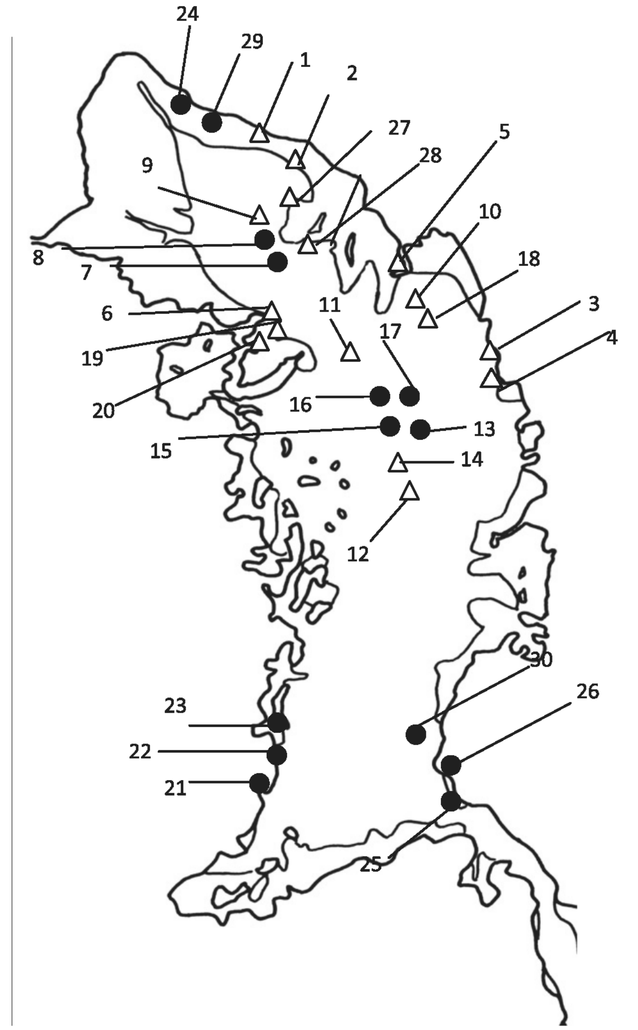


Fig. 1. Sample sites in Strangford Lough. 1. Cunningburn, 2. Newtownards Boat Club, 3. Kircubbin, 4. Horse Island, 5. Greyabbey, 6. Nendrum, 7. South Boretree Rock, 8. West Boretree Rock, 9. Boretree Island West, 10. Ragheries, 11. Downey's Rock, 12. Woman's Rock, 13. West Dougherty Rock, 14. South Dougherty Rock, 15. South Sheelah's Island, 16. Sheelah's Rock, 17. Boretree Island East, 18. Gabbock, 19. Drum Hill, 20. Paddy's Point, 21. Nicky's Point, 22. Killyleagh Quay, 23. Holm Bay, 24. Ballyreagh, 25. Castleward, 26. Ballyhenry Island, 27. Pig Island, 28. Peggy's Island, 29. Ballyreagh Mussel Beds and 30. Marlfield Bay. Open triangles denote the sites where *C. gigas* were present, black circles signify the sites where *C. gigas* were not found.

2. Materials and methods

2.1. Study area

Strangford Lough is located on the east coast of Northern Ireland in County Down and lies between 54°35′ N and 5°41′ N and between 5°20′ W and 5°34′ W. Water temperatures used during this investigation were recorded by the AFBINI datalogger situated in midwater in the northern basin (054° 31.55 N 005° 38.10 W).

2.2. Survey technique

To gain an insight into the structure of oyster populations in different locations within Strangford Lough, surveys were conducted between January and March in 2008 and 2009. Thirty sample sites (Fig. 1) were selected on the basis that they provided suitable substrata for oyster settlement and had been previously surveyed at intervals since 1998 (Kennedy and Roberts, 1999; Smyth et al., 2009) and encompassed the northern and southern basins of the lough. At each site three 100 m transects were marked out in the low intertidal zone at three meter intervals. A 0.25 m^2 quadrat was placed on alternating sides of the transect at four meter intervals; the numbers of oysters within each quadrat were recorded along with their shell lengths.

2.3. Population structure and ageing

To determine the age–size relationship for *C. gigas* in Strangford Lough, a large sample of oysters ranging from 55 to 153 mm in length was collected from Paddy's Point. The shells were air dried and marked with a unique identification number. Age was determined using the acetate-peel technique following the methodology of Richardson et al. (1993). The umbonal area of one valve of each shell was then removed using a diamond saw and embedded into resin (Kleer set Type FF, MetPrep Ltd.). A transverse cut was then made through the resin blocks to reveal a section through the umbone. The cut faces of these blocks were then polished using grades of sand paper and a final polishing medium before being washed thoroughly with a dilute detergent solution and rinsed with water. After air drying, the blocks were then bathed in 0.01 M HCl, rinsed and allowed to dry. The etched surfaces were then flooded with acetone and a strip of acetate replication material (Agar Scientific Ltd.) was placed over the cut side, taking care to exclude any bubbles in the acetone. After the acetone had evaporated the replication material was peeled off and mounted on a slide for later interpretation.

2.4. Pilot cull scheme

In order to test the efficiency of manual removal of *C. gigas*, a pilot cull was initiated in August 2008. Sites found to have high densities of *C. gigas* during the survey in 2008 were chosen for the pilot study. These included: Greyabbey, Cunningburn, Newtownards yacht club and Horse Island. The areas on the shore where the density surveys took place were revisited by a team of three people who walked belt transects parallel to the low water mark. The shell length of each *C. gigas* encountered along the transects was recorded; each individual was then destroyed using a hammer to break the valves.

3. Results

3.1. Distribution and densities of oysters

C. gigas was found at 18 sites sampled (Fig. 1). No oysters were found during the present study at: South Boretree Rock, Boretree Island East, Gabbock, Nicky's Point, Holm Bay, Ballyreagh, Castleward, Ballyhenry Island and Marlfield Bay (Fig. 1). Boretree Island West and Paddy's Point were found to have oyster densities exceeding 1 m^{-2} but at the majority of sites densities were below 1 m^{-2}, (Fig. 2). Although the highest recorded density was at a major licensed culture site there was no trend in terms of density declining with distance from the culture site (Fig. 2).

3.2. Ageing and population structure

The oysters sampled ranged from 55 to 155 mm in length and from 3 to 6 years in age (Table 1). The length-age data was used to convert pooled size frequency data for all sites to generate an age-frequency diagram (Fig. 3). Oysters <55 mm shell length were grouped as <3 years old and oysters >153 mm were grouped as >6 years old (Fig. 3). Approximately 50% of oysters in the pooled sample were estimated to be 3 years old (Fig. 3) suggesting a major recruitment event in 2005.

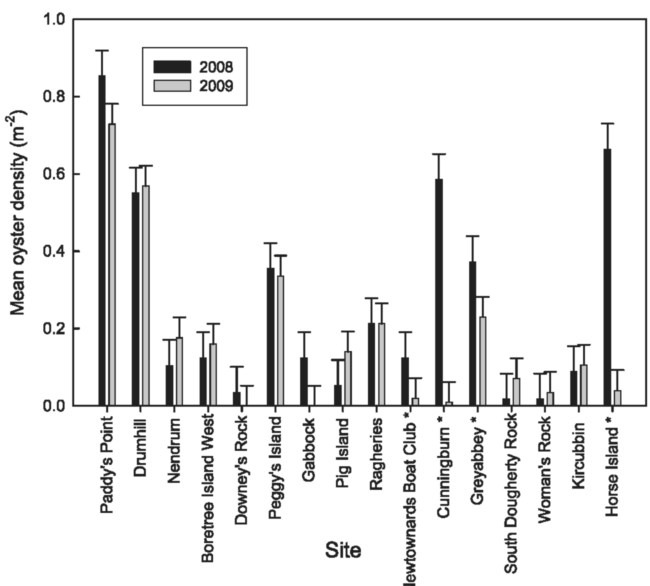


Fig. 2. Mean densities (m^{-2}) of *Crassostrea gigas* at sample sites during 2008 and 2009 surveys with standard error bars, ranked by distance from an original, major licensed culture site at Paddy's Point. * Denotes sites where pilot cull was carried out.

Table 1
The mean lengths at age for *Crassostrea gigas* from Paddy's Point, Strangford Lough (with standard error). Ages of individuals were estimated using acetate peels of shell sections.

Estimated age (years)	Mean length (mm)
3	89.28 ± 2.12 (n = 35)
4	106.44 ± 1.14 (n = 47)
5	121.69 ± 1.9 (n = 15)
6	134.35 ± 3.5 (n = 8)

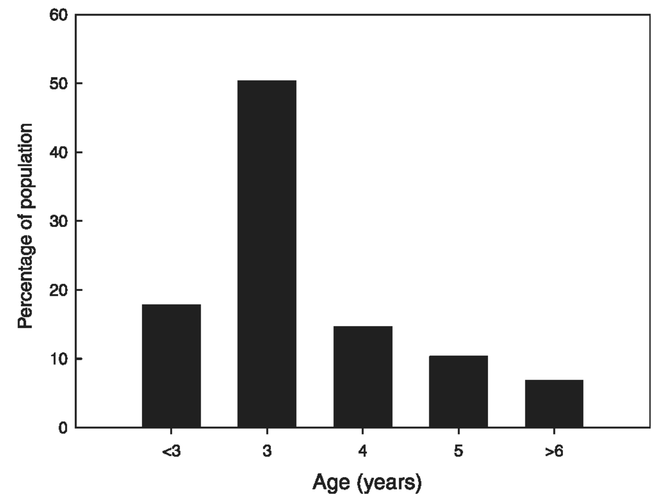


Fig. 3. Percentage age-frequency distributions of *C. gigas* in Strangford Lough in 2008 based on pooled samples for all sites.

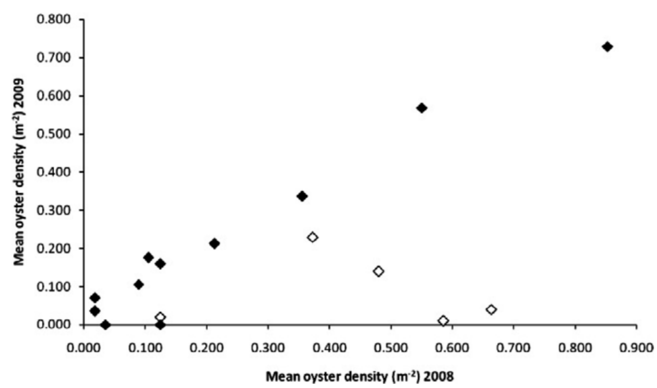


Fig. 4. Comparison of mean oyster densities for 2008 and 2009 at sites where *C. gigas* was culled (open diamonds) and not culled (solid diamonds).

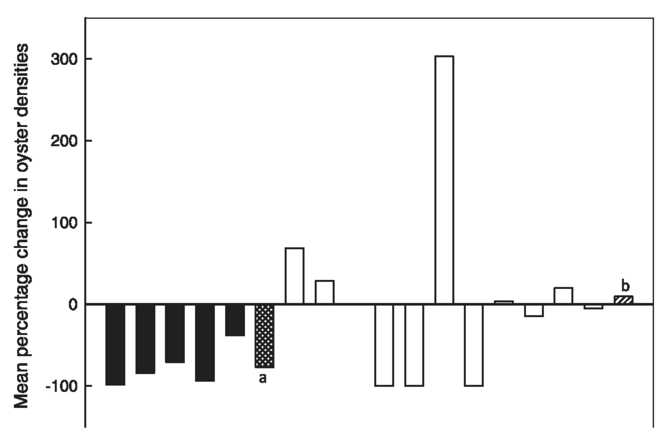


Fig. 5. The percentage change in mean oyster densities at culled sites (shaded), mean (a) and non culled sites (open), mean (b).

3.3. Pilot cull study

At sites where pilot cull trials were conducted, mean densities of *C. gigas* declined between 2008 and 2009 and were negatively related (Figs. 2, 4 and 5). At sites where no cull took place mean oyster density varied between 2008 and 2009 but generally

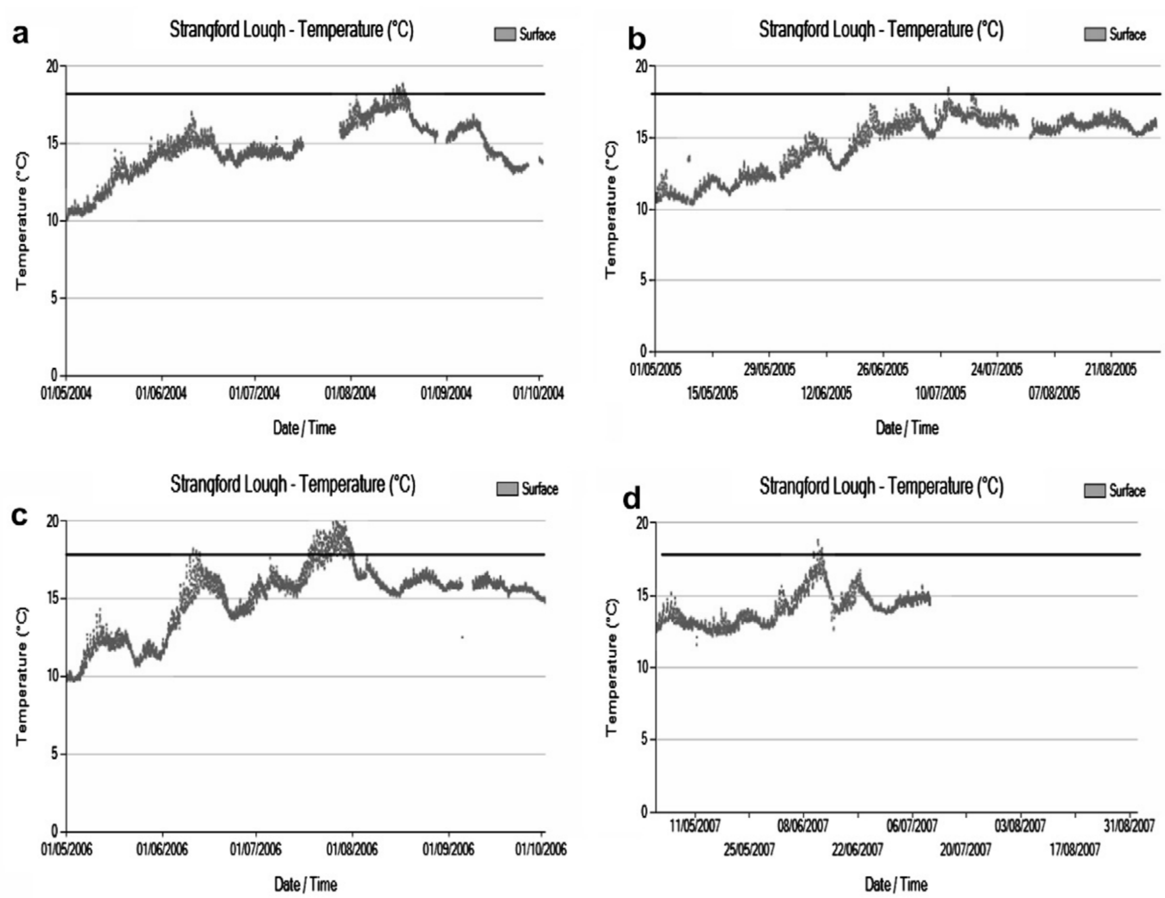


Fig. 6. Temperature (°C) plots for Strangford Lough compiled using AFBINI datalogger for A. 2004; B. 2005; C. 2006, and D. 2007. With line denoting 18 °C which is the minimum temperature thought to facilitate spawning in *C. gigas*.

increased and were negatively correlated (Figs. 2, 4 and 5). Mean oyster density between the years at culled and non culled sites were significantly different (Mann–Whitney-U, $P = 0.019$).

3.4. Temperature regime

The water temperature regimes of the past 8 years in Strangford Lough are available from the AFBINI datalogger. Graphs of the temperature data during the spawning period were produced in an attempt to explain the variation age-frequency data (Fig. 3). The temperature data (Fig. 6) showed particularly elevated water temperatures for an extended period of time during 2006 which would explain the high age-frequency result for individuals aged at 3 years old during the acetate-peel analysis bearing in mind that sampling took place during 2009.

4. Discussion

Although feral populations of *C. gigas* have been reported elsewhere in Europe (Detertre et al., 2009; Smaal et al., 2009), this is the first paper to establish the distribution and densities of populations outside licensed aquaculture sites within the Strangford Lough SAC. *C. gigas* has spread via natural spatfall to areas throughout the northern basin (Fig. 2). Numbers of *C. gigas* were low in the southern basin despite an abundance of suitable substrata. This pattern in distribution is probably driven by the hydrological regime of the lough rather than factors such as availability of space and food which could otherwise be limiting. The northern basin is shallow, and consequently subject to more rapid warming and relatively self contained with water being retained and recirculated. By contrast, waters of the southern basin have much greater exchange with the Irish Sea (Boyd, 1973) and are likely to be less subject to rapid warming than the northern basin. Therefore, it is likely that *C. gigas* will remain contained within the northern basin, with very little or no settlement in the southern basin any planktonic larvae are liable to be washed out to the Irish Sea before they have a chance to settle. There was no trend with regards to density declining in relation to distance from a licensed culture location (Fig. 2). The distribution pattern is likely to be linked to the complicated water circulation patterns in the northern basin.

It has not yet been documented but recent diving surveys suggest *C. gigas* is not widespread in the subtidal zone of Strangford Lough (Smyth, *pers com*). In the Oosterschelde area, dense subtidal aggregations of Pacific oysters have been located using 'side scan sonar' techniques (Nehls and Büttger, 2007). This highlights an area which requires further investigation to more accurately determine the distribution of *C. gigas* within Strangford Lough.

When *C. gigas* was first introduced into northern European waters for aquaculture it was thought that low winter water temperatures would prevent any reproduction (Cardoso et al., 2007), it was noted that some spatfall occurred in mainland Britain but that *C. gigas* commonly failed to release gametes and that larvae did not metamorphose in Ireland (Steele and Mulcahy, 1999). However sea temperature changes have now been widely recorded, especially for European waters which appear to be rising faster than other areas (Halpern et al., 2008; Coppini and Pinardi, 2007; Meehl et al., 2007). Age-frequency data for recent years indicate that *C. gigas* has recruited successfully in Strangford Lough every year since before 2002. In 2004, 2005, 2006 and 2007 the water temperatures reached levels exceeding 18 °C (Fig. 6) which is cited as the minimum threshold temperature required to facilitate spawning (Kobayashi et al., 1997). The peak in age-frequency occurred at 3 years and bearing in mind this data was collected in 2008 this would relate back to a spawning year of 2005. During this year the temperatures peaked in excess of 17 °C and remained above 15 °C for an extended period of time during these years which is thought to be sufficient to allow spat development and settlement (Child and Laing, 1998; Ruesink et al., 2005). Observed increases in recruitment elsewhere have been found to correspond with extended periods of high water temperatures (Wehrmann et al., 2000). The temperature regime in 2006 also seemed to be conducive to favourable spawning conditions (Fig. 6) so it is possible that another increase in oyster spatfall as a result of recruitment from 2006 will be observed in future density surveys. The high 2006 temperatures recorded in Strangford by the continuous datalogger mirror trends recorded in sea surface temperatures of Irish waters (Cannaby and Hüsrevoğlu, 2009). The continuous data recorder is deployed in deep water and so represents temperature trends rather than shallow water temperatures in the lough. Temperatures have been recorded at in excess of 22 °C in some shallow bays (personal observations). Recruitment in years which appear to be sub-optimal in terms of temperature range could perhaps be explained due to such localised heating of shallow water.

In contrast to the unsuccessful large-scale dredging attempted in the Wadden Sea, small scale hand removal of *C. gigas* undertaken in August 2008 resulted in average population declines of 89% at culled sites (Fig. 5). These results show that hand removal of *C. gigas* is an effective means of controlling populations of this particularly invasive species at early stages of its spread. The fluctuation in densities at non culled sites may be due to the very small initial densities of oysters. In some non culled areas a 100% reduction in population density of *C. gigas* was recorded in 2009. This is likely to be due to the continued effects of very low densities recorded in 2008 at these sites and sampling error.

It is important to bear in mind that the species appears to be able to recruit small numbers of individuals annually due to elevated water temperatures in shallow bays. It would therefore seem prudent to repeat the cull annually in all areas where *C. gigas* are present. As there may be a lag period before recruitment from a particularly warm summer becomes apparent during population surveys, it is recommended that density surveys are repeated for at least 5 years at culled sites to take into consideration the long term effects of culling and recruitment on population numbers. These measures may also help to generate a high Allee effects between individuals of populations and thus reduce the likelihood of successful fertilisation and in turn minimise recruitment during summers with particularly high water temperatures. Thus culling should be considered as a realistic option for limiting the spread of *C. gigas* at the early stages of invasion in areas, such as Strangford Lough, where conservation issues are important. This, together with the use of polyploid oysters for commercial aquaculture, should help minimise the spread of the species outside licensed aquaculture sites.

The evidence suggests that *C. gigas* is spreading beyond licensed aquaculture sites through natural spatfall within Strangford Lough. Although population size is still relatively low (highest recorded mean density of *C. gigas* is 0.729 m^{-2}) there is still the potential for it to rise more rapidly in the future. Initial lag periods where there is very little recruitment of non-native species during the early stages of invasion have been described by invasive species biologists (Crooks and Soulé, 1996). The reasons behind these lags are often unknown but they can result in misleading assumptions that the non-native species are not causing detrimental effects in the recipient environment (Simberloff, 2005). However, if conditions become more favourable or the introduced species becomes sufficiently adapted to its new environment then the population can potentially rapidly expand. This signals the end of the time frame when action to halt the invasion may have been most effective. There are numerous examples in the literature where failure to act promptly has facilitated the establishment of a non-native species, often with deleterious consequences (Simberloff, 2003).

The relatively high survival rates of *C. gigas* larvae compared with other bivalve species combined with the resistance of adult individuals to cold winter temperatures could make up for sporadic recruitment patterns (Diederich, 2006). With the threat of rising sea temperatures due to climate change twinned with the possibility of *C. gigas* acclimatizing to lower water temperatures there is the potential threat that the species will be able to successfully breed more frequently. Increased spatfall could lead to the formation of reefs on mudflats (Smaal and Wijsman, 2007) which elsewhere have rendered the intertidal zone unsuitable for human leisure activities (Dankers et al., 2007). It has been suggested that the formation of *C. gigas* reefs in the Wadden Sea could cause major shifts in benthic filter feeding populations which could ultimately have detrimental knock on effects on bird populations (Smaal et al., 2005).

In the Oosterschelde area, large-scale removal of *C. gigas* has been attempted using dredges. This technique does not appear to have been totally effective and the long term impacts of such mechanical removal are as yet unknown (Wijsman, 2007). In 2001 the use of mobile fishing gear was banned in Strangford Lough by the Department of Agriculture and Rural Development after a sharp decline in the horse mussel (*Modiolus modiolus*) populations (Roberts et al., 2004). Therefore it is important to try to manage the spread of *C. gigas* within Strangford Lough before it has the opportunity to spread further and potentially form extensive subtidal reefs that may threaten native biogenic reefs. Manual removal of *C. gigas* appears to be successful, non-intrusive and together with the use of polyploid oysters in commercial aquaculture operations (Guy and Roberts, 2007) may prevent its spread.

Acknowledgements

This research was funded by the Department of Agriculture and Rural Development. AFBINI were kind enough to provide me with temperature records for the area. I would also like to thank Dr. D. Smyth for all his advice and help with field work and thanks to Meryl Norris and Suzanne McBride for help with the acetate peel analysis work.

References

Ayers, P., 1991. Introduced Pacific oysters in Australia. In: Sutherland, J., Osman, R. (Eds.), The Ecology of *Crassostrea gigas* in Australia, New Zealand, France and Washington State. College Park.

Bayne, M.J., 1999. Physiological components of growth differences between individual oysters (*Crassostrea gigas*) and a comparison with *Saccostrea commercialis*. Physiological and Biochemical Zoology 72, 705–713.

Boyd, R.J., 1973. The relation of the plankton to physical, chemical and biological features of Strangford Lough, Co. down. Proceedings of the Royal Irish Academy 73B, 317–353.

Cannaby, H., Hüsrevoğlu, Y.S., 2009. The influence of low-frequency variability and long-term in North Atlantic sea surface temperature on Irish waters. ICES Journal of Marine Science: Journal du Conseil 66 (7), 1480–1489.

Cardoso, J.F.M.F., Langlet, D., Loff, J.F., Martins, A.R., Witte, J.R.J., Santos, P.T., van der Veer, H.W., 2006. Spatial variability in growth and reproduction of the Pacific oyster *Crassostrea gigas* (Thunberg, 1793) along the European coast. Journal of Sea Research 15 (4), 307–318.

Cardoso, J.F.M.F., Langlet, D., Loff, J.F., Martins, J.R., Witte, J.I.J., Santos, P.T., van der Veer, H.W., 2007. Spatial variability in growth and reproduction of the Pacific oyster *Crassostrea gigas* (Thunberg, 1793) along the west European Coast. Journal of Sea Research 57 (4), 303–315.

Child, A.R., Laing, I., 1998. Comparative low tolerance of small juvenile European, *Ostrea edulis* L., and Pacific oysters, *Crassostrea gigas* Thunberg. Aquatic Resources 29, 103–113.

Cognie, B., Haure, J., Barille, L., 2006. Spatial distribution in a temperate coastal ecosystem of the wild stock of the farmed oyster *Crassostrea gigas* (Thunberg). Aquaculture 259, 249–259.

Coppini, G., Pinardi, N., 2007. Compiled for EEA by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) based on Datasets made Available by the Hadley Center HADISST1. <http://hadobs.metoffice.com/hadisst/data/download.html>.

Crooks, J., Soulé, M.E., 1996. Lag times in population explosions of invasive species: causes and implications. In: Sandlund, O.T., Schei, P.J., Viken, Å. (Eds.), Proceedings of the Norway/UN Conference on Alien Species. Directorate for Nature Management and Norwegian Institute for Nature Research, Trondheim, Norway.

Dankers, N., Fey, F., Goudswaard, P.C., 2007. Development of the Pacific oyster (*Crassostrea gigas*) in the Dutch Wadden Sea. In: 10th International Conference on Shellfish Restoration (ICSR) 3007, Vlissingen, The Netherlands.

Detertre, M., Beninger, P.G., Barillé, L., Papin, M., Rosa, P., Barillé, A.-L., Haure, J., 2009. Temperature and seston quality and quantity effects of fielf reproduction of farmed oysters *Crassostrea gigas*, in Bourgneuf Bay, France. Aquatic Living Resources 22, 319–329.

Diamond, J., 1989. Overview of recent extinctions. In: Western, D., Pearl, M.C. (Eds.), Conservation for the Twenty-first Century, vol. 37, pp. 39–41.

Diederich, S., 2005. Differential recruitment of introduced Pacific oysters and native mussels at the North Sea coast: coexistence possible? Journal of Sea Research 53, 269–281.

Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. Journal of Experimental Biology and Ecology 328, 211–227.

Grosholz, E.D., Ruiz, G.M., 1996. Predicting the impact of introduced marine species: lessons from the multiple invasions of the European green crab *Carcinus maenas*. Biological Conservation 78, 59–66.

Guy, C., Roberts, D., 2007. Status of the Pacific oyster, *Crassostrea gigas*. In: Strangford Lough: 2007. Report to the Environment and Heritage Service of Northern Ireland.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952.

Kennedy, R.J., Roberts, D., 1999. A survey of the current status of the flat oyster *Ostrea edulis* in Strangford Lough, Northern Ireland, with a view to the restoration of its oyster beds. Proceedings of the Royal Irish Academy 99B (2), 79–88.

Kideys, A.E., 2002. Fall and rise of the Black Sea ecosystem. Science 297, 1482–1484.

Kobayashi, M., Hofmann, E.E., Powel, E.N., Klinck, J.M., Kusaka, K., 1997. A population dynamics model for the Japanese oyster, *Crassostrea gigas*. Aquaculture 149, 285–321.

Mack, R.N., Simberloff, D., Londsdale, W.M., Evans, H., Clout, M., Bazzaz, F.A., 2000. Biotic invasions: causes, epidemiology, global consequences and control. Ecological Applications 10, 689–710.

Mann, R., 1979. Some biochemical and physiological aspects of growth and gametogenesis in *Crassostrea gigas* and *Ostrea edulis* grown at sustained elevated temperatures. Journal of the Marine Biological Association, U.K. 59, 95–110.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., Zhao, Z.-C., 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

Nehls, G., Büttger, H., 2007. Spread of the Pacific oyster *Crassostrea gigas* in the Wadden Sea: causes and consequences of a successful invasion. HARBASINS Report, on Behalf of: The Common Wadden Sea Secretariat, Wilhelmshaven.

Nehring, S., 2003. Pacific oysters in the European Wadden Sea: an irreversible impact in a highly protected ecosystem. Aliens 17, 19–21.

Nell, J.A., 1993. Farming the Sydney rock oyster *Saccostrea glomerata* (Gould 1850) breeding programme: progress and goals. Aquaculture Research 31 (1), 45–49.

Olden, J.D., LeRoy Poff, N., Douglas, M.R., Douglas, M.E., Fausch, K.D., 2004. Ecological and evolutionary consequences of biotic homogenization. Trends in Ecology and Evolution 19 (1), 18–24.

Orensanz, J.M., Schwindt, E., Pastorino, G., Bortolus, A., Casas, G., Darrigan, G., Elías, R., López Grapa, J.J., Obernat, S., Pascual, M., Penchaszadeh, P., Piriz, M.L., Scarabino, F., Spivak, E.D., Vallarino, E.A., 2002. No longer the pristine confines of the world ocean: a survey of exotic marine species in the southwestern Atlantic. Biological Invasions 4, 115–143.

Richardson, C.A., Collis, S.A., Ekaratne, K., Dare, P., Key, D., 1993. The age-determination of the European flat oyster, *Ostrea edulis*, in British waters determined from acetate peels of umbo growth lines. Journal of Marine Science 50 (4), 493–500.

Roberts, D., Davies, C., Mitchell, A., Moore, H., Picton, B., Portig, A., Preston, J., Service, M., Smyth, D., Strong, D., Vize, S., 2004. Strangford Lough Ecological Change Investigation (SLECI). Report to Environment and Heritage Service by the Queen's University, Belfast.

Ruesink, J.L., Lwnihan, H.S., Trimble, A.C., Heiman, K.W., Micheli, F., Byers, J.E., Kay, M.C., 2005. Introduction of non-native oysters. Effects and restoration implications. Annual Review of Ecology, Evolution and Systematics 36, 643–649.

Simberloff, D., 2003. How much information on population biology in needed to manage introduced species. Conservation Biology 17 (1), 83–92.

Simberloff, D., 2005. Non-native species *do* threaten the natural environment! Journal of Agricultural and Environmental Ethics 18, 595–607.

Smaal, A., Wijsman, J.W.M., 2007. Exploitation capacity for shellfish in the Oosterschelde estuary (SW Netherlands): threatened by the introduced Pacific oyster? In: 10th International Conference on Shellfish Restoration (ICSR) Vlissingen, The Netherlands.

Smaal, A., van Stralen, M., Craeymeersch, J., 2005. Does the introduction of the Pacific oyster *Crassostrea gigas* lead to species shifts in the Wadden Sea? In: Dame, R.F., Olenin, S. (Eds.), The Comparative Roles of Suspension Feeders in Ecosystems. NATO Series IV – Earth and Environmental Sciences. Springer Dordrecht, The Netherlands.

Smaal, A., Kater, B.J., Wijsman, J., 2009. Introduction, establishment and expansion of the Pacific oyster *Crassostrea gigas* in the Oosterschelde (SW Netherlands). Helgoland Marine Research 63 (1), 75–83.

Smyth, D., 2007. Impacts of stock-enhancement strategies on *Ostrea edulis* in Strangford Lough. Unpublished PhD Thesis. Queen's University, Belfast.

Smyth, D., Roberts, D., Browne, L., 2009. Impacts of unregulated harvesting on recovering stock of native oysters (*Ostrea edulis*). Marine Pollution Bulletin 58, 916–922.

Spencer, B.E., Edwards, D.B., Kaiser, M.J., Richardson, C.A., 1994. Spatfalls of the non-native Pacific oyster, *Crassostrea gigas* in British waters. Aquatic Conservation 4, 203–217.

Steele, S., Mulcahy, M.F., 1999. Gametogenesis of the oyster *Crassostrea gigas* in Southern Ireland. Journal of the Marine Biological Association, U.K. 79, 673–686.

Wehrmann, A., Herlyn, M., Bungenstock, F., Hertweck, G., Millat, G., 2000. The distribution gap is closed – first records of naturally settled Pacific oysters *Crassostrea gigas* in the east Frisian Wadden Sea, North Sea. Senckenbergiana Maritime 30, 153–160.

Wijsman, J.W.M., Dubbeldam, M., Van Zanten, E., Smaal, A.C., 2007. Ecological impact of an experimental large scale removal of Pacific oysters (*Crassostrea gigas*) from natural beds in the Oosterschelde. In: 10th International Conference on Shellfish Restoration (ICSR) 2007 Vlissingen, The Netherlands.

Wolff, W.J., Reise, K., 2002. Oyster imports as a vector for the introduction of alien species into the northern and western European waters. In: Leppäkoski, E., Olenin, S. (Eds.), Invasive Aquatic Species of Europe. Distribution, Impacts and Management. Kluwer, Dordrecht.

Journal of Sea Research 64 (2010) 145–165

Contents lists available at ScienceDirect

Journal of Sea Research

journal homepage: www.elsevier.com/locate/seares

Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries

Karin Troost

Marine Benthic Ecology and Evolution, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands
IMARES-Delta, P.O. Box 77, 4400AB Yerseke, The Netherlands

ARTICLE INFO

Article history:
Received 19 July 2009
Received in revised form 29 January 2010
Accepted 4 February 2010
Available online 12 February 2010

Keywords:
Crassostrea Gigas
Wadden Sea
Oosterschelde Estuary
Characteristics of Invasive Species
Consequences of Marine Invasions
Non-indigenous Species

ABSTRACT

Since the 1960's, the Pacific oyster *Crassostrea gigas* has been introduced for mariculture at several locations within NW Europe. The oyster established itself everywhere and expanded rapidly throughout the receiving ecosystems, forming extensive and dense reef structures. It became clear that the Pacific oyster induced major changes in NW European estuaries. This paper reviews the causes of the Pacific oyster's remarkably successful establishment and spread in The Netherlands and neighbouring countries, and includes a comprehensive review of consequences for the receiving communities.

Ecosystem engineering by *C. gigas* and a relative lack of natural enemies in receiving ecosystems are identified as the most important characteristics facilitating the invader's successful establishment and expansion. The Pacific oyster's large filtration capacity and eco-engineering characteristics induced many changes in receiving ecosystems. Different estuaries are affected differently; in the Dutch Oosterschelde estuary expanding stocks saturate the carrying capacity whereas in the Wadden Sea no such problems exist. In general, the Pacific oyster seems to fit well within continental NW European estuarine ecosystems and there is no evidence that the invader outcompetes native bivalves. *C. gigas* induces changes in plankton composition, habitat heterogeneity and biodiversity, carrying capacity, food webs and parasite life cycles.

The case of the Pacific oyster in NW European estuaries is only one example in an increasing series of biological invasions mediated by human activities. This case-study will contribute to further elucidating general mechanisms in marine invasions; invasions that sometimes appear a threat, but can also contribute to ecological complexity.

Contents

E-mail address: troost.karin@gmail.com.

1385-1101/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.seares.2010.02.004

1. Introduction

The Pacific oyster *Crassostrea gigas* is one of the best known non-indigenous animals in coastal north-western Europe. Whether the species is an enrichment to estuarine and coastal ecosystems, or a nuisance, or both, is currently under debate. On one hand it adds habitat heterogeneity and hence promotes biodiversity, on the other hand it may eventually out-compete native bivalves and induce cascading effects on other trophic levels. In this paper the spatial spread of *C. gigas* throughout the NW European countries The Netherlands, Belgium, Germany, Denmark, Sweden and Norway is discussed, followed by reviews of causes of the species' successful establishment and natural spread, and consequences of induced changes in receiving ecosystems. Causes of success are mainly based on the situation in The Netherlands, where *C. gigas* was first introduced. Consequences of induced changes are reviewed for continental NW Europe in general, with a focus on The Netherlands and Germany, where the most studies were performed (specifically in the Oosterschelde estuary and Wadden Sea). Finally, a future perspective is given which includes expected effects of climate change. This case-study of the introduced Pacific oyster will contribute to further elucidating general mechanisms in marine invasions.

In this paper, the term "invasions" refers to non-indigenous species that were moved outside their natural range both by human activities (deliberate and accidental introductions) and natural range expansions (after Carlton, 1989). The term "introduced species" is used specifically for species introduced by human activities, while "invasive species" refers to non-indigenous species that manage to establish successfully and have a certain impact on the receiving ecosystem.

2. Biology of *C. gigas*

Pacific oysters are lamellibranch suspension-feeding bivalves of the class Pelecypoda. They live attached to hard substrates along exposed shores and form reef structures on tidal flats (Fig. 1) (Arakawa, 1990a; Reise, 1998; Dupuy et al., 1999). Pacific oysters are oviparous; in the Northern Hemisphere they release their gametes into the water mainly in July and August, when water temperatures are highest. After a pelagic phase of about 3 weeks (Fig. 2), the veliger larvae settle onto hard substrate: oyster shells, rocks, or pieces of other hard substrate. After settlement, by excretion of cement their lower (left) cupped valve

Fig. 1. Left: Oyster reef in the Oosterschelde estuary (Neeltje Jans); Right: aggregation of oysters settled onto each other.

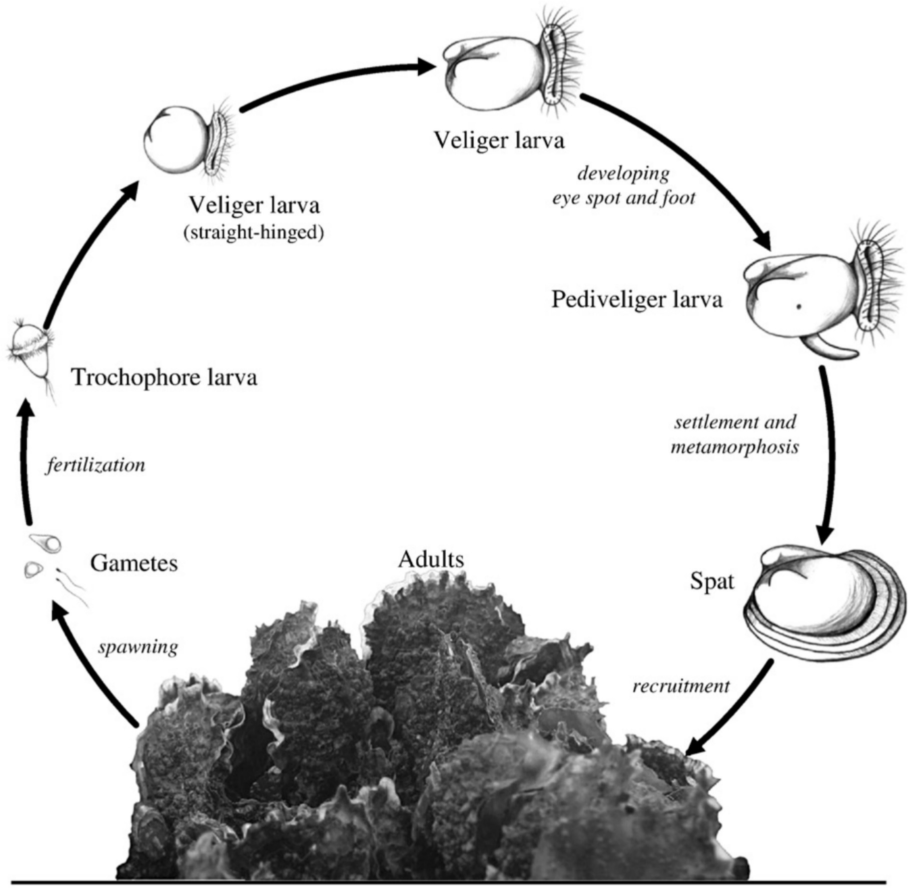


Fig. 2. Life cycle of oviparous bivalve filter-feeders (*C. gigas* as example; not drawn to scale). Adults release eggs and sperm into the water column where fertilisation takes place. Fertilised eggs usually develop via the trochophore stage into veliger larvae within approximately 2 days. The veliger larvae, about 70 to 300 μm in length, swim and forage with their velum. The first veliger stage is called the D-veliger or straight-hinged veliger. Veligers continue to develop through the veliconcha stage into the pediveliger stage, in which the larvae have developed a foot and eye spot. At this stage the velum begins to degenerate, resulting in reduced swimming abilities. The larvae are now competent to settle on a suitable substrate and to metamorphose into the benthic juvenile stage, approximately 3 weeks after fertilisation. The benthic juveniles grow and recruit into sexually mature adults (Seed, 1976; Butman, 1987; Arakawa, 1990b; Gosling, 2003).

becomes partially or almost completely attached to the substrate. As the oyster grows, generally the shell assumes the form of the substrate to which it attaches (Arakawa, 1990a; Reise, 1998; Gosling, 2003). Pacific oysters reach maturity at a shell length of about 50 mm (Kobayashi et al., 1997), which may already be reached in the first year after settlement. Pacific oysters feed by filtering planktonic organisms and detritus from the surrounding water. Relative to other bivalve species in Dutch estuaries individual *C. gigas* process larger volumes of water per time unit (Table 1).

Table 1
Filtration rates measured (as clearance rates) for mussels *M. edulis*, cockles *C. edule*, Pacific oysters *C. gigas* and European oysters *O. edulis*, given per individual and per standardized gram dry-tissue-weight.

Species	Dry tissue weight (g)	Temperature (°C)	Individual filtration rate ($l\ h^{-1}\ ind^{-1}$)	Bodymass-specific filtration rate ($l\ h^{-1}\ g^{-1}$)	References
M. edulis	0.06–0.5	10–20	1.5–6.0	0.7–11.0	1–7
M. edulis	0.5–1.0	10–15		9.2	12
C. edule	0.3–0.5	10–15	1.3–5.0	0.7–7.4	1, 7–9
C. gigas	1.0–2.0	5–25	1.2–12.5	2.0–5.9	4, 10–11
O. edulis	0.5–2.0	20–22	5.7–10.3		4

References: 1) Møhlenberg and Riisgård, 1979, 2) Prins et al., 1996, 3) Petersen et al., 2004, 4) Walne, 1972, 5) Riisgård, 1977, 6) Famme et al., 1986, 7) Smaal et al., 1997, 8) Widdows and Navarro, 2007, 9) Foster-Smith, 1975, 10) Bougrier et al., 1995, 11) Gerdes, 1983.

3. Spatial spread of *C. gigas*

3.1. Initial introduction in The Netherlands

Nowadays, *C. gigas* is the main oyster species cultured in The Netherlands. Traditionally however, from the 1870's until the 1970's, Dutch oyster culture concentrated on European flat oysters *Ostrea edulis*. Between 1940 and 1950, flat oysters had already largely disappeared from the Dutch Wadden Sea due to habitat change and overfishing (Dijkema, 1997; Drinkwaard, 1999a). A combination of severe winters, mixing of native brood stocks with foreign strains and the accidental introduction of the parasite *Bonamia ostreae* led to the final downfall of the European oyster in Dutch waters (Drinkwaard, 1999b; Haenen, 2001). The decline of the European flat oyster instigated a search for alternative oyster species to culture. In 1964 a successful trial with Pacific oyster spat imported from British Columbia was carried out in the Oosterschelde estuary (Shatkin et al., 1997; Drinkwaard, 1999b). More introductions followed. In 1966, oyster farmers were told that the introduction of the Pacific oyster was acceptable since water temperatures in The Netherlands were assumed to be too low for this species to be able to reproduce, as had been the case with the closely related Portuguese oyster *C. angulata* (Dijkema, 1997; Drinkwaard, 1999b). Additionally, plans for closing off the Oosterschelde estuary from the North Sea had already been made. According to plan, this would have resulted in a fresh or brackish tide-free lake, unsuitable for oyster growth and reproduction. But plans were changed and the Oosterschelde estuary remained a marine tidal system (Smies and Huiskes, 1981). The Pacific oyster soon proved to be able to reproduce in Dutch waters after all. In 1971, young *C. gigas* of approximately one year old were collected from the harbour of Zierikzee by F. Kerckhof (in prep.). In 1975, Pacific oyster spat were observed to have settled onto mussel shells and some intertidal mussel beds. In 1976 and 1982 extensive spatfalls were observed, which were attributed to prolonged periods of high water temperatures. From then on, most oyster farmers started to culture *C. gigas* (Drinkwaard, 1999b).

3.2. Area of origin

Pacific oysters occur from the Russian island of Sakhalin and Primorskiy Kray on the continent in the north (latitude ~48° N) to the Japanese island of Kyushu and the east coast of China in the south (latitude ~30° N; Fig. 3; Arakawa, 1990a). In Japan four regional strains of *C. gigas* were discerned by Imai and Sakai (1961), that originate from different geographical areas: Hokkaido, Miyagi, Hiroshima, and Kumamoto. However, the Kumamoto oyster was later shown to be a different species, *Crassostrea sikamea*, by Buroker et al. (1979) for Japanese populations and by Banks et al. (1994) for cultured oysters from the United States. The Miyagi and Hokkaido oysters come from a relatively cool climate with temperate conditions. They are relatively larger and grow faster than Hiroshima oysters that originate from a warmer region (Imai and Sakai, 1961). Oysters imported in British Columbia and The Netherlands were mainly (but not exclusively) of the Miyagi and Kumamoto strains, but experiments with Hiroshima oysters have also been conducted in The Netherlands (Shatkin et al., 1997; Drinkwaard, 1999b). It is not clear what happened with the Kumamoto *C. sikamea* oysters in The Netherlands. They may have hybridized with *C. gigas*, or they may have disappeared (see English et al., 2000). *C. sikamea* also seems to have disappeared from its native range in Japan and may now only be found in culture in North America (Banks et al., 1994). Mann et al. (1991) described *C. gigas* oysters in North American and European cultures as Miyagi-like and pointed out that there has been much intentional inter-breeding of introduced stocks, but that precise pedigrees are lacking.

The Portuguese oyster *Crassostrea angulata* was introduced in Portugal already somewhere between 1500 and 1800, probably on ships' hulls (Wolff, 2005). These "Portuguese" oysters originated from a strain of *C. gigas* living at Taiwan (Ó Foighil et al., 1995; Boudry et al., 1998) and are therefore the same species as *C. gigas*. From Portugal these Portuguese oysters were introduced elsewhere in continental NW Europe but the species never established itself in Belgium, The Netherlands, and Germany and was completely wiped out by a disease in France around 1970 (Wolff and Reise, 2002).

3.3. Feral Pacific oysters in Dutch estuaries

Natural spatfall of *C. gigas* throughout the Oosterschelde estuary resulted in the formation of large and dense feral oyster reefs in the intertidal and subtidal areas. By means of stock assessments and reconstructions, the RIVO (Netherlands Institute for Fisheries Research, presently "IMARES") estimated that on the 118 km^2 of intertidal flats in the Oosterschelde estuary the cover by oyster beds increased from 0.25 km^2 in 1980 to 8.1 km^2 in 2003 (Kater and Baars, 2004; Dankers et al., 2006). Oyster cover on hard substrates (160 km of dikes and sea walls, 2–4% of the total bottom surface area; Leewis et al., 1994) generally increased from 0–10% in 1985 to 50–60% in 2002, and even to 90% on some locations (AquaSense, 2003). Within this period, during the 1990's, stocks of the native blue mussel *M. edulis* and common cockle *C. edule* showed a decrease (Geurts van Kessel et al., 2003; Dankers et al., 2006).

The introduction of *C. gigas* into the Wadden Sea goes back to the late 1970's at the island of Texel, in the cooling water basin of a power and desalinization plant. In 1976, someone intentionally released a bucket-full of Pacific oyster spat here (Tydeman, 2008). In 1978, the RIVO released juvenile Pacific oysters that were mixed with *O. edulis* spat from a French hatchery in the relatively warm waters of the cooling water basin (Smaal et al., 2009). Today, the oysters are still steadily spreading throughout the Dutch Wadden Sea where they locally cover rubble-mound breakwaters and tidal flats (mostly on existing mussel beds and shell banks) in high densities (Cadée, 2001; Tydeman et al., 2002; Wolff, 2005; Fey et al., 2009). Total cover of the intertidal by oyster beds was estimated at 4 km^2 in 2004 (Smaal et al., 2005) and at 5.5 km^2 in 2005 (Dankers et al., 2006).

In Lake Grevelingenmeer a first natural spatfall of *C. gigas* was observed in 1987 (Drinkwaard, 1999b) and the Pacific oyster is now one of the dominant bivalve species (Sistermans et al., 2005). In the

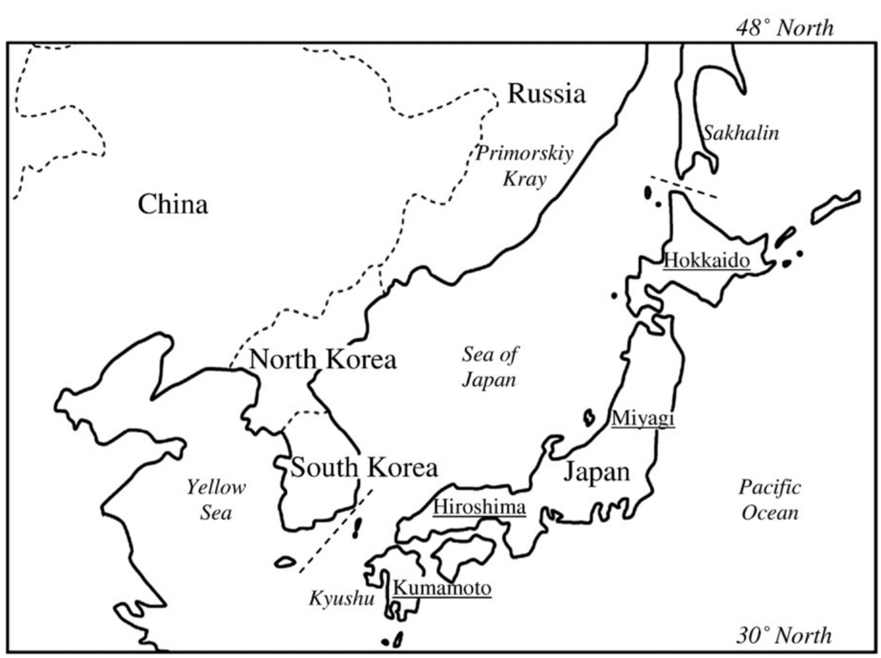


Fig. 3. Native range of the Pacific oyster *C. gigas*.

Westerschelde estuary, Pacific oysters are only found in low numbers and almost exclusively on man-made hard substrates (Drinkwaard, 1999b; pers. obs.).

3.4. Introduction and spread of Pacific oysters in Belgium

Following the initial introduction in The Netherlands in 1964, Pacific oysters were also introduced in Belgium (1969), Germany (1971), Denmark (1972), Sweden (1973) and Norway (1979). In Belgium, oysters of different species and from different regions have been imported in the Sluice Dock of Ostend (Kerckhof et al., 2007). The Sluice Dock was used for cultivating and/or relaying oysters from the 1930's until World War II and again from 1957 to 1974. European flat oysters *O. edulis* were cultured here, but also *C. virginica* imported from the east coast of the United States and *C. angulata* imported from southern Europe (Kerckhof et al., 2007). Neither *C. virginica* nor *C. angulata* became established in Belgian coastal waters. In 1969 and the early 1970's, Pacific oysters *C. gigas* were imported. The first oysters originated from The Netherlands, but later imports were also made from Japan, Canada, France and the Mediterranean (Kerckhof et al., 2007; F. Kerckhof, pers. comm.). In 1974 oyster culture in the Sluice Dock stopped because of poor water quality. Although all imports and culture activities were stopped, *C. gigas* remained a resident of the Sluice Dock. Apparently this species was able to reproduce in Belgian waters (Kerckhof et al., 2007). Since the 1970's the Pacific oyster has colonized the Belgian coast, and now forms extensive reefs in the harbours of Ostend, Nieuwpoort, Zeebrugge and Blankenberge (Kerckhof et al., 2007). The species is regularly found living on piers and jetties and washed ashore (Kerckhof, 1997; Jonckheere, 2006). Especially the 1990's saw a rapid proliferation of the species in Belgian waters (F. Kerckhof, pers. comm.). Since 1996, oyster culture in the Sluice Dock has resumed. Next to the limited use of local brood stock, again *C. gigas* are imported from European countries and Canada (Kerckhof et al., 2007).

3.5. Introduction and spread of Pacific oysters in Germany

Pacific oysters are also spreading throughout the German Wadden Sea (Fig. 4; Reise, 1998; Diederich et al., 2005; Nehls et al., 2006). The western part of the German Wadden Sea, the East Frisian Wadden Sea, has been systematically searched for wild *C. gigas* on mussel beds since 1996 (Wehrmann et al., 2000). Here, the first naturally dispersed oysters were detected in 1998. Although an experimental culture plot for *C. gigas* had existed for one farming season in 1987 near the island of Norderney, this was considered an unlikely source for the observed wild *C. gigas*. Instead, the East Frisian Wadden Sea

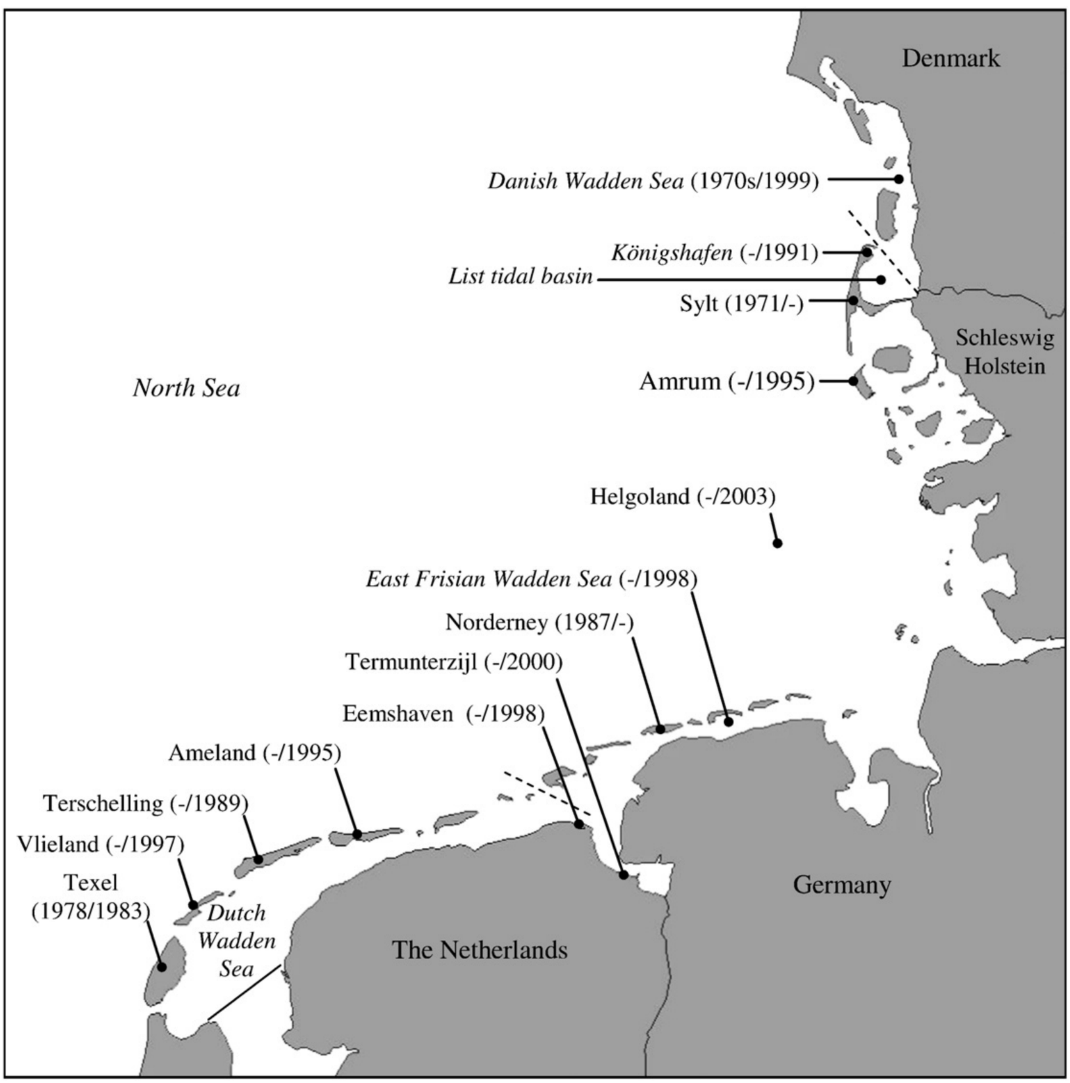


Fig. 4. Locations where *C. gigas* was first introduced/encountered (years between brackets) in the Wadden Sea area (Bruins, 1983; Reise, 1998; Drinkwaard, 1999b; Tydeman, 1999; Wehrmann et al., 2000; Tydeman et al., 2002; Diederich et al., 2005; Wolff, 2005; Nehls et al., 2006). Locations of islands and water bodies are given, not exact locations of introductions/encounters.

was probably invaded from the Dutch Wadden Sea (Wehrmann et al., 2000).

In the northern part of the German Wadden Sea, the List tidal basin in the Wadden Sea of Schleswig–Holstein was colonized from an oyster culture site at the northernmost German island of Sylt (Reise, 1998; Wehrmann et al., 2000). Here, *C. gigas* spat from a Scottish hatchery were imported for the first time in 1971 and again in 1972 for a raft culture experiment (Drinkwaard, 1999b). At the end of the 1970's, outdoor experiments on growth and fattening and indoor experiments on rearing of spat from larvae were continued (Drinkwaard, 1999b). At Sylt, regular oyster culture on trestles started in 1986 (Reise, 1998; Drinkwaard, 1999b). Juvenile and seed oysters were imported regularly from hatcheries and a nursery on the British Isles and Ireland (Drinkwaard, 1999a,b). The first *C. gigas* individual outside the culture plot at the island of Sylt was observed in 1991 in the Königshafen Bay (Reise, 1998; Drinkwaard, 1999b). Since 1995, *C. gigas* is also found on mussel beds near the island of Amrum, south of Sylt, which became the second centre of oyster distribution in the Wadden Sea of Schleswig–Holstein (Nehls et al., 2006). Since 2000, the abundance of *C. gigas* in this area increased markedly. In Schleswig–Holstein, as in the East Frisian Wadden Sea and the Dutch Wadden Sea, *C. gigas* settles preferentially on mussel beds (Reise, 1998), and by 2004 almost all mussel beds in the List tidal basin near Sylt had been colonized (Nehls et al., 2006). Densities of *C. gigas* on mussel beds in Schleswig–Holstein were on average 290 m^{-2}, up to a maximum of 600 m^{-2} (Nehls et al., 2006). Highest densities were found in the List tidal basin near Sylt (Diederich et al., 2005). The first wild oysters on the offshore German island of Helgoland were found in 2003 (Diederich et al., 2005).

3.6. Introduction and spread of Pacific oysters in Scandinavia

Also in Scandinavia, Pacific oysters were introduced for culture purposes (reviewed by Wrange et al., 2009). In Denmark, the first introduction took place in Limfjorden in 1972. In the following years, seed oysters were introduced to establish cultures in the Limfjorden, the Wadden Sea and at several locations along the Danish Baltic coast (Little Belt, Isefjorden, Mariager Fjord, and Horsens Fjord). At some of these sites, farming continued during the 1980's and 1990's. In the 1990's the first naturally occurring oysters were found in the Danish Wadden Sea (Diederich et al., 2005). In the period 2005–2008, Wrange et al. (2009) made an effort to map the distribution and abundance of Pacific oysters in Scandinavian waters. By then, the population in the Wadden Sea had increased rapidly. Densities of up to 55.8 kg m^{-2} were found in 2007. In Limfjorden, densities of several to <20 specimens m^{-2} were found and a reef structure was observed in the western part of the fjord. Five size cohorts were discerned (unfortunately not supported by graphs, Wrange et al., 2009). At the Baltic coast locations, densities of <1 m^{-2} were found.

In Sweden, oyster spat were imported at the west coast, northern Bohuslän, between 1973 and 1976. Only few specimens were reported from the wild until 2007, when feral Pacific oysters were reported from many locations along the west coast. In the period 2007–2008, a mean density of <1 m^{-1} was found, with a maximum density of 505 ± 173 m^{-2} in the most northern region (mostly 60–70 mm shell length). Two size cohorts were discerned (Wrange et al., 2009).

In Norway, Pacific oysters were imported in 1979 for the establishment of a brood stock population. Three hatcheries produced millions of spat from 1987 to 1990 (in Vallersund, Espevik and Øygarden, 64°–60° North). From 1981 until 1986, farmers imported seed oysters from Scotland for cultivation along the Norwegian coast. This practise became largely restricted in 1986. During the last two decades, adult oysters have been imported and re-laid in Norwegian waters. In the period 2006–2008, Wrange et al. (2009) only found single oysters at several locations, but discerned 4 size cohorts. The largest oysters may have been remnants of live-stored imported oysters (Wrange et al., 2009).

Although in Scandinavia water temperatures had been assumed to be too low for reproduction of *C. gigas*, as had been the case in The Netherlands, Pacific oysters are now naturally reproducing in Danish, Swedish and Norwegian waters. The recent success of *C. gigas* in Scandinavia and northern Germany appears to be related to the occurrence of exceptionally warm summers and mild winters during the last decade (Diederich et al., 2005; Wrange et al., 2009).

4. Causes of successful establishment and natural spread

4.1. Characteristics of successful invaders and invasible ecosystems

In many cases an invader is not discovered until after the invasion event, at a point where the invader already is a part of the ecosystem (Williamson, 1996). Consequently, ecological responses to the invasion may go unnoticed for a long time, and the mechanism of invasion and the causes of its success may never be elucidated. A large body of scientific work is devoted to finding general rules in invasion ecology. What characteristics determine whether species are invasive? And what characteristics determine whether a community is invasible? Species that are introduced into new habitats encounter many abiotic and biotic barriers (Colautti et al., 2006). They have to be able to live in or adapt to the new habitats. Generally three determining stages are identified in invasion ecology: 1) colonization of the receiving habitat, 2) establishment in the receiving habitat, 3) natural range expansion after establishment (Sakai et al., 2001). Common causes of failure to establish are: an unsuitable climate, disturbance, predation, competition and disease. Species that do manage to establish themselves face many different interactions with native species in the new community (Lodge, 1993; Sakai et al., 2001). Many attempts have been made to identify characteristics of species that allow predictions about their invasiveness (Lodge, 1993; Williamson and Fitter, 1996; Morton, 1997; Kolar and Lodge, 2001; Sakai et al., 2001). For a successful invasion, different traits may be required for the different stages of the invasion (colonization, establishment and natural range expansion)(Sakai et al., 2001). The applicability of these traits to the introduced Pacific oyster will further be discussed for each of these three invasion stages (Table 2) except for the first stage: colonization. Traits contributing to successful

Table 2
A selection of characteristics generally attributed to successful invaders, especially relevant for bivalve invaders and for the three principal stages from first colonization to natural range expansion (from Lodge, 1993; Williamson and Fitter, 1996; Morton, 1997; Sakai et al., 2001; Marvier et al., 2004; Wallentinus and Nyberg, 2007; and references therein).

Stage	Trait
Colonization	*r*-selected life history strategy:
	Rapid growth
	Rapid sexual maturation
	High fecundity
	Generalists:
	Ability to colonize wide range habitat types
	Broad diet
	Tolerance to wide range environmental conditions
	Gregarious behaviour
	Genetic variability and phenotypic plasticity
	Ability to recolonize after population crash
Establishment (Section 4.2)	Lack of natural enemies
	Ecosystem engineering
	Association with humans
	Repeated introductions
	Genetic variability and phenotypic plasticity
	Competitiveness
Natural range expansion (Section 4.3)	Traits of successful colonists (see above)
	Dispersability

colonization are important for invaders that are accidentally and incidentally introduced somewhere, but are of minor importance for invaders that are imported multiple times for cultivation, such as *C. gigas*. Initial colonization by *C. gigas* was entirely facilitated by oyster farmers. Pacific oysters were introduced repeatedly, providing the species with a repeated chance at every reproduction season of becoming established.

4.2. Traits contributing to successful establishment

4.2.1. Lack of natural enemies

A lack of natural enemies in the receiving community is often suggested as a reason for fast proliferation of introduced non-indigenous species (Table 2; Williamson and Fitter, 1996; Keane and Crawley, 2002; Liu and Stiling, 2006). To find out whether this "enemy release hypothesis" is applicable to the successful establishment and rapid expansion of *C. gigas* in Dutch waters, an overview of predators, parasites and diseases affecting *C. gigas* in the North-West Pacific and in The Netherlands is given here.

In the Wadden Sea and Dutch estuaries native bivalves are generally heavily preyed upon by various bird species (Reise, 1978; Beukema et al., 1993; Nehls et al., 1997), but *C. gigas* is affected much less by bird predation. Herring gulls (*Larus argentatus*) and oystercatchers (*Haematopus ostralegus*) are the only bird species reported to feed on *C. gigas*. Herring gulls prey upon *C. gigas* locally. They take a loose individual up in the air, and break the shell by dropping the oyster several times on a hard surface, usually a stone-covered dike (Cadée, 2001; 2008b at Texel, Wadden Sea; own unpublished observations in the Oosterschelde estuary). Recent anecdotal information suggests that oystercatchers *H. ostralegus* are learning to feed on *C. gigas* in the Wadden Sea (Scheiffarth et al., 2007; Cadée, 2008a) and Oosterschelde estuary (Baptist, 2005) by prying gaping individuals open with their beak. However, predation by herring gulls and oystercatchers in Dutch estuaries still occurs locally at low rates and is not expected to cause significant losses (Cadée, 2008b).

Little information on the role of bird predation in the North-West Pacific could be found. The local species of oystercatcher (*H. ostralegus osculans*) is said to be an uncommon species (Del Hoyo et al., 1996). The black-tailed gull *Larus crassirostris* is a common omnivore in Japan, and reported to feed on molluscs (Del Hoyo et al., 1996). However, no information was found on whether Pacific oysters are also included in its diet. No indications were found that bird predation pressure in the Pacific differs very much from that in The Netherlands.

Fish species in The Netherlands reported to feed on bivalve spat are the gobies *Pomatoschistus microps* and *P. minutus*, and juvenile flatfish of the species *Pleuronectes platessa*, *Platichthys flesus* and *Solea solea* (Hiddink et al., 2002 and references therein). Whether these fish also predate on spat of *C. gigas* is not known. In Japan, Pacific oyster spat is reportedly predated by the black sea bream *Acanthopagrus schlegelii* and the fine-patterned puffer *Takifugu poecilonotus* in Hiroshima Bay (Saito et al., 2008).

In The Netherlands especially juvenile stages of bivalves are preyed upon by a variety of epibenthic invertebrate predators (Beukema, 1991; Beukema et al., 1998; Van der Veer et al., 1998; Hiddink et al., 2002). The most common invertebrate shellfish predators in the Wadden Sea and Dutch estuaries are the brown shrimp *Crangon crangon*, the shore crab *Carcinus maenas* and the common starfish *Asterias rubens*. Of these the shore crab and the starfish have been shown in laboratory experiments to predate on *C. gigas* as well (Diederich, 2005a: oysters with shell lengths of up to 40 mm offered to and predated by *C. maenas*, and oysters of up to 60 mm offered to and predated by *A. rubens*). However, both predators have a preference for *Mytilus edulis* over *C. gigas* of similar shell length, and Diederich (2005b) found no significant effects of predation on post-settlement survival of *C. gigas* juveniles in the German Wadden Sea at Sylt. *C. crangon* causes high mortality rates among native bivalve spat (Van der Veer et al., 1998), but no empirical studies on whether it also feeds on *C. gigas* spat were found. *C. crangon* may not be adapted to scrape oyster spat from shells or stones.

In its native range, the Pacific oyster is predated by crabs (Fukui, 1988). It is also attacked by a variety of other epibenthic predators not occurring in Dutch waters. In Japan oysters are predated by several species of predatory flatworms (Turbellaria, Polycladida; Kato, 1944; Galleni et al., 1980) among which *Pseudostylochus ostreophagus*, especially dangerous to oyster spat, and *Stylochus ijimai* that predates on adult oysters (Korringa, 1976). Gruet et al. (1976) describe how Pacific oysters imported from Japan into France were immersed in freshwater to kill these flatworms; apparently this treatment was successful. Fujiya (1970) describes the following natural enemies of *C. gigas* in hanging-culture in Japan, all oyster drills: *Thais tumulosa clavigera*, *Thais bronni*, *Tritonalia japonica*, *Rapana thomasiana* (presently referred to as *R. venosa*), and *Ceratostoma burnetti*. Among these species, *T. tumulosa clavigera* is the most serious enemy of oysters (Fujiya, 1970). Some of these predators were introduced with early oyster shipments to North America, before Canadian and American authorities developed and implemented control measures in cooperation with Japanese authorities and seed growers (Quayle, 1988). Lavoie (2005) mentions the flatworm *P. ostreophagus* and the Japanese oyster drill *Ocenebra japonica* (Dunker 1860) (also called *Tritonalia japonica* (Dunker 1850), *Ceratostoma inornatum* (Recluz 1851), and presently referred to as *Ocinebrellus inornatus* (Recluz 1851)). This oyster drill originates from the same geographical range as *C. gigas*, and was introduced in North America in 1924 and, from there, to France in 1995 (Martel et al., 2004). The veined whelk *Rapana venosa* was introduced to several areas over the world (Black Sea, Aegean Sea, Adriatic Sea, Uruguay, the eastern USA, and north-western France) and was found in the southern North Sea in 2005 (Kerckhof et al., 2006). So far no veined whelks or flatworms predating on *C. gigas* have been reported from Dutch estuaries. The oyster drills *Ocinebrellus inornatus* and *Urosalpinx cinerea* (native to the US east coast) have been found in the Oosterschelde estuary in 2007 and 2008 (Faasse and Ligthart, 2007; Goud et al., 2008). They were likely introduced only recently and still occur very locally and in low numbers. It may therefore be concluded that the predation pressure from epibenthic invertebrate predators in previous years was likely to be much higher in the North-West Pacific than in the Netherlands, thus giving support to the "enemy release hypothesis" as an explanation for the proliferation of *C. gigas* in Dutch estuaries. In addition, Schmidt et al. (2008) observed exceptionally low mortality rates among juvenile Pacific oysters and decreasing survival rates during the early years of invasion. Among other possible explanations they suggested that predators may gradually adapt to the new prey items available (Schmidt et al., 2009, a reply to Beukema and Dekker, 2009), but this needs further investigation. Pacific oysters are furthermore also predated by humans. In the Oosterschelde estuary Pacific oysters are hand-picked for consumption mainly by Asian immigrants (unpublished observations). This suggests that collection of seafood by hand may be a more common practise in Asian countries (see Sechena et al., 1999) and that predation pressure on oysters by humans is higher in the NW Pacific than it is in NW Europe.

The "enemy release hypothesis" does not appear applicable to parasites and diseases. From Japan and British Columbia, live adult Pacific oysters were introduced directly into the Oosterschelde estuary. Therefore, most parasites and diseases that are present in the areas of origin and that have been able to survive and establish in the receiving ecosystem, are likely to be present in the Oosterschelde estuary. The copepod parasites of the Pacific oyster *Mytilicola orientalis* and *Myicola ostreae* were thus introduced with Pacific oyster imports from Japan or British Columbia (Stock, 1993; Wolff, 2005). It is not known whether the latter species is presently established in Dutch waters (Wolff, 2005). *M. orientalis* causes loss of gonadal mass in *M. edulis* (Mann 1956 and Williams 1969 in Steele and Mulcahy, 2001), but it hardly affects *C. gigas* (Steele and Mulcahy, 2001). The bacterium *Nocardia crassostreae* also seems to have been introduced from Japan and/or the west coast of North America. In these regions, occurrence of this bacterium in Pacific oysters is associated with summer mortalities (references in Engelsma et al., 2008). *N. crassostreae* was recently found, together with the bacterium *Vibrio aestuarianus*, in *C. gigas* from Lake Grevelingenmeer (The Netherlands; Engelsma et al., 2008). The infected oysters were collected after an extensive mortality in the summer of 2006. However, Engelsma et al. (2008) concluded that the oysters had mainly died because of physiological stress due to adverse environmental conditions in Lake Grevelingenmeer, and the bacteria may only have contributed as a secondary cause to the observed mortality. Parasites of *C. gigas* that were already described from Dutch estuaries before the first introduction of *C. gigas* are the fungus *Ostracoblabe implexa* and spionid polychaetes of the genus *Polydora* (Korringa, 1952). The fungus *O. implexa* affects and weakens *C. gigas*' shell, but this does not seem to lead to significant mortalities (Engelsma and Haenen, 2004). *Polydora* spp. weaken the shell of *C. gigas* and the native oyster *O. edulis* by burrowing into it (Korringa, 1951; Almeida et al., 1996), but this does not appear to cause mortalities among the two species (Engelsma and Haenen, 2004). In Japan, *C. gigas* is also infected by polychaetes of the genus *Polydora*, but as in The Netherlands these do not cause serious damage (Fujiya, 1970). In the German Wadden Sea, *C. gigas* is furthermore infected by the native trematode *Renicola roscovita* and a single infection by the native turbellarian *Paravortex* sp. was reported near the island of Sylt (Krakau et al., 2006). Krakau et al. (2006) demonstrated that introduced bivalves (*C. gigas* and *Ensis americanus*) are infected by a fraction of the native parasites of bivalves present, and that trematode intensity was always lower in the introduced species. *C. gigas* was furthermore infected by the native trematode *Himasthla elongata* in the laboratory, but in *C. gigas* the cercariae did not develop into metacercariae, as they would normally do in their common second intermediate host *M. edulis* (Thieltges et al., 2009). No infections with *H. elongata* were found in the field (Krakau et al., 2006). Krakau et al. (2006) hypothesized that native parasites adapt to the new hosts, possibly leading to significant infestations in the future. The Pacific oyster is furthermore not affected by bonamiosis (Renault, 1996). After its introduction with oyster imports from Brittany in 1980, bonamiosis has caused very high mortality rates among *O. edulis* (Drinkwaard, 1999a). The protist *Bonamia ostreae* that causes bonamiosis possibly originates from the north-east Pacific (Wolff, 2005 and references therein). Tentatively, Pacific oysters do not seem to be released from their Pacific parasites and diseases in the receiving NW European estuaries, and are infected by native European parasites as well. In comparison to native bivalves, however, Pacific oysters do seem to be affected less by these natural enemies.

4.2.2. Ecosystem engineering by *Crassostrea gigas*

Habitat modification by introduced and invasive ecosystem engineers facilitates establishment and subsequent colonization of new areas (Table 2) by adapting the encountered habitat, that may have been suboptimal, to the demands of the invader (Cuddington and Hastings, 2004). The Pacific oyster is such an invasive ecosystem engineer since it modifies habitats by constructing large three-dimensional reef structures (Jones et al., 1994; Gutiérrez et al., 2003). Reef formation is enhanced by the gregarious settling behaviour of Pacific oyster larvae. The larvae preferentially settle onto shells of Pacific oysters (Diederich, 2005a) and settlement is triggered by presence of adult oysters (Tamburri et al., 2007) and apparently also by previously settled spat (Troost, 2009). By settling on top of each other, cementing their shells together during growth, Pacific oysters create a strong reef structure. The reef structure modifies the habitat to the demands of the invader in several ways. Besides through gregarious behaviour, larval settlement is also enhanced by the baffling of water movements by the oysters in the bed (Commito and Rusignuolo, 2000). The three-dimensional structure provides shelter against extreme environmental conditions such as heat and desiccation (Bartol et al., 1999; Gutiérrez et al., 2003). It also offers a refuge from predation by e.g. birds that have difficulty reaching into the oyster bed, and from benthic predators such as crabs. The high degree of structural complexity in an oyster reef reduces the predator–prey encounter rate (Bartholomew et al., 2000; Grabowski, 2004) resulting in higher growth and survival of oyster spat (Nestlerode et al., 2007). Additionally, the firm attachment of oyster spat and juveniles to adult oysters may serve to reach a size refuge from the beginning with respect to predators that consume solitary individuals. Oyster beds may also affect particle and solute transports by altering near-bed flow (Gutiérrez et al., 2003). The roughness of oyster reefs enhances near-bed turbulence levels, thereby increasing the food flux towards the bivalves and reducing refiltration of already filtered seawater (Jonsson et al., 2005; Widdows and Navarro, 2007; Troost et al., 2009b). Furthermore, the reef structure offers a large area of suitable settlement substrate that, in general, seems very persistent. Pacific oyster reefs, consisting mainly of empty oyster shells cemented together after a mass mortality, were observed to largely remain in place (Fey et al., 2009; own unpublished observations). Following mass mortality, an extensive spatfall of larvae from another brood stock will then be sufficient to recolonize the entire reef. Pacific oysters therefore increase the area suitable for settlement by building reefs, and in this way ensure settlement possibilities on a longer time scale. This process will be enhanced by the oysters' gregarious settling behaviour and high dispersability.

4.2.3. Other traits contributing to successful establishment of *Crassostrea gigas*

Other traits generally thought to contribute to successful establishment (Table 2) all seem applicable to *C. gigas*. Because Pacific oysters are associated closely to humans in the sense that they are cultured world-wide for consumption, they have been introduced all over the world. In The Netherlands, Pacific oysters have been introduced repeatedly from 1964 to around 1980 (Drinkwaard, 1999b). Propagule pressure was therefore high, increasing the genetic variation of the introduced stock, widening the genetic bottleneck and increasing chances of establishment and adaptation to the new environment. Japanese populations show a high genetic variation, and most of this high variation appears to have been retained by populations of *C. gigas* introduced for mariculture world-wide (Hedgecock et al., 1996; English et al., 2000; references therein). In addition to the relatively large gene pool in the new area, the species also appears highly adaptable phenotypically, as are many species of sessile bivalves (Bayne, 2004). In terms of survival, growth and reproductive effort, *C. gigas* responds plastically to spatial variability in food abundance (Ernande et al., 2003). Pacific oysters are also flexible in the morphology of their feeding organs (relative sizes of gills and labial palps; Honkoop et al., 2003), and in their limits of thermal tolerance (Hamdoun et al., 2003). As in many other bivalves, also the larvae and spat of *C. gigas* exhibit high phenotypic variation, particularly in terms of growth and survival (Taris et al., 2006). High phenotypic flexibility enables an invader to adapt to a wide range of conditions, and increases chances of becoming established and of competing successfully with native species.

Pacific oysters apparently have all the right tools to adapt to new environments quickly. But did they really need to adapt to Dutch waters that much? Diederich et al. (2005) showed that the invasion of the northern German Wadden Sea was accelerated by an increasing frequency of warm summers. The more southern and relatively warmer Oosterschelde estuary, however, has sea surface temperatures that are comparable to those in the area of origin of the Miyagi and Kumamoto strains that were mainly imported in the Netherlands (Oceanographic atlas of the Bering Sea, Okhotsk Sea and Japan/East

Sea, www.pacificinfo.ru/en/, January 2009). Summer temperature was therefore likely not limiting for recruitment of the Pacific oyster in the Oosterschelde estuary, which will have contributed to its fast establishment. The natural occurrence at the Russian island of Sakhalin, between the Sea of Japan and the subpolar Okhotsk Sea, should have been a warning that Dutch waters were not at all too cold for *C. gigas* to reproduce.

Competitiveness is also a characteristic contributing to successful establishment of non-native species. Its applicability to *C. gigas* will be discussed in Section 5.

4.3. Traits contributing to successful natural spread after establishment

4.3.1. Colonization capabilities

Once an invader is established, subsequent spread is related to the dispersability and colonization capabilites of the invader (Table 2). Successful colonists are generally species with fast reproductive rates. They are characterized by fast growth rates, rapid sexual maturation and a high fecundity (Lodge, 1993; Williamson and Fitter, 1996; Morton, 1997; Sakai et al., 2001) (Table 2). These are traits of an *r*-selected life history strategy (Pianka, 1970) of which the Pacific oyster exhibits many features. Growth of Pacific oysters is rapid. Two-year old Pacific oysters have been reported to reach lengths of up to 80 mm at Sylt, Germany (Diederich, 2006), and lengths of 30 mm on average at Texel and Yerseke, The Netherlands (Cardoso et al., 2007). The oysters, that can live up to about 10 years (Cardoso et al., 2007), reach maximum lengths of up to 300 mm (Reise, 1998; Cardoso et al., 2007; own unpublished observations). Fast growth may enable the oysters to reach a size refuge from invertebrate and fish predation quickly. In addition, Diederich (2006) observed very high survival rates of *C. gigas* juveniles in comparison to native species. The combination of fast growth and high survival may account for a fast population increase, and may compensate for recruitment failures near the distribution limits (Diederich, 2006).

Another trait of successful colonists that may have contributed to successful natural spread after establishment is habitat generalism (Marvier et al., 2004). Characteristics of habitat generalists include: broad tolerances for wide ranges of environmental conditions, the ability to occupy a wide range of habitat types, and a broad diet (Table 2; Lodge, 1993; Morton, 1997; Sakai et al., 2001; Marvier et al., 2004). Although Pacific oysters in first instance settle onto hard substrates in the subtidal and intertidal, they also develop beds on soft bottoms by first settling onto small pieces of shell and stones (Quayle, 1988; Mann et al., 1991; Leewis et al., 1994; Wolff, 2005; Dankers et al., 2006). This is facilitated by their gregarious settling behaviour. The native geographical range of *C. gigas* is very wide (Fig. 3), comprising a large range of abiotic conditions. The regions where *C. gigas* was successfully introduced also cover a wide geographical range (including countries in North and South America, Europe, Asia, Africa and Oceania; Arakawa, 1990a; Dinamani, 1991; Grizel and Héral, 1991; Shatkin et al., 1997; FAO, 2004; Wolff, 2005). Hence, the Pacific oyster was already adapted to a wide range of environmental conditions, and appears able to quickly adapt to new habitats. This is confirmed by its ability to sustain a wide range of environmental conditions. The oysters can survive water temperatures up to 40 °C (Shamseldin et al., 1997) and at low tide air temperatures as low as −5 °C (Korringa, 1952) and even lower, depending on the salinity of the water enclosed in their shells (>75% survival at 30 psu, at −12 °C air temperature; exposure during 7 days, 6 h per day, mimicking tidal emersion; Wa Kang'eri, 2005). Growth occurs between 10–40 °C and 10–30 psu, and spawning between 16–30 °C and 10–30 psu. Larvae can sustain temperatures between 18 and 35 °C and salinities between 19 and 35 psu (Mann et al., 1991 and references therein; Rico-Villa et al., 2009).

Furthermore, gregarious settlement of the larvae, genetic variability and phenotypic plasticity, as well as an ability to recolonize areas rapidly following a population crash are considered to be general traits of successful colonists (Table 2). The applicability of these traits to *C. gigas* was already established in the previous section (Section 4.2. Traits contributing to successful establishment). The ability of recolonizing areas results from the Pacific oyster's ecosystem engineering capacities and its high dispersability (discussed below).

4.3.2. Dispersability

Pacific oysters are broadcast spawners and are highly fecund. An oyster female may produce more than 50 million eggs per spawning, which is high compared to native bivalves (Helm et al., 2004). A *M. edulis* female may produce 5–12 million eggs per spawning (Helm et al., 2004), a *C. edule* female 0.2–0.7 million eggs (Honkoop and Van der Meer, 1998) and a *Macoma balthica* female 0.02–0.07 million eggs (Honkoop and Van der Meer, 1998). Per square meter bed, however, total egg production of *C. gigas* and *M. edulis* is comparable because the latter generally occurs in higher densities (see Nehls et al., 2006). In The Netherlands, Pacific oysters produce more and relatively smaller eggs than their more southern kin in France (Cardoso et al., 2007). These smaller eggs have a lower energy content and therefore result in a longer duration of the pelagic larval phase (Van der Veer et al., 2006; Cardoso et al., 2007). This enables a wider dispersion range, although smaller eggs may also result in a lower fertilisation rate (Luttikhuizen et al., 2004) and a prolonged pelagic phase may result in an increased pre-settlement mortality. Although the bulk of the larvae travel up to 5 to 15 km, a smaller part will be carried further with residual currents (Wehrmann et al., 2000; Brandt et al., 2008). The Pacific oyster shows a large capability of spreading rapidly after first introduction and establishment. From the moment the first spatfall was observed the rate of spread to new areas has been very fast in France, The Netherlands and Germany (Grizel and Héral, 1991; Kater and Baars, 2004; Diederich, 2005b; Cognie et al., 2006; Nehls et al., 2006; Fey et al., 2009). This illustrates the high potential for range expansion of *C. gigas*.

4.4. Invasiveness of receiving communities

Many attempts have been made to identify characteristics that determine the invasiveness of receiving communities. Despite conflicting evidence, disturbance is often considered such a characteristic (Lodge, 1993; Occhipinti-Ambrogi and Savini, 2003; Marvier et al., 2004). Although many coastal ecosystems in continental NW Europe are considered to be disturbed, the nature of these disturbances varies widely from one ecosystem to another (e.g. pollution, dredging, shipping, coastal engineering). Furthermore, anthropogenic disturbance is a factor which is hard to quantify. *C. gigas* has invaded so many ecosystems that it is difficult to believe that disturbance played an important role and it seems impossible to prove so, or otherwise.

A lack of predators in the receiving community is furthermore often suggested as a reason for fast proliferation of introduced non-indigenous species. This was already concluded to have played a role in the fast proliferation of *C. gigas* in Section 4.2.

Finally, species-poor estuarine communities seem more susceptible to invasions than species-rich, more saturated communities (Wolff, 1973; Lodge, 1993; Stachowicz et al., 1999; Wolff, 1999). This is thought to be a contributing factor to the relatively large number of non-indigenous species recorded in brackish (5–20 psu) estuaries (Wolff, 1973; Wolff, 1999; Nehring, 2006). Highest densities of *C. gigas* are, however, found at salinities higher than 20 psu. The Oosterschelde estuary itself is not at all poor in native species (Wolff, 1973; Hostens and Hamerlynck, 1994; Sistermans et al., 2005; Wolff, 2005), and moreover harbours many non-indigenous species that were imported through shellfish culture activities (Wolff, 2005). Hence, species richness did not play a part in the establishment of *C. gigas* in the Oosterschelde estuary. The Wadden Sea has lost many habitat building species and associated communities due to overexploitation (Reise, 1982; Wolff, 2000; Lotze, 2005; Airoldi and

Beck, 2007) although it also gained some non-indigenous species (Reise et al., 1999). Macro-benthic species richness of the tidal flats is rather low compared to other marine soft-bottom areas, which is likely related to the harsh and unstable environment (Beukema, 1976). Whether this has contributed to establishment success of *C. gigas* in the Wadden Sea cannot be excluded.

4.5. Causes of success

All traits of successful invaders investigated in this review and listed in Table 2 are applicable to *C. gigas*, without any exceptions. However, some traits will have contributed more strongly to the Pacific oyster's remarkably successful establishment and subsequent natural spread to other areas. Regarding many of the traits considered, *C. gigas* does not appear very different from native bivalves. An *r*-selected life history strategy, wide tolerances (generalism), genetic variability and phenotypic plasticity, competitiveness and dispersability all contributed to *C. gigas*' success but are rather common traits among sessile bivalves inhabiting the often unstable environment of the intertidal zone, where the bivalves have to be adapted to environmental extremes. A close association with humans, which was responsible for initial colonization by *C. gigas* and which contributed to its establishment success, is common for bivalve species that are of commercial interest, especially ones that are cultured intensively such as *M. edulis* and *C. gigas*. Both successful establishment and successful natural spread by *C. gigas* seem mainly attributable to two traits in which the species appears to differ the most from native bivalves: "ecosystem engineering" (associated with "gregarious behaviour" and "ability to recolonize after population crash", Table 2) and a "lack of natural enemies". In continental NW European estuaries, the lack of natural invertebrate predators applies specifically to *C. gigas* and not to native bivalves. A lack of invertebrate predators resulted in exceptionally high survival rates of spat and juveniles and offered *C. gigas* a competitive advantage over native bivalves. The only native bivalve reef-building ecosystem engineer is *M. edulis*. Ecosystem engineering facilitated successful establishment by *C. gigas* by modifying habitats to the oyster's demands in several ways: by facilitating settlement, by enhancing food intake and by offering shelter. Whether competition with native bivalves for resources also contributed to successful establishment will be discussed in the following chapter.

Additionally, life history theory predicts a trade-off between fast reproductive rates, that facilitate colonization, and competitive ability, that facilitates establishment (Pianka, 1970). In some invaders both strategies are represented (Keddy et al., 1994). Blossey and Notzold (1995) suggested that non-indigenous species that have been released from the pressure of diseases or predators in their native habitat, reallocate energy used for defence into reproduction and growth. Whether this is applicable to *C. gigas*, that also appears to be a successful competitor, needs further investigation.

5. Changes induced by *C. gigas* in NW European estuarine ecosystems

In this paragraph, a review is given of (potential) consequences of the expansion of Pacific oyster beds on the receiving ecosystems in The Netherlands and neighbouring countries. Changes induced by the ecosystem engineering *C. gigas* in receiving estuaries are mainly caused by the complexity of the added structure and by the suspension feeders' filtration activity. Potential ecological consequences as discussed below are therefore subdivided in effects of habitat modification and effects of the oysters' filtration activity.

5.1. Consequences of habitat modification by *C. gigas*

5.1.1. Habitat modification by Pacific oysters

Although Pacific oyster beds are expanding in both the Oosterschelde estuary and the Wadden Sea, the habitat that they are modifying differs between both ecosystems. In the Oosterschelde estuary, oyster reefs mainly developed on hard substrates (e.g. dikes, jetties), former mussel culture plots, and former culture sites for the European flat oyster *O. edulis*. Former culture sites for *M. edulis* may still have contained some mussels or mussel shell debris, offering some hard substrate that stimulated colonization by *C. gigas*. On former culture sites for *O. edulis*, hard substrate was present in the form of low walls constructed of roof tiles. From these initial pieces of hard substrate the oyster beds have been mainly developing on former essentially bare flats. The speed of reef formation on soft substrates appears dependent on the amount of hard substrate (generally shell debris) present (Wijsman et al., 2008). In the Wadden Sea area, *C. gigas* is reported to mainly colonize areas with a high cover of hard substrate, such as mussel beds and (cockle-)shell ridges (Dankers et al., 2006; Nehls et al., 2006; Schmidt et al., 2008). Spatfall and an increasing biomass is mainly observed within existing oyster beds, mussel beds and shell banks (Dankers et al., 2006) and to a lesser extent outside these beds (pers. comm. G. Nehls).

Mussel beds are argued to raise and stabilize the sediment surface locally (Reise, 2002; Commito et al., 2008). Pacific oyster reefs have the same effect on the sediment surface, but mature oyster reefs appear more persistent and may therefore stabilize the sediments on a larger time scale. These mature reefs are anchored deep in the sediment thereby consolidating the substrate firmly (Reise and Van Beusekom, 2008; own unpublished observations). Because of this property Pacific oyster reefs have been suggested to be a valuable tool in preventing further erosion of intertidal flats in the Oosterschelde estuary. Here, as a consequence of the construction of a storm surge barrier and compartmentalisation dams (the "Delta" coastal engineering project) sediment deposition on tidal flats is reduced while erosion still continues, causing tidal flats to slowly submerge (Van Zanten and Adriaanse, 2008). Oyster reefs may thus locally protect the intertidal habitat of native bivalves and other invertebrate fauna, and the intertidal foraging grounds of species at higher trophic levels (such as shorebirds). Furthermore, by excreting vast amounts of faeces and pseudofaeces Pacific oysters, like mussels, enrich the sediment organically. This results in fine-grained sediments with high organic content, ammonia and hydrogen sulphide, and low oxygen levels (Hartstein and Rowden, 2004; Commito et al., 2008). How this impacts local macrofaunal communities will be discussed in the following paragraph.

5.1.2. Consequences for species richness and biodiversity

Overexploitation of living resources and habitat destruction are the main causes for biodiversity loss and species extinctions worldwide (Wolff, 2000). In the Wadden Sea and other estuaries in NW Europe, many habitat building species have been lost due to overexploitation in the 20th century (Reise, 1982; Wolff, 2000; Lotze, 2005; Airoldi and Beck, 2007). Associated communities consequently disappeared due to habitat loss. Seagrass meadows, oyster beds (*O. edulis*), mussel beds (*M. edulis*), *Sabellaria spinulosa* reefs, and sea moss stands provided hard substrate, shelter and food to associated species in NW European estuarine areas. Of these, only mussel beds remain today although old and mature mussel beds with a relatively higher complexity are not encountered anymore (Reise, 1982; Lotze, 2005). The Pacific oyster, although an alien species, reintroduces structural complexity and may be considered to restore habitat diversity and biodiversity. Pacific oyster reefs, especially the more mature ones, are furthermore avoided by most fishermen because they can cause damage to the netting. Hence, the associated benthic community may be given better opportunities to mature in the more stable environment of an oyster reef, compared to mussel beds and other, largely disappeared, biogenic structures. In the following text, a review is given of species richness and associated communities in Pacific oyster reefs, in comparison to mussel beds and bare tidal flats in the Wadden Sea and Oosterschelde estuary.

In the Wadden Sea Pacific oysters mainly settle onto intertidal mussels beds (Reise, 1998; Schmidt et al., 2008). Mussel beds are thereby transformed to mixed oyster/mussel beds with varying proportions of oysters and mussels. Soft bottom mytilid beds were already known to generally enhance habitat heterogeneity and species diversity at the ecosystem level (Günther, 1996; Buschbaum et al., 2009). Because *C. gigas* also enhances habitat heterogeneity by constructing complex reef structures, oyster reefs are expected to enhance local biodiversity as well. This was confirmed by two studies in the German Wadden Sea. Markert et al. (2009) and Kochmann et al. (2008) made a comparison between macrofaunal communities associated with mussel beds and oyster reefs. Markert et al. (2009) selected a mussel bed in the back barrier area of the island of Juist that had been colonized by *C. gigas*. They compared the macrofaunal communities between an area dominated by *M. edulis* and an area dominated by *C. gigas*. Kochmann et al. (2008) chose an experimental approach, and constructed artifical reefs of *C. gigas*, *M. edulis*, and a mix of both, in the outer Königshafen bay at the island of Sylt. They compared the number of invertebrate recruits of several species, and the abundance of vagile epifauna. Both studies showed that associated communities of *C. gigas* and *M. edulis* are largely similar, although they revealed some significant differences that were attributed mainly to differences in the structure of the beds. Markert et al. (2009) found a higher species richness in the oyster bed compared to the mussel bed, an exclusive occurrence of anthozoans and a higher abundance and diversity of sessile suspension feeders, epibionts, epibenthic predators (*Carcinus maenas*, *Asterias rubens*, and *Harmothoe imbricata*) and infauna. This was explained by a permanently sediment-free upper part of the reef (in contrast to mussels that are frequently buried) and a more turbulent current flow that enhances food flux towards suspension feeders. Markert et al. (2009) concluded that *Crassostrea*-reefs compensate for the conceivable loss of *Mytilus*-beds in the intertidal of the Wadden Sea by replacing the ecological function of *M. edulis*. The earlier study by Kochmann et al. (2008) confirmed that *C. gigas* beds harbour a higher abundance of sessile suspension feeders. In contrast to the results by Markert et al. (2009), they found higher abundances of *Carcinus maenas* in mussel plots compared to oyster plots. However, survival appeared higher in the oyster plots, possibly due to a higher level of shelter offered by the structurally more complex oyster beds (Kochmann et al., 2008). Furthermore, biodeposition enriches the sediments underneath both oyster and mussel beds, enhances local species abundance and structures the infaunal community (Kochmann et al., 2008; Markert et al., 2009). Both Kochmann et al. (2008) and Markert et al. (2009) found subtle differences in dominant associated infaunal species between Pacific oyster reefs and mussel beds.

A Pacific oyster bed offers a high level of habitat heterogeneity. The oyster shells themselves represent a large area of hard substrate settlement opportunities for species that previously only occurred on man-made structures (e.g. dikes and embankments), mussel beds and other (disappearing) biogenic structures. Furthermore, most oyster beds in Dutch and German coastal areas do not show a 100% cover of the substrate, and contain many bare patches (see Fig. 5) where soft-bottom communities are still present (Dittmann, 1990; Commito and Dankers, 2001). This resembles the topography of structurally complex older mussel beds (Bayne, 1976). In the shallow water retained in these patches during low tide, many species such as shrimps and gobies can be observed (own unpublished observation). Many species find refuge from physical stress and predation within the oyster bed, but may also serve as prey for shorebirds. Commito et al. (2008) demonstrated effects of small-scale variability within bivalve (*M. edulis*) beds on macrofaunal communities and stressed its importance for most macrofauna and biodiversity. This was also confirmed for Pacific oyster beds in the Oosterschelde estuary by Van Broekhoven (2005). He showed that species richness is higher in oyster beds compared to the surrounding bare flat, with the highest species richness occurring at the edge of oyster bed where oyster patches are alternated with bare patches. Concluding, increased habitat heterogeneity generally results in a higher biodiversity in an oyster bed as a whole, compared to the surrounding bare flats and also compared to mussel beds.

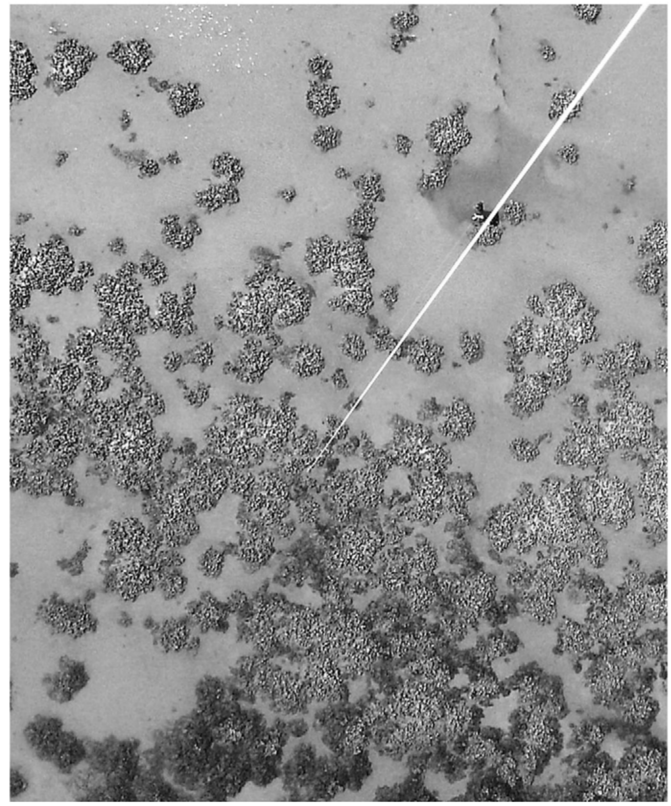


Fig. 5. Aerial photograph of part of the oyster bed at Neeltje Jans, the Oosterschelde estuary (courtesy Johan van de Koppel). The picture shows patches of oysters, and bare patches in between. In the lower part of the picture, the oyster patches are fringed by sea lettuce *Ulva* sp. The person in the upper right corner and her foot prints give an indication of scale. The picture was taken in July 2005, from a height of about 50 m (with a camera suspended from a blimp (balloon); the white line in the picture is the line holding the blimp, see www.blimppics.com).

Pacific oyster reefs may furthermore facilitate establishment of other exotics from the same region of origin. For example, Pacific oyster beds in The Netherlands already offer substrate and shelter to the japweed *Sargassum muticum*, wakame weed *Undaria pinnatifida*, the red alga *Heterosiphonia japonica*, the crab *Hemigrapsus penicillatus*, the sea squirts *Botrylloides violaceus* and *Styela clava*, and many more species originating from north-east Asian Pacific coasts (Wolff, 2005; Haydar and Wolff in prep.). By increasing local biodiversity Pacific oysters may, alternatively, decrease the success of future invasions from regions other than the NW Pacific coasts (Stachowicz et al., 1999; Stachowicz et al., 2002).

5.1.3. Competition for space with native bivalves

Pacific oysters are strong competitors for space, since persistent oyster reefs can develop very fast once a sufficient amount of hard substrate is present (e.g. shell debris, a mussel bed or a pioneer-stage oyster bed). This is facilitated by their gregarious settling behaviour (Diederich, 2005a; Tamburri et al., 2007; Troost, 2009). Pacific oyster beds increase the area suitable for settlement of hard substrate species and locally turn former soft-substrate communities into hard substrate communities. Infaunal species would be expected to be affected negatively by expansion of oyster beds, since the area suitable for settlement decreases, and oyster reefs are difficult if not impossible to recolonize for infaunal species. However, only a limited fraction of the total estuarine intertidal area available to bivalves can actually be occupied at a given time, due to limiting physical processes at local scale (e.g. current velocity, mixing) and limiting primary production on a system scale (Heip et al., 1995).

Furthermore, *C. gigas* does not occupy exactly the same habitat as most native bivalves. While *C. gigas* are generally found around MLW and below, cockles *C. edule* are generally found at higher elevations (Table 3). Significant competition for space between the two species primarily occurs at locations that are less suitable for cockles (Kater et al., 2006). In the Oosterschelde estuary, the area of locations suitable for cockles is decreasing because the tidal flats are slowly submerging. Competition for space among both species is therefore expected to become relatively more important in the coming decades. Another dominant native burrowing bivalve in NW European estuaries is the Baltic tellin *Macoma balthica*. This species is found from the high intertidal to the subtidal (Table 3). Therefore, it does not occupy the exact same locations as *C. gigas* that is mainly found in the low intertidal to subtidal. The soft-shelled clam *M. arenaria*, introduced centuries ago and therefore treated here as a native species, is found at roughly the same range in tidal elevations as *M. balthica* and therefore also does not have to compete for space with *C. gigas* in the higher intertidal areas. Additionally, in the Wadden Sea the distribution of endobenthic bivalves appears to shift towards the shore, towards higher intertidal levels (Beukema and Dekker, 2005) and therefore away from the oyster bed locations in the lower intertidal. This appears to result from increasing predation by benthic invertebrates (further discussed in Section 6.1). Pacific oysters do occupy the same habitat as *M. edulis*. In the Wadden Sea, Pacific oysters occupy areas with mussels or areas where sometime in the past mussels have been before. This suggests that either shell rubble was left behind that facilitated first settlement of *C. gigas*, or that these sites are particularly suitable for epibenthic suspension feeders. The latter explanation could mean that, although bivalve suspension feeders may not compete directly for the same space, they do interfere with each other by reducing the availability of potential high quality sites.

In the German and Danish Wadden Seas a long-term decline in mussel bed area is observed (Nehls et al., 2006; Nehls and Büttger, 2007). Roughly in the same period Pacific oyster bed area showed an increase. However, both trends do not appear to be causally related but rather an effect of global change (Nehls et al., 2006). Moreover, mussel beds showed a recovery in the eastern part of the Dutch Wadden Sea since 2002 (Nehls and Büttger, 2007). Any evidence for a large scale displacement of *M. edulis* by *C. gigas* is therefore lacking. Diederich (2005a) concluded that *C. gigas* and *M. edulis* may co-exist since *M. edulis* settle and grow in oyster beds. She also found that mussels may find a refuge from the invading oyster under a canopy of *Fucus vesiculosus* (forma *mytili* Nienburg). Kochmann et al. (2008) furthermore observed oyster settlement mainly on adult conspecifics while *M. edulis* showed no preference for either oyster or mussel shells. They hypothesized that the lack of substrate specificity in *M. edulis* will secure a coexistence of *M. edulis* with a dominant *C. gigas* in the Wadden Sea. Mussels were also frequently found growing between oysters in the Oosterschelde estuary (Van Broekhoven, 2005; Troost, 2009). With an increasing oyster biomass in an oyster bed in the northern compartment, numbers of *M. edulis* increased but their condition decreased (Troost, 2009). The decrease in condition suggests food limitation, but the increasing numbers suggest good settlement opportunities and/or shelter from predation and environmental extremes. Similar results were also obtained by Markert et al. (2009), who found a lower abundance of juvenile *M. edulis* in an oyster patch compared to a mussel patch within the same bivalve bed. Mortality of juvenile and adult *M. edulis* appeared to be lower in the oyster patch than in the mussel patch. A lower abundance of juveniles may be explained by larviphagy by the adult suspension feeders (further addressed in Section 5.2.3). Reduced mortality of the mussels may be explained by reduced predator–prey encounter rates in the structurally more complex oyster reef (Bartholomew et al., 2000; Grabowski, 2004; Section 4.2), as well as a reduced accessibility for predatory birds such as the oystercatcher *H. ostralegus*. Cadée (2007) even suggested that Pacific oyster beds may facilitate a return of *M. edulis* to tidal flats of the western Dutch Wadden Sea. This is similarly hypothesized for the Oosterschelde estuary that has not seen natural intertidal mussel beds since several decades (pers. comm. A.C. Smaal). Here, mussels *M. edulis* are almost exclusively found hidden between the oysters, just above the bottom (Troost, 2009).

5.2. Consequences of the Pacific oysters' filtration activity

5.2.1. Competition for food with native bivalve filter-feeders

Bivalve filter-feeders feed on phytoplankton, but also on other particles in the water column that are large enough to be retained by the gills and that are not too large or evasive, such as dead particulate organic material or certain species of zooplankton (Fréchette et al., 1989; Navarro et al., 1992; Smaal, 1997; Dupuy et al., 1999; Davenport et al., 2000; Dupuy et al., 2000; Karlsson et al., 2003; Lehane and Davenport, 2004; Troost et al., 2008a). All particles above a species-specific retention threshold (2–12 µm, Møhlenberg and Riisgård, 1978; Barillé et al., 1993) are retained by the gills (Fig. 6). Selection of particles for ingestion takes place on the gills and labial palps (Shumway et al., 1985; Ward et al., 1998). Particles retained on the gills are transported towards the labial palps through ciliary movement. At the labial palps, rejected particles are covered in mucus and excreted as pseudofaeces. Particles selected for ingestion move into the stomach through the mouth (Gosling, 2003). Post-ingestive selection of particles for absorption occurs in the stomach and guts (Brillant and MacDonald, 2002). The species may differ in selection and absorption efficiencies, but also in how they optimize a food flux towards the bed, how they minimize refiltration inside the bed, and how efficiently they entrain zooplankton. A comparison of these aspects between *C. gigas* and native bivalves will be made in the

Table 3
Habitat occupation of native bivalves dominant in Dutch estuaries, and the introduced Pacific oyster *C. gigas* (From Korringa, 1952; Bayne, 1976; Hayward and Ryland, 1990; Mann et al., 1991; Gosling, 2003; De Bruyne, 2004).

	Crassostrea gigas	*Mytilus edulis*	*Cerastoderma edule*	*Mya arenaria*[a]	*Macoma balthica*
Tidal range	Low intertidal to subtidal	Mid intertidal to subtidal	High intertidal to shallow subtidal	High intertidal to shallow subtidal (to 200 m depth)	High intertidal to subtidal
Sediment	Attachment to hard surfaces, bed occurrence on any substrate	Attachment to hard and filamental surfaces, bed occurrence on any substrate	Sand, soft mud, gravel	Firm mud/sand	Mud to muddy sand
Salinity	Estuarine to fully marine	Estuarine to fully marine	Estuarine to fully marine	Estuarine	Estuarine to fully marine
Burrowing depth	–	–	<5 cm	~15 cm	5–10 cm
Exposure	Semi-exposed to sheltered	Exposed to sheltered	Semi-exposed to sheltered	Sheltered	Semi-exposed to sheltered

[a] *Mya arenaria* is not native to Dutch waters, but is included here because its introduction dates centuries back.

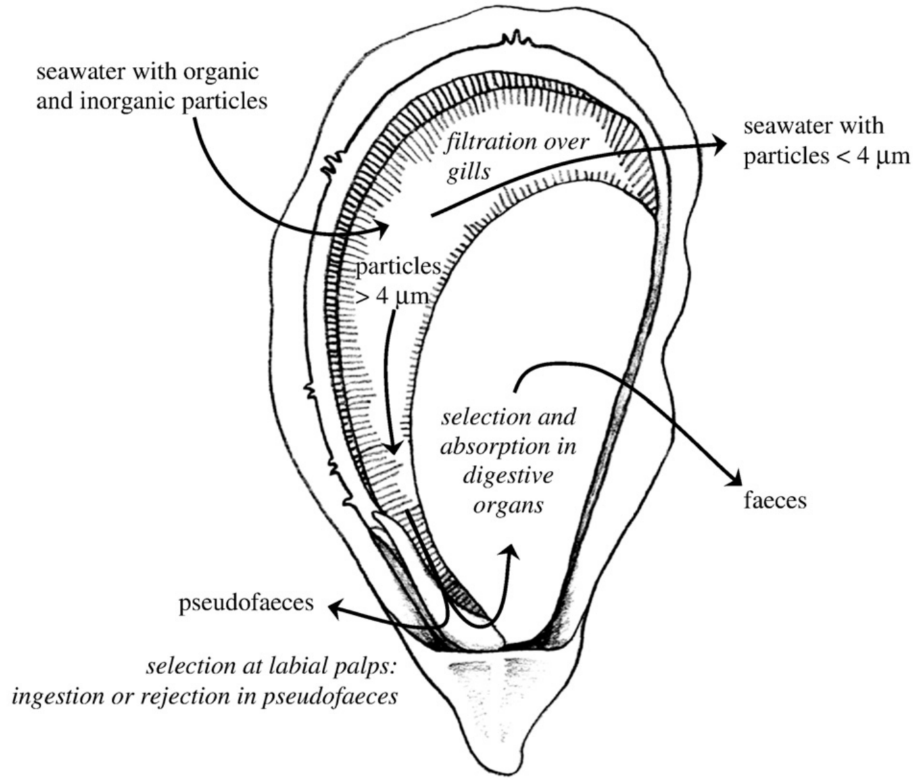


Fig. 6. Schematic drawing of filtration, selection, ingestion and digestion of food particles in bivalves (example: *C. gigas*). Bivalve filter-feeders collect their food by filtering and sorting particles from the water column. Their ciliated gills create a water current through the mantle cavity and over the gills. Particles above a certain threshold size, generally 2–7 µm (Møhlenberg and Riisgård, 1978), are retained efficiently. Selection of particles for ingestion takes place on the gills and labial palps (Shumway et al., 1985; Ward et al., 1998). Particles retained on the gills are transported towards the labial palps through ciliary movement. At the labial palps, rejected particles are covered in mucus and excreted as pseudofaeces. Particles selected for ingestion move into the stomach through the mouth (Gosling, 2003). Post-ingestive selection of particles for absorption occurs in the stomach and guts (Brillant and MacDonald, 2002).

following sections, with the purpose of evaluating whether *C. gigas* competes for food with native bivalves, and whether *C. gigas* is a stronger competitor.

5.2.1.1. Food intake of bivalves in relation to hydrodynamics. Troost et al. (2009b) showed that differences in inhalant feeding currents of individual *C. gigas*, *M. edulis* and *C. edule* are small despite apparent differences in morphology. Differences in inhalant feeding currents are therefore not expected to result in differences in food intake between the introduced oyster and native bivalves. However, processes on a larger scale (a patch or bed of bivalves) may be more determining. Bivalve filter-feeders can optimize food flux towards the bed by enhancing near-bed turbulence levels with their filtration activity (mainly with their exhalant feeding currents) and/or physical roughness of the bed. Although exhalant feeding current speeds of *C. gigas* were found to be higher than in the two other species, differences were modest (Troost et al., 2009b). Moreover, exhalant feeding currents in *C. gigas* were oriented horizontally instead of vertically as in *M. edulis* and *C. edule*. How this affects differences between the species in their effect on the benthic boundary layer is not known yet. In conclusion, Troost et al. (2009a, b) predicted no important differences in food intake as a result of differences in exhalant jet speeds of individual animals.

The much larger differences in roughness height of oyster, mussel and cockle beds are expected to contribute more strongly to differences in food intake (Troost et al., 2009b and references therein). Oysters create larger roughness structures than mussels and cockles. Cockles do not produce any protruding roughness structures at all and seem entirely dependent on roughness created by their filtration activity. By creating larger roughness structures, Pacific oysters probably affect near-bed turbulence levels more strongly than native bivalves (that are all infaunal except for *M. edulis* and the now rare *O. edulis*). In that way they may enhance food flux and intake rate that is also facilitated by their large filtration capacity. Additionally, since many zooplankton species use hydromechanical signals to detect and escape from predators (Singarajah, 1975; Kingsford et al., 2002; Titelman and Kiørboe, 2003), higher levels of turbulent mixing cause more "background noise" to these zooplankters, reducing (the effectivity of) escape reactions, potentially resulting in a higher zooplankton intake rate by oysters than by mussels and cockles (Troost et al., 2009b).

5.2.1.2. Diet of filter-feeding bivalves. That Pacific oysters and native bivalves may not utilize the exact same diet was shown in various studies. Bougrier et al. (1997) showed in the laboratory that from various algal species simultaneously available in the surrounding water, *C. gigas* and *M. edulis* selected different species for ingestion. Based on different stable isotope signatures of $\delta^{13}C$ (ratio of ^{13}C to ^{12}C) and $\delta^{15}N$ (ratio of ^{15}N to ^{14}N) of the bivalve tissue, *C. gigas* was found to utilize a diet different from that of *M. edulis* and the filter-feeding snail *Crepidula fornicata* in the French Bays of Veys (Dubois et al., 2007) and Mont Saint Michel (Riera, 2006) and the Dutch Oosterschelde estuary (Riera et al., 2002). Differences in these signatures can indicate different food sources, but also a utilization of the same food sources but in different proportions is possible. Riera et al. (2002) and Riera (2006) hypothesized that the differences found between *C. gigas* and *C. fornicata* in the Oosterschelde estuary and Bay of Mont Saint Michel may be due to utilization of different size classes of consumed particulate organic matter. They therefore concluded that both species may not necessarily be competitors for the same food sources. Results from the Bay of Veys indicated that *C. gigas* is capable of a greater trophic plasticity than *M. edulis*. Pacific oysters showed a larger spatial variation in isotope signatures, indicating that they are better able to adapt to the local environmental availability of food items (Dubois et al., 2007).

Ostreids have reduced eulatero-frontal cirri and have a slightly higher retention threshold than species with long latero-frontal cirri (such as *C. edule*, *M. edulis* and *M. arenaria*). In the latter, all particles larger than 4 µm are 100% efficiently retained (Møhlenberg and Riisgård, 1978). Ostreids have a retention threshold of 4–6 µm (Møhlenberg and Riisgård, 1978; Riisgård, 1988; Barillé et al., 1993). In addition, at high seston load the retention threshold in *C. gigas* changes from about 4 µm to 12 µm (Barillé et al., 1993). This is thought to ensure a good functioning of the ciliary systems at the gills and labial palps, but it also renders *C. gigas* unable to utilize plankton <12 µm at high seston load (Barillé et al., 1993). In addition to this mechanism and in comparison to Dutch native species of bivalve filter-feeders, larger components of the seston, such as ciliates, larger phytoplankton cells, debris of macro-algae and zooplankton, may play a more important role in the diet of *C. gigas* (see Dupuy et al., 1999). Although lower thresholds have been determined experimentally, it is more difficult to determine the upper size limit of what bivalves can still filter. Davenport et al. (2000) found 260 planktonic animals in stomach contents of 100 mussels *M. edulis* from the field. The mussels appeared to routinely ingest particles of 100–1000 µm, and occasionally particles of 3–6 mm.

Furthermore, Pacific oysters may be more efficient in entrapping zooplankton because they probably create more background turbulence than native bivalves (although this yet needs to be studied, see previous section). Hence, they may utilize a broader diet. Zooplankton has been shown to be a useful additional food source. Bivalves grown on a mix of phytoplankton and zooplankton showed faster growth than bivalves fed with phytoplankton only (Wong and Levinton, 2004).

Concluding, although Pacific oysters and native bivalves appear not to utilize the exact same diet, they filter largely the same particles from the surrounding water (barring zooplankton species that may have different escape successes for different species of bivalves). This includes particles that they do not ingest, but instead reject in their pseudofaeces. Therefore, even if they do not compete directly for the same food sources, they do interfere with each other by reducing food levels available to other species (Green, 1971; Case and Gilpin, 1974).

5.2.1.3. Feeding physiology of filter-feeding bivalves. Bivalve filter-feeders adjust their feeding rate and feeding and absorption efficiencies to changes in total particulate matter (TPM) and organic content of the TPM (e.g. Navarro et al., 1992; Hawkins et al., 1998; Bayne, 2002). Species with a relatively high food intake, efficient particle selection and absorption, and low metabolic loss will have a relatively high net energy gain and will be stronger competitors for food (Hawkins et al., 1998; Bayne, 2002). In the Bay of Marennes-Oléron, at the French Atlantic coast, Hawkins et al. (1998) found differences in feeding physiology parameters between *C. gigas*, *M. edulis* and *C. edule* (after standardizing for 0.5 g dry soft tissue weight). The infaunal *C. edule*, feeding on natural seston, showed a lower efficiency in selecting organic particles for ingestion than the other two species at higher TPM levels, but this was probably compensated by a longer gut passage time for the extraction of available nutrients. This appears to be an adaptation to less turbid, more sandy habitats (Hawkins et al., 1998). Compared to *M. edulis* the Pacific oyster had a higher ingestion rate but handled filtered particles less efficiently. Because the absorption rate of ingested organic matter in the stomach and gut by *M. edulis* was twice as fast compared to *C. gigas*, ultimately *C. gigas* gained less energy from filtered matter than *M. edulis* (Hawkins et al., 1998). However, *C. gigas* may be metabolically more efficient than native bivalves. *C. gigas* has a competitive advantage over the Sydney rock oyster *Saccostrea glomerata* in Australia, due to faster rates of feeding and greater metabolic efficiencies of both feeding and growth (Bayne, 2002).

5.2.1.4. Growth of bivalve filter-feeders. Food-limited growth is a common phenomenon among bivalves, demonstrated to occur on a local scale in the Wadden Sea (Kamermans, 1993; Beukema and Cadée, 1997) and on a larger scale in the Oosterschelde estuary (Hoek, 1902; Van Stralen and Dijkema, 1994; Smaal et al., 2001). The most efficient feeder, *M. edulis*, would be expected to show a lower dependence of growth on food availability. This could, however, not be confirmed by field observations in NW European estuaries. Using the Dynamic Energy Budget theory (Kooijman, 1986, 2000), Cardoso et al. (2006) reconstructed food conditions for different bivalve species in Dutch estuaries, based on growth curves determined from the field. The results suggested that growth of both *M. edulis* and *C. gigas* is suboptimal in Dutch coastal waters (in contrast to *M. balthica* and *C. edule*), probably due to food limitation during some months (Cardoso et al., 2006). Diederich (2006) studied growth of juvenile *C. gigas* and *M. edulis* in an oyster bed, a mussel bed and on a sandflat in the German Wadden Sea, and found density-dependent growth in *M. edulis* but not in *C. gigas*. This corresponds to the results of a graduate (MSc) study in the Oosterschelde estuary (in Troost, 2009). Here, growth of caged mussels in an intertidal bed of wild Pacific oysters was negatively related to local oyster biomass, whereas caged oysters at the same locations showed density-independent growth. The results of these studies suggest that Pacific oysters either ingest more food, or an additional different type of food (e.g. zooplankton), or utilize the ingested food more efficiently. The first option is supported by e.g. the oyster's large filtration rate and large roughness of oyster beds (Section 5.2.1.1). The second option is supported by results of Riera et al. (2002; 2006) and Dubois et al. (2007) (Section 5.2.1.2). The third option is refuted by the results of Hawkins et al (1998) (Section 5.2.1.3).

5.2.2. Carrying capacity of estuarine ecosystems

Food competition between bivalve filter-feeders becomes more and more important as food levels drop and the carrying capacity of the ecosystem for bivalve filter-feeders is reached. Rapid expansion of *C. gigas* in the Oosterschelde estuary resulted in an increasing filtration capacity of the bivalve filter-feeder stock (Troost et al., 2009a). This apparently already has a large effect on the phytoplankton community, as indicated by the observed shift towards smaller phytoplankton species (Noren et al., 1999; Geurts van Kessel et al., 2003). Furthermore, after comparing the turn-over time of the phytoplankton in the Oosterschelde estuary with the estimated time needed for oysters, mussels and cockles to filter the volume of these compartments, Geurts van Kessel et al. (2003) concluded that the carrying capacity (total bivalve biomass supported by a given estuarine ecosystem) may already have been reached in some parts of the estuary. Although the approach of Geurts van Kessel et al. (2003) ignored the complex dynamics of carrying capacity, and did not take into account the various feedback mechanisms between bivalve grazing and ecosystem processes (Prins et al., 1998), field observations on growth and condition of cultured stocks of *M. edulis* and *C. gigas* seem to confirm a saturated carrying capacity (unpublished data IMARES, the Dutch Fish Product Board and A. Cornelisse). A simple model shows that the Dutch (and probably the entire international) Wadden Sea may have a relatively larger carrying capacity for bivalve filter-feeders than the Oosterschelde estuary. In the Dutch Wadden Sea, where *C. gigas* is presently not a dominant species, the carrying capacity does not appear to be reached yet. Carrying capacity may be defined as a function of the water residence time, primary production time and bivalve clearance time (Dame and Prins, 1998). The water residence time is the time it takes for the entire volume of the estuary to be refreshed by tidal exchange with the coastal sea. Import of nutrients and organic matter from the coastal zone into estuaries through tidal exchange enhances the carrying capacities of these estuaries for bivalve filter-feeders (Bacher et al., 1998; Dame and Prins, 1998; Van Beusekom and De Jonge, 2002; Wetsteyn et al., 2003). Heip et al. (1995) demonstrated an inverse relationship between water residence time and biomass of bivalve filter-feeders in different estuaries (based on data collected by Smaal and Prins, 1993). Primary production time (PPT) is the ratio of yearly averages of phytoplankton biomass to phytoplankton primary production within the estuary. It describes the time it takes for primary production within the system to replace the standing crop biomass of phytoplankton within the system. Bivalve clearance time is defined as the time that is theoretically needed for the total bivalve filter-feeder biomass to filter particles from a volume of water equivalent to the total system volume (Smaal and Prins, 1993). In comparison to the Oosterschelde estuary the Wadden Sea is a more open and shallow system with higher rates of tidal exchanges with the coastal zone. The western Dutch Wadden Sea has a much shorter residence time (on average 10 days) than the Oosterschelde estuary (40 days). Around 1990 the phytoplankton turnover time was shorter than in the Oosterschelde estuary (a PPT of 0.97 days vs. 3.08 days for the Oosterschelde estuary, references in Dame and Prins, 1998), but this difference was apparently reduced during the 1990's due to a decrease in primary production in the Wadden Sea which resulted in an increase in PPT (twofold at most) (Philippart et al., 2007).

Determining the carrying capacity of an estuarine area is, however, very difficult because of the narrow and complex coupling between the filter-feeder community and food availability (Prins et al., 1998). Bivalve suspension feeders enrich their immediate environment by producing biodeposits. These biodeposits are mineralized rapidly, resulting in a release of nutrients that stimulate primary production (Prins and Smaal, 1994; Prins et al., 1998). The complexity of such processes, and difficulties in monitoring them, makes it difficult to accurately predict the carrying capacity of the system. Like mineralization, bivalve clearance time is also very difficult to estimate and capture in a model. It is a function of the biomass of the bivalves and the seasonal influences of particulate concentrations, seston quality, and temperature on the filtration rate of the bivalves (Smaal and Prins, 1993). Due to the increase in total bivalve filter-feeder stock as a result of the expansion of *C. gigas*, bivalve clearance time in the Oosterschelde estuary decreased from roughly 10 days in 1990 to 7 days in 2000 (Geurts van Kessel et al., 2003). In the Dutch Wadden Sea, the total filtration pressure does not appear to have increased significantly since the introduction of *C. gigas* (Brinkman and Jansen, 2007; Philippart et al., 2007). Here, the oyster still constitutes only a fraction of the total filter-feeder biomass in the Dutch Wadden Sea (Brinkman and Jansen, 2007) although it is now the most dominant bivalve in the Oosterschelde estuary (Troost et al., 2009a). Finally, the carrying capacities of the Oosterschelde estuary and (Dutch) Wadden Sea are difficult to compare, especially when carrying capacity is considered as the maximum achievable bivalve biomass given natural recruitment processes. The Oosterschelde estuary differs markedly from the Wadden Sea in that recruitment success of *M. edulis* is very low and the stock size is controlled for >95% through import and removal by mussel farmers (Van Stralen and Dijkema, 1994). Effects of feedback mechanisms between adult stock size and recruitment on the total *M. edulis* stock, through effects on primary production and phytoplankton composition, are therefore presently negligible in the Oosterschelde estuary but may still play a role in the Wadden Sea (Bos et al., 2006).

In conclusion, considering the more open and shallow character of the Wadden Sea and the consequently shorter water residence time and faster primary production time, the carrying capacity of the Wadden Sea will probably not be reached in the near future. On a smaller spatial scale however, food competition does occur in the Wadden Sea (Kamermans, 1993; Beukema and Cadée, 1997). Competitive interactions between *C. gigas* and native bivalve filter-feeders (especially *M. edulis*) are therefore expected to structure the composition of epifaunal bivalve beds locally.

5.2.3. Larviphagy

Bivalve filter-feeders retain all particles above a certain threshold size (2–6 μm: Møhlenberg and Riisgård, 1978; Riisgård, 1988; Barillé et al., 1993), and selection of particles only occurs after retention, on the gills, labial palps and/or in the stomach and guts (e.g. Shumway et al., 1985; Brillant and MacDonald, 2002). Larviphagy, the feeding on (bivalve) larvae, therefore must be a common phenomenon among bivalve filter-feeders (Lehane and Davenport, 2004; Troost et al., 2008a). Increasing stocks of bivalve filter-feeders, as happened in the Oosterschelde estuary due to the expansion of *C. gigas*, may not only reduce food levels but also bivalve larval abundance.

Adult *C. gigas*, *M. edulis* and *C. edule* were shown to routinely filter and ingest larvae of both *C. gigas* and *M. edulis* in a laboratory study (Troost et al., 2008a). However, a difference in filtration risk was found between the larvae of both species. Larvae of *C. gigas* were filtered approximately 50% less than larvae of *M. edulis* in still water in a laboratory study (Troost et al., 2008a). The reduction in filtration rate was not caused by escape reactions of the larvae in response to hydro-mechanical stimuli in the inhalant flow field of the adult bivalves, since both *M. edulis* and *C. gigas* larvae did not respond to a suction current mimicking a bivalve inhalant current in another laboratory study (Troost et al., 2008b). Instead, the difference appeared to be caused by *C. gigas* larvae migrating upwards in the water column in response to the presence of an adult filter-feeder on the bottom (Troost, 2009). Larvae of *M. edulis* did not show this response but remained distributed homogeneously over the water column whether an adult filter-feeder was present or not.

The hypothesis that larviphagy reduces bivalve larval abundance was confirmed by a field study (Troost et al., 2009a). In the water column overlying a dense oyster bed in the northern compartment of the Oosterschelde estuary, abundance of *M. edulis* larvae was reduced but abundance of *C. gigas* larvae was not. Reduction of mussel larvae must have been due to larviphagy by the relatively high filter-feeder biomass in the oyster bed. The results of *C. gigas* larvae were thought to have been influenced by spawning activity of the adult oysters, since significantly more newly produced oyster veligers were caught at the oyster bed location than at the reference site (Troost et al., 2009a). Furthermore, Troost et al. (2009a) calculated the order of magnitude of the mortality rate of bivalve larvae through larviphagy in the Oosterschelde estuary. Assuming a homogeneous distribution of larvae throughout the Oosterschelde estuary, a homogeneous distribution of adult bivalves on the bottom of the estuary, a continuous complete mixing of the estuary and no washing out of larvae to the North Sea with tidal exchange, 95% of the larvae would have been filtered during an average pelagic stage of 20 days. In this calculation a *CR* of 398 million m^3 day^{-1} for the year 2000 was used, as (roughly) estimated by Kater (2003). A larviphagy mortality rate f of 0.95 is in the same order of magnitude as total mortality rates generally estimated or determined for bivalve larvae and larvae of other benthic invertebrates (Thorson, 1950; Rumrill, 1990). Therefore, larviphagy appears to contribute significantly to mortality of bivalve larvae in the Oosterschelde estuary. Considering the magnitude of the effect, recruitment is expected to be affected as well. Although sucessful oyster spatfall appears mainly dependent on calm weather conditions (pers. comm. A. Cornelisse, oyster farmer) and high water temperatures during spatfall (Diederich et al., 2005), Brandt et al. (2008) show that recruitment of *C. gigas* in the German East Frisian Wadden Sea, during the early stage of invasion, was dominated by larval supply rather than environmental factors at the location of settlement. This supports the hypothesis that recruitment of *C. gigas* itself may also be affected by the estimated high mortality rate due to larviphagy in the Oosterschelde estuary.

Troost et al. (2008a) showed that *C. gigas* larvae were filtered 50% less than *M. edulis* larvae in a still-water set-up in the laboratory. Regardless of the reservations in translating this result directly to the field (see discussion in Troost et al., 2008a), for the situation in 2000 this would result in a reduction of *f* from 0.95 to 0.78 for *C. gigas* larvae whereas *f* would still remain 0.95 for *M. edulis* larvae. An increasing stock of *C. gigas* in the Oosterschelde estuary may therefore affect larval abundance and subsequent recruitment of *M. edulis* more strongly than its own larval abundance and recruitment. A contributing factor is the increased larval production of *C. gigas* with an increasing parent-stock. Potential effects on recruitment remain, however, hypothetical. A study into the effect of the increasing filter-feeder stock in the Oosterschelde estuary (mainly due to the increase in Pacific oyster stock) on larval abundance of *C. gigas* and *M. edulis* showed a decline in larval abundance of oysters but, unexpectedly, no effect on larval abundance of mussels (Troost et al., 2009a). The declining Pacific oyster larval abundance was suggested to be a result of increased larviphagy, possibly in combination with food limitation (reducing the reproductive output of adults and/or reducing the survival of larvae). A trend in larval abundance of mussel larvae may have been undetectable due to the relatively short sampling period of 6 years (vs. 13 years for oyster larvae).

Summarizing, the results for *M. edulis* larvae on bed scale and the results for *C. gigas* larvae on estuary scale do suggest that larviphagy may be an important mortality factor for bivalve veliger larvae. The increasing stock of filter-feeders in the Oosterschelde estuary is therefore expected to reduce abundance of bivalve larvae, but also of other slow-swimming zooplankton species with weak escape capabilities (see Singarajah, 1969, 1975; Kiørboe and Visser, 1999; Titelman and Kiørboe, 2003; Maar et al., 2007). Eventually, bivalve grazing may exert a top-down control on zooplankton communities through direct grazing on weak escapers and weak swimmers, and on benthic communities through filtration of pelagic larvae. In addition, larvae of *C. gigas* swim faster than larvae of *M. edulis*, and can migrate faster in vertical direction (Troost et al., 2008b). This may enable them to more successfully avoid benthic predators, find food-rich water layers (Raby et al., 1994) or transport themselves with the tides into favourable directions (Shanks and Brink, 2005).

5.3. Consequences of induced changes for other trophic levels

Hypothetically, *C. gigas* may change entire ecosystems through cascading effects on other trophic levels. The increased filtration pressure in the Oosterschelde estuary due to an increased oyster stock already appears to have affected the phytoplankton community. The oysters exert a top-down control on phytoplankton abundance and composition that may in turn affect higher trophic levels in the food web (e.g. zooplankton → fish → fish-eating birds and seals). Similarly, the oysters might induce cascading effects by exerting a top-down control on zooplankton abundance and composition.

Since Pacific oysters are hardly eaten by birds in the Netherlands, expansion of *C. gigas* may threaten the food supply of shorebirds if they (partially) replace native bivalves. With expanding oyster reefs, the foraging area available for birds that feed on infaunal invertebrates would be expected to decrease only slightly. Stronger effects may be expected for shorebirds that preferentially or obligatory feed on *M. edulis*, if mussel biomass within the now mixed beds would be reduced below a critical level. Scheiffarth et al. (2007) consider the Eider duck *Somateria mollissima* and to a lesser extent the oystercatcher *H. ostralegus* and the herring gull *L. argentatus* as the most vulnerable birds in this respect. On the other hand, development of oyster beds may also have a positive influence on food availability for shorebirds. In the Oosterschelde estuary more intertidal mussels may now be available to foraging birds because of their natural occurrence in expanding oyster reefs on tidal flats. Since the replacement of all mussel culture plots to the subtidal in the 1990's, this may constitute the only availability of mussels to shorebirds such as the oystercatcher *H. ostralegus*. This species was observed to feed on mussels in an intertidal oyster bed (own unpublished observation). Oyster beds furthermore harbour high abundances of epifaunal invertebrates that may constitute a suitable food source for shorebirds. However, hardly any studies have been conducted that could support or refute this hypothesis. In the Oosterschelde estuary, some observations on the occurrence of foraging birds in oyster reefs and nearby reference sites indicated no apparent differences (Wijsman et al., 2008). Furthermore, mussels may again disappear from the intertidal of the Oosterschelde estuary as a consequence of reduced food levels (see Section 5.2.2).

C. gigas may also interfere with native parasite–host interactions, thereby affecting the life cycle of parasites and reducing the parasite load in final hosts. Thieltges et al. (2009) demonstrated that both the introduced *C. gigas* and gastropod *Crepidula fornicata* reduce the parasite load of mussels in mixed beds by acting as a decoy, and argued that the invaders interfere with the life cycle of parasites. All cercariae of the trematode *Himasthla elongata* that had infected invaders in a laboratory set-up were blocked from developing into the following stage and hence from infecting their final host. Final hosts of trematodes are mostly birds. Krakau et al. (2006) argued that for the trematode *Renicola roscovita* infecting *C. gigas*, transmission of metacercariae into their final host may be reduced considerably if potential final hosts do not consume oysters.

6. Future scenarios and conclusions

6.1. Expected effects of climate change

Predicting effects of climate change on biomass and species composition of bivalve suspension feeders is difficult because of the variety of possible effects, complexity of food-web relationships and interactions between different aspects of climate and global change. Here, I will make an effort to predict effects of global warming on the development of *C. gigas* in NW European estuaries, relative to stocks of dominant native bivalves.

In the western Dutch Wadden Sea, global warming decreases the frequency of severe winters, thereby increases the abundance of benthic invertebrate predators of bivalve spat, causing a decline in abundance of the native bivalves *C. edule*, *M. arenaria* and *M. balthica* in the lower intertidal (Beukema and Dekker, 2005). Successful recruitment of these species (including *M. edulis*) is dependent on severe winters as these reduce benthic invertebrate predator abundance and retard their arrival in spring (Beukema, 1991, 1992; Beukema et al., 1998; Strasser and Günther, 2001; Strasser et al., 2001). *C. edule*, *M. arenaria* and *M. balthica* still find a refuge from predation at higher intertidal levels (Beukema and Dekker, 2005). Whether recruitment of the Pacific oyster is also dependent on severe winters has not been studied yet. Survival of Pacific oyster spat appears to be high, even in severe winters (Reise, 1998) although higher in mild winters (Diederich, 2006). Successful recruitment of Pacific oysters may be less dependent on severe winters if the spat of *C. gigas* is less vulnerable to predation by benthic invertebrate predators. Shrimps and crabs may prefer to feed on bivalve spat that do not have to be scraped off a hard substrate over spat of *C. gigas*. Recruitment success of *C. gigas* is rather dependent on warm summers that promote extensive spatfalls near its northern distribution limit (Diederich et al., 2005). Global warming may therefore increase spatfall success of *C. gigas* in summer and survival of spat in the following winter, leading to increased rates of population increase of the Pacific oyster while the abundance of native bivalves is expected to decline due to increased predation rates in the subtidal and lower intertidal.

Furthermore, Reise and Van Beusekom (2008) predict that a combination of global warming and reduced nutrient loads will lead to a composition shift and a reduction in biomass of phytoplankton. This is expected to severely impact bivalve filter-feeders although it is at this stage impossible to predict the outcome. Reduced phytoplankton biomass will likely cause a reduced carrying capacity for bivalve filter-feeders and affect the condition of most species as is presently observed in the Oosterschelde estuary. This may eventually, in a worst-case scenario, lead to extirpations of species that are the weakest competitors for food. This may be *M. edulis* although the possibility that *C. gigas* is a weaker competitor for food cannot be excluded (Section 5.2.1). However, we are currently still unable to measure and model the complex coupling between bivalves and food availability accurately enough to predict the potential of the different estuaries for bivalve biomass.

Another consequence of global warming is sea level rise. The Oosterschelde estuary is already slowly turning into a lagoon as a result of the "Delta" coastal engineering project, which will be accelerated by sea level rise. The same is expected to happen in the Wadden Sea when sedimentation cannot keep pace with sea level rise anymore. This is expected to affect the Pacific oyster less than native bivalves that are more dependent on the higher intertidal. The rate of new species introductions is furthermore expected to increase in the coming years as a result of increasing facilitation by man (e.g. a proliferating global trade) in synergism with global warming (Reise and Van Beusekom, 2008). Introduction of species from the Pacific may be facilitated by the existence of Pacific oyster beds (see Section 5.1).

6.2. Conclusions and expected future developments

The Pacific oyster possesses all traits that are generally attributed to successful invaders. Especially the oyster's close association to humans, ecosystem engineering and (relative) lack of predators probably facilitated the species' successful establishment in continental NW European estuaries, in the most northern areas aided by relatively warm summers and mild winters. The advantage of *C. gigas* over native bivalve filter-feeders caused by its relative lack of predators may, however, disappear in the future since more and more non-native species, including invertebrate predators of *C. gigas*, are introduced in NW Europe. Competitive ability of *C. gigas* also contributed to its establishment success. Competition with native species in receiving communities is often a bottleneck for establishment, but may also lead to replacement of native species. Although *C. gigas* is a strong competitor, the species only appears to compete with native bivalves on a local scale. Habitat requirements overlap, but not completely. *C. gigas* appears to partially fill in an empty niche (possibly the one left behind by *O. edulis*; Reise, 1998; Cadée, 2007; Troost, 2009) and to only compete with native bivalves in the margins. Invasion by *C. gigas* may thus have caused a decrease in actual niche breadth of native bivalves (Colwell and Futuyma, 1971); they will only compete for resources where requirements overlap, and only if resources are limiting.

Although the Pacific oyster induced many changes in the receiving ecosystems, mainly related to its ecosystem engineering activities and high filtration rate and sediment bio-deposition, these effects appear relatively small and local considering the remarkably rapid expansion of the oyster. Instead of threatening the Wadden Sea ecosystem by inducing major changes, the Pacific oysters merely seem to benefit from on-going large scale changes. Furthermore, development of oyster reefs may compensate for habitat loss and biodiversity loss in estuarine environments that were caused by human activities in previous decades. Oyster reefs may in the future even play an important role in the capturing of sediment and the protection of tidal flats from erosion, thereby buffering the effects of sea level rise.

Compared to the Wadden Sea, however, effects induced by *C. gigas* have a higher impact on the Oosterschelde estuary. The rapid increase in stock size of *C. gigas*, combined with the presence of large stocks of cultured bivalves, already led to a saturation of the carrying capacity of the Oosterschelde estuary for bivalve filter-feeders. This apparently resulted in a reduced condition of cultured bivalves and could, in a worst-case scenario, lead to a replacement of the native *M. edulis* locally although it is still not clear whether *C. gigas* is a better competitor for food than *M. edulis*.

Future developments of the Pacific oyster stock are difficult to predict because of interacting effects of climate change. In the Oosterschelde estuary, expansion of *C. gigas* appears to have come to a halt due to the saturated carrying capacity. In the Wadden Sea however, there is still ecological space left for expansion of the Pacific oyster stock. Considering the development until now, further expansion of Pacific oysters in the Wadden Sea is expected to occur more rapidly on hard substrates presented by existing mussel/oyster beds and shell banks than on soft bottoms. All mussel beds will probably turn into mixed mussel/oyster beds with different proportions of both species depending on local environmental parameters. Eventually an equilibrium situation would be expected to establish, with more or less stable stock sizes of native bivalves and the introduced oyster. However, different aspect of global change such as new biological invasions and climate change are expected to frequently upset these ecosystems in the coming decades and may constantly prevent the establishment of a new stable state.

Acknowledgements

Comments by Wim Wolff, Pauline Kamermans, Gerhard Cadée, Georg Nehls, Maria van Leeuwe, Aad Smaal, Peter Herman, Norbert Dankers, Eize Stamhuis and anonymous reviewers greatly improved earlier versions of the manuscript. The author was sponsored by the Netherlands Organization for Scientific Research — Earth and Life Sciences (NWO–ALW) (project number 812.03.003). This publication was partially financed by the Wadden Sea Society.

References

Airoldi, L., Beck, M.W., 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology: An Annual Review 45, 345–405.

Almeida, M.J., Machado, J., Coimbra, J., 1996. The effect of *Polydora* sp. infestation on the shell calcification of the oyster *Crassostrea gigas*. Bulletin de l'Institut océanographique (Monaco) Numéro spécial 14, 195–202.

AquaSense, 2003. De sublittorale hard-substraat levensgemeenschappen in de Oosterschelde. Uitgebreide omschrijving van de ontwikkelingen in de periode 1985–2002. AquaSense, commissioned by the National Institute of Coastal and Marine Management (RWS-RIKZ), The Netherlands, Report, pp. 1972–1973.

Arakawa, K.Y., 1990a. Commercially important species of oysters in the world. Marine Behaviour and Physiology 17, 1–13.

Arakawa, K.Y., 1990b. Natural spat collecting in the Pacific oyster *Crassostrea gigas* (Thunberg). Marine Behaviour and Physiology 17, 95–128.

Bacher, C., Duarte, P., Ferreira, J.G., Héral, M., Raillard, O., 1998. Assessment and comparison of the Marennes-Oléron Bay (France) and Carlingford Lough (Ireland) carrying capacity with ecosystem models. Aquatic Ecology 31, 379–394.

Banks, M.A., McGoldrick, D.J., Borgeson, W., Hedgecock, D., 1994. Gametic incompatibility and genetic divergence of Pacific and Kumamoto oysters. *Crassostrea gigas* and *C. sikamea*. Marine Biology 121, 127–135.

Baptist, H., 2005. Habitattoets proef weghalen oesterbanken in de Oosterschelde. Ecologisch Adviesbureau Henk Baptist, Kruisland, The Netherlands.

Barillé, L., Prou, J., Héral, M., Bougrier, S., 1993. No influence of food quality, but ration-dependent retention efficiencies in the Japanese oyster *Crassostrea gigas*. Journal of Experimental Marine Biology and Ecology 171, 91–106.

Bartholomew, A., Diaz, R.J., Cicchetti, G., 2000. New dimensionless indices of structural habitat complexity: predicted and actual effects on a predator's foraging success. Marine Ecology Progress Series 206, 45–58.

Bartol, I.K., Mann, R., Luckenbach, M., 1999. Growth and mortality of oysters (*Crassostrea virginica*) on constructed intertidal reefs: effects of tidal height and substrate level. Journal of Experimental Marine Biology and Ecology 237, 157–184.

Bayne, B.L., 1976. Marine Mussels: their Ecology and Physiology. Cambridge University Press, Cambridge.

Bayne, B.L., 2002. A physiological comparison between Pacific oysters *Crassostrea gigas* and Sydney Rock oysters *Saccostrea glomerata*: food, feeding and growth in a shared estuarine habitat. Marine Ecology Progress Series 232, 163–178.

Bayne, B.L., 2004. Phenotypic flexibility and physiological tradeoffs in the feeding and growth of marine bivalve molluscs. Integrative and Comparative Biology 44, 425–432.

Beukema, J.J., 1976. Biomass and species-richness of the macro-benthic animals living on the tidal flats of the Dutch Wadden Sea. Netherlands Journal of Sea Research 10, 236–261.
Beukema, J.J., 1991. The abundance of shore crabs *Carcinus maenas* (L.) on a tidal flat in the Wadden Sea after cold and mild winters. Journal of Experimental Marine Biology and Ecology 153, 97–113.
Beukema, J.J., 1992. Dynamics of juvenile shrimp *Crangon crangon* in a tidal-flat nursery of the Wadden Sea after mild and cold winters. Marine Ecology Progress Series 83.
Beukema, J.J., Essink, K., Michaelis, H., Zwarts, L., 1993. Year-to-year variability in the biomass of macrobenthic animals on tidal flats of the Wadden Sea: how predictable is this food source for birds? Netherlands Journal of Sea Research 31, 319–330.
Beukema, J.J., Cadée, G.C., 1997. Local differences in macrozoobenthic response to enhanced food supply caused by mild eutrophication in a Wadden Sea area: food is only locally a limiting factor. Limnology and Oceanography 42, 1424–1435.
Beukema, J.J., Honkoop, P.J.C., Dekker, R., 1998. Recruitment in *Macoma balthica* after mild and cold winters and its possible control by egg production and shrimp predation. Hydrobiologia 375 (376), 23–24.
Beukema, J.J., Dekker, R., 2005. Decline of recruitment success in cockles and other bivalves in the Wadden Sea: possible roles of climate change, predation on postlarvae and fisheries. Marine Ecology Progress Series 287, 149–167.
Beukema, J.J., Dekker, R., 2009. Extraordinarily low mortality rates reported in juvenile Pacific oysters in the German Wadden Sea. Helgoland Marine Research. doi:10.1007/s10152-009-0169-4 Available online DOI.
Blossey, B., Notzold, R., 1995. Evolution of increased competitive ability in invasive non-indigenous plants: a hypothesis. Journal of Ecology 83, 887–889.
Bos, O.G., Hendriks, I.E., Strasser, M., Dolmer, P., Kamermans, P., 2006. Estimation of food limitation of bivalve larvae in coastal waters of north-western Europe. Journal of Sea Research 55, 191–206.
Boudry, P., Heurtebise, S., Collet, B., Cornette, F., Gérard, A., 1998. Differentiation between populations of the Portuguese oyster, *Crassostrea angulata* (Lamark) and the Pacific oyster, *Crassostrea gigas* (Thunberg), revealed by mtDNA RFLP analysis. Journal of Experimental Marine Biology and Ecology 226, 279–291.
Bougrier, S., Geairon, P., Deslous-Paoli, J.M., Bacher, C., Jonquières, G., 1995. Allometric relationships and effects of temperature on clearance and oxygen consumption rates of *Crassostrea gigas* (Thunberg). Aquaculture 134, 143–154.
Bougrier, S., Hawkins, A.J.S., Héral, M., 1997. Preingestive selection of different microalgal mixtures in *Crassostrea gigas* and *Mytilus edulis*, analysed by flow cytometry. Aquaculture 150, 123–134.
Brandt, G., Wehrmann, A., Wirtz, K.W., 2008. Rapid invasion of *Crassostrea gigas* into the German Wadden Sea dominated by larval supply. Journal of Sea Research 59, 279–296.
Brillant, M.G.S., MacDonald, B.A., 2002. Postingestive selection in the sea scallop (*Placopecten magellanicus*) on the basis of chemical properties of particles. Marine Biology 141, 457–465.
Brinkman, A.G., Jansen, J.M., 2007. Draagkracht en exoten in de Waddenzee. Wageningen IMARES, Institute for Marine Resources and Ecosystem Studies, Report C073/07, Yerseke, The Netherlands.
Bruins, R.W.B., 1983. *Crassostrea gigas* (Thunberg, 1793) op Texel. Correspondentieblad van de Nederlandse Malacologische Vereniging 215, 1436–1438.
Buroker, N.E., Hershberger, W.K., Chew, K.K., 1979. Population genetics of the family Ostreidae, I. Intraspecific studies of *Crassostrea gigas* and *Saccostrea commercialis*. Marine Biology 54, 157–169.
Buschbaum, C., Dittmann, S., Hong, J.-S., Hwang, I.-S., Strasser, M., Thiel, M., Valdivia, N., Yoon, S.-P., Reise, K., 2009. Mytilid mussels: global habitat engineers in coastal sediments. Helgoland Marine Research 63, 47–58.
Butman, C.A., 1987. Larval settlement of soft-sediment invertebrates: the spatial scales of pattern explained by active habitat selection and the emerging role of hydrodynamical processes. Oceanography and Marine Biology: an Annual Review 25, 113–165.
Cadée, G.C., 2001. Herring gulls learn to feed on a recent invader in the Dutch Wadden Sea, the Pacific oyster *Crassostrea gigas*. Basteria 65, 33–42.
Cadée, G.C., 2007. Vervangen de recente Japanse oesterriffen de vroegere oesterbanken? De Levende Natuur 108, 62–65.
Cadée, G.C., 2008a. Oystercatchers *Haematopus ostralegus* catching Pacific oysters *Crassostrea gigas*. Basteria 72, 25–31.
Cadée, G.C., 2008b. Herring gulls feeding again on Pacific oysters *Crassostrea gigas* in the Dutch Wadden Sea near Texel. Basteria 72, 33–36.
Cardoso, J.F.M.F., Witte, J.I., Van der Veer, H.W., 2006. Intra- and interspecies comparison of energy flow in bivalve species in Dutch coastal waters by means of the Dynamic Energy Budget (DEB) theory. Journal of Sea Research 56, 182–197.
Cardoso, J.F.M.F., Langlet, D., Loff, J.F., Martins, A.R., Witte, J.I., Santos, P.T., Van der Veer, H.W., 2007. Spatial variability in growth and reproduction of the Pacific oyster *Crassostrea gigas* (Thunberg, 1793) along the west European coast. Journal of Sea Research 57, 303–315.
Carlton, J.T., 1989. Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conservation Biology 3, 265–273.
Case, T.J., Gilpin, M.E., 1974. Interference competition and niche theory. Proceedings of the National Academy of Sciences of the United States of America 71, 3073–3077.
Cognie, B., Haure, J., Barillé, L., 2006. Spatial distribution in a temperate coastal ecosystem of the wild stock of the farmed oyster *Crassostrea gigas* (Thunberg). Aquaculture 259, 249–259.
Colautti, R.I., Grigorovich, I.A., MacIsaac, H.J., 2006. Propagule pressure: a null model for biological invasions. Biological Invasions 8, 1023–1037.
Colwell, R.K., Futuyma, D.J., 1971. On the measurement of niche breadth and overlap. Ecology 52, 567–576.
Commito, J.A., Rusignuolo, B.R., 2000. Structural complexity in mussel beds: the fractal geometry of surface topography. Journal of Experimental Marine Biology and Ecology 255, 133–152.
Commito, J.A., Dankers, N., 2001. Dynamics of spatial and temporal complexity in European and North American soft-bottom mussel beds. In: Reise, K. (Ed.), Ecological Comparisons of Sedimentary Shores. Springer-Verlag, Heidelberg, pp. 39–59.
Commito, J.A., Como, S., Grupe, B.M., Dowa, W.E., 2008. Species diversity in the soft-bottom intertidal zone: biogenic structure, sediment, and macrofauna across mussel bed spatial scales. Journal of Experimental Marine Biology and Ecology 366, 70–81.
Cuddington, K., Hastings, A., 2004. Invasive engineers. Ecological Modelling 178, 335–347.
Dame, R.F., Prins, T.C., 1998. Bivalve carrying capacity in coastal ecosystems. Aquatic Ecology 31, 409–421.
Dankers NMJA, Meijboom A., De Jong, M.L., Dijkman EM, Cremer J.S.M., Fey, F.E., Smaal AC, Craeymeersch J.A., Brummelhuis EBM, Steenbergen J., Baars, J.M.D.D., 2006. De ontwikkeling van de Japanse oester in Nederland. Wageningen IMARES, Institute for Marine Resources and Ecosystem Studies, Report C040/06, Yerseke, The Netherlands.
Davenport, J., Smith, R.J.J.W., Packer, M., 2000. Mussels *Mytilus edulis:* significant consumers and destroyers of mesozooplankton. Marine Ecology Progress Series 198, 131–137.
De Bruyne, R.H., 2004. Veldgids Schelpen. KNNV Uitgeverij, Utrecht.
Del Hoyo, J., Elliott, A., Sargatal, J., 1996. Handbook of Birds of the World. Volume 3: Hoatzin to Auks. Birdlife International and Lynx Edicions, Barcelona. pp 821 pp.
Diederich, S., 2005a. Differential recruitment of introduced Pacific oysters and native mussels at the North Sea coast: coexistence possible? Journal of Sea Research 53, 269–281.
Diederich S (2005b) Invasion of Pacific oysters (*Crassostrea gigas*) in the Wadden Sea: competitive advantage over native mussels. PhD thesis, University of Kiel, Germany, 154 pp.
Diederich, S., Nehls, G., Van Beusekom, J.E.E., Reise, K., 2005. Introduced Pacific oysters (*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers? Helgoland Marine Research 59, 97–106.
Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. Journal of Experimental Marine Biology and Ecology 328, 211–227.
Dijkema, R., 1997. Molluscan fisheries and culture in the Netherlands. In: Mackenzie Jr., C.L., Burrell Jr., V.G., Rosenfield, A., Hobart, W.L. (Eds.), The History, Present Condition and Future of the Molluscan Fisheries of North and Central America and Europe, 129. NOAA Technical Report NMFS, Europe, pp. 115–135.
Dinamani, P., 1991. The Pacific oyster, *Crassostrea gigas* (Thunberg, 1793), in New Zealand. In: Menzel, W. (Ed.), Estuarine and Marine Bivalve Mollusk Culture. CRC Press, Boca Raton, USA, pp. 343–352.
Dittmann, S., 1990. Mussel beds — amensalism or amelioration for intertidal fauna? Helgoländer Meeresuntersuchungen 44, 335–352.
Drinkwaard, A.C., 1999a. Introductions and developments of oysters in the North Sea area: a review. Helgoländer Meeresuntersuchungen 52, 301–308.
Drinkwaard, A.C., 1999b. History of cupped oyster in European coastal waters. Aquaculture Europe 15 (7), 14–41.
Dubois, S., Orvain, F., Marin-Léal, J.C., Ropert, M., Lefebvre, S., 2007. Small-scale spatial variability of food partitioning between cultivated oysters and associated suspension-feeding species, as revealed by stable isotopes. Marine Ecology Progress Series 336, 151–160.
Dupuy, C., Le Gall, S., Hartmann, H.J., Bréret, M., 1999. Retention of ciliates and flagellates by the oyster *Crassostrea gigas* in French Atlantic coastal ponds: protists as a trophic link between bacterioplankton and benthic suspension-feeders. Marine Ecology Progress Series 177, 165–175.
Dupuy, C., Vaquer, A., Lam-Höai, T., Rougier, C., Mazouni, N., Lautier, J., Collos, Y., Le Gall, S., 2000. Feeding rate of the oyster *Crassostrea gigas* in a natural planktonic community of the Mediterranean Thau Lagoon. Marine Ecology Progress Series 205, 171–184.
Engelsma, M.Y., Haenen, O.L.M., 2004. Jaarverslag schelpdierziekten 2003. Resultaten van onderzoek naar ziekten, plagen en mortaliteiten in schelpdierbestanden van het Grevelingenmeer en de Oosterschelde in 2003. CIDC-Lelystad, Report 04/0009045, Lelystad, The Netherlands.
Engelsma, M.Y., Roozenburg, I., Joly, J.-P., 2008. First isolation of *Nocardia crassostreae* from Pacific oysters (*Crassostrea gigas*) in Europe. Diseases of Aquatic Organisms 80, 229–234.
English, L.J., Maguire, G.B., Ward, R.D., 2000. Genetic variation of wild and hatchery populations of the Pacific oyster, *Crassostrea gigas* (Thunberg), in Australia. Aquaculture 187, 283–298.
Ernande, B., Boudry, P., Clobert, J., Haure, J., 2003. Plasticity in resource allocation based life history traits in the Pacific oyster. *Crassostrea gigas*. I. Spatial variation in food abundance. Journal of Evolutionary Biology 17, 342–356.
Faasse, M., Ligthart, M., 2007. The American oyster drill, *Urosalpinx cinerea* (Say, 1822), introduced to The Netherlands — increased risks after ban on TBT? Aquatic Invasions 2, 402–406.
Famme, P., Riisgård, H.U., Jørgensen, C.B., 1986. On direct measurement of pumping rates in the mussel *Mytilus edulis*. Marine Biology 92, 323–327.
FAO, 2004. Aquaculture production 2002. FAO Fishery Information, Data and Statistics Unit, Rome.
Fey, F., Dankers, N., Steenbergen, J., Goudswaard, K., 2009. Development and distribution of the non-indigenous Pacific oyster (*Crassostrea gigas*) in the Dutch Wadden Sea. Aquaculture International. doi:10.1007/s10499-009-9268-0 Available online.

Foster-Smith, R.L., 1975. The effect of concentration of suspension on the filtration rates and pseudofaecal production for *Mytilus edulis* L., *Cerastoderma edule* (L.) and *Venerupis pullastra* (Montagu). Journal of Experimental Marine Biology and Ecology 17, 1–22.

Fréchette, M., Butman, C.A., Geyer, W.R., 1989. The importance of boundary-layer flows in supplying phytoplankton to the benthic suspension feeder, *Mytilus edulis* L. Limnology and Oceanography 34, 19–36.

Fujiya, M., 1970. Oyster farming in Japan. Helgoländer Meeresuntersuchungen 20, 464–479.

Fukui, Y., 1988. Comparative studies on the life history of the grapsid crabs (Crustacea, Brachyura) inhabiting intertidal cobble and boulder shores. Publications of the Seto Marine Biological Laboratory 33, 121–162.

Galleni, L., Tongiorgi, P., Ferrero, E., Salghetti, U., 1980. *Stylochus mediterraneus* (Turbellaria Polycladida), a predator of *Mytilus galloprovincialis*. Marine Biology 35, 317–326.

Gerdes, D., 1983. The Pacific oyster *Crassostrea gigas*. Part I. Feeding behaviour of larvae and adults. Aquaculture 31, 195–219.

Geurts van Kessel, A.J.M., Kater, B.J., Prins, T.C., 2003. Veranderende draagkracht van de Oosterschelde voor kokkels. National Institute for Coastal and Marine Management (RIKZ) and Netherlands Institute for Fisheries Research (RIVO) Report RIKZ/2003.043 / RIVO C062/03, Middelburg, The Netherlands.

Gosling, E., 2003. Bivalve molluscs. Biology, Ecology and Culture. Blackwell Publishing, Oxford.

Goud, J., Titselaar, F.F.L.M., Mulder, G., 2008. Weer een "verstekeling": de Japanse Stekelhoren *Ocinebrellus inornatus* (Récluz, 1851) (Gastropoda, Muricidae) levend aangetroffen in de Oosterschelde. Spirula 365, 134–136.

Grabowski, J.H., 2004. Habitat complexity disrupts predator–prey interactions but not the trophic cascade on oyster reefs. Ecology 85, 995–1004.

Green, R.H., 1971. A multivariate statistical approach to the Hutchinsonian niche: bivalve molluscs of central Canada. Ecology 52, 544–556.

Grizel, H., Héral, M., 1991. Introduction into France of the Japanese oyster (*Crassostrea gigas*). ICES Journal of Marine Science 47, 399–403.

Gruet, Y., Héral, M., Robert, J.M., 1976. Premières observations sur l'introduction de la faune associée au naissain d'huîtres Japonaises *Crassostrea gigas* (Thunberg), importé sur la côte Atlantique Française. Cahiers de Biologie Marine 17, 173–184.

Günther, C.P., 1996. Development of small *Mytilus* beds and its effects on resident intertidal macrofauna. P.S.Z.N I. Marine Ecology 17, 117–130.

Gutiérrez, J.L., Jones, C.G., Strayer, D.L., Iribarne, O.O., 2003. Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. Oikos 101, 79–90.

Haenen, O., 2001. Jaarverslag Oesterziekten 2000. Resultaten in 2000 van onderzoek naar ziekten, plagen en mortaliteiten in de oesterbestanden van de Oosterschelde (Yerseke bank) en het Grevelingenmeer. ID Lelystad, ID 01/00-10833, Lelystad, The Netherlands.

Hamdoun, A.M., Cheney, D.P., Cherr, G.N., 2003. Phenotypic plasticity of HSP70 and HSP70 gene expression in the Pacific oyster (*Crassostrea gigas*): implications for thermal limits and induction of thermal tolerance. The Biological Bulletin 205, 160–169.

Hartstein, N.D., Rowden, A.A., 2004. Effect of biodeposits from mussel culture on macroinvertebrate assemblages at sites of different hydrodynamic regime. Marine Environmental Research 57, 339–357.

Hawkins, A.J.S., Bayne, B.L., Bougrier, S., Héral, M., Iglesias, J.I.P., Navarro, E., Smith, R.F.M., Urrutia, M.B., 1998. Some general relationships in comparing the feeding physiology of suspension-feeding bivalve molluscs. Journal of Experimental Marine Biology and Ecology 219, 87–103.

Hayward, P.J., Ryland, J.S., 1990. The marine fauna of the British Isles and North-West Europe. Molluscs to Chordates, Vol. II. Clarendon Press, Oxford.

Hedgecock, D., Langdon, C., Blouin, M., Allen, S.K.J., 1996. Genetic improvement of cultured Pacific oysters by selection. Agricultural Experiment Station, Oregon State University, Coastal Marine Experiment Station Annual Report, Special Report, 968. 40 pp.

Heip, C.H.R., Goosen, N.K., Herman, P.M.J., Kromkamp, J.C., Middelburg, J., Soetaert, K., 1995. Production and consumption of biological particles in temperate tidal estuaries. Oceanography and Marine Biology: An Annual Review 33, 1–149.

Helm, M.M., Bourne, N., Lovatelli, A., 2004. Hatchery culture of bivalves — a practical manual. FAO Fisheries Technical Paper. FAO, Rome.

Hiddink, J.G., Marijnissen, S.A.E., Troost, K., Wolff, W.J., 2002. Predation on 0-group and older year classes of the bivalve *Macoma balthica*: interaction of size selection and intertidal distribution of epibenthic predators. Journal of Experimental Marine Biology and Ecology 269, 223–248.

Hoek, P.P.C., 1902. Rapport over de oorzaken van den achteruitgang in hoedanigheid van de zeeuwsche oester. Staatsuitgeverij, Den Haag, The Netherlands. 176 pp.

Honkoop, P.J.C., Van der Meer, J., 1998. Experimentally induced effects of water temperature and immersion time on reproductive output of bivalves in the Wadden Sea. Journal of Experimental Marine Biology and Ecology 220, 227–246.

Honkoop, P.J.C., Bayne, B.L., Drent, J., 2003. Flexibility of size of gills and palps in the Sydney rock oyster *Saccostrea glomerata* (Gould, 1850) and the Pacific oyster *Crassostrea gigas* (Thunberg, 1793). Journal of Experimental Marine Biology and Ecology 282, 113–133.

Hostens, K., Hamerlynck, O., 1994. The mobile epifauna of the soft bottoms in the subtidal Oosterschelde estuary: structure, function and impact of the storm-surge barrier. Hydrobiologia 282 (283), 479–496.

Imai, T., Sakai, S., 1961. Study of breeding of Japanese Oyster, *Crassostrea gigas*. Tohuku Journal of Agricultural Research 12, 125–171.

Jonckheere, I., 2006. Nieuwe vestigingsplaats voor Japanse oesters *Crassostrea gigas* (Thunberg, 1793). De Strandvlo 26, 135–138.

Jones, C.G., Lawton, J.H., Shachak, M., 1994. Organisms as ecosystem engineers. Oikos 69, 373–386.

Jonsson, P.R., Petersen, J.K., Karlsson, Ö., Loo, L.-O., Nilsson, S., 2005. Particle depletion above experimental bivalve beds: in situ measurements and numerical modelling of bivalve filtration in the boundary layer. Limnology and Oceanography 50, 1989–1998.

Kamermans, P., 1993. Food limitation in cockles (*Cerastoderma edule* (L.)): influences of location on tidal flat and of nearby presence of mussel beds. Netherlands Journal of Sea Research 31, 71–81.

Karlsson, Ö., Jonsson, P.R., Larsson, A.I., 2003. Do large seston particles contribute to the diet of the bivalve *Cerastoderma edule*? Marine Ecology Progress Series 261, 161–173.

Kater, B.J., 2003. De voedselsituatie voor kokkels in de Oosterschelde. Netherlands Institute for Fisheries Research (RIVO), Report C018/03, Yerseke, the Netherlands.

Kater, B.J., Baars, J.M.D.D., 2004. The potential of aerial photography for estimating surface areas of intertidal Pacific oyster beds (*Crassostrea gigas*). Journal of Shellfish Research 23, 773–779.

Kater, B.J., Geurts van Kessel, A.J.M., Baars, J.M.D.D., 2006. Distribution of cockles *Cerastoderma edule* in the Eastern Scheldt: habitat mapping with abiotic variables. Marine Ecology Progress Series 318, 221–227.

Kato, K., 1944. Polycladida of Japan. Sigenkagaku Kenkyusho 1, 257–318.

Keane, R.M., Crawley, M.J., 2002. Exotic plant invasions and the enemy release hypothesis. Trends in Ecology and Evolution 14, 164–170.

Keddy, P.A., Twolan-Strutt, L., Wisheu, I.C., 1994. Competitive effect and response ranking in 20 wetland plants: are they consistent across three environments? Journal of Ecology 82, 635–643.

Kerckhof, F., 1997. De schaalhoorn *Patella vulgata* en de Japanse oester *Crassostrea gigas* na de koude winters 1995/1996 en 1996/1997. De Strandvlo 17, 49–51.

Kerckhof, F., Vink, R.J., Nieweg, D.C., Post, J.N.J., 2006. The veined whelk *Rapana venosa* has reached the North Sea. Aquatic Invasions 1, 35–37.

Kerckhof, F., Haelters, J., Gollasch, S., 2007. Alien species in the marine and brackish ecosystem: the situation in Belgian waters. Aquatic Invasions 2, 243–257.

Kingsford, M.J., Leis, J.M., Shanks, A., Lindemand, K.C., Morgan, S.G., Pineda, J., 2002. Sensory environments, larval abilities and local self-recruitment. Bulletin of Marine Science 70, 309–340.

Kiørboe, T., Visser, A.W., 1999. Predator and prey perception in copepods due to hydromechanical signals. Marine Ecology Progress Series 179, 81–95.

Kobayashi, M., Hofmann, E.E., Powell, E.N., Klinck, J.M., Kusaka, K., 1997. A population dynamics model for the Japanese oyster, *Crassostrea gigas*. Aquaculture 149, 285–321.

Kochmann, J., Buschbaum, C., Volkenborn, N., Reise, K., 2008. Shift from native mussels to alien oysters: differential effects of ecosystem engineers. Journal of Experimental Marine Biology and Ecology 364, 1–10.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends in Ecology and Evolution 16, 199–204.

Kooijman, S.A.L.M., 1986. Energy budgets can explain body size relations. Journal of Theoretical Biology 121, 269–282.

Kooijman, S.A.L.M., 2000. Dynamic Energy and Mass Budgets in Biological Systems. Cambridge University Press, Cambridge.

Korringa, P., 1951. Polydora als vijand van de oestercultuur. Ministerie van Landbouw, Visserij en Voedselvoorziening.

Korringa, P., 1952. Recent advances in oyster biology. The Quarterly Review of Biology 27 (266–308), 339–365.

Korringa, P., 1976. Farming the Cupped Oysters of the Genus Crassostrea. Elsevier Scientific Publishing Company, Amsterdam.

Krakau, M., Thieltges, D.W., Reise, K., 2006. Native parasites adopt introduced bivalves of the North Sea. Biological Invasions 8, 919–925.

Lavoie, R.E., 2005. Oyster culture in North America. History, Present and Future. Oyster Research Institute News 17.

Leewis, R.J., Waardenburg, H.W., Van der Tol, M.W.M., 1994. Biomass and standing stock on sublittoral hard substrates in the Oosterschelde estuary (SW Netherlands). Hydrobiologia 282 (283), 397–412.

Lehane, C., Davenport, J., 2004. Ingestion of bivalve larvae by *Mytilus edulis*: experimental and field demonstrations of larviphagy in farmed blue mussels. Marine Biology 145, 101–107.

Liu, H., Stiling, P., 2006. Testing the enemy release hypothesis: a review and meta-analysis. Biological Invasions 8, 1535–1545.

Lodge, D.M., 1993. Biological invasions: lessons for ecology. Trends in Ecology and Evolution 8, 133–137.

Lotze, H.K., 2005. Radical changes in the Wadden Sea fauna and flora over the last 2,000 years. Helgoland Marine Research 59, 71–83.

Luttikhuizen, P.C., Honkoop, P.J.C., Drent, J., Van der Meer, J., 2004. A general solution for optimal egg size during external fertilization, extended scope for intermediate optimal egg size and the introduction of Don Ottavio "tango". Journal of Theoretical Biology 231, 333–343.

Maar, M., Nielsen, T.G., Bolding, K., Burchard, H., Visser, A.W., 2007. Grazing effects of blue mussel *Mytilus edulis* on the pelagic food web under different turbulence conditions. Marine Ecology Progress Series 339, 199–213.

Mann, R., Burreson, E.M., Baker, P.K., 1991. The decline of the Virginia oyster fishery in Chesapeake Bay: considerations for introduction of a non-endemic species, *Crassostrea gigas* (Thunberg, 1793). Journal of Shellfish Research 10, 379–388.

Markert, A., Wehrmann, A., Kröncke, I., 2009. Recently established *Crassostrea*-reefs versus native *Mytilus*-beds: differences in ecosystem engineering affects the macrofaunal communities (Wadden Sea of Lower Saxony, southern German Bight). Biological Invasions. doi:10.1007/s10530-009-9425-4 Available online, 18 pp.

Martel, C., Viard, F., Bourguet, D., Garcia-Meunier, P., 2004. Invasion by the marine gastropod *Ocinebrellus inornatus* in France I. Scenario for the source of introduction. Journal of Experimental Marine Biology and Ecology 305, 155–170.

Marvier, M., Kareiva, P., Neubert, M.G., 2004. Habitat destruction, fragmentation, and disturbance promote invasion by habitat generalists in a multispecies metapopulation. Risk Analysis 24, 869–878.
Møhlenberg, F., Riisgård, H.U., 1978. Efficiency of particle retention in 13 species of suspension feeding bivalves. Ophelia 17, 239–246.
Møhlenberg, F., Riisgård, H.U., 1979. Filtration rate, using a new indirect technique, in thirteen species of suspension-feeding bivalves. Marine Biology 54, 143–147.
Morton, B., 1997. The aquatic nuisance species problem: a global perspective and review. In: D'Itri, F.M. (Ed.), Zebra Mussels and Aquatic Nuisance Species. CRC Press, Boca Raton, USA, pp. 1–54.
Navarro, E., Iglesias, J.I.P., Ortega, M.M., 1992. Natural sediment as a food source for the cockle *Cerastoderma edule* (L.): effect of variable particle concentration on feeding, digestion and the scope for growth. Journal of Experimental Marine Biology and Ecology 156, 69–87.
Nehls, G., Hertzler, I., Scheiffarth, G., 1997. Stable mussel *Mytilus edulis* beds in the Wadden Sea. They're just for the birds Helgoländer Meeresuntersuchungen, 51, pp. 361–372.
Nehls, G., Diederich, S., Thieltges, D.W., Strasser, M., 2006. Wadden Sea mussel beds invaded by oysters and slipper limpets: competition or climate control? Helgoland Marine Research 60, 135–143.
Nehls, G., Büttger, H., 2007. Spread of the Pacific Oyster *Crassostrea gigas* in the Wadden Sea. Causes and Consequences of a Successful Invasion. BioConsult SH, Husum, on behalf of the Common Wadden Sea Secretariat, Wilhelmshaven, HARBASINS report, Husum, Germany.
Nehring, S., 2006. Four arguments why so many alien species settle into estuaries, with special reference to the German river Elbe. Helgoland Marine Research 60, 127–134.
Nestlerode, J.A., Luckenbach, M.W., O'Beirn, F.X., 2007. Settlement and survival of the oyster *Crassostrea virginica* on created oyster reef habitats in Chesapeake Bay. Restoration Ecology 15, 273–283.
Noren, F., Haamer, J., Lindahl, O., 1999. Changes in the plankton community passing a *Mytilus edulis* mussel bed. Marine Ecology Progress Series 191, 187–194.
Ó Foighil, D., Gaffney, P.M., Hilbish, T.J., 1995. Differences in mitochondrial 16 s ribosomal gene sequences allow discrimination among American [*Crassostrea virginica* (Gmelin)] and Asian [*C. gigas* (Thunberg) *C. ariakensis* Wakiya] oyster species. Journal of Experimental Marine Biology and Ecology 192, 211–220.
Occhipinti-Ambrogi, A., Savini, D., 2003. Biological invasions as a component of global change in stressed marine ecosystems. Marine Pollution Bulletin 46, 542–551.
Petersen, J.K., Bougrier, S., Smaal, A.C., Garen, P., Robert, S., Larsen, J.E.N., Brummelhuis, E.B.M., 2004. Intercalibration of mussel *Mytilus edulis* clearance rate measurements. Marine Ecology Progress Series 267, 187–194.
Philippart, C.J.M., Beukema, J.J., Cadée, G.C., Dekker, R., Goedhart, P.W., Van Iperen, J.M., Leopold, M.F., Herman, P.M.J., 2007. Impacts of nutrient reduction on coastal communities. Ecosystems 10, 95–118.
Pianka, E.R., 1970. On r- and K-selection. American Naturalist 104, 592–597.
Prins, T.C., Smaal, A.C., 1994. The role of the blue mussel *Mytilus edulis* in the cycling of nutrients in the Oosterschelde estuary (The Netherlands). Hydrobiologia 282 (283), 413–429.
Prins, T.C., Smaal, A.C., Pouwer, A.J., Dankers, N., 1996. Filtration and resuspension of particulate matter and phytoplankton on an intertidal mussel bed in the Oosterschelde estuary (SW Netherlands). Marine Ecology Progress Series 142, 121–134.
Prins, T.C., Smaal, A.C., Dame, R.F., 1998. A review of the feedbacks between bivalve grazing and ecosystem processes. Aquatic Ecology 31, 349–359.
Quayle, D.B., 1988. Pacific oyster culture in British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 218, 1–241.
Raby, D., Lagadeuc, Y., Dodson, J.J., Mingelbier, M., 1994. Relationship between feeding and vertical distribution of bivalve larvae in stratified and mixed waters. Marine Ecology Progress Series 103, 275–284.
Reise, K., 1978. Experiments on epibenthic predation in the Wadden Sea Helgoländer Meeresuntersuchungen, 31, pp. 55–101.
Reise, K., 1982. Long-term changes in the macrobenthic invertebrate fauna of the Wadden Sea: are polychaetes about to take over? Netherlands Journal of Sea Research 16, 29–36.
Reise, K., 1998. Pacific oysters invade mussel beds in the European Wadden Sea. Senckenbergiana Maritima 28, 167–175.
Reise, K., Gollasch, S., Wolff, W.J., 1999. Introduced marine species of the North Sea coasts. Helgoländer Meeresuntersuchungen 52, 219–234.
Reise, K., 2002. Sediment mediated species interactions in coastal waters. Journal of Sea Research 48, 127–141.
Reise, K., Van Beusekom, J.E.E., 2008. Interactive effects of global and regional change on a coastal ecosystem. Helgoland Marine Research 62, 85–91.
Renault, T., 1996. Appearance and spread of diseases among bivalve molluscs in the northern hemisphere in relation to international trade. Revue scientifique et technique de l'office international des épizooties 15, 551–561.
Rico-Villa, B., Pouvreau, S., Robert, R., 2009. Influence of food density and temperature on ingestion, growth and settlement of Pacific oyster larvae, *Crassostrea gigas*. Aquaculture 287, 395–401.
Riera, P., Stal, L.J., Nieuwenhuize, J., 2002. $\delta^{13}C$ versus $\delta^{15}N$ of co-occurring molluscs within a community dominated by *Crassostrea gigas* and *Crepidula fornicata* (Oosterschelde, The Netherlands). Marine Ecology Progress Series 240, 291–295.
Riera, P., 2006. Trophic subsidies of *Crassostrea gigas*, *Mytilus edulis* and *Crepidula fornicata* in the Bay of Mont Saint Michel (France): a $\delta^{13}C$ and $\delta^{15}N$ investigation. Estuarine, Coastal and Shelf Science 72, 33–41.
Riisgård, H.U., 1977. On measurements of the filtration rates of suspension feeding bivalves in a flow system. Ophelia 16, 167–173.
Riisgård, H.U., 1988. Efficiency of particle retention and filtration rate in 6 species of Northeast American bivalves. Marine Ecology Progress Series 45, 217–223.
Rumrill, S.S., 1990. Natural mortality of marine invertebrate larvae. Ophelia 32, 163–198.
Saito, H., Nakanishi, Y., Shigeta, T., Umino, T., Kawai, K., Imabayashi, H., 2008. Effect of predation of fishes on oyster spats in Hiroshima Bay. Nippon Suisan Gakkaishi 74, 809–815.
Sakai, A.K., Allendorf, F.W., Holt, J.S., Lodge, D.M., Molofsky, J., With, K.A., Baughman, S., Cabin, R.J., Cohen, J.E., Ellstrand, N.C., McCauley, D.E., O'Neil, P., Parker, I.M., Thompson, J.N., Weller, S.G., 2001. The population biology of invasive species. Annual Review of Ecology and Systematics 32, 305–332.
Scheiffarth, G., Ens, B., Schmidt, A., 2007. What will happen to birds when Pacific Oysters take over the mussel beds in the Wadden Sea? Wadden Sea Newsletter 33, 10–14.
Schmidt, A., Wehrmann, A., Dittmann, S., 2008. Population dynamics of the invasive Pacific oyster *Crassostrea gigas* during the early stages of an outbreak in the Wadden Sea (Germany). Helgoland Marine Research 62, 367–376.
Schmidt, A., Wehrmann, A., Dittmann, S., 2009. Low mortality rates of juvenile Pacific oysters in the German Wadden Sea are characteristic for invasive species: a reply to Beukema and Dekker. Helgoland Marine Research. doi:10.1007/s10152-009-0170-y Available online.
Sechena, R., Nakano, C., Liao, S., Polissar, N., Lorenzana, R., Truong, S., Fenske, R., 1999. Asian and Pacific Islander Seafood Consumption Study. United States Environmental Protection Agency, Report EPA 910/R-99-003. .
Seed, R., 1976. Ecology. In: Bayne, B.L. (Ed.), Marine Mussels: Their Ecology and Physiology. Cambridge University Press, Cambridge, pp. 13–65.
Shamseldin, A.A., Clegg, J.S., Friedman, C.S., Cherr, G.N., Pillai, M.C., 1997. Induced thermotolerance in the Pacific oyster, *Crassostrea gigas*. Journal of Shellfish Research 16, 487–491.
Shanks, A.L., Brink, L., 2005. Upwelling, downwelling, and cross-shelf transport of bivalve larvae: test of a hypothesis. Marine Ecology Progress Series 302, 1–12.
Shatkin, G., Shumway, S.E., Hawes, R., 1997. Considerations regarding the possible introduction of the Pacific Oyster (*Crassostrea gigas*) to the Gulf of Maine: a review of global experience. Journal of Shellfish Research 16, 463–477.
Shumway, S.E., Cucci, T.L., Newell, R.C., Yentsch, C.M., 1985. Particle selection, ingestion and absorption in filter-feeding bivalves. Journal of Experimental Marine Biology and Ecology 91, 77–92.
Singarajah, K.V., 1969. Escape reactions of zooplankton: the avoidance of a pursuing siphon tube. Journal of Experimental Marine Biology and Ecology 3, 171–178.
Singarajah, K.V., 1975. Escape reactions of zooplankton: effects of light and turbulence. Journal of the Marine Biological Association of the United Kingdom 55, 627–639.
Sistermans, W.C.H., Hummel, H., Van Hoesel, O.J.A., Markusse, M.M., Rietveld, M., Van Soelen, E., 2005. Het macrobenthos van de Westerschelde, de Oosterschelde, het Veerse meer en het Grevelingenmeer in het najaar 2004. Netherlands Institute of Ecology — Centre for Estuarine and Marine Ecology (NIOO—CEME), Rapportage in het kader van het Biologisch Monitoring Programma, Yerseke, The Netherlands.
Smaal, A.C., Prins, T.C., 1993. The uptake of organic matter and the release of inorganic nutrients by bivalve suspension feeder bed. In: Dame, R.F. (Ed.), Bivalve Filter Feeders in Estuarine and Coastal Ecosystem Processes. Springer Verlag, Heidelberg, pp. 273–298.
Smaal AC (1997) Food supply and demand of bivalve suspension feeders in a tidal system. PhD thesis, University of Groningen, the Netherlands, 237 pp.
Smaal, A.C., Vonck, A.P.M.A., Bakker, M., 1997. Seasonal variation in physiological energetics of *Mytilus edulis* and *Cerastoderma edule* of different size classes. Journal of the Marine Biological Association of the United Kingdom 77, 817–838.
Smaal, A.C., Van Stralen, M.R., Schuiling, E., 2001. The interaction between shellfish culture and ecosystem processes. Canadian Journal of Fisheries and Aquatic Sciences 58, 991–1002.
Smaal, A.C., Van Stralen, M.R., Craeymeersch, J., 2005. Does the introduction of the Pacific oyster *Crassostrea gigas* lead to species shifts in the Wadden Sea? In: Dame, R.F., Olenin, S. (Eds.), The Comparative Roles of Suspension-Feeders in Ecosystems. Springer, pp. 277–289.
Smaal, A.C., Kater, B.J., Wijsman, J.W.M., 2009. Introduction, establishment and expansion of the Pacific oyster *Crassostrea gigas* in the Oosterschelde (SW Netherlands). Helgoland Marine Research 63, 75–83.
Smies, M., Huiskes, A.H.L., 1981. Holland's Eastern Scheldt estuary barrier scheme: some ecological considerations. Ambio 10, 158–165.
Stachowicz, J.J., Whitlatch, R.B., Osman, R.W., 1999. Species diversity and invasion resistance in a marine ecosystem. Science 286, 1577–1579.
Stachowicz, J.J., Fried, H., Osman, R.W., Whitlatch, R.B., 2002. Biodiversity, invasion resistance, and marine ecosystem function: reconciling pattern and process. Ecology 83, 2575–2590.
Steele, S., Mulcahy, M.F., 2001. Impact of the copepod *Mytilicola orientalis* on the Pacific oyster *Crassostrea gigas* in Ireland. Diseases of Aquatic Organisms 47, 145–149.
Stock, J.H., 1993. Copepoda (Crustacea) associated with commercial and non-commercial Bivalvia in the East Scheldt, The Netherlands. Bijdragen tot de Dierkunde 63, 61–64.
Strasser, M., Günther, C.P., 2001. Larval supply of predator and prey: temporal mismatch between crabs and bivalves after a severe winter in the Wadden Sea. Journal of Sea Research 46, 57–67.
Strasser, M., Reinwald, T., Reise, K., 2001. Differential effects of the severe winter of 1995/96 on the intertidal bivalves *Mytilus edulis*, *Cerastoderma edule* and *Mya arenaria* in the Northern Wadden Sea. Helgoland Marine Research 55, 190–197.
Tamburri, M.N., Zimmer, R.K., Zimmer, C.A., 2007. Mechanisms reconciling gregarious larval settlement with adult cannibalism. Ecological Monographs 77, 255–268.
Taris, N., Ernande, B., McCombie, H., Boudry, P., 2006. Phenotypic and genetic consequences of size selection at the larval stage in the Pacific oyster (*Crassostrea gigas*). Journal of Experimental Marine Biology and Ecology 333, 147–158.

Thieltges, D.W., Reise, K., Prinz, K., Jensen, K.T., 2009. Invaders interfere with native parasite–host interactions. Biological Invasions 11, 1421–1429.
Thorson, G., 1950. Reproductive and larval ecology of marine bottom invertebrates. Biological Reviews of the Cambridge Philosophical Society 25, 1–45.
Titelman, J., Kiørboe, T., 2003. Predator avoidance by nauplii. Marine Ecology Progress Series 247, 137–149.
Troost, K., Kamermans, P., Wolff, W.J., 2008a. Larviphagy in native bivalves and an introduced oyster. Journal of Sea Research 60, 157–163.
Troost, K., Veldhuizen, R., Stamhuis, E.J., Wolff, W.J., 2008b. Can bivalve veligers escape feeding currents of adult bivalves? Journal of Experimental Marine Biology and Ecology 358, 185–196.
Troost K (2009) Pacific Oysters in Dutch Estuaries: Causes of Success and Consequences for Native Bivalves. PhD thesis, University of Groningen, the Netherlands, 255 pp.
Troost, K., Gelderman, E., Kamermans, P., Smaal, A.C., Wolff, W.J., 2009a. Effects of an increasing filter feeder stock on larval abundance in the Oosterschelde estuary (SW Netherlands). Journal of Sea Research 61, 153–164.
Troost, K., Stamhuis, E.J., Van Duren, L.A., Wolff, W.J., 2009b. Feeding current characteristics of three morphologically different bivalve suspension feeders, *Crassostrea gigas*, *Mytilus edulis* and *Cerastoderma edule*, in relation to food competition. Marine Biology 156, 355–372.
Tydeman, P., 1999. Japanse oesters in de Eemshaven. Het Zeepaard 59, 58–63.
Tydeman, P., Kleef, H.L., De Vlas, J., 2002. Ontwikkeling van de Japanse oester (*Crassostrea gigas*) in het Eems-Dollard estuarium in de periode 1998–2001. National Institute for Coastal and Marine Management (RIKZ), Report (werkdocument) RIKZ/OS/2002.601x, Haren, the Netherlands.
Tydeman, P., 2008. Japanse oesters naar de (Wadden)zee gedragen? Het Zeepaard 68, 109–114.
Van Beusekom, J.E.E., De Jonge, V.N., 2002. Long-term changes in Wadden Sea nutrient cycles: importance of organic matter import from the North Sea. Hydrobiologia 475 (476), 185–194.
Van Broekhoven W (2005) Macrofaunal diversity on beds of the Pacific oyster (*Crassostrea gigas*) in the Oosterschelde estuary. MSc thesis, 36 pp.
Van der Veer, H.W., Feller, R.J., Weber, A., Witte, J.I., 1998. Importance of predation by crustaceans upon bivalve spat in the intertidal zone of the Dutch Wadden Sea as revealed by immunological assays of gut contents. Journal of Experimental Marine Biology and Ecology 231, 139–157.
Van der Veer, H.W., Cardoso, J.F.M.F., Van der Meer, J., 2006. Estimation of DEB parameters for various Northeast Atlantic bivalve species. Journal of Sea Research 56, 107–124.
Van Stralen, M.R., Dijkema, R.D., 1994. Mussel culture in a changing environment: the effects of a coastal engineering project on mussel culture (*Mytilus edulis* L.) in the Oosterschelde estuary (SW Netherlands). Hydrobiologia 282 (283), 359–379.
Van Zanten, E., Adriaanse, L.A., 2008. Verminderd getij. Verkenning naar mogelijke maatregelen om het verlies van platen, slikken en schorren in de Oosterschelde te beperken. Rijkswaterstaat Zeeland, Middelburg, The Netherlands.
Wa Kang'eri AK (2005) Winter mortality and freeze tolerance in the Pacific oyster, *Crassostrea gigas* (Thunberg). MSc thesis, 53 pp.
Wallentinus, I., Nyberg, C.D., 2007. Introduced marine organisms as habitat modifiers. Marine Pollution Bulletin 55, 323–332.
Walne, P.R., 1972. The influence of current speed, body size and water temperature on the filtration rate of five species of bivalves. Journal of the Marine Biological Association of the United Kingdom 52, 345–374.
Ward, J.E., Levinton, J.S., Shumway, S.E., Cucci, T., 1998. Particle sorting in bivalves: in vivo determination of the pallial organs of selection. Marine Biology 131, 283–292.
Wehrmann, A., Herlyn, M., Bungenstock, F., Hertweck, G., Millat, G., 2000. The distribution gap is closed — first record of naturally settled Pacific oysters *Crassostrea gigas* in the East Frisian Wadden Sea, North Sea. Senckenbergiana Maritima 30, 153–160.
Wetsteyn LPMJ, Duijn R.N.M., Kromkamp, J.C., Latuhihin MJ, Peene J., Pouwer, A., Prins, T.C., Wetsteyn, L.P.M.J., Duijn, R.N.M., Kromkamp, J.C., Latuhihin, M.J., Peene, J., Pouwer, A., Prins, T.C., 2003. Verkenning draagkracht Oosterschelde. Onderzoek naar veranderingen en trends in de Oosterschelde in de periode 1990 t/m 2000. National Institute for Coastal and Marine Management (RWS-RIKZ), Report RIKZ/2003.049.
Widdows, J., Navarro, J.M., 2007. Influence of current speed on clearance rate, algal cell depletion in the water column and resuspension of biodeposits of cockles (*Cerastoderma edule*). Journal of Experimental Marine Biology and Ecology 343, 44–51.
Wijsman, J.W.M., Dubbeldam, M., De Kluijver, M.J., Van Zanten, E., Van Stralen, M.R., Smaal, A.C., 2008. Wegvisproef Japanse oesters in de Oosterschelde. Eindrapportage. Wageningen IMARES, Institute for Marine Resources and Ecosystem Studies, Report C063/08, Yerseke, The Netherlands.
Williamson, M., 1996. Biological Invasions. Chapman & Hall, London.
Williamson, M.H., Fitter, A., 1996. The characters of successful invaders. Biological Conservation 78, 163–170.
Wolff, W.J., 1973. The estuary as a habitat. An analysis of data on the soft-bottom macrofauna of the estuarine area of the rivers Rhine, Meuse, and Scheldt. Zoölogische Verhandelingen 126, 1–242.
Wolff, W.J., 1999. Exotic invaders of the meso-oligohaline zone of estuaries in The Netherlands: why are there so many? Helgoländer Meeresuntersuchungen 52, 393–400.
Wolff, W.J., 2000. Causes of extirpations in the Wadden Sea, an estuarine area in The Netherlands. Conservation Biology 14, 876–885.
Wolff, W.J., Reise, K., 2002. Oyster imports as a vector for the introduction of alien species into northern and western European coastal waters. In: Leppäkoski, E., Gollasch, S., Olenin, S. (Eds.), Invasive Aquatic Species of Europe. Distribution, Impacts and Management. Kluwer Academic Publishers, Dordrecht, pp. 193–205.
Wolff, W.J., 2005. Non-indigenous marine and estuarine species in The Netherlands. Zoologische Mededelingen 79 116 pp.
Wong, W.H., Levinton, J.S., 2004. Culture of the blue mussel *Mytilus edulis* (Linnaeus, 1758) fed both phytoplankton and zooplankton: a microcosm experiment. Aquaculture Research 35, 965–969.
Wrange, A.-L., Valero, J., Harkestad, L.S., Strand, Ø., Lindegarth, S., Christensen, H.T., Dolmer, P., Kristensen, P.S., Mortensen, S., 2009. Massive settlements of the Pacific oyster, *Crassostrea gigas*, in Scandinavia. Biological Invasions. doi:10.1007/s10530-009-9535-z Available online.

Vol. 334: 179–192, 2007 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published March 26

Exploitation of natural food sources by two sympatric, invasive suspension-feeders: *Crassostrea gigas* and *Crepidula fornicata*

Priscilla Decottignies[1,*], Peter G. Beninger[1], Yves Rincé[1], Richard J. Robins[2], Pascal Riera[3]

[1]Université de Nantes, Laboratoire de Biologie Marine, UPRES EA 2663, Faculté des Sciences et des Techniques, 2 Rue de la Houssinière, Nantes 44322, France

[2]Université de Nantes, Laboratoire d'Analyse Isotopique et Électrochimique des Métabolismes, Faculté des Sciences et des Techniques, 2 Rue de la Houssinière, Nantes 44322, France

[3]Université de Paris 6, Centre d'Etudes d'Océanographie et de Biologie Marine, UMR 7127, Station Biologique de Roscoff, Place Georges-Teissier, Roscoff 29682, France

ABSTRACT: The natural diets of the introduced suspension-feeders *Crassostrea gigas* (Thunberg) and *Crepidula fornicata* (L.) were determined at a mid-latitudinal oyster-farming site within their European range (Bourgneuf Bay, France). Carbon and nitrogen stable isotope deviations of Pacific oysters and slipper limpets were compared with potential food sources on 3 sampling dates (March, July and November 2003). Four end-members were assimilated by the 2 species: C_3 angiosperm detritus, macroalgae-C_4 plant detritus, marine phytoplankton and benthic diatoms. Given the lack of source digestibility data for suspension-feeders, and these 2 species in particular, extreme feasible combinations of relative end-member contributions were calculated according to 2 assimilation scenarios, using either IsoSource software or a concentration-dependent model. For both *Crassostrea gigas* and *Crepidula fornicata*, benthic and planktonic microalgae dominated diets on the 3 sampling dates. Planktonic microalgae were ingested in greater proportions than benthic species in July and November; however, benthic diatoms also formed a constant and significant part of diets in these months, and were consumed in greater proportions than planktonic species in March. Plant (especially macroalgal) detritus played a major role in the diets of the 2 suspension-feeders, notably in March 2003 when it became the principal ingested source. The substantial contribution of plant detritus to the natural diets of these species has not previously been reported. Although *Crassostrea gigas* and *Crepidula fornicata* showed significantly different isotopic deviations in March and July 2003, trophic niches of *Crassostrea gigas* and *Crepidula fornicata* overlapped on all 3 sampling dates, with a greater ingestion of identical sources in November. These 2 invasive species could therefore be trophic competitors in the context of end-member supply limitation. Contrary to previous analyses conducted on these 2 species in Europe, this study reports significant dietary overlap. Ecosystem-specific diet studies of invasive species are thus necessary in order to understand trophic overlap/competition as a function of the diversity and availability of local food sources.

KEY WORDS: Slipper limpet · Oyster · Diet · Stable isotopes · IsoSource · $\delta^{13}C$ · $\delta^{15}N$

INTRODUCTION

The ecological and evolutionary consequences of invasive species (sensu Davis & Thompson 2000) within coastal marine systems have only become the focus of scientific investigation relatively recently (see Grosholz 2002). To date, the approach has generally been to study the effects of invasive species relative to indigenous communities. European oyster rearing sites represent a special situation, because an accidentally

*Email: priscilla.decottignies@univ-nantes.fr

introduced suspension-feeder *Crepidula fornicata* L. is sympatric with the intentionally established species *Crassostrea gigas* Thunberg, and trophic competition between the two is suspected (Blanchard 1997). Moreover, *C. gigas* shows signs of proliferation outside of oyster rearing sites, making it both a 'desired' species within farms and a 'pest' species (Ruesink et al. 2005).

Despite long-standing concerns over the potential effects of the slipper limpet *Crepidula fornicata* on indigenous communities, there was no research interest in this species until quite recently, and this was largely motivated by problems encountered in regions of high density where shellfish are also exploited, in particular the introduced Pacific oyster *Crassostrea gigas*. Multiple ecosystem impacts have since been documented: sediment transformation (Ehrhold et al. 1998), macrozoobenthos modifications (de Montaudouin et al. 1999, Le Pape et al. 2004) and changes in food web structure (Chauvaud et al. 2000).

Concerns over the impact of slipper limpets on oyster production were reinforced by observations of simultaneous larval presence and juvenile recruitment (Cole & Hancock 1956), oyster larvae consumption (Korringa 1951), feeding mode and qualitative analyses of stomach contents (Orton 1912). More recent studies (e.g. de Montaudouin et al. 1999, Riera et al. 2002) raised the possibility that a partial overlap of trophic niches exists, and stressed the importance of taking into account the specific trophic dynamics of each ecosystem occupied by both *Crepidula fornicata* and *Crassostrea gigas*. Furthermore, although both suspension-feeders were found to have equivalent biomass and the same filtration impact in Bourgneuf Bay, France (Barillé et al. 2006), it is necessary to determine the particle types consumed by each species in order to estimate the eventual degree of trophic competition.

Apart from early qualitative studies (Orton 1912), the diets of sympatric cultivated oysters and slipper limpets are largely unknown. Currently, multiple natural stable isotope analyses are widely used in food web studies, notably to determine the food sources of suspension-feeders (e.g. Kang et al. 1999, Page & Lastra 2003), which are exposed to seasonal variations in food availability. Such an approach was successfully used to compare the nutritional resources of *Crepidula fornicata* and *Crassostrea gigas* in a Northern European coastal ecosystem (Riera et al. 2002).

Here we present a stable isotope study that determined the sources of carbon and nitrogen assimilated by *Crepidula fornicata* and *Crassostrea gigas* on 3 seasonal sampling dates in a high-turbidity oyster-farming site, which is characterized by decreasing yields concomitant with slipper limpet proliferation (Barillé-Boyer et al. 1997). The site chosen was Bourgneuf Bay, a mid-latitudinal point in the European distribution of these species.

MATERIALS AND METHODS

Study area. The 34 000 ha of Bourgneuf Bay, located south of the Loire Estuary on the French Atlantic coast (Fig. 1), is comprised of 10 000 ha of intertidal area (mean tidal range: 4 m). The large northern opening into the Atlantic Ocean allows considerable mixing of bay and oceanic waters, whereas the southern narrows restricts water exchange. Similarly, the deeper (mean: 10 m) northern part of the bay is strongly influenced by W and SW winds, swells and gyratory currents. These hydrodynamic characteristics transport resuspended sediment from mudflats, resulting in particularly high turbidity in the northern reaches of the Bay (annual mean: 150 mg l^{-1}; Barillé-Boyer et al. 1997). The bay is also variably affected by the Loire estuary, depending on discharge rates and prevailing winds.

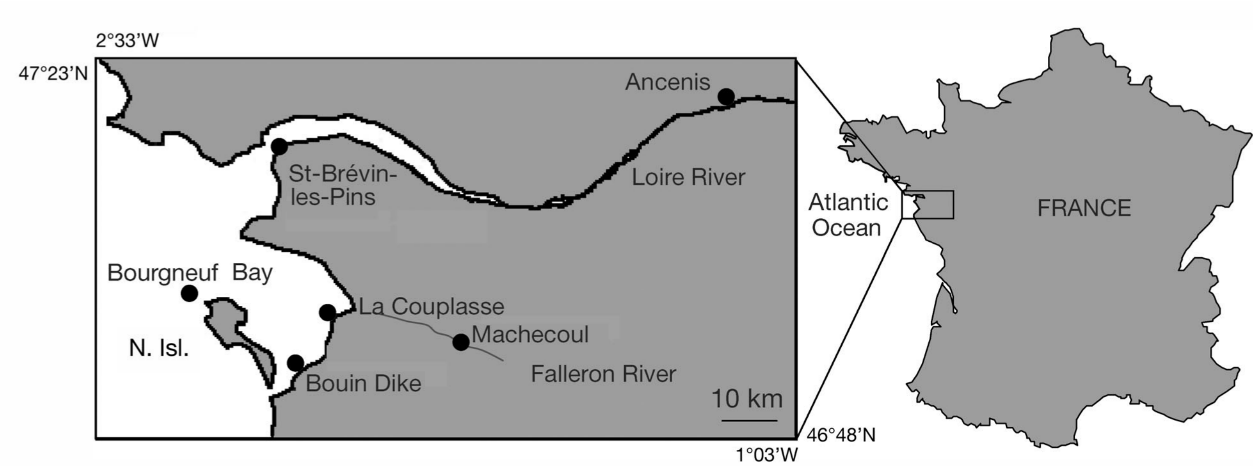


Fig. 1. Location of sampling sites (●) in Bourgneuf Bay, Loire Estuary and River. N. Isl.: Noirmoutier Island

The sampling site for oysters and slipper limpets was an oyster farm at La Couplasse (Fig. 1), where a high biomass of slipper limpets *Crepidula fornicata* (L. Barillé pers. comm.) is located directly adjacent to cultured oyster *Crassostrea gigas* stocks. This area is characterized by high residence times, which increase the influence of freshwater input from the Falleron River (Barillé-Boyer et al. 1997), and by an important diatom-dominated microphytobenthos proliferation on mudflats, which covers 19 to 25% of the surface (Méléder et al. 2003).

Sampling plan. Five Pacific oysters (mean shell length ± SD: 9.7 ± 1.4 cm) and 5 slipper limpets (mean linear shell length ± SD: 3.2 ± 0.5 cm) were collected at low spring tide at La Couplasse in March, July and November 2003. All possible sources of organic matter available to suspension-feeders at this site were collected concomitantly: freshwater, brackish water, oceanic microplankton, microphytobenthos, macroalgal and higher plant detritus.

Sub-surface oceanic water samples were taken during sampling cruises off Noirmoutier Island. Brackish water was collected at the Bouin seawall and from the Loire estuary at St-Brévin-les-Pins. Freshwater was sampled upriver from the Loire estuary at Ancenis, and from the Falleron River at Machecoul (Fig. 1); 20 l of each water sample were collected in plastic containers.

Microphytobenthos was sampled at La Couplasse. The upper 5 mm of a 1 m^2 mudflat area with dense brown microphytobenthic covering was collected with a spatula. Macroalgal thalli and marine angiosperm leaves were collected at La Couplasse and Bouin, and terrestrial angiosperm leaves at Ancenis and Machecoul (Fig. 1). The selected plant species were common at the different sampling sites: *Enteromorpha* sp., *Fucus serratus* and *Fucus vesiculosus* represented macroalgae; *Halimione portulacoides*, *Salicornia* sp. and *Spartina* sp. represented marine angiosperms; and *Alnus* sp., *Populus* sp. and *Robinia pseudoacacia* represented terrestrial angiosperms. As *Alnus* sp. and *Populus* sp. leaves were not present on the March sampling date, data for these potential food sources were limited to June and November.

Sample preparation. Sampled individuals were cleaned of epibionts in the laboratory and gut contents were purged in 0.2 µm filtered seawater from the sampling site for 12 to 24 h. The individuals were killed by freezing, and then soft tissues were separated from the shells, bathed for 1 to 2 min in 1 M HCl in order to eliminate trace shell carbonates, rinsed in Milli-Q ultrapure water and then homogenized with an Ultra-Turrax blender. Samples were stored at –80°C, freeze-dried, and reduced to a powder with a mortar and pestle prior to analysis.

Triplicate water samples were vacuum-filtered onto 47 mm or 25 mm GF/F pre-combusted (500°C, 4 h) filters until clogged. The retentate was acidified with several drops of 1 M HCl in order to remove carbonates, rinsed with ultrapure water, and stored at –80°C prior to freeze-drying.

Benthic microalgae, mainly motile diatoms, were extracted as per Riera & Richard (1996). The sediment sample was spread onto a tray to a thickness of about 1 cm, covered with a 63 µm mesh nylon net, and then with a thin layer of pre-combusted (500°C, 4 h) fine (150 to 300 µm) silicious sand. The size of the mesh was chosen to include all migrating pennate forms, whose widths are smaller than the mesh size. The tray contents were regularly wetted with vaporized (0.2 µm-filtered) seawater from the sample site and illuminated until the following diurnal tide, because benthic diatoms maintain an endogenous rhythm (Mitbavkar & Anil 2004). After migration of the diatoms to the sand layer, visible as a brownish coloration, the superficial layer was then carefully removed with a spatula, placed in a 63 µm mesh screen and rinsed with filtered seawater. The resulting liquid was then processed as above for water samples.

When present, epibionts were discarded from plant samples, which were then acidified and treated as above for mollusks.

Stable isotope and % organic C and N. Duplicate powdered samples or pieces of filter were sealed in ultraclean tin capsules and analyzed for nitrogen and carbon content (% dry weight) and composition ($\delta^{13}C$ and $\delta^{15}N$) using a Carlo-Erba NA 2100 elemental analyzer coupled (via a Thermo Finnigan CONFLO II interface) with a Thermo Finnigan Delta S mass spectrometer. Carbon and nitrogen isotope compositions were expressed in standard delta notations (‰ deviations from a reference): $\delta X = [(R_{sample} \times R_{reference}^{-1}) - 1] \times 10^3$, where X is either ^{13}C or ^{15}N and R is the corresponding ^{13}C:^{12}C or ^{15}N:^{14}N ratio. Results were referred to Vienna Pee Dee Belemnite for carbon and to atmospheric N_2 for nitrogen. A regularly calibrated working reference (glutamic acid) was run every 11 samples. The SD of 200 $\delta^{13}C$ and $\delta^{15}N$ working reference measurements was 0.2 and 0.4‰ respectively. Isotope readings were validated when the difference between duplicate capsules of the same sample was less than 0.4 and 0.5‰ for carbon and nitrogen deviations respectively; otherwise, samples were analyzed a second time.

As described above, microphytobenthos and marine particulate organic matter (POM) were obtained by GF/F filtration. Insufficient material was collected to allow removal from filters without including glass fibers. Consequently, it was not possible to calculate the carbon and nitrogen content of the masses sealed in capsules; we therefore calculated mean C:N ratios and assigned %C and %N content according to data from fiber-free samples available in the literature (Abed-Navandi & Dworschak 2005).

Statistics. R freeware (R Development Core Team 2005) was used for all statistical computing. Data normality was verified using the Shapiro-Wilks test, and heteroscedasticity checked with either an *F*-test (2 samples) or a Bartlett's test (>2 samples) before choosing parametric or non-parametric statistical analysis.

For each source, isotope composition according to sampling date was analysed with a 1-way parametric or non-parametric (Kruskal-Wallis) ANOVA as appropriate. As data for *Alnus* sp. and *Populus* sp. were only available from the June and November samples, their carbon and nitrogen isotope deviations were tested using a Welch 2-sample *t*-test or Wilcoxon rank sum test, as appropriate. Two-way ANOVAs, followed by Tukey's honestly significant difference (HSD) test, were performed to compare oyster and slipper limpet isotope compositions, with sampling dates and species as factors.

Dietary analysis. A certain amount of debate has been generated concerning the enrichment factors to be used in diet calculations (e.g. Gannes et al. 1997, Post 2002). The most widely-used values, specifically recommended since the inception of the stable isotope technique, are 1 and 3.4‰ for carbon and nitrogen deviations respectively (DeNiro & Epstein 1978, Post 2002). These enrichment factors have recently been corroborated for bivalve soft tissues (Yokoyama et al. 2005). Alternate values of 0.5 and 2‰ were proposed (McCutchan et al. 2003), and we also completed our calculations using these values; however, as this did not affect our main results or conclusions, the more widely-accepted values of 1 and 3.4‰ were maintained in the present study.

After determination of the food sources implicated in *Crepidula fornicata* and *Crassostrea gigas* diets (see 'Results'), isotopic values were combined *a priori* to characterize source types according to functional considerations, e.g. the C_3 saltmarsh angiosperm group. The squared nearest neighbor distances (NND^2) (Lubetkin & Simenstad 2004) were then calculated to determine whether the isotopic deviations of these source types were distinct or required pooling. The number of source types (> n isotopes + 1) precluded the use of linear mixing models, and hence calculation of the exact proportional contributions of each end-member. We therefore used IsoSource 1.2 software (Phillips & Gregg 2003) to estimate the ranges of biomass contributions of each end-member to the oyster and slipper limpet diets. We also wrote a Scilab 3.1.1 program (INRIA, ENPC) to estimate elemental concentration-weighted biomasses (Newsome et al. 2004). These models determined all feasible end-member combinations by successively incrementing each source proportion by 1% from 0 to 100%. A combination was considered feasible if the calculated mixture composition was equal to the measured composition or within a mass balance tolerance of 0.2‰. This tolerance greatly exceeded the recommended minimum (0.5 × source increment × maximum difference between sources, i.e. 0.09‰ for our data; Phillips & Gregg 2003), given the observed sample variability.

The range of feasible solutions was used in all subsequent representations (frequency distributions and bivariate graph matrices) of feasible dietary contributions. However, means were used in calculations of trophic niche parameters, because single values are required and it was not possible to associate oyster and slipper limpet combinations. Niche breadths of *Crassostrea gigas* and *Crepidula fornicata* were compared using Levins' standardized measure (Krebs 1999)

$$B_A = \frac{B-1}{n-1} \qquad B = \frac{1}{\sum_{1}^{n} p_j^2} \tag{1}$$

where B_A is Levins' standardized niche breadth, B is Levins' measure of niche breadth, n is the number of possible source types and p_j is the fraction of food category j in the diet (mean of IsoSource simulations).

Niche overlap (Krebs 1999) between *Crassostrea gigas* and *Crepidula fornicata* was determined as Pianka's measure

$$O_{jk} = \frac{\sum_{i}^{n} p_{ij} p_{ik}}{\sqrt{\sum_{i}^{n} p_{ij}^2 \sum_{i}^{n} p_{ik}^2}} \tag{2}$$

where O_{jk} is Pianka's measure of niche overlap between species j and k, and p_{ij} and p_{ik} are the proportions of food source i (mean of IsoSource simulations) of the total sources used by species j and k.

RESULTS

Source $\delta^{13}C$ and $\delta^{15}N$

Mean isotopic deviations of the source samples and results of statistical tests among dates are presented in Tables 1 & 2 respectively. The $\delta^{13}C$ deviations of river freshwater POM of the Loire and Falleron were similar at approx. –30‰, which is characteristic of terrestrial inputs. Estuarine POM carbon isotope values (approx. −25‰) were intermediate between freshwater POM and open sea phytoplankton (approx. −22‰). The bay POM $\delta^{13}C$ was clearly marine, with values close to −23‰. The most depleted carbon deviations of POM were encountered in March 2003, and the most-enriched in November (in most cases). Although the origin of this trend is not clear, similar results were reported by Sará et al. (2003), one of the few marine studies dealing with seasonal changes.

Alnus sp., *Fraxinus* sp., *Populus* sp. and *Robinia pseudoacacia* displayed carbon deviations between −26 and −29‰, typical of terrestrial C_3 angiosperms. *Spartina* sp. presented characteristic C_4 $\delta^{13}C$ values (approx. −14‰), which were ^{13}C-enriched relative to the two C_3 marsh angiosperms, *Salicornia* sp. and *Halimione portulacoides* that presented carbon isotope deviations of about −26‰. Macroalgae also exhibited typical carbon values (approx. −16‰). In marine angiosperms and macroalgae, the most ^{13}C-enriched compositions were measured in March 2003, especially for *Enteromorpha* sp., which presented an extremely high $\delta^{13}C$ value (−6.4‰). The majority of $\delta^{13}C$ values, as well as $\delta^{15}N$ (7 to 11‰), were within the ranges measured in the same species elsewhere, e.g. in France and in the Netherlands (Riera et al. 1996, 2002).

Saltmarsh plant (genera *Halimione*, *Salicornia* and *Spartina*) nitrogen deviations (8.3 to 10.8‰ and one outlier of 17.3‰; Table 1) were relatively ^{15}N-enriched compared with previous studies conducted in France or elsewhere, with values of 3 to 9‰ (e.g. Currin et al. 1995, Créach et al. 1997). This could be related to the incorporation of ^{15}N-rich ammonium and nitrate either from anthropogenic inputs or more probably from nitrification or denitrification processes in marsh sediments (Wada & Hattori 1991).

Benthic diatom $\delta^{13}C$ and $\delta^{15}N$ values were within the ranges previously measured in Oosterschelde (The Netherlands) and in Marennes-Oléron Bay (France) (−14.5 to −11.3‰ and 4.6 to 6.6‰ respectively; Riera et al. 1996, 2002).

Table 1. Bourgneuf Bay: $\delta^{13}C$ and $\delta^{15}N$ (mean ‰ ± SD) of sampled sources; and (in **bold**) end-member input data (mean $\delta^{13}C$ and $\delta^{15}N$ [‰] and mean C and N [g 100 g dry matter^{-1}]) for mixing programs. –: not sampled, n: no. of samples analyzed

		March 2003					July 2003					November 2003				
		$\delta^{13}C$	$\delta^{15}N$	C	N	n	$\delta^{13}C$	$\delta^{15}N$	C	N	n	$\delta^{13}C$	$\delta^{15}N$	C	N	n
Microphytobenthic material																
	Benthic diatoms	**−13.1** ± 0.2	**5.3** ± 0.2	**5.0**	**0.9**	3	**−13.8** ± 0.1	**4.6** ± 0.8	**5.0**	**0.9**	3	**−11.9** ± 0.1	**5.9** ± 0.2	**5.0**	**0.9**	3
Particulate organic matter																
	Falleron (freshwater)	−30.4 ± 0.3	4.0 ± 0.9			3	−30.4 ± 0.6	1.7 ± 1.6			4	−28.1 ± 0.2	3.7 ± 0.6			4
	Loire (freshwater)	−30.7 ± 0.0	2.4 ± 0.3			3	−30.8 ± 0.1	6.5 ± 0.4			3	−28.8 ± 0.4	6.3 ± 0.8			4
	Loire (estuarine)	−26.0 ± 0.0	1.5 ± 1.2			3	−24.7 ± 0.5	2.4 ± 1.5			3	−24.8 ± 0.3	2.2 ± 1.2			4
	Bay (brackish)	−23.3 ± 0.3	−0.7 ± 1.1			3	−22.8 ± 0.3	2.6 ± 0.6			3	−22.3 ± 0.7	3.8 ± 0.2			4
	Marine (open sea)	**−22.9** ± 0.2	**1.7** ± 1.7	**18.0**	**2.5**	3	**−21.4** ± 0.4	**4.0** ± 1.7	**18.0**	**2.5**	3	**−22.0** ± 0.2	**4.2** ± 0.9	**18.0**	**2.5**	4
Macroalgae and C_4 marine angiosperms		**−14.7**	**8.5**	**36.6**	**1.9**		**−15.3**	**8.1**	**34.4**	**1.8**		**−16.0**	**8.5**	**38.1**	**2.5**	
Macroalgae	*Fucus serratus*	−13.7 ± 0.1	8.4 ± 1.6			4	−14.2 ± 0.1	7.0 ± 1.3			4	−17.3 ± 0.1	7.6 ± 1.0			4
	Fucus vesiculosus	−16.7 ± 0.3	8.1 ± 0.5			4	−18.0 ± 0.5	7.0 ± 1.7			4	−17.0 ± 0.2	10.2 ± 0.9			4
	Enteromorpha sp.	−6.4 ± 0.2	8.3 ± 0.9			4	−14.9 ± 0.2	10.8 ± 1.4			4	−15.5 ± 0.2	7.8 ± 0.8			4
C_4 angiosperms	*Spartina* sp.	−13.7 ± 0.0	9.1 ± 1.2			4	−14.1 ± 0.1	8.6 ± 0.8			4	−14.2 ± 0.2	8.3 ± 0.4			4
C_3 marine angiosperms		**−25.9**	**9.2**	**33.0**	**2.2**		**−26.9**	**9.4**	**28.9**	**2.1**		**−26.4**	**13.1**	**32.4**	**1.8**	
	Halimione portulacoides	−24.8 ± 0.2	9.2 ± 1.0			4	−25.9 ± 0.1	10.8 ± 0.8			4	−25.5 ± 0.3	17.3 ± 2.0			4
	Salicornia sp.	−26.5 ± 0.3	9.2 ± 1.4			8	−27.4 ± 0.1	8.7 ± 1.1			8	−26.9 ± 0.4	10.8 ± 2.1			8
Terrestrial angiosperms																
	Alnus sp.	–	–				−26.1 ± 0.2	−2.3 ± 1.7			4	−28.3 ± 0.2	−1.3 ± 0.5			4
	Fraxinus sp.	–	–				−28.7 ± 1.1	7.9 ± 1.9			8	–	–			
	Populus sp.	–	–				−27.8 ± 0.1	2.0 ± 1.2			4	−28.7 ± 0.4	0.5 ± 1.2			4
	Robinia pseudoacacia	–	–				–	–				−29.1 ± 0.2	2.1 ± 0.3			4

Table 2. Statistical tests of differences in $\delta^{13}C$ and $\delta^{15}N$ values of sampled sources among months. For 2-way ANOVAs, degrees of freedom (df) between and within groups (= error or residual) are indicated by the first and second number respectively. Test statistics are values of *F*, χ^2, *W* and *t* for ANOVAs, Kruskal-Wallis ANOVAs (KW), Wilcoxon tests (W) and *t*-tests respectively. MS: mean squares. *: p ≤ 0.05, **: p ≤ 0.01, ***: p ≤ 0.001, ns: not significant

	$\delta^{13}C$						$\delta^{15}N$					
	Test	df	MS	Test statistic	p		Test	df	MS	Test statistic	p	
Benthic diatoms	ANOVA	2, 6	2.823, 0.017	161.130	6×10^{-6}	***	ANOVA	2, 6	1.246, 0.244	5.112	0.051	ns
Falleron (freshwater)	KW	2		7.053	0.029	*	ANOVA	2, 8	6.018, 1.304	4.614	0.046	*
Loire (freshwater)	KW	2		6.564	0.038	*	KW	2		5.982	0.050	ns
Loire (estuarine)	ANOVA	2, 7	1.514, 0.093	16.230	0.002	**	ANOVA	2, 6	0.758, 1.677	0.452	0.656	ns
Bay (brackish)	ANOVA	2, 7	0.811, 0.246	3.291	0.098	ns	ANOVA	2, 7	18.187, 0.467	38.945	2×10^{-4}	***
Marine (open sea)	ANOVA	2, 7	1.686, 0.065	26.087	6×10^{-4}	***	ANOVA	2, 7	6.433, 2.100	3.064	0.111	ns
Fucus serratus	KW	2		9.846	0.007	**	ANOVA	2, 9	1.914, 1.742	1.099	0.374	ns
Fucus vesiculosus	ANOVA	2, 9	1.669, 0.136	12.240	0.003	**	ANOVA	2, 9	10.473, 1.316	7.959	0.010	*
Enteromorpha sp.	KW	2		9.846	0.007	**	ANOVA	2, 8	8.377, 1.100	7.618	0.014	*
Spartina sp.	KW	2		7.538	0.023	*	ANOVA	2, 8	0.656, 0.733	0.895	0.446	ns
Halimione portulacoides	ANOVA	2, 9	1.270, 0.049	25.954	2×10^{-4}	***	ANOVA	2, 8	68.332, 1.902	35.923	1×10^{-4}	***
Salicornia sp.	KW	2		17.165	2×10^{-4}	***	ANOVA	2, 20	8.706, 2.420	3.597	0.046	*
Alnus sp.	W			16.000	0.029	*	W			2	0.400	ns
Populus sp.	W			16.000	0.029	*	*t*-test	5		1.688	0.159	ns

Stable isotope deviations of oysters and slipper limpets

Compared with the only previously recorded values of *Crepidula fornicata* (Riera et al. 2002), our results (Figs. 2 & 7) are depleted in both carbon and nitrogen heavy isotopes by about 1‰. However, the deviations measured in the present study for *Crassostrea gigas* are within the ranges previously reported in the more extensive literature for this species (e.g. Riera 1998, Hsieh et al. 2000).

Two-way ANOVAs revealed significant differences between species for carbon and nitrogen deviations (df = 1, $F = 22.93$, $p \leq 0.001$ and $F = 6.872$, $p = 0.015$ respectively). Significant ^{13}C-enrichment in slipper limpets (approx. 0.9‰) relative to values of oysters was observed in March and July 2003 (Tukey's HSD: p = 0.007 and p = 0.002 respectively). Nitrogen deviations of oysters were significantly higher (approx. 1.1‰) than those of slipper limpets in March 2003 (Tukey's HSD: p < 0.001). No significant differences were observed in November samples (Tukey's HSD: p = 0.101 for $\delta^{13}C$; p = 0.552 for $\delta^{15}N$).

Although carbon deviations of *Crepidula fornicata* tissues did not differ significantly among the 3 sampling dates (2-way ANOVA: df = 2, $F = 2.829$, p = 0.079; Tukey's HSD: p > 0.05), the nitrogen deviations were significantly different (2-way ANOVA: df = 2, $F = 37.904$, $p \leq 0.001$), with a ^{15}N depletion of approx. 0.8‰ in November compared with March (Tukey's HSD: p = 0.021). The $\delta^{15}N$ values of oysters sampled in March were also significantly higher relative to July and November (approx. 2 and 1.7‰ respectively; 2-way ANOVA: df = 2, $F = 37.904$, $p \leq 0.001$; Tukey's HSD: p < 0.001). There was no significant difference in carbon deviations of *Crassostrea gigas* among the 3 sampling dates (2-way ANOVA: df = 2, $F = 2.829$, p = 0.079; Tukey's HSD: p > 0.05).

Determination of *Crepidula fornicata* and *Crassostrea gigas* food sources

Dual plot graphs of $\delta^{15}N$ versus $\delta^{13}C$ (Fig. 2) allowed us to determine the food sources of *Crassostrea gigas* and *Crepidula fornicata*. On the 3 sampling dates, calculated diets had values of –19.5 to –18.3‰ carbon and 5.4 to 7.4‰ nitrogen.

Nearshore POM is a complex mixture of marine phytoplankton, plant organic detritus and various other components (Heip et al. 1995); owing to the heterogeneous nature of such POM, it was thus not possible to include Bourgneuf Bay POM as a dietary component. However, since the bay isotopic composition was clearly not influenced by the continental Loire and Falleron discharges (in contrast to estuarine POM), we could exclude freshwater seston and terrestrial plants from the diets.

The isotopic values of the various source diet components assimilated by oysters and slipper limpets in Bourgneuf Bay (i.e. sources within polygons, Fig. 2) were pooled according to ecological categories: C_3 saltmarsh angiosperms (*Salicornia* sp. and *Halimione portulacoides*), C_4 shore angiosperms (*Spartina* sp.), macroalgae (*Fucus serratus*, *Fucus vesiculosus* and/or *Enteromorpha* sp.), marine POM and benthic diatoms.

The $\delta^{13}C$ values indicated a dominance of the latter 4 sources. However, the macroalgae and C_4 angiosperms were not isotopically distinct, because the total NND^2 of their carbon and nitrogen isotope values was less than 0.1. Hence, 4 end-members (Table 1) were used in diet contribution estimations: macroalgae and C_4 angiosperms, C_3 angiosperms, marine POM and benthic diatoms. They presented distinct ($NND^2 > 0.1$) and significantly different (Kruskal-Wallis: $p < 0.001$) isotopic compositions.

End-member elemental content and dietary contributions

End-members implicated in both diets differed in elemental content (Table 1). The plant sources of the present study were typically low in N. Benthic diatoms and phytoplankton exhibited the lowest C:N ratios (5.6 and 7.2 respectively), whereas the highest ratios were observed in macroalgae-C_4 angiosperms (15.2 to 19.4). The C:N ratios of benthic diatoms and phytoplankton were similar to the published values of diatom mats and plankton (Abed-Navandi & Dworschak 2005) on which we based our calculation of carbon and nitrogen content (see 'Materials and methods').

The IsoSource program assumes similar carbon and nitrogen concentrations and equal digestibility of each end-member (Newsome et al. 2004). Because we were interested in elucidating ecological relationships (food proportions ingested), 2 potential error sources were evident in our dietary contribution estimations: the different proportions of C and N in microalgae and plant detritus, and the potential differential assimilation of these sources (which contain different amounts of refractory carbon). However, combined use of IsoSource and of the elemental concentration-dependent model allowed us to estimate the extreme feasible contributions of end-members according to 2 alternate scenarios.

(1) The elemental assimilation efficiencies of both *Crepidula fornicata* and *Crassostrea gigas* were similar for microalgae and plant detritus; hence, it was necessary to distinguish between the C and N content of these sources. The biomasses ingested from the 4 end-members were therefore estimated by the elemental concentration-dependent model.

(2) The elemental assimilation efficiencies of both species were lower for plant detritus than for microalgae (as might occur if putatively high plant refractory carbon was poorly-assimilated). Even if the C and N content of these sources differed, similar C and N concentrations could be assimilated. The biomasses ingested from the 4 end-members were therefore estimated using the IsoSource model.

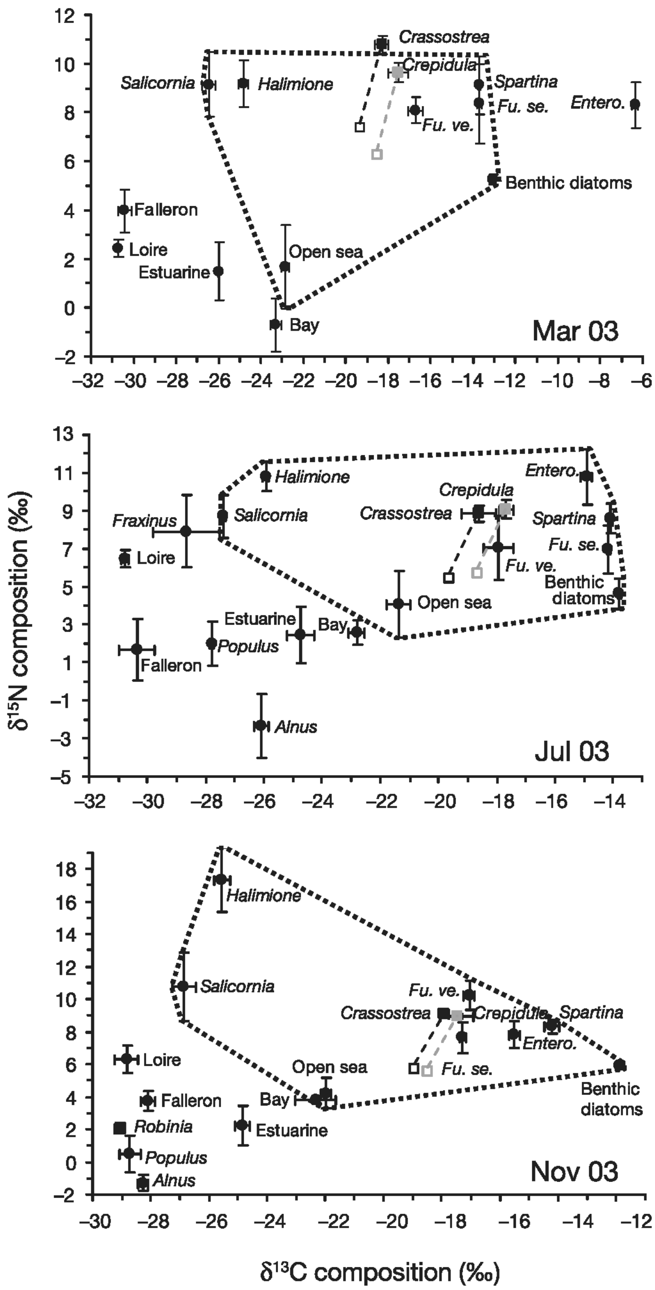


Fig. 2. Dual $\delta^{13}C$ and $\delta^{15}N$ isotopic compositions (mean ‰ ± SD) of 2 suspension-feeders (■,■) and food sources (●) in March, July and November 2003; $\delta^{13}C$ and $\delta^{15}N$ values of calculated diets (□,□) of *Crepidula fornicata* (grey) and *Crassostrea gigas* (black) were determined by subtracting trophic enrichments (dashed lines) of 1 and 3.4‰, respectively, from $\delta^{13}C$ and $\delta^{15}N$ values of both species. Dotted polygons delimit sources implicated in the dietary mixture; these sources are pooled to constitute 4 end-members in subsequent analyses. *Entero.*: *Enteromorpha* sp.; *Fu. se.*: *Fucus serratus*; *Fu. ve.*: *Fucus vesiculosus*. POM samples are: Falleron, Loire (freshwater), estuarine, bay (brackish) and open sea. *Enteromorpha* sp. was discarded from the mixing polygon in March 2003 owing to extreme carbon deviation, which disagreed with other macroalgae and with values from the other 2 sampling events and from previous studies

IsoSource mixing model

For each end-member on each sampling date, IsoSource provided distributions of feasible contribution ranges to the 2 consumer diets (Fig. 3). The distributions were quite dispersed and included zero contributions in most cases. Nevertheless, dietary proportions differed among sampling dates. The greatest ranges of feasible end-member contributions were observed in March 2003, whereas the smallest ranges were found in November 2003, especially for marine POM and C_3 angiosperms. Both suspension-feeders consumed more phytoplankton in November than in March (50 to 61% vs. 0 to 36%). At the same time, *Crassostrea gigas* and *Crepidula fornicata* ingested lower macrophyte proportions (0 to 37% vs. 0 to 59%, and 0 to 12% vs. 6 to 50%, respectively, for macroalgae-C_4 angiosperms and C_3 angiosperms). Thus, phytoplankton contributed 52 to 61% to the diet of oysters and 50 to 59% to the diet of slipper limpets in November, whereas 0 to 22% and 7 to 36% were assimilated by the 2 species, respectively, in March 2003. C_3 angiosperms represented 0 to 12% of the diet of oysters and 0 to 10% of the diet of slipper limpets in November, compared with 24 to 50% and 7 to 37% in March. In July, intermediate ranges were observed for both species. The significant difference in isotope compositions between *C. gigas* and *C. fornicata* in March and July thus appeared to be a result of differential utilization of macrophytes and phytoplankton. The major food source of both species was microalgae (marine phytoplankton and microphytobenthos) in July and November 2003 (but to a lesser extent for slipper limpets in July).

In contrast to the depiction provided in Fig. 3, bivariate graph matrices (Phillips & Gregg 2003; see Fig. 5) allowed us to examine all feasible end-member contribution combinations. As the contributions summed to 100%, the contribution of 1 trophic source constrains the possible contributions of other sources. Approximately 92% of feasible sets of solutions implicated 4 sources in all simulations, i.e. the trophic niches of both species overlapped for 4 food resources. In March, only 16 and 15% of feasible combinations made identical contributions to both species' diets: benthic diatoms and macroalgae-C_4 angiosperms, and marine POM and C_3 angiosperms respectively. In November, higher overlaps were observed: up to 40% of feasible combinations contributed equally to slipper limpet and oyster diets. However, no combination showed more than 2 identical percent contributions between diets of either species.

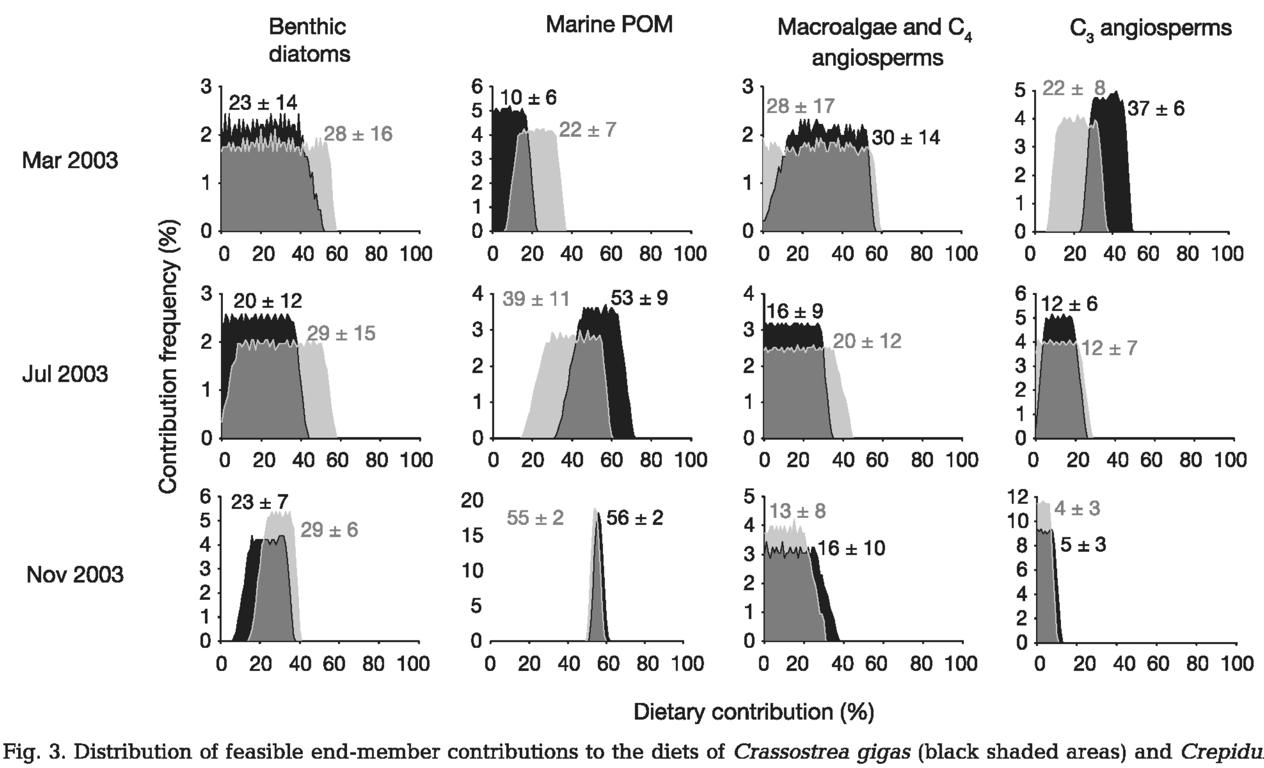


Fig. 3. Distribution of feasible end-member contributions to the diets of *Crassostrea gigas* (black shaded areas) and *Crepidula fornicata* (light grey shaded areas) calculated using IsoSource. Mid-grey shading represents overlapping areas. Mean (% ± SD) contributions are indicated

Elemental concentration-dependent program

The concentration-dependent model (Figs. 4 & 5) gave larger ranges of feasible microalgae contributions and smaller ranges of C_3 angiosperm contributions to *Crepidula fornicata* and *Crassostrea gigas* diets. The tissue production of these 2 species may thus derive more from benthic diatoms than was estimated by the IsoSource program. C_3 angiosperms contributed 20 to 36% and 10 to 22% to the diet of oysters and slipper limpets, respectively, in March 2003; *Crepidula fornicata* appeared to derive its biomass mainly from microalgae, whereas *Crassostrea gigas* depended more on macrophytes.

Feasible combinations (Fig. 5) of oyster and slipper limpet diets were more similar in March and July than estimated by IsoSource. However, as noted above for the IsoSource estimations, the concentration-dependent model did not estimate more than 2 identical percent contributions in dietary combinations to either species. Four sources also contributed up to 90% to feasible sets of dietary solutions, i.e. the trophic niches of both species overlapped for all 4 sources using this concentration-dependent program, as was observed using IsoSource.

Characteristics of trophic niches

Using results from IsoSource, Levins' standardized niche breadth of *Crepidula fornicata* was wider than that of *Crassostrea gigas* in March and July 2003. Calculated slipper limpet niche breadth varied from 0.50 to 0.98, whereas that of oysters varied between 0.51 and 0.81. From March 2003 onwards, the 2 mollusks displayed a progressive reduction in niche breadth, attaining the same minimal value in November (~0.5). Over the same period, Pianka's measure exhibited a progressively increasing niche overlap, from 92 to 99% (Fig. 6). The niche breadths of *Crepidula fornicata* and *Crassostrea gigas* calculated from the concentration-dependent model were more similar, showing the same reduction from March to November. Niche overlap was also slightly greater in July and November.

DISCUSSION

Food sources of *Crassostrea gigas* and *Crepidula fornicata*

The food supply available to suspension-feeders in mudflat ecosystems such as Bourgneuf Bay is conven-

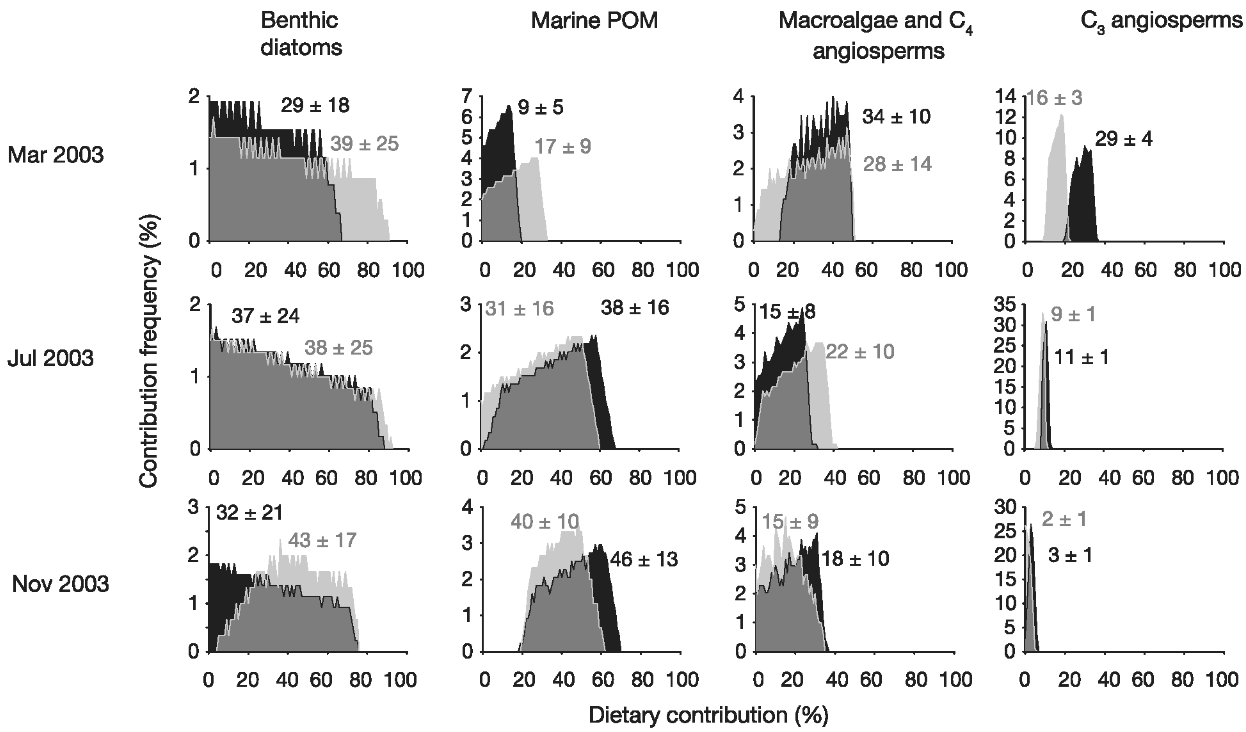
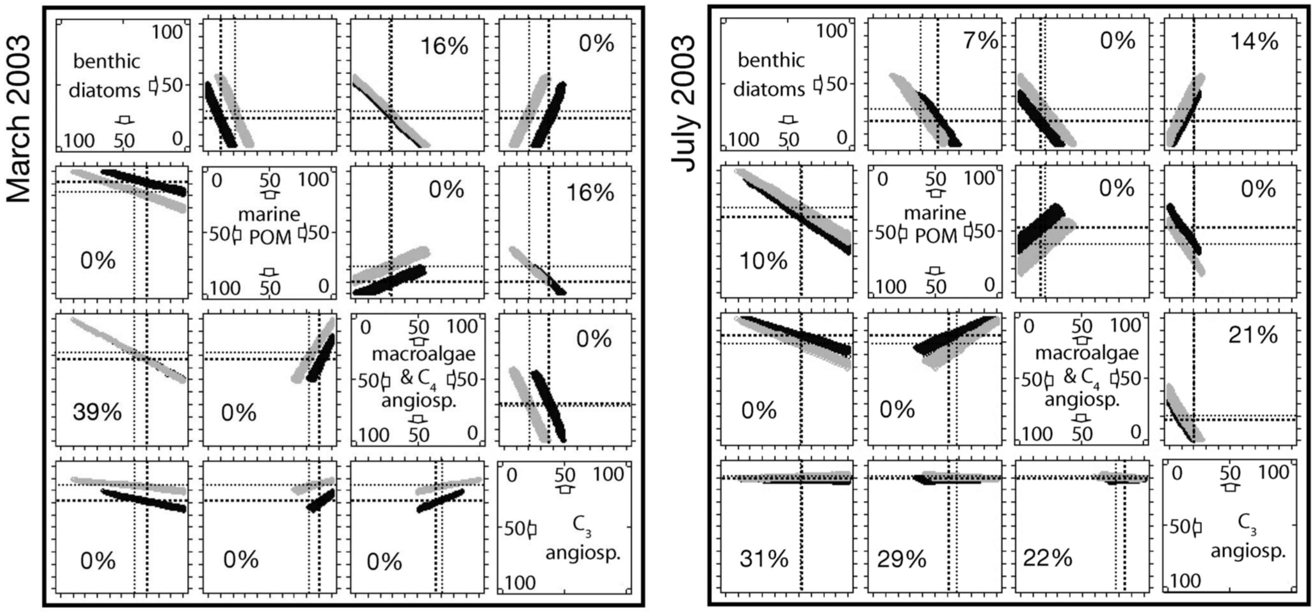


Fig. 4. Distribution of feasible end-member contributions to the diets of *Crassostrea gigas* (black shaded areas) and *Crepidula fornicata* (light grey shaded areas) satisfying concentration-dependent conditions. Mid-grey shading represents overlapping areas. Mean (% ± SD) contributions are indicated



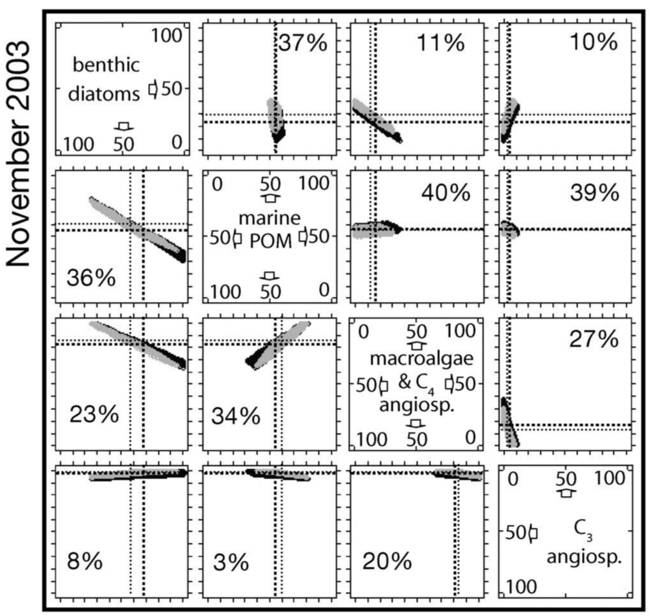


Fig. 5. Bivariate graph matrices showing contributions (%) of 4 end-members for all feasible dietary combinations in March, July and November 2003. Black shading indicates contributions to diets of *Crassostrea gigas* and grey shading indicates contributions to *Crepidula fornicata*; where they intersect, grey surfaces are superimposed on black surfaces. Graphs above the diagonal separation show IsoSource results, whereas those below the diagonal panels show feasible combinations calculated from the concentration-dependent model. Thick and fine dotted lines show contribution means for oysters and slipper limpets respectively; % of contributions common to both species' diets are given in each panel

tionally considered to be chiefly composed of benthic diatoms (Riera & Richard 1996, Leguerrier et al. 2003). However, our comparison of isotopic compositions of the potential food sources and tissues of *Crepidula fornicata* and *Crassostrea gigas* revealed that 4 primary production sources were predominantly assimilated: suspended POM (essentially phytoplankton; up to 70%), benthic diatoms (up to 90%), angiosperms and macroalgae (up to 60%). The relative contribution of each component differed according to sampling date (more markedly for oysters): macrophytes were more important in March 2003, and microalgae (phytoplankton and benthic diatoms) became more important in July and November.

Diets can also differ qualitatively despite a high degree of similarity in natural isotope deviations (e.g. Carman & Fry 2002). Slipper limpets and oysters may ingest different species or sizes of microalgae; indeed, the differential selective capability of these 2 species (Beninger et al. 2007, this volume) makes this highly probable. Complementary stomach content analyses would help to elucidate this particular aspect.

The $\delta^{13}C$ and $\delta^{15}N$ deviations of oysters from Bourgneuf Bay extended further beyond those of benthic diatom, especially in March, compared with oysters of the previously-studied Marennes-Oléron site (also on the French Atlantic coast) that presented a diet primarily based on microphytobenthos (Fig. 7; Riera & Richard 1996, Riera 1998). In addition, the difference between isotopic deviations of oysters or slipper limpets and benthic diatoms was greater in Bourgneuf Bay than in Oosterschelde (Fig. 7; Riera et al. 2002). Nonetheless, benthic diatoms feasibly contributed a substantial portion to the diets of *Crepidula fornicata*

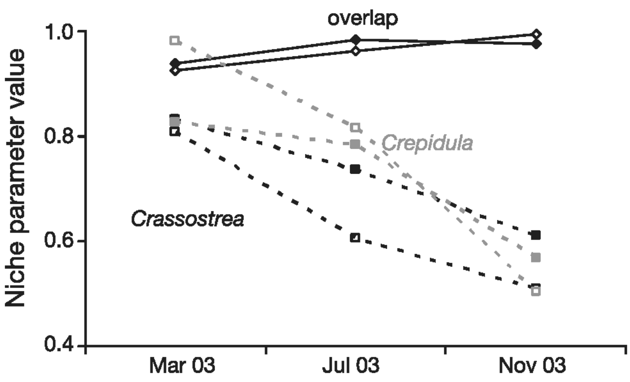


Fig. 6. Levins' standardized niche breadth (dashed lines) of *Crepidula fornicata* (grey) and *Crassostrea gigas* (black), and Pianka's measure of niche overlap between both species (continuous line); obtained from IsoSource (filled symbols) and concentration-dependent model (open symbols) simulations

and *Crassostrea gigas* on all 3 sampling occasions (Figs. 3 & 4). Microphytobenthos, which has an organic composition more readily assimilated than that of angiosperms, may be a major food source to secondary producers (e.g. Currin et al. 1995, Kang et al. 2003).

Phytoplankton was also an important component of the diets of both suspension-feeders. Concomitant grazing on resuspended microphytobenthos and phytoplankton is well documented for intertidal suspension-feeders (e.g. Kang et al. 1999, Rossi et al. 2004). Phytoplankton variability is thus a determinant of individual and population bivalve dynamics in the field (Grant 1996).

Stable isotope compositions of *Crassostrea gigas* and *Crepidula fornicata* in Bourgneuf Bay, together with mixing model analyses, indicated a generally high input by angiosperms and macroalgae. Suspended, variably degraded plant detritus has been shown to be a major trophic substrate for coastal secondary producers, including suspension-feeders, in American saltmarsh food webs (e.g. Currin et al. 1995, Deegan & Garritt 1997). Our *Crepidula fornicata* and *Crassostrea gigas* sampling site, La Couplasse, is close to a total of 9.34 ha of saltmarsh composed of *Halimione portulacoides*, *Salicornia* sp. and *Spartina* sp., and is adjacent to 234.8 ha of macroalgal cover. In addition, infralittoral seaweed beds of unknown extent exist at the entry to the bay (Y. Gruet, Université de Nantes, pers. comm.). Relatively long residence times in Bourgneuf Bay (approx. 2 mo) facilitates physico-chemical and biological modification of detritus particles in the water column.

The estimations of end-member dietary contributions suggested that macroalgae and C_4 angiosperms contributed more than C_3 angiosperms to *Crepidula fornicata* and *Crassostrea gigas* diets, even though C_3 plants predominate in saltmarshes of the French Atlantic coast (European Natura 2000 code 1330; http://natura2000.environnement.gouv.fr/habitats/HAB1330.html). Suspension-feeders obtain maximum benefit from plant detritus in earlier stages of decomposition, before most of the nutrient and energy-rich compounds are used by microheterotrophs (Stuart 1982). Although trophic mediation through bacteria or

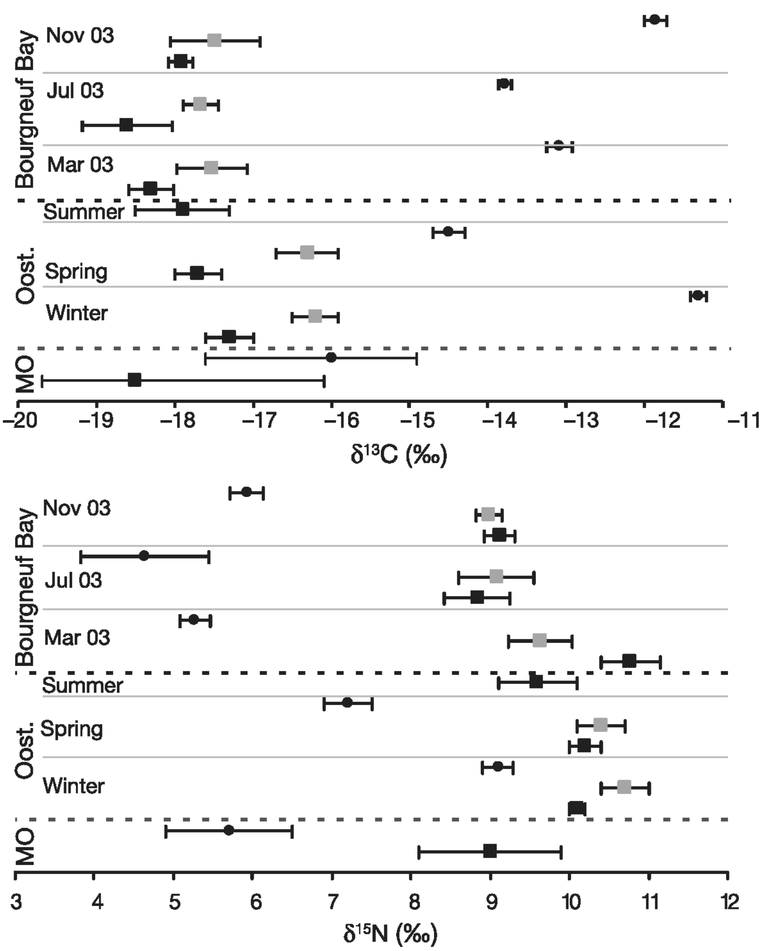


Fig. 7. Mean $\delta^{13}C$ and $\delta^{15}N$ of *Crassostrea gigas* (■), *Crepidula fornicata* (n) and benthic diatoms (●) measured in Bourgneuf Bay (France; present study), the Oosterschelde ('Oost.', The Netherlands; Riera et al. 2002) and Marennes-Oléron Bay ('MO', France; Riera & Richard 1996, Riera 1998). Error bars are either SD or ranges of mean $\delta^{13}C$ from MO. Dashed lines separate locations; grey solid lines separate seasons or months for which data was collected

microzooplankton is often necessary for the digestion of angiosperm tissues (Mann 1988, Langdon & Newell 1990, Riera 1998), no such mediation was observed in the suspension-feeders of the present study: $\delta^{15}N$ values indicated no corresponding trace of enrichment.

In contrast, macroalgal tissues contain relatively large amounts of nitrogen, protein and energy that is readily assimilated by primary consumers (Mann 1988, Bowen et al. 1995); these tissues also constitute a significant source of nutrient-rich detritus, used by suspension-feeders as sources of carbon and nitrogen throughout the year (Bustamante & Branch 1996). In the present study, an increased contribution by plant detritus was observed in March 2003 (i.e. winter assimilation), when microalgal production is minimal. It is thus possible that these suspension-feeders exploit the increased proportion of plant detritus in the winter period, as has been previously reported for other suspension-feeding bivalves (Lucas et al. 1987, Cranford & Grant 1990).

Direct assimilation of plant tissues by oysters and slipper limpets depends on the variety and nature of their digestive enzymes. The extracellular digestive enzymes of bivalves, including oysters, comprise especially cellulases, amylases and laminarinases (Brock et al. 1986). Oysters are thus capable of degrading the major organic components present in detritus (Newell & Langdon 1986). In particular, *Crassostrea virginica* assimilates significant amounts of saltmarsh angiosperm carbon (Newell & Langdon 1986, Langdon & Newell 1990).

Advantages of combined use of IsoSource and concentration-dependent models

Previous stable isotope studies of suspension-feeder diets either did not estimate relative contributions, or quantified source contributions using simple mixing equations in which no more than 2 sources were implicated (Riera et al. 1999, Page & Lastra 2003). We used IsoSource-type linear mixing models to statistically define the feasible relative contributions of end-members to the diets of these 2 suspension-feeders.

The assimilation of food sources was shown to vary according to mollusk species and source type (Tsikhon-Lukanina 1982). The diverse source types implicated in both *Crepidula fornicata* and *Crassostrea gigas* diets could present dissimilar digestible C and N fractions, in addition to different elemental content. Although abundant literature exists on the digestibility of food for humans or bears (Koch & Phillips 2002, Newsome et al. 2004), we are unaware of any such studies on microphage food quality values, and hence the digestibility of the various C and N fractions. Our results, obtained by combined use of IsoSource and concentration-dependent models, described most probable overlaps between the diets of *Crepidula fornicata* and *Crassostrea gigas* despite the lack of literature on digestibility of the different end-members. Based on the incorporation of C and N concentrations, results from the concentration-dependant model indicated a greater similarity in the diets of these 2 species, with a lesser importance of detritus, than did those from the IsoSource model.

Trophic relationships between *Crassostrea gigas* and *Crepidula fornicata*

Given that *Crepidula fornicata* and *Crassostrea gigas* both feed on seston and, that in contrast to the oyster (Cognie et al. 2003), *C. fornicata* does not appear capable of qualitative selection, diet overlap appeared highly probable (Beninger et al. 2007). Isotope comparisons confirmed this assumption: the same food types were ingested on 3 seasonal sampling dates. However, significant differences in the tissue isotope deviations of these 2 species in March and July 2003 revealed that diets differed substantially in winter and spring. Similar conclusions—i.e. same source types but different diets—were reported for these 2 species in the Oosterschelde (The Netherlands; Riera et al. 2002; Fig. 7). In comparison with our study, the dietary differences of specimens from the Oosterschelde were consistently more pronounced, especially with respect to carbon deviations. However, substantial ingestion of macrophyte detritus by these suspension-feeders has not been previously reported from other European Atlantic sites (Oosterschelde and Marennes-Oléron). Interestingly, this corresponds to reduced presence of macrophytes at these sites (Riera & Richard 1996, Riera et al. 2002). These observations bring to attention the need for site-specific diet studies of these invasive species, in order to obtain a realistic understanding of their feeding biology in European coastal ecosystems.

The trophic niche breadth of slipper limpets was either similar to or broader than that of Pacific oysters, indicating that *Crepidula fornicata* is a more generalist suspension-feeder than *Crassostrea gigas*. This may be due, at least in part, to their different capacities for qualitative selective feeding (Beninger et al. 2007). On all 3 sampling dates of the present study, the trophic niches of *Crepidula fornicata* and *Crassostrea gigas* overlapped to variable degrees in Bourgneuf Bay, with greater overlap in November when niche breadths were narrower. This high degree of overlap (consistently > 90%) emphasizes the potential for trophic competition between these 2 invasive species; however, competition can only be demonstrated when resources are limiting for both species. In the absence of complete source data and functional ecosystem models, demonstration of actual competition must therefore rely on specific physiological and isotopic indices (e.g. shifts in filtration, use of specific diet components). The findings of the present study show that the characteristics of trophic overlap/competition between *Crepidula fornicata* and *Crassostrea gigas* are likely to be highly variable throughout their sympatric range, depending on types and abundances of local food sources.

Acknowledgements. We thank S. Derrien for performing mass spectrometry of prepared samples, Dr. D. Phillips for his help with mixing programs, and Mr. J. L. Decottignies for his skilled dexterity in the construction of a sampling apparatus. We are extremely grateful to Mr. A. Lamour and crew for open-sea sampling aboard the SNSM vessel 'Georges Clemenceau II'.

LITERATURE CITED

Abed-Navandi D, Dworschak PC (2005) Food sources of tropical thalassinidean shrimps: a stable-isotope study. Mar Ecol Prog Ser 291:159–168

Barillé-Boyer AL, Haure J, Baud JP (1997) L'ostréiculture en baie de Bourgneuf. Relation entre la croissance des huîtres *Crassostrea gigas* et le milieu naturel : synthèse de 1986 à 1995. Report No. DRV/RA/RST/97/Num, IFREMER

Barillé L, Cognie B, Beninger PG, Decottignies P, Rincé Y (2006) Feeding responses of the gastropod *Crepidula fornicata* to changes in seston concentration. Mar Ecol Prog Ser 322:169–178

Beninger PG, Decottignies P, Guiheneuf F, Barillé L, Rincé Y (2007) Comparison of particle processing by two introduced suspension feeders: selection in *Crepidula fornicata* and *Crassostrea gigas*. Mar Ecol Prog Ser 334: 165–177

Blanchard M (1997) Spread of the slipper limpet *Crepidula fornicata* (L. 1758) in Europe. Current state and consequences. Sci Mar 61:109–118

Bowen SH, Lutz EV, Ahlgren MO (1995) Dietary protein and energy as determinants of food quality: trophic strategies compared. Ecology 76:899–907

Brock V, Kennedy VS, Brock A (1986) Temperature dependency of carbohydrase activity in the hepatopancreas of thirteen estuarine and coastal bivalve species from the North American east coast. J Exp Mar Biol Ecol 103: 87–101

Bustamante RH, Branch GM (1996) The dependence of intertidal consumers on kelp-derived organic matter on the west coast of South Africa. J Exp Mar Biol Ecol 196:1–28

Carman KR, Fry B (2002) Small-sample methods for $\delta^{13}C$ and $\delta^{15}N$ analysis of the diets of marsh meiofaunal species using natural-abundance and tracer-addition isotope techniques. Mar Ecol Prog Ser 240:85–92

Chauvaud L, Jean F, Ragueneau O, Thouzeau G (2000) Long-term variation of the Bay of Brest ecosystem: benthic-pelagic coupling revisited. Mar Ecol Prog Ser 200:35–48

Cognie B, Barillé L, Massé G, Beninger PG (2003) Selection and processing of large suspended algae in the oyster *Crassostrea gigas*. Mar Ecol Prog Ser 250:145–152

Cole HA, Hancock DA (1956) Progress in oyster research in Britain 1949–1954, with special references to the control of pests and diseases. Cons Int Explor Mer Rapp Proc Verb 140:24–29

Cranford PJ, Grant J (1990) Particle clearance and absorption of phytoplankton and detritus by the sea scallop *Placopecten magellanicus* (Gmelin). J Exp Mar Biol Ecol 137: 105–121

Créach V, Schricke MT, Bertru G, Mariotti A (1997) Stable isotopes and gut analyses to determine feeding relationships in saltmarsh macroconsumers. Estuar Coast Shelf Sci 44:599–611

Currin CA, Newell SY, Paerl HW (1995) The role of standing dead *Spartina alterniflora* and benthic microalgae in salt marsh food webs: considerations based on multiple stable isotope analysis. Mar Ecol Prog Ser 121:99–116

Davis MA, Thompson K (2000) Eight ways to be a colonizer; two ways to be an invader: a proposed nomenclature scheme for invasion ecology. Bull Ecol Soc Am 81:226–230

Deegan LA, Garritt RH (1997) Evidence for spatial variability in estuarine food webs. Mar Ecol Prog Ser 147:31–47

de Montaudouin X, Audemard C, Labourg PJ (1999) Does the slipper limpet (*Crepidula fornicata*, L.) impair oyster growth and zoobenthos biodiversity? A revisited hypothesis. J Exp Mar Biol Ecol 235:105–124

DeNiro MJ, Epstein S (1978) Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochim Acta 42:495–506

Ehrhold A, Blanchard M, Auffret JP, Garlan T (1998) The role of Crepidula proliferation in the modification of the sedimentary tidal environment in Mont-Saint-Michel Bay (The Channel, France). CR Acad Sci Paris 327:583–588

Gannes LZ, O'Brien DM, Martínez del Rio C (1997) Stable isotopes in animal ecology: assumptions, caveats, and a call for more laboratory experiments. Ecology 78:1271–1276

Grant J (1996) The relationship of bioenergetics and the environment to the field growth of cultured bivalves. J Exp Mar Biol Ecol 200:239–256

Grosholz E (2002) Ecological and evolutionary consequences of coastal invasions. Trends Ecol Evol 17:22–27

Heip CHR, Goosen NK, Herman PMJ, Kromkamp J, Middelburg JJ, Soetaert K (1995) Production and consumption of biological particles in temperate tidal estuaries. Oceanogr Mar Biol Ann Rev 33:1–149

Hsieh HL, Kao WY, Chen CP, Liu PJ (2000) Detrital flows through the feeding pathway of the oyster (*Crassostrea gigas*) in a tropical shallow lagoon: $\delta^{13}C$ signals. Mar Biol 136:677–684

Kang CK, Sauriau PG, Richard P, Blanchard GF (1999) Food sources of the infaunal suspension-feeding bivalve *Cerastoderma edule* in a muddy sandflat of Marennes-Oléron Bay, as determined by analyses of carbon and nitrogen stable isotopes. Mar Ecol Prog Ser 187:147–158

Kang CK, Kim JB, Lee KS, Kim JB, Lee PY, Hong JS (2003) Trophic importance of benthic microalgae to macrozoobenthos in coastal bay systems in Korea: dual stable C and N isotope analyses. Mar Ecol Prog Ser 259:79–92

Koch PA, Phillips DL (2002) Incorporating concentration dependence in stable isotope mixing models: a reply to Robbins, Hilderbrand and Farley (2002). Oecologia 133: 14–18

Korringa P (1951) *Crepidula fornicata* as an oyster-pest. Cons Int Explor Mer Rapp Proc Verb 128:55–59

Krebs CJ (1999) Ecological methodology. Benjamin Cummings, Menlo Park, CA

Langdon CJ, Newell RIE (1990) Utilization of detritus and bacteria as food sources by two bivalve suspension-feeders, the oyster *Crassostrea virginica* and the mussel *Geukensia demissa*. Mar Ecol Prog Ser 58:299–310

Leguerrier D, Niquil N, Boileau N, Rzeznik J, Sauriau PG, Le Moine O, Bacher C (2003) Numerical analysis of the food web of an intertidal mudflat ecosystem on the Atlantic coast of France. Mar Ecol Prog Ser 246:17–37

Le Pape O, Guérault D, Désaunay Y (2004) Effect of an invasive mollusc, American slipper limpet *Crepidula fornicata*, on habitat suitability for juvenile common sole *Solea solea* in the Bay of Biscay. Mar Ecol Prog Ser 277:107–115

Lubetkin SC, Simenstad CA (2004) Multi-source mixing models to quantify food web sources and pathways. J Appl Ecol 41:996–1008

Lucas MI, Newell RC, Shumway SE, Seiderer LJ, Bally R (1987) Particle clearance and yield in relation to bacterioplankton and suspended particulate availability in estuarine and open coast populations of the mussel *Mytilus edulis*. Mar Ecol Prog Ser 36:215–224

Mann KH (1988) Production and use of detritus in various freshwater, estuarine, and coastal marine ecosystems. Limnol Oceanogr 33:910–930

McCutchan JHJ, Lewis WMJ, Kendall C, McGrath CC (2003) Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. Oikos 102:378–390

Méléder V, Launeau P, Barillé L, Rincé Y (2003) Cartographie des peuplements du microphytobenthos par télédétection visible-infrarouge dans un écosystème conchylicole. CR Biol 326:377–389

Mitbavkar S, Anil AC (2004) Vertical migratory rhythms of benthic diatoms in a tropical intertidal sand flat: influence and tides. Mar Biol 145:9–20

Newell RIE, Langdon CJ (1986) Digestion and absorption of refractory carbon from the plant *Spartina alterniflora* by the oyster *Crassostrea virginica*. Mar Ecol Prog Ser 34: 105–115

Newsome SD, Phillips DL, Culleton BJ, Guilderson TP, Koch PL (2004) Dietary reconstruction of an early to middle Holocene human population from the central California coast: insights from advanced stable isotope mixing models. J Archaeol Sci 31:1101–1115

Orton JH (1912) The mode of feeding of Crepidula, with an account of the current-producing mechanism in the mantle cavity, and some remarks on the mode of feeding in Gastropods and Lamellibranchs. J Mar Biol Assoc UK New Series 9:444–478

Page HM, Lastra M (2003) Diet of intertidal bivalves in the Ría de Arosa (NW Spain): evidence from stable C and N isotope analysis. Mar Biol 143:519–532

Phillips DL, Gregg JW (2003) Source partitioning using stable isotopes: coping with too many sources. Oecologia 136: 261–269

Post DM (2002) Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecology 83: 703–718

R Development Core Team (2005) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Riera P (1998) δ^{15}N of organic matter sources and benthic invertebrates along an estuarine gradient in Marennes-Oléron Bay (France): implications for the study of trophic structure. Mar Ecol Prog Ser 166:143–150

Riera P, Richard P (1996) Isotopic determination of food sources of *Crassostrea gigas* along a trophic gradient in the estuarine bay of Marennes-Oléron. Estuar Coast Shelf Sci 42:347–360

Riera P, Richard P, Grémare A, Blanchard G (1996) Food source of intertidal nematodes in the Bay of Marennes-Oléron (France), as determined by dual stable isotope analysis. Mar Ecol Prog Ser 142:303–309

Riera P, Stal LJ, Nieuwenhuize J, Richard P, Blanchard G, Gentil F (1999) Determination of food sources for benthic invertebrates in a salt marsh (Aiguillon Bay, France) by carbon and nitrogen stable isotopes: importance of locally produced sources. Mar Ecol Prog Ser 187:301–307

Riera P, Stal LJ, Nieuwenhuize J (2002) δ^{13}C versus δ^{15}N of co-occurring molluscs within a community dominated by *Crassostrea gigas* and *Crepidula fornicata* (Oosterschelde, The Netherlands). Mar Ecol Prog Ser 240:291–295

Rossi F, Herman PMJ, Middelburg JJ (2004) Interspecific and intraspecific variation of δ^{13}C and δ^{15}N in deposit- and suspension-feeding bivalves (*Macoma balthica* and *Cerastoderma edule*): evidence of ontogenic changes in feeding mode of *Macoma balthica*. Limnol Oceanogr 49:408–414

Ruesink JL, Lenihan HS, Trimble AC, Heiman KW, Micheli F, Byers JE, Kay MC (2005) Introduction of non-native oysters: ecosystem effects and restoration implications. Annu Rev Ecol Evol Syst 36:643–689

Sarà G, Vizzini S, Mazzola A (2003) Sources of carbon and dietary habits of new Lessepsian entry *Brachidontes pharaonis* (Bivalvia, Mytilidae) in the western Mediterranean. Mar Biol 143:713–722

Stuart V (1982) Absorbed ration, respiratory costs and resultant scope for growth in the mussel *Aulacomya ater* (Molina) fed on a diet of kelp detritus of different ages. Mar Biol Lett 3:289–306

Tsikhon-Lukanina YA (1982) Food assimilability in bottom mollusks. Oceanology 22:619–622

Wada E, Hattori A (1991) Nitrogen in the sea: forms, abundances, and processes. CRC Press, Boca Raton, FL

Yokoyama H, Tamaki A, Harada K, Shimoda K, Koyama K, Ishihi Y (2005) Variability of diet-tissue isotopic fractionation in estuarine macrobenthos. Mar Ecol Prog Ser 296: 115–128

Editorial responsibility: Otto Kinne (Editor-in-Chief), Oldendorf/Luhe, Germany

Submitted: April 19, 2004; Accepted: July 11, 2005
Proofs received from author(s): March 13, 2007

Fishery Natura Plan for Native oysters in Lough Swilly

2012-2017

Proposed by

Lough Swilly Wild Oyster Society Limited (LSWOSL)

Native oysters on the sorting table off the stern of an oyster fishing vessel in L. Swilly.

Contents

Background

History

Wild oyster (*Ostrea edulis*) was first documented in Lough Swilly in 1604 when the British Admiralty report identified that oysters existed in commercial quantities in the bay. There has been a traditional native oyster fishery in the bay ever since. In 1904 the first comprehensive survey was conducted and documented in the "Brown Report" which stated that "there are two natural oyster beds in Lough Swilly one on the north side between Ballygreen Point and Ardrummon, in the Letterkenny Rural District and the other on the south side of the Lough between Drumbiy and Ballyaghan." Recent surveys by O Sullivan and Dennis (2001) and in 2011 by the Marine Institute (Anon 2011) provide updated information on the distribution of oysters in the Lough. Local knowledge also suggests that there are additional beds not included in these surveys (Fig. 1).

Current arrangements for governance and regulation of the fishery

The Lough Swilly Wild Oyster Development Association was formed in 2000 to represent the interests of fishermen licensed to gather wild oysters on the Swilly beds. Subsequently the Lough Swilly Wild Oyster Society Limited (LSWOSL) was formed as a friendly Society registered with the Irish Co-operative Organisation Society Limited. It has 29 members from the wild oyster (*Ostrea edulis*) fishing community. The Society currently has no legal authority to manage the fishery but has been active in promoting the conservation and management of wild oyster in L Swilly since 2000.

All oyster fishermen are required to hold dredge licences issued by Inland Fisheries Ireland (IFI) which specifies the season during which the dredge can be used. In addition the oyster fishing vessel should be registered on the National Sea Fishing Register administered by The Department of Agriculture, Food and Marine (DAFM) and hold the requisite bivalve or polyvalent capacity. Annually up to 30 oyster dredge licences have been issued to traditional fishermen in the locality to dredge for oysters (Table 1).

Table 1. Number of dredge licences issued annually for fishing of oysters in L. Swilly

Year	Number of Licences Issued
2012	24
2011	22
2010	16
2009	21
2008	27
2007	28
2006	30

The fishery is regulated by minimum landing size of 76mm and by a closed season from June 1st to August 30th. These regulations are enforced by IFI.

Current status of oyster stocks and fisheries in Lough Swilly

In March 2011 a limited survey of the oyster populations of Lough Swilly was undertaken by the Marine Institute and BIM. This was not comprehensive and excluded sites already licensed for aquaculture. This survey indicated that the wild oyster population was at a low level and that previous fishing had resulted in removal of a high proportion of larger oysters (>76mm). The survey also indicated that a naturalised Pacific oyster (*Crassostrea gigas*) population was established, occurred in the native oyster bed at various densities and was of multiple year classes. A second survey was completed in November 2011 and included both wild Oyster beds and aquaculture sites. This confirmed and extended the conclusions of the March 2011 survey that generally stocks were low and that Pacific oysters were widespread. The surveys also showed however that some annual recruitment was occurring and growth rates appear to be strong (Anon 2012).

Output from the fishery has varied annually depending on stock availability, fishing effort and market price. As recently as 2008 55 tons of oysters were taken. The really significant development in the fishery has been the landing of 300 tonnes of naturalised Pacific oyster in 2010. This fishery continued in 2011 (Table 2).

Table 2. Estimated annual output of oysters from Lough Swilly 2006-2011. Data for 2011 is incomplete.

Year	Tonnage sales
2011	4 Tons *Ostrea edulis*; 15 Tons *Pacific oyster* (*yr to date)
2010	40 Tons *Ostrea edulis*; 300 Tons *Pacific oyster*
2009	45-50 Tons *Ostrea edulis*
2008	55 Tons *Ostrea edulis*
2007	Unknown
2006	Unknown

Current challenges

There are several major challenges facing the oyster stocks and oyster fishery in L. Swilly.

- There is no comprehensive plan the Lough that would afford protection to the native oyster stocks and fisheries.
- There is no legal mechanism currently in place that could limit the number of vessels fishing for oysters, the total fishing effort or the annual outtake. Other oyster fisheries in the country have either a fishery order which authorises the local co-op to manage the fishery or they have an aquaculture licence which gives them this same authority
- Scientific advice and data provision to inform management of the fishery has been weak
- Licences (for shellfish other than wild oysters) have been granted to aquaculture activities which overlap wild oyster habitat. Some of these licenced areas are extensive. Relaying of mussel and trestle production of Pacific oyster are the main activities in these sites
- There are a number of Aquaculture sites that are apparently licensed, but not being utilised but cannot be fished by native oyster fishermen even though there may be native oysters in these areas
- Pacific oysters have become established as a self-seeding population in Lough Swilly. Their distribution suggests that they are a threat to wild oyster stocks and habitat.
- *Bonamia* was accidentally introduced into the bay in or around 2006 and this disease has led to increased mortality of native oyster. In addition there is no biosecurity plan for the area that would reduce the risk of introduction of other non native species.

Management plan objective

The overall objective of this management plan is to develop a sustainable wild Oyster (*Ostrea edulis*) fishery that is consistent with the conservation objectives for wild oyster habitat and other habitats in the Lough. To achieve this the plan acknowledges and specifically responds to the Conservation Objectives for oyster habitat described in NPWS (2011).

To achieve the overall objective of the plan a number of strategies are envisaged each of which will be implemented by adopting a number of procedural, legislative and management measures.

The plan will operate over the distributional extent of oyster beds in L. Swilly. The distributional extent has been determined from a 2001 BIM survey, a 2011 MI survey and local knowledge (Fig. 1). Together these data and information sources provide a best estimate of the current and potential distributional extent of native oysters in L. Swilly (Fig. 2). The LSWOSL intends that the management plan described here for native oyster will operate over this entire area. Temporary closures of some of these areas to oyster fishing will be for the purpose of restoration of stocks and will not mean that such areas can or should be used for other purposes.

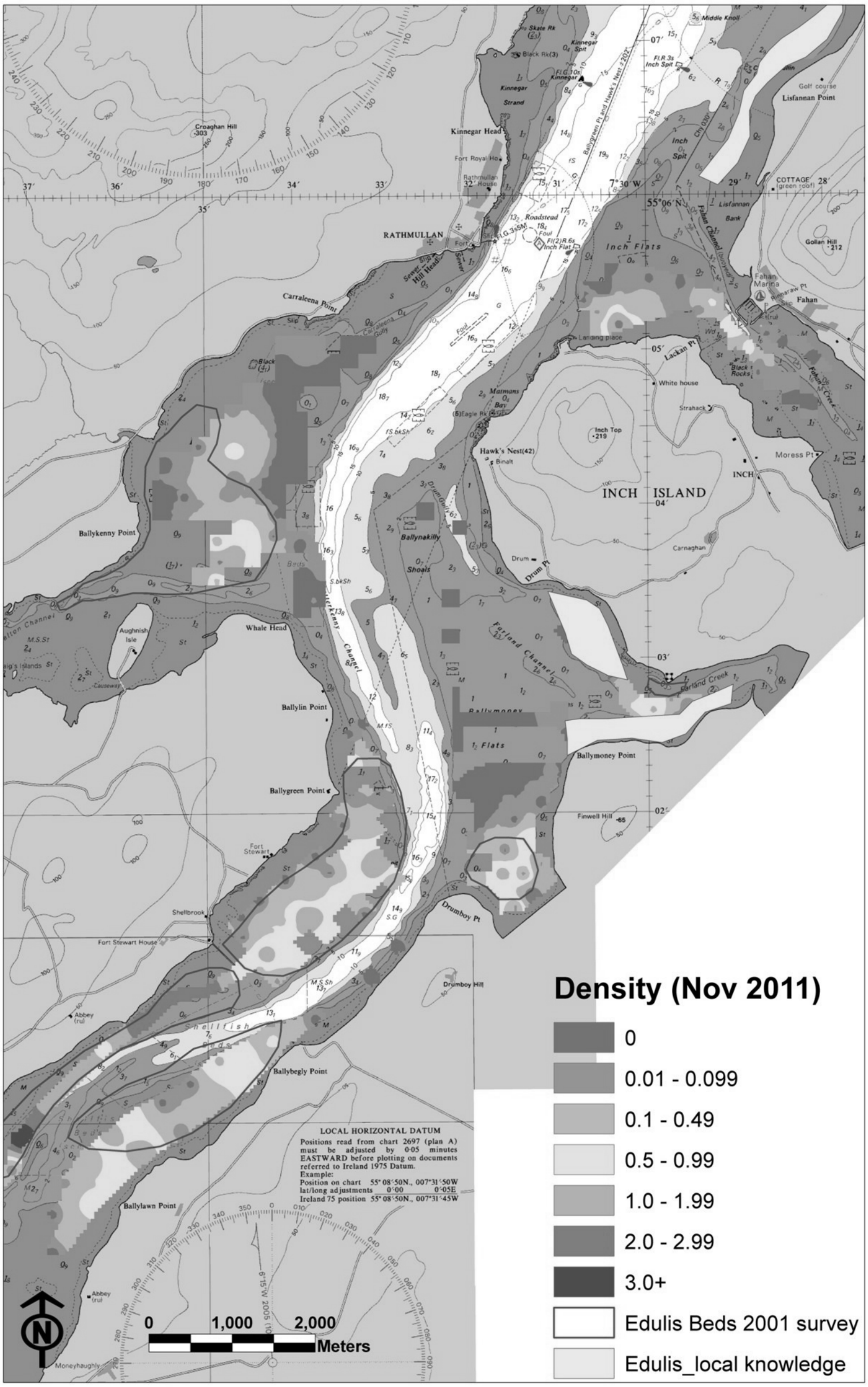


Fig. 1. Distribution of native oyster in L. Swilly derived from surveys in 2001, 2011 and local knowledge.

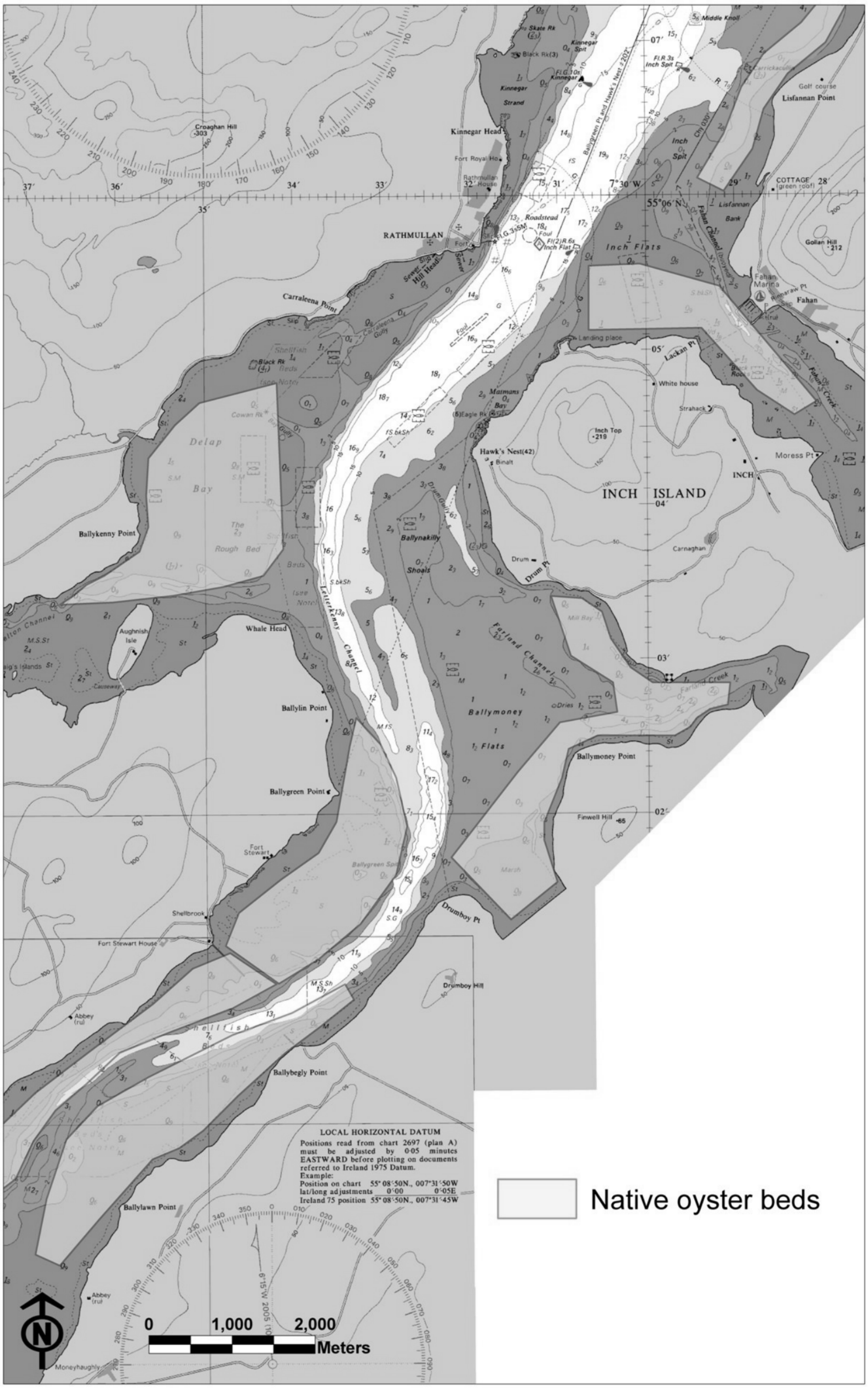


Fig 2. The extent of oyster beds based on information in Fig 1.The proposed management plan will operate over this area which is 1771ha.

Management Strategies

1. *Increased data provision for stock assessment*

Generally, and in particular prior to 2011, no data has been available for provision of advice on the management of oyster stocks in L. Swilly. This has been a significant impediment to the co-op in developing rational management measures. From 2012 the Marine Institute have indicated that an annual survey will be conducted to provide the relevant data and advice.

2. *Re-build and maintain native oyster biomass at levels that maximise productivity and spat fall potential*

Although the maximum annual production and sustainable yield of oysters in L. Swilly is unknown it is clear that stocks were previously at a significantly higher level than they are today. Re-building of stocks is, therefore, a reasonable and feasible objective from both fishery management and conservation objective (NPWS 2011) perspectives.

3. *Develop a control programme for Pacific oyster*

It is clear from the 2011 survey that Pacific oysters are widely distributed in the Lough, occur on what was formerly known to be native oyster habitat and may be expanding their distribution. Any re-building programme for native oysters has to include an intense and sustained control programme for Pacific oysters if it is to be successful.

4. *Increase monitoring of Bonamia to identify its role in mortality of oysters in the Lough*

Monitoring of the prevalence of *Bonamia* was last carried out in the Lough in 2008. The current spatial distribution of prevalence and the mortality caused by *Bonamia* in the Lough is unknown. Together with Pacific oysters *Bonamia* is a significant threat to any re-building programme for native oysters and monitoring of prevalence is essential in evaluating the feasibility of an oyster re-building programme. In addition to *Bonamia* monitoring biosecurity measures that would reduce the risk of accidental introduction of other non-native competing species or diseases should be developed.

5. ***Develop a legal framework and governance structure with the capacity to limit inputs and out-takes of oyster from the Lough***

   Maintaining a sustained re-building programme for native oysters in the Lough and operating a fishery under a range of control measures requires a system of governance in which LSWOSL are central players. Management measures adopted by LSWOSL need to be backed up by legislative support. A number of mechanisms exist in other oyster fisheries but these are currently not in place in Lough Swilly.

6. ***Ensure that the management measures adopted in the plan are implemented through an effective monitoring and control programme***

   The success of the plan hinges on the effective implementation of the management measures described. Monitoring and control of the fishery will be important in building confidence and buy in among the LSWOSL members and permit holders.

7. ***Review strategies and measures annually and ensure a management response to monitoring programmes in relation to conservation objectives***

   The future effectiveness of the management measures outlined in this management plan are unknown because of the inherent variability in spawning, spat settlement, growth and survival of oysters. Monitoring of stocks, annual review of the effectiveness of measures taken and adaptive management are therefore very important aspects of this plan.

Management Measures

The management strategies outlined above will be implemented using a range of measures as follows.

1. ***Increased data provision***

   a. Annual surveys and assessment of stocks and associated habitat

      Annual dredge and grab surveys will report the following indicators for all oyster beds

      i. Density of all oysters
      ii. Density of oysters over MLS
      iii. Density of oysters 1+ years

iv. Qualitative index of 0+ settlement and development of an index of settlement using collectors
v. The shell content of oyster habitat (excluding live *Pacific oyster*)
vi. Macrofauna (including *Pacific oyster*) associated with oysters
vii. Total annual mortality rates derived from length composition and growth data

b. All oysters harvested shall be landed at agreed landing points and all bags shall be tagged with a tag identifiable back to the individual boat and dredge licence so that accurate estimates of landings are recorded.

c. Fishing vessel operators will provide catch and fishing effort data to inform the management plan and allow for in season control of fishing activity and areas fished. This will allow for the following real time management measures to be taken if necessary
   i. Low or declining catch rates could be used to close areas prior to the official closing date of the season
   ii. The occurrence of a high (>80%) percentage of oysters under 55mm in the catch could be used to close areas and to support data obtained in the annual survey

These data will provide accurate records to the LSWOSL on landings and be used to cross check landings data collected by IFI.

2. *Re-build stocks of native oyster*

Re-building stocks, by increasing oyster density and biomass, over and above their current status is consistent with the conservation objectives for oyster habitat. Incrementally this will lead to oyster habitat achieving favourable conservation status and, as described above, will also achieve the fishery management objective for native oyster in L. Swilly. The following measures are proposed.

a. Ensure the minimum landing size (MLS) is above the size at maturity
   i. Biological assessment of size at maturity will be used to re-assess the MLS in year 1 of the plan. The appropriate MLS and the size at which a given cohort reaches maximum biomass also depend on the relationship between natural mortality and growth rates. Information on these biological

parameters of oysters in L. Swilly will be improved annually during the lifetime of the plan

b. Restrictions on dredge design
    i. The maximum dredge width will be 150cm
    ii. Only blade dredges (rather than toothed dredges) will be used to minimise disturbance of sub-surface habitat and breakage of dead shell

c. In areas where native oyster comprise at least 50%[1] of all oysters the exploitation rate and total fishing activity will be limited as follows:
    i. The exploitation rate will be limited to 33% of the pre-fishery spawning stock biomass in this area as determined by the annual survey and new estimates of size at maturity to be determined in 2012
    ii. Areas where density of oysters is less than 0.25 oysters m^{-2}, as determined in the first year of the plan by the Nov 2011 survey, will be closed until density and biomass of oysters recovers above this threshold[2]. Generally, fishing in any given year will not occur in areas where density is below this level or when densities are depleted to this level during the fishing season (as derived from fishing activity data).
    iii. The fishing season will be shortened. The current opening date of Sept 1st will be delayed until Sept 19th while the current closing date of April 30th will be changed to Mar 31st. Fishing will not, therefore, occur during periods when juvenile oysters are actively growing to minimise negative effects of dredging on growth rates and mortality of juveniles
    iv. Areas where more than 70% of oysters are juveniles (<55mm), as determined by annual surveys, will not be fished

d. Develop a spawning reserve that will be closed to fishing
    i. An area of 55hectares will be closed to fishing in order to establish and conserve a high density of spawning stock, to increase fertilisation success and larval production from this area (Fig. 3).

[1] Areas where Pacific oysters constitute >50% of oysters will be subject to the Pacific oyster control plan (measure 3)
[2] This is an arbitrary starting threshold for the management plan that will be reviewed annually

ii. In year 1 of the plan Pacific oyster will be removed, by dredging, from the closed area
iii. In year 2, following the removal of Pacific oyster from this area, mature native oysters (>55mm) will be transplanted into the 'spawning reserve'. These oysters will be sourced from the fishery
iv. The location of the reserve in the upper Swilly will lead to larval dispersal to other oyster beds seaward of the reserve

e. Relay cultch in a trial area to demonstrate potential benefits of cultching to spatfall
   i. Mussel and oyster shell will be deposited in a trial area (50.5 hectares) initially to demonstrate beneficial effects of cultching on spatfall and restoration of oyster density. Spat fall in this area will be compared to a nearby area which will not be cultched (Fig 3). The cultch and cultch control areas are intertidal and can be monitored using standard survey methods
   ii. In the first year of the plan Pacific oyster will be removed from the cultch and control areas.
   iii. Shell content on the seabed will be estimated prior to and after cultching in the cutch area and in a nearby control area. Spat settlement and survival will be monitored after the spawning season in both areas.
   iv. This area will be closed to fishing until a proportion of spat settling on the cultch have grown to the minimum size.

f. Spatial elements of the plan will also take into account the prevalence and distribution of *Bonamia* in the Lough

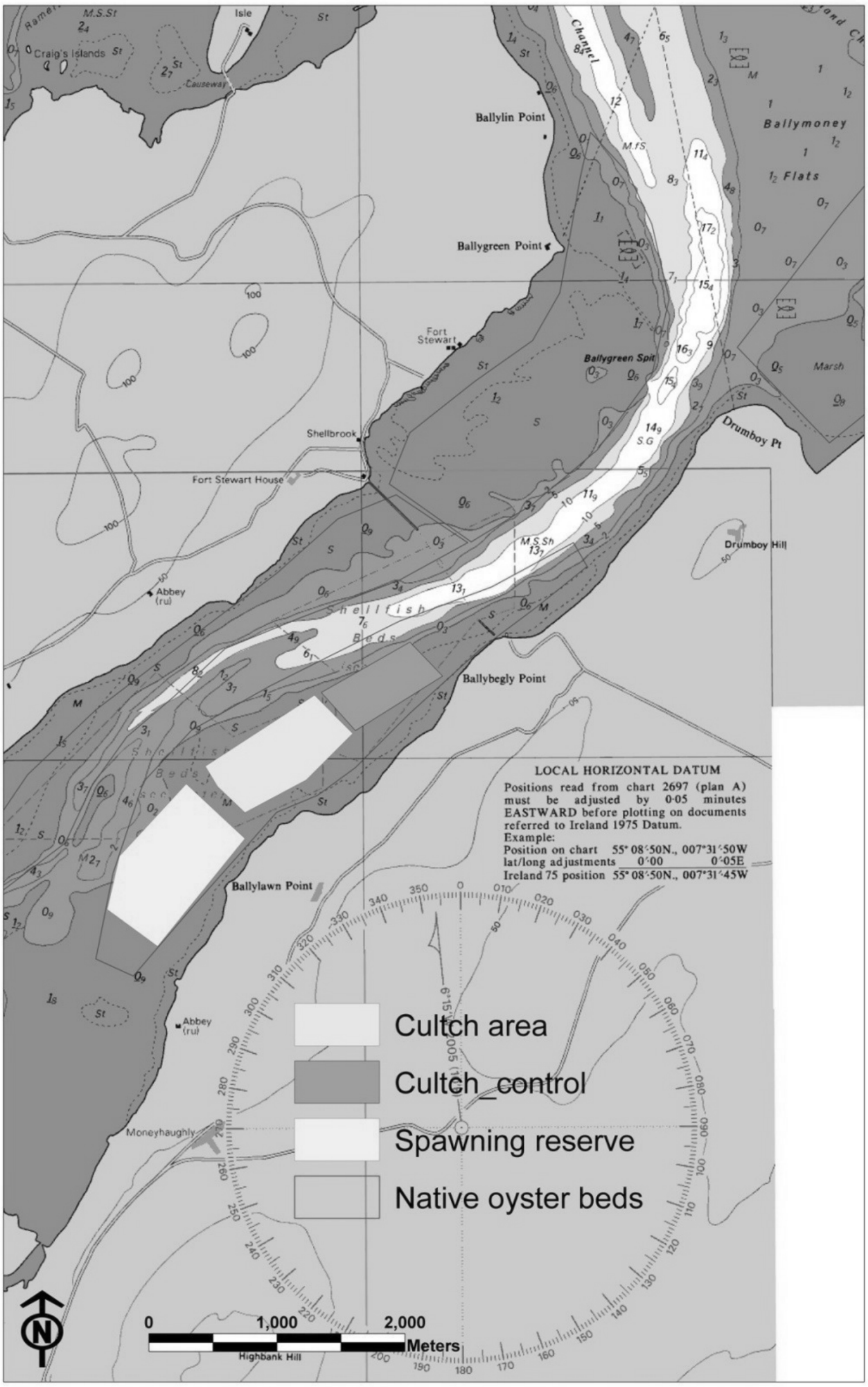


Fig. 3. Location of a proposed spawning reserve, cultch area and a cultch control area for native oysters. The spawning area will be closed to fishing for the duration of the management plan. The cultch area will be closed until spat have reached MLS. The cultch control area will be used to compare spat settlement densities with the cultched area and will be open to fishing.

3. Control of Pacific oyster

The 2011 survey showed that Pacific oyster was widely distributed and in many areas was the pre-dominant species of oyster present on what were previously described as native oyster beds. A control programme for this species is necessary as a first step in re-building native oyster stocks and achieving favourable conservation status for oyster habitat as defined in NPWS (2011). This will be achieved as follows

a. Develop a spatial control plan (fishery) for Pacific oyster
    i. Allow unrestricted fishing, between Sept and March, in areas where >50% of oysters are *Pacific oyster* (Fig. 4,5) irrespective of the density of native oyster. Areas where Pacific oyster are pre-dominant are well defined and it is feasible to target a fishery at these areas. Some of these areas may not have been included in the 2011 survey but are known by fishermen (Fig. 4,5). The area where Pacific oyster constitutes more than 50% of oysters is 482 hectares based on the 2011 survey (Fig. 5)
    ii. All juvenile and adult Pacific oyster will be removed
    iii. This fishery will operate in year 1 of the plan only and will be reviewed at that point
    iv. Native oysters under the MLS captured in this fishery will be transplanted to the spawning reserve so they are not exposed to repeat dredging
    v. When *Pacific oyster* is removed from these areas the suitability of the habitat for settlement of native oyster will be assessed and cultch will be re-laid if necessary
    vi. If the market for *Pacific oyster* is not available the control plan should be subsidised by state grant aid. The members of the co-op cannot fund the control plan in the absence of a market for *Pacific oyster*.
    vii. Areas where native oysters comprise greater than 50% of all oysters will be subject to the fishery management measures outlined above. All *Pacific oyster* captured in these areas will also be landed.

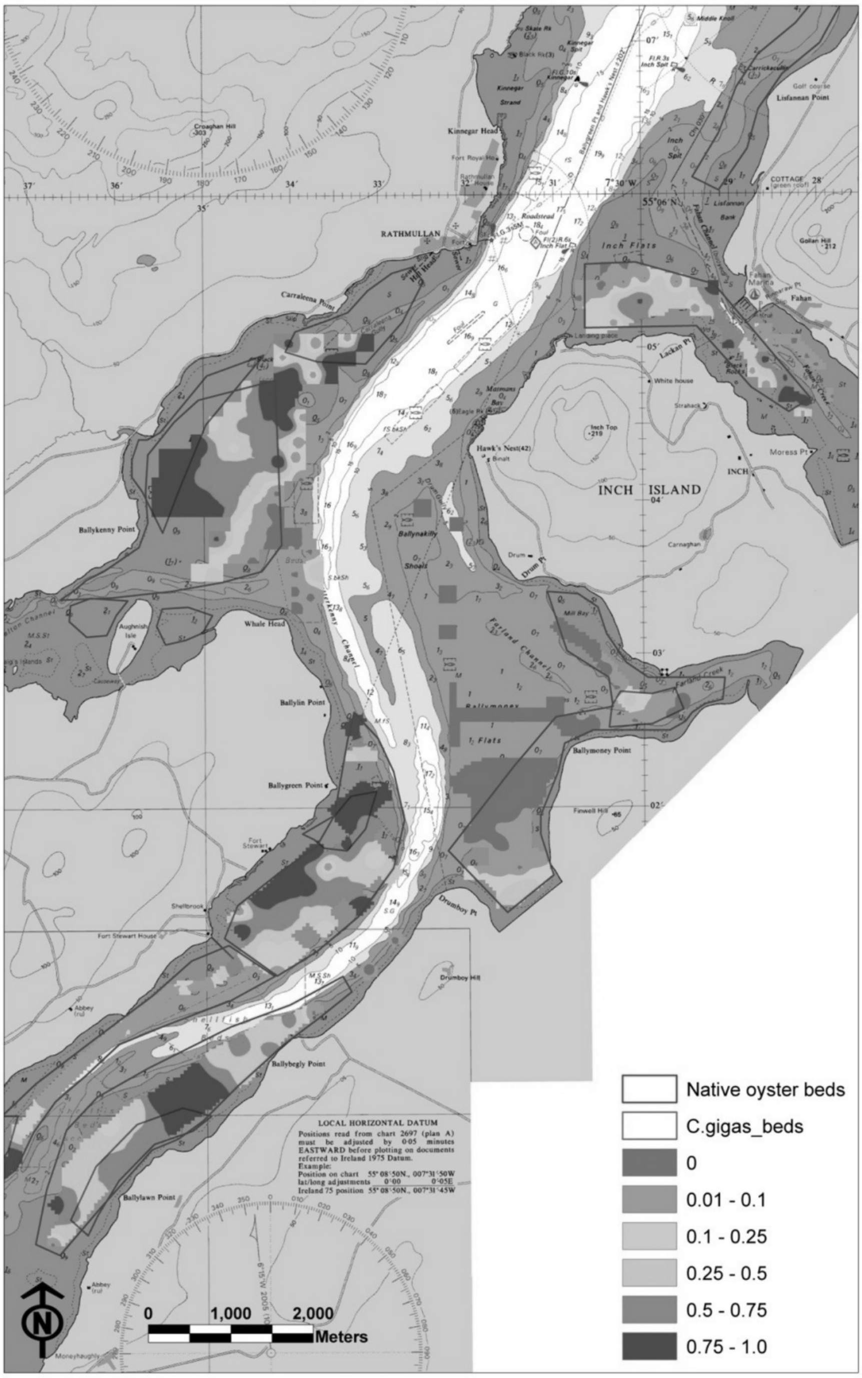


Fig. 4. Distribution of Pacific oyster as a proportion of all oysters present in native oyster beds in L. Swilly as of Nov 2011. Pacific oyster beds known by local fishermen and which were also targeted in a 2010 and 2011 fishery are also shown

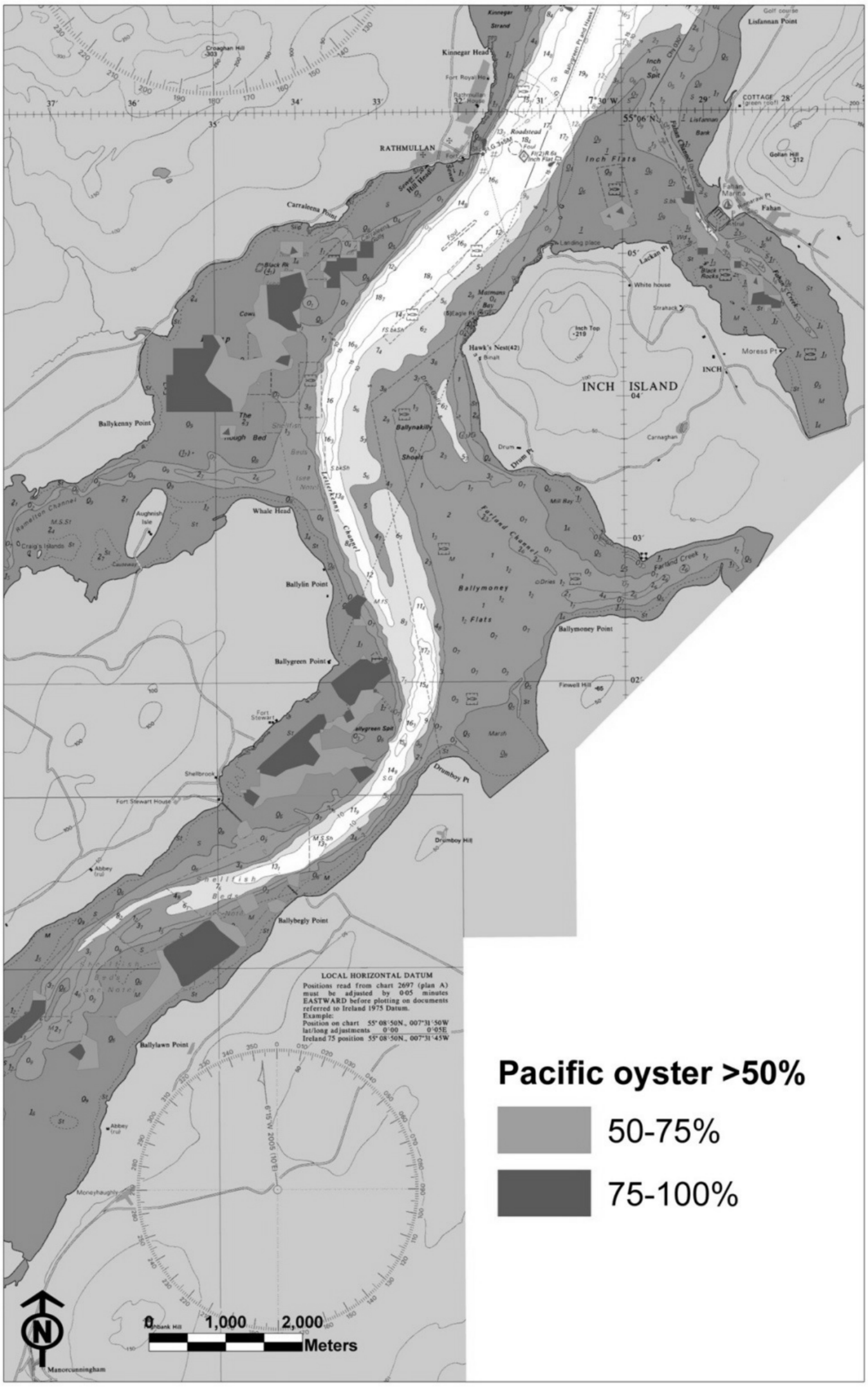


Fig. 5. Areas where Pacific oyster constitutes >50% of all oysters in native oyster beds in L. Swilly as of Nov 2011.The total area is 482 hectares.

4. *Bonamia monitoring*

a. The current prevalence and distribution of *Bonamia* in the Lough needs to be established as this will determine the capacity to recover native oyster stocks and the effectiveness of the management measures described here.

5. *Legal framework and governance*

This management plan cannot be implemented under existing regulations in force in L. Swilly. A new legal framework and governance arrangement is needed if the plan is to be implemented. The proposers of this plan, the Lough Swilly Wild Oyster Society Ltd. (LSWOSL), currently have no authority to implement any of the measures outlined although its members support the measures. Some options that could be considered might include

- An annual Statutory Instrument be developed to give legal effect to the management plan and its annual variations
- A range of conditions, outlined in the plan, be included in annual dredge permits issued by IFI
- Give legal authority to manage the fishery to the LSWOS in the same way that other oyster co-ops in the country has legal authority to manage their fisheries in the form of a Fishery Order or an Aquaculture licence
- Any new legal framework should enable restriction on the number of vessels in the fishery. Otherwise the plan is not operational
- In order to promote stewardship of the fishery among licence holders and to provide them with a return on the medium and long term objectives outlined in the management plan the dredge licence should be transferable to first degree relatives

In addition

- Given the special circumstances in L. Swilly regarding *Pacific oyster* and the need to develop a strategic and effective control plan for this species with the aim of removing naturalised Pacific oysters from native oyster beds, a dedicated fishery manager for the area should be appointed for years 1-2 of the plan at a minimum
- Given that Pacific oyster has naturalised in the Lough aquaculture of this species in the Lough should only use triploid, non-reproducing, oysters

6. *Monitoring and control*

Measures outlined in this plan require effective monitoring and control.

- Effective control and enforcement of landings, minimum landing size, landing points and spatial extent of fishing activity is required.
- All boats will maintain a logbook to identify the quantities and species of Oyster caught and landed and tags utilised and date caught
- All oysters harvested shall be landed at agreed landing points and each and every bag shall be tagged with a tag identifiable back to the individual boat and dredge licence
- Arrangements for the monitoring and control of fishing in areas dominated by Pacific oysters and Native oysters will be agreed annually. The boundaries of these areas may need to be rationalised to enable effective control of fishing activity.

7. *Review*

Annual review of the measures that have been implemented and their effects, as shown by the improved data provision will be key to the success of the management plan. This will require an integrated approach to management with the management plan objectives at the centre of the review process. The annual review in respect of the Oyster fishery will be led by the LSWOSL with assistance from IFI and scientific and development advice from the Marine Institute and other agencies as appropriate. This management committee will propose amendments and changes to the annual plan and consult with members of LSWOSL prior to proposing any changes to legislation. Specifically the following measures will be reviewed annually

b. Effectivenss of the Pacific oyster control programme as indicated by landings, catch rates, size structure and estimated density of this species in the controlled areas
c. Spawning stock biomass of native oyster in the spawning reserve as indicated by survey
d. Volume of cultch spread
e. Shell content of habitat particularly in the clutched area
f. Spat fall density in the clutched area and elsewhere
g. Catch rates in the fishery and changes in catch rates during the season
h. Distribution and size structure of native oysters in the Lough
i. Distribution and size structure of Pacific oysters in the Lough

j. Prevalance of *Bonamia* in different oyster beds

References

O'Sullivan, A. and Dennis, J. (2001). Lough Swilly Oyster Survey 2001. Aquaculture Initiative and BIM, 41 pp. BIM Crofton Road, DunLaoghaire, Co. Dublin.

Anon (2012). Shellfish stocks and fisheries review. Marine Institute and BIM. 67pp. Marine Institute Rinville, Oranmore, Co. Galway.

NPWS (2011). Lough Swilly SAC (site code 2287). Conservation objectives supporting document – marine habitats. Version 1.0.

INVASIVE SPECIES IN IRELAND

Prepared for
Environment & Heritage Service and
National Parks & Wildlife Service

by

Kate Stokes, Kate O'Neill & Robbie McDonald

***Quercus* project QU03-01**
Quercus is a partnership between
Environment & Heritage Service, Northern Ireland and
Queen's University, Belfast
www.quercus.ac.uk

This report is made jointly to the Environment & Heritage Service of the Department of Environment (Northern Ireland) and the National Parks and Wildlife Service of the Department of Environment, Heritage and Local Government (Republic of Ireland) in fulfilment of a contract to Quercus (Northern Ireland's Research Centre for Biodiversity and Conservation Biology).

Prior to formal publication, the report should be cited as follows:
Stokes, K., O'Neill, K. & McDonald, R.A. (2004) *Invasive species in Ireland.* Unpublished report to Environment & Heritage Service and National Parks & Wildlife Service. Quercus, Queens University Belfast, Belfast.

Please note Stokes and O'Neill are joint primary authors of this report.

For all queries contact quercus@qub.ac.uk or consult www.quercus.ac.uk.

Executive summary

1. Invasions by non-native species are a major threat to global biodiversity. Terrestrial and aquatic habitats can be negatively affected, resulting in grave damage to conservation and economic interests, such as agriculture, forestry and civil infrastructure. In some cases public, animal and plant health may also be threatened.

2. Northern Ireland and the Republic of Ireland have international obligations to address invasive species issues, principally the Convention on Biological Diversity, International Plant Protection Convention, Bern Convention and the Habitats Directive. The National Parks and Wildlife Service of the Department of the Environment, Heritage and Local Government of the Republic of Ireland and the Environment and Heritage Service of The Department of the Environment for Northern Ireland commissioned this all-Ireland review of invasive species with the objective of presenting recommendations to both Governments in March 2004.

3. This report documents the effects of invasive non-native species, recognising that many non-native species do not become invasive but provide considerable benefits to society, particularly in relation to agriculture, forestry and aquaculture. The impacts of invasive species on Irish biodiversity are categorized according to whether the introduction has had a negative, positive or no significant impact upon native biota. Negative impacts are further categorized according to the mechanism by which native biota are affected. For example, through competition, herbivory, predation, alteration of habitat, introduction of parasites and pathogens or dilution of native gene pools.

4. The vectors and pathways by which non-native species are transported are numerous and result from the diverse array of human activities which operate over a range of scales. Primary introductions often result from the accidental transport of species, for example via hull fouling or ballast water. Secondary introductions result from the expansion of exotic species from the initial place of establishment. Secondary spread will normally include a wider range of vectors that may act either separately or together. International and national measures need to take account of these pathways so that contingency plans for management, control and prevention of spread are feasible. There is an urgent need to engage with the commercial sector early in this process to retain their support in the development and maintenance of flexible and effective codes of practice.

5. In Ireland the most prominent of the negative impacts appears to be direct competition with native biota, whilst alteration to habitats and the influence of parasites and pathogens are also important. Specific habitat types currently under threat in Ireland from invasive species include freshwater river systems, ponds, mesotrophic lakes, native woodland, lowland heath, coastal floodplain, coastal saltmarsh and coastal sand dunes. A variety of native species are also threatened by invasives, including red squirrels, white-clawed crayfish, red deer and earthworms.

6. We recommend 10 key actions that will reduce the risks of invasions, help control and manage new and established invasive species, monitor impacts, raise public awareness, improve legislation and address international obligations:

Key Action 1. Detailed risk assessments and contingency plans should be urgently prepared for species that are likely to invade Ireland in advance of their arrival.

Key Action 2. Barriers to a rapid and decisive response to new invasions should be minimized by high level cross-jurisdictional and inter-departmental support for and funding of contingency plans.

Key Action 3. The ecological and economic impact of long-standing alien species and technology for their control should be investigated in detail in order to plan and execute cost-effective strategies for control and eradication.

Key Action 4. Legislative provisions should be analysed and new legal frameworks developed specifically for dealing with invasive species, while facilitating beneficial introductions.

Key Action 5. A framework, including support for specialist identification skills, should be established for the collation and cross-border exchange of information on non-native species.

Key Action 6. Measures for the prevention and eradication of invasive species should be incorporated into agri-environment schemes.

Key Action 7. The dissemination of information to the public and the engagement of stakeholders, particularly in the commercial sector, should be prioritised by developing online, educational and scientific resources, and by targeted public awareness campaigns.

Key Action 8. The use of native species in amenity planting and stocking and related community actions to reduce the introduction and spread of non-native species should be encouraged.

Key Action 9. The two jurisdictions should continue to work through international mechanisms to improve the regulatory and policy framework for dealing with invasive non-native species.

Key Action 10. A cross-border specialist group should establish a dedicated agency to lead on invasive species issues, beyond the immediate actions prioritised above.

Contents

Background to the project

i Introduced species

Introduced species and genetic material have a major impact on biodiversity. When non-native species become invasive they can transform ecosystems, and threaten native and endangered species. The problems caused by invasive non-native species are so serious that the introduction of these species is identified as one of the main causes of biodiversity loss worldwide. This has been recognised in decisions on alien species agreed by the contracting parties to the Convention on Biological Diversity (CBD), including Ireland and the United Kingdom. Proposals for addressing the impact of alien species on native biodiversity have been published in the biodiversity action plans produced in both Northern Ireland (*Biodiversity in Northern Ireland: Recommendations to Government for a biodiversity strategy 2002*) and the Republic of Ireland (*The National Biodiversity Plan for Ireland 2002*).

Recommendation 48 of *Biodiversity in Northern Ireland* is that the Government should "Review the past and current effects of introduced species and genetic material in Ireland, assess the risks of further introductions, and apply the guiding principles of the Conference of parties of the CBD". The Environment and Heritage Service (EHS) has a set target to "Complete a review of introduced species and genetic material in conjunction with the Republic of Ireland and make recommendations to the Minister by March 2004".

Action 28 of The National Biodiversity Plan for Ireland is to "Prepare strategies in consultation with Northern Ireland, to control introduced species and to prevent, or minimise, future (accidental or deliberate) introduction of alien species, which might threaten biodiversity. Unless clearly safe, all deliberate introductions of non-native species into Ireland will require a risk assessment."

The current project addresses the requirements of these two documents by undertaking an all-Ireland review of introduced species and by developing recommendations which can be proposed to the two Governments by March 2004.

ii. Recent work in Great Britain

There has been much recent research activity relating to introduced species in Great Britain. A review of non-native species policy was published by the Department of the Environment, Food and Rural Affairs (DEFRA) in March 2003. This evaluated the effectiveness of current statutory and non-statutory procedures, identified vectors of invasive species, put forward practical and proportionate proposals and identified appropriate organisations to take forward any measures recommended. The scope of the review excluded micro-organisms, invaders of agricultural crops and GMOs but included involvement of all appropriate stakeholders.

iii. Purpose of this review

The aims of this project are to review the impact of existing and potential future alien species on native biodiversity in Ireland and to recommend actions to Government in both jurisdictions that will address the requirements of the CBD decisions on alien species and improve their capacity to avoid or limit the ecological impact of alien species.

iv. Report structure

The report is structured as follows:

Section 1: The effects of introduced species on native biodiversity in Ireland.

Section 2: Vectors for the introduction and spread of non-native species.

Section 3: Legislation pertaining to non-native species.

Section 4: Practical management of invasive species.

Section 5: Recommendations to the two jurisdictions.

v. Project team

Dr. Kate O'Neill
Dr. Kate Stokes
Dr. Robbie McDonald
Dr. Jaimie Dick
Dr. Christine Maggs
Prof. Ian Montgomery

Section 1: The effects of introduced species on native biodiversity in Ireland

1 The effects of introduced species on native biodiversity in Ireland

1.1 Introduction: the costs and benefits of non-native species

Non-native species bring both costs and benefits which may accrue to different sectors of society (Callaghan, 2003). Benefits are wide-ranging and include new crop or pasture species, new aquaculture opportunities, ornamental plants and fish and novel biological control agents for economic pests. Costs include damage to existing economic interests, harm to native species and habitats, and the, often substantial, costs associated with preventing introductions of harmful species, monitoring existing populations and conducting control or eradication schemes.

The damage to native species and ecosystems worldwide caused by invasive non-native species is estimated to be as serious as the loss and degradation of habitats (IUCN, 2000). The economic and social costs of non-native species can be immense. A particularly prominent case is the introduction of the European zebra mussel *Dreissena polymorpha* to the Great Lakes of North America. Zebra mussels smother native clams and mussels and cluster around warm water outflow pipes from power stations. Mitigating the damage caused by zebra mussels has so far cost the USA 5 billion dollars (Marine Conservation Society, 2001).

Williamson's (1992, 1993) 'tens rule' suggests that 10% of non-native species imported into a region subsequently appear in the wild, 10% of these establish themselves as self-sustaining populations and 10% of the established species, i.e. 0.1% of imported species, then become invasive. Of established, non-native species in the UK, 8.5% of vertebrates, 6.5% of insects and 13.6% of plants have been described as having pest status though this is often a subjective term (Brown, 1986). A more recent review of the proportions of non-native species which are designated as "pests" is lacking. However it is worth noting that the designation of a non-native species as a "pest" generally reflects its potential to cause economic losses rather than impacts on biodiversity.

On a global scale, the most severe impacts of non-native species on native biodiversity have occurred on remote islands, where the native flora and fauna is less diverse, more isolated and so is more susceptible to invasion (Drake & Mooney, 1989). Ireland is comparatively isolated from continental Europe, reflecting its separation by sea since the last glaciation. As a result Ireland is home to a reduced number of native species in comparison with much of continental Europe (Costello, 1993). In the recent past, the majority of species introductions to Ireland have originated from Great Britain, also an island. Thus a filtering effect has been in operation, Ireland being the last land mass in a fragmented chain. As a result of its geographical location the number of introductions of alien species into Ireland has been smaller in comparison to much of continental Europe. However increasing global trade and migration over the last century have led to a marked increase in the rates of species introductions to Ireland, resulting in more frequent and noticeable impacts upon native biota.

1.2 Classification of the impacts of introductions on native biodiversity

The impacts of introductions on Irish biodiversity may be categorized according to whether the introduction has had a negative, positive or no significant impact upon native biota. Negative impacts may be further categorized according to the mechanism by which species are affected.

a) Competition Competitive impacts arise when non-native invaders and native species compete for resources (Table 1.1).
b) Herbivory Introduced herbivores may directly affect plant populations through grazing and trampling (Table 1.2) and have indirect effects by altering habitat. This could be a particular problem in more isolated ecosystems or on islands where species may have evolved without grazing pressure.
c) Predation Non-native species may kill and/or eat native species (Table 1.3), or themselves sustain higher populations of native or non-native predators.
d) Parasites or pathogens Introduced species may be parasites or pathogens (Table 1.4).
e) Alteration of habitat form or function. Introduced species alter the water table, fire regime, soil properties or vegetation structure and can make habitats unsuitable for native species (Table 1.5).
f) Genetic impacts. Hybridization may occur between non-native species and related native species (Table 1.6). The change in genetic constitution and in phenotype can be considered a loss in biodiversity, whilst hybridization may dilute the degree of local adaptations of native species to the local environment. Examples of hybridization have been most frequently reported for species of birds on a global scale (Cade 1983), although fish, mammals and plants are also affected. A particularly prominent Irish example is the hybridization between native red deer (*Cervus elaphus*) and Sika deer (*Cervus nippon nippon*) (Hayden & Harrington, 2000). A second consideration is the introduction of species of foreign provenance, for example many trees used in forestry are imported rather than using seed of local origin.

Post-invasion effects on the affected environment may be identified only at the community level, or after long term growth in the density/abundance of the invasive species. A lack of native predators in the invaded environment can result in alien predator populations achieving far higher densities in the invasive range than in the native range. The concept of hyperpredation (Smith & Quinn, 1996) predicts that an introduced prey species, well adapted to high predation pressure, could induce the extinction of an indigenous prey, through the sudden increased population size of an introduced predator. Alternatively, negative post-invasion effects may result from an alteration in the population dynamics of the invasive species. For example, within a new environment an invasive species may have a higher reproductive rate, reproduce at an earlier age or increase the number of reproductive events during its lifetime, subsequently resulting in greater population sizes in the introduced range than in the native range.

The assessment of alien species based on their effects on biodiversity may not be appropriate for alien species that have only recently established wild populations (Bullock *et al.*, 1996). Species that do not seem to be causing problems may still be expanding their range and/or building up populations, and may become a problem at a later date. It should be expected that assessing whether species achieve some stability in their numbers could be a lengthy process. An Irish example of this phenomenon is the belated explosive spread of American Willowherb (*Epilobium ciliatum*). This is a weedy, rosette-forming alien perennial from North America, first recorded in Ireland in County Wicklow in 1958 (Doogue *et al.*, 1985). After a delay of approximately 20 years this species began to spread in Ireland in an explosive manner typical of many successful introduced species (R. Forbes, pers. comm.). *Epilobium ciliatum* has been known to form hybrids with native willowherbs, *E. hirsutum* and *E. montanum*, and is known to compete with the latter (Doogue *et al.*, 1985). Whilst the impact of this process on native biodiversity appears minimal at present, it illustrates the potential for delayed rapid expansion of populations.

1.3 The importance of population dynamics

To gain a thorough understanding of the processes contributing to the decline of a native species or habitat as a result of the impact of an invasive species requires knowledge of the local and regional population dynamics of both, and the time scales over which such processes operate. Without such knowledge, predictive power and economic forecasting will be severely limited.

Populations are frequently subject to delicate balances unobservable to the casual eye and fluctuations in the processes maintaining these balances may result in rapid declines or increases. Some populations appear to be self regulating, in that specific processes are initiated when the population reaches a certain density of individuals (density-dependent processes). Other processes occur irrespective of the size of a population (density-independent processes). Quantifying the various density-dependent and density-independent processes that determine population size allows one to forecast the potential distribution of a species, i.e. the proportion of habitat where the births and immigrants exceed the deaths and emigrants, allowing population persistence. Some of the stabilizing processes operating in populations and the consequences of their disruption as a result of invasive non-native species are discussed below. Box 1.1 summarizes some of the main population processes involved in species invasions.

1.4 Impacts of invasive species in Ireland

Invasive species can have varying and complex effects on native biodiversity and economics. A few individual species are seen to have both positive and negative effects. An example of an accidental introduction known to have multiple influences is the brown seaweed, *Sargassum muticum*, commonly known as wire weed, strangle weed or "Jap weed". This species has increased the biological productivity of previously unproductive waters, in that it frequently colonises habitats not utilised by native algae. *S. muticum* stands can also provide shelter to young fish and crustaceans and fishermen have reported higher catches of eels, mullet, bass and prawns in seaweed stands (Davison, 1996). Negative impacts are attributed to *S. muticum* in that it simultaneously competes with native plant species, fouls marinas and aquaculture structures and clogs the intake pipes of boats and coastal power stations (Table 1.1). Dense growth on commercial shellfish beds may hinder shellfish growth and harvesting and buoyant *S. muticum* plants can float off, carrying away the shellfish to which they are attached (Davison, 1996; Strong, 2003).

Intentional introductions have been made in Ireland mainly for some specific economic gain. The intentional introduction of common cordgrass *Spartina anglica* was initially thought beneficial in protecting Irish coastlines from erosion before subsequent negative impacts were identified (Case Study 1.1). Introductions of fish species for sport fishing have generated increased tourist revenue but also impacted upon native fish populations (Table 1.1).

1.5 The domino effect of invasive species

Ecological processes are interlinked, resulting in a series of "knock-on" effects due to disruption of one initial component within an ecosystem. In Ireland, the introduction of the roach *Rutilus rutilus* has been implicated in the reduction of populations of several fish species through competitive superiority (Johannson & Persson, 1986). Native Atlantic salmon and brown trout *Salmo trutta* may be affected (Kennedy & Strange, 1978), rudd *Scardinius erythropthalmus* species have been displaced (Cragg-Hine, 1973) and perch *Perca fluviatilis* populations are highly susceptible to roach introductions (Johannson & Persson, 1986). The roach has, however, improved feeding for birds, to the extent that great crested grebe *Podiceps cristatus* and cormorant *Phalacrocorax carbo* populations have increased (Winfield *et al.*, 1994). However, increased winter feeding for cormorants in Lough Neagh has been implicated in increasing predation pressures by these birds on young salmonids in the River Bush (Kennedy & Greer, 1988), an example of hyperpredation.

Finally, the indirect impacts of an invasive species upon habitat sustainability are unknown. Bottom feeding fish can result in increased nutrient loading in lake environments, resulting in damage to an ecosystem and reduction of its amenity value (Table 1.5).

Competitive effects

Examples of direct competition between native and invasive species are documented in Table 1.1. *Rhododendron ponticum*, an invasive plant species, reduces native plant cover due to the dense shade spread by the many, low-lying branches of the plant (Case Study 1.2).

Herbivory

A number of economically damaging examples of herbivory by non-native species exist in Ireland (Table 1.2). The impacts of herbivory are not necessarily related to the size of an individual; invertebrate species like the red lily beetle *Lilioceris lilii* can cause extensive damage as can larger animals like the grey squirrel *Sciurus carolinensis* (Case Study 1.3) and sika deer *Cervus nippon*.

Predation

New Zealand flatworm *Arthurdendyus triangulatus* is the most serious predatory introduced species in Ireland, due to the choice of earthworms as a prey item (Table 1.3). Earthworms are fundamental in maintaining soil quality and their loss or reduction in numbers could have extensive economic impacts on agricultural production.

Parasites and pathogens

Some non-native parasites and pathogens in Ireland have been introduced via the aquaculture industry (Table 1.4). The high densities at which farmed fish populations are kept have resulted in increased probability of disease transfer from farmed fish to native populations.

Alterations to habitat

Invasive plant species in Ireland appear to be documented more frequently as the instigators of habitat change, although non-native fish species have also impacted significantly on freshwater lakes (Table 1.5). Giant hogweed *Heracleum mantegazzianum* in particular is responsible for alteration in river habitats (Case Study 1.4).

1.6 Genetic impacts

Hybridizations between native and non-native species of both plants and animals have been observed in Ireland (Table 1.6). Sika deer are perhaps one of the most extreme cases as they hybridise with the native red deer resulting in viable hybrids (Case study 1.5). An example of economic importance is the genetic impact of escaped farmed Atlantic salmon on native populations (Case study 4.1). To determine the likelihood and impact of such genetic change an experiment was undertaken, in a natural spawning tributary of the Burrishoole system in western Ireland, to compare the performance of wild, farmed and hybrid Atlantic salmon progeny (McGinnity *et al.*, 2003). This study demonstrated that farmed and hybrid progeny can survive in the wild to the smolt stage and these smolts can survive at sea and home to their river of origin. This indicates that escaped farm salmon can produce long-term genetic changes in natural populations. While some of these changes may be advantageous from an angling management perspective, they are likely, in specific circumstances, to reduce population fitness and productivity (McGinnity *et al.*, 2003).

1.7 Summary of impacts on biodiversity

In Ireland the most prominent negative impacts, in terms of the number of studies reporting the effects of non-native invasive species, appears to be direct competition with native biota (Table 1.1), whilst alteration to habitats (Table 1.5) and the influence of parasites and pathogens (Table 1.4) jointly take second place. However, the most serious impacts in terms of economic damage remain to be assessed.

1.8 Impacts of invasive species on the Irish tourism industry

Invasive species can potentially both enhance and detract from the economic value of the natural landscape. Natural biodiversity is a highly valuable asset to Ireland's tourist industry and the protection of this valuable resource should be a priority. Unintentional species introductions which reduce the capacity for tourist activities (such as Giant Hogweed restricting riverbank access) degrade the economic value of the landscape. Alternatively, the stocking of rivers with fish such as rainbow trout has increased the attraction of Ireland as a venue in which sport fishing can be enjoyed within an enriched landscape.

The Tourism Policy Review Group (2003) state that "the Irish tourism industry is, arguably, the most important Irish-owned sector of enterprise, national and regional wealth creation and employment generation". The economic contribution of tourism is of particular value, given its very low import content in comparison with other exports and its significant contribution to regional development.

It is vital that any features which are perceived as unique to the Irish landscape are retained as regional attractions, as it is these features which enhance Ireland's appeal as a tourist attraction. Examples of such features could include red squirrels and Irish hares.

1.9 Ireland's international obligations

The biodiversity plans for Northern Ireland and Ireland must meet international obligations. For example, the main danger posed by introductions of the North American ruddy duck, *Oxyura jamaicensis*, is that it threatens the survival of a long-term European species, the white-headed duck *Oxyura leucocephala*, which is not found in Ireland but is a native species of conservation interest in continental Europe (Hughes, 1996). Ruddy ducks from feral UK populations began to reach Spain in the mid-1980s and threaten the white-headed duck with extinction through hybridisation and competition.

1.10 Irish Priorities

An essential priority is to integrate information across the island of Ireland, in order to quantify population distribution and abundance across landscapes and increase our knowledge of the population dynamics of both native and invasive species. The Centre for Environmental Data and Recording (CEDaR), established in 1994 by the Ulster Museum and funded by EHS provides local records for Northern Ireland. However, there is a need to develop and maintain a comprehensive database of species for the Republic of Ireland. Case-specific studies in Ireland remain a priority, in that identification of the regulatory processes determining population growth rates in Ireland will aid in both conserving natives and reducing the distribution and abundance of invasive species. Further exploration of the consequences of non-native species invasions should be investigated through assessment of the ecological impacts of functional and performance consequences on affected species, on habitats, ecological processes and ecosystems. Increased accessibility of scientific results should be made available to policy makers, through categorizing the existing research and presenting it in a non-technical and easily accessible manner.

Box 1.1 Examples of population processes affecting the invasive properties of non-native species

Minimum Viable Population (MVP)
The Minimum Viable Population (MVP) is the minimum population size below which the population will go extinct through ecological or genetic factors (Lehmkuhl 1984, Wielgus, 2002). If populations are isolated from immigration they may be potentially limited by low internal genetic variability, stemming from small population size and potential inbreeding. Populations of invasive species may be prevented from reaching a sufficiently high density to maintain positive population growth rates due to competition, predation or herbivory from native species, fluctuating environmental conditions or maladaptation.

Allee effects
Allee effects are positive relationships between any component of individual fitness and either numbers or density of individuals of the same species (Stephens *et al.*, 1999). Allee effects indicate that populations will be depressed at very low levels of abundance. Small populations, below a lower threshold, are proportionally more prone to extinction (Stephens & Sutherland, 1999). Allee effects will slow the rate of advance of an invasive species (Lewis & Kareiva, 1993). However, native species' ranges may be truncated, even where suitable habitat is available, should their populations fall below a threshold as a result of competition with an invasive species.

Dispersal
To gauge the effects of invasive species accurate information is needed on species' distribution and spread. Immigration from source populations towards the edge of a species range may maintain positive population growth rates in the recipient sink populations (Pulliam, 1989). The rate of spread of a species is often determined by processes at the fringe of a population where densities are low and under the influence of Allee effects. Among native species, the disruption of dispersal processes, such as increased death rate during dispersal attributable to the introduction of a novel predator, would reduce population persistence.

Positive density-dependent habitat selection
For mobile species, distribution patterns may be based not only on their ability to disperse successfully but also decisions on site selection influenced by competition within habitats. Site occupancy will reflect habitat quality, with high quality habitats being occupied first and animals only moving to poorer quality habitats at high density. This type of density-dependent habitat selection has been termed the buffer effect (Kluyver & Tinbergen, 1953) because poor quality habitat effectively buffers good quality habitat from any changes in numbers when total population size fluctuates. Buffer effects result in increases in range size with abundance, as individuals either expand into or contract out of poorer quality habitats as population size changes (Watkinson *et al.*, 2003). However, in a situation of competitive displacement by invasive species, alterations in native communities may result from enforced migration. Alternatively habitat quality may be insufficient effectively to buffer the native population from an overall reduction in size.

Metapopulation processes
The population dynamics of organisms can vary according to the distribution of individuals at a range of spatial scales (Telfer *et al.* 2001, Hanski *et al.* 2002). Metapopulation theory (Levins, 1970; Levins & Culver, 1971) considers the regional dynamics of species through investigation of the proportion of suitable habitat patches that are occupied relative to the rates of colonization and extinction. Reductions in habitat quality as a result of the introduction of invasive species could disrupt metapopulation dynamics of native species and reduce their persistence.

Case study 1.1 Common cordgrass *Spartina anglica*

Category of introduction Intentional.

Reasons for introduction *Spartina anglica* was introduced during the 1940s to increase sediment accretion in coastal protection schemes (Bleakley 1979). It has been effective in this respect.

Pathway for introduction *S. anglica* is a relatively new species formed from the hybridization of *S. alterniflora* and *S. maritima* approximately 100 years ago. The natural distribution of *S. anglica* is thought to be between Poole, Dorset and Pugham, Sussex and possibly northern France, all other distributions round the world being intentional introductions. Between 1924 and 1936 more than 175, 000 fragments and many seed samples from Poole Harbour were shipped to 130 sites round the world (Hubbard, 1965). *S. anglica* spreads vegetatively and once established can cover large areas rapidly.

Problems caused by the introduction In the past *Spartina* has been associated with lowering invertebrate faunal diversities and densities and changing the course of mudflat-saltmarsh succession by altering plant communities, although there is recent controversy regarding these effects (McCorrey *et al.* 2003). *S. anglica* replaces the mudflat habitat with a less diverse, monospecific sward and subsequently reduces the intertidal feeding ground for waders and other birds. Mud and saltflat communities based on bottom-dwelling microalgae will decline, being replaced by food webs driven by the supply of *Spartina* detritus. *Spartina* also alters the physical shape of coastal areas. Prior to colonization, in areas where the norm is gently-sloping mudflats and shallow estuaries, *Spartina* alters the landscape to form badly drained marshes that commonly have steeply sloping seaward edges and deep, steep-sided channels (McCorrey *et al.* 2003). As a result flooding can be a problem, particularly near river mouths. In addition infestations can block some navigational channels and reduce the recreational amenity value of an area.

How the effects could be mitigated
S. anglica is a relatively new species and therefore there are relatively few herbivores and diseases that affect the plant, even in its native range. However due to its low genetic variability, and the fact that the plant spreads largely by vegetative means, *S. anglica* is potentially vulnerable to parasite and pathogen infestation. In Northern Ireland the 1985 Wildlife Order makes it an offence to plant, or cause to grow in the wild, any species of *Spartina*. Partially successful attempts have been made to control *S. anglica* spread on Bull Island, Dublin, on Strangford Lough and on Lough Foyle since the early 1970s with herbicide applications.

Invasion dynamics outside of Ireland *Spartina* is native to the Atlantic and Gulf coasts of North America but an aggressive, exotic invader in the Pacific Northwest. Recent greenhouse studies have shown that *Spartina* clones were severely stressed or killed by moderate populations of *Prokelisia marginata*, a leafhopper common in *Spartina's* home range (Daehler & Strong, 1997). Research is currently underway in America to evaluate the host range of *P. marginata* and to prepare a parasite-free and disease-free culture for distribution as a biological control agent.

References
Bleakley, B. 1979. *Spartina* – an unwelcome immigrant, *Irish Hare*, 2, 10-12.
Hubbard, J.C.E., 1965. *Spartina* marshes in southern England. VI. Pattern of invasion in Poole Harbour. *Journal of Ecology*, 53; 799-813.
McCorrey, M, Curtis, T.G.F. & Otte, M.L., 2003. *Spartina in Ireland*. In *Wetlands of Ireland, distribution, ecology, uses and economic value*. Otte, M.L. (ed.) University College Press Dublin, 44-50.

Case study 1.2 *Rhododendron ponticum*

Category of introduction Intentional.

Reasons for introduction Ornamental plant.

Pathway for the introduction
Rhododendron was brought to Britain as seed from southern Spain in 1763. From Kew Gardens the species was distributed widely across Britain and Ireland. Initially it was unpopular; its mauve flower colour was unfashionable at the time and it was also relatively expensive to buy. A severe UK winter (1879-1880) revealed the extreme hardiness of *R. ponticum* and the species became increasingly used as game cover on sporting estates, as wildlife habitat and as a windbreak. The plant began to propagate itself by wind-dispersed seed, reducing the cost of seedlings, and by 1849 the plant suddenly became fashionable as an ornamental. The plant has been used extensively as rootstock for other rhododendrons in horticulture and it can be beneficial to the tourist industry. It is now a rampant invasive species in Killarney (Cross, 1981, 1982; Kelly 1981), where upwards of 650 acres (260 ha) of Killarney National Park are completely infested.

Problems caused by the introduction
The plant invades three habitats that are considered internationally important under the Habitats Directive: upland oak woods, bogs and heath. *Rhododendron* plants form impenetrable thickets which cast deep shade and reduce native plant cover (Rotherham & Read, 1988). The plants also secrete allelopathic toxins which reduce regeneration of native plants. Tissues of *Rhododendron ponticum* contain high concentrations of phenols, which are highly toxic if ingested by herbivores, and there are few natural enemies. The plant is difficult to control because of successful regeneration after cutting, herbicide application or fire. *Rhododendron ponticum* spreads locally by layering (vegetative spread) and abundantly through the production of huge numbers of tiny wind dispersed seeds and it is economically expensive to control. The plant is an economic pest for forestry as it affects natural regeneration, establishment, management and harvesting. Rhododendron is also host to the plant fungus *Phytophthora ramorum* which has been detected at three locations on nursery stock in Northern Ireland and three locations on "wild" stands in the Republic of Ireland. This fungus has caused extensive problems in California as the causative agent of "Sudden Oak Death", although European oak species appear more resilient.

Control methods
Practical control includes manual labour, mechanical removal, herbicide application (Imazapyr and Glyphosate) and stem injection with herbicides (Edwards *et al.*, 1993, 1996, 1997, 1999, 2000). Physical methods of control may cost between £1500 – 7000 (€ 2236-10435) per hectare at the upper end of the range and require hard physical labour. The general costs of herbicide are estimated at £85 – 400 (€ 127-600) per hectare for the chemicals alone. However, the waxy foliage can provide a barrier to herbicide uptake and there are health and environmental risks associated with volatilization, drift and leaching into watercourses. There is a strong case for biological control and a number of natural enemies have been identified in the native range of the species, including a rust fungus from Portugal.

Invasion dynamics outside of Ireland
The plant is native to Turkey and Spain but severely invasive and ecologically damaging in Britain. It has also naturalized in France, Belgium and New Zealand but is not regarded as an invasive problem there. Even in its native habitat, the plant is considered a pest of managed forests in northern Turkey.

References

Cross, J.R., 1981. The establishment of *Rhododendron ponticum* in the Killarney oakwoods, SW Ireland. Journal of Ecology, 69, 807-824.

Cross, J.R., 1982. The invasion and impact of *Rhododendron ponticum* in native Irish vegetation. Journal of Life Sciences Royal Dublin Society, 3, 209-220.

Edwards, C., Tracy D. & Morgan J., 1993. *Rhododendron* control by imazapyr. Research Information Note 233, Forestry Commission, Edinburgh

Edwards, C, & Morgan J.L., 1996. Control of *Rhododendron ponticum* by stump applications of herbicides following mechanical clearance. Proceedings Crop Protection in Northern Britain II, 213-218.

Edwards, C. & Morgan J., 1997. Cut stump applications with imazapyr. Forestry Commission Research Information Note 293, Edinburgh

Edwards, C., Clay D.V. & Dixon F.L., 2000. Stem treatment to control *Rhododendron ponticum* under woodland canopies. Aspects of Applied Biology, 58, 39-46.

Edwards, C., 1999. Herbicide control of *Rhododendron ponticum* following mechanical clearance by hydraulic flail. Proceedings Crop Protection in Northern Britain

Kelly, D.L., 1981. The native forest vegetation of Killarney , south-west Ireland : an ecological account. Journal of Ecology, 69, 437-472.

Rotherham I.D. & Read D.J., 1988. Aspects of ecology of *Rhododendron ponticum* L. with special reference to its competitive and invasive properties. Aspects of Applied Biology, 16, 327-335.

Case study 1.3 American grey squirrel *Sciurus carolinensis*

Category of introduction Intentional.

Reasons for introduction Recreational and aesthetic.

Pathway for the introduction
Introduced from England into Ireland at Castle Forbes, Co. Longford in 1911 (Watt, 1923), where six pairs were released for aesthetic reasons. Within ten years they had reached pest proportions. From County Longford they were recorded in Westmeath (1927), Cavan (1946), Fermanagh (1946) and Armagh (1953). Grey squirrels have spread freely since their introduction, colonising areas of deciduous woodland and Ireland's extensive hedgerow network. There have been some natural barriers to the spread of the grey squirrel: the River Shannon slowed its expansion westwards, Lower Lough Erne northward and Lough Neagh/Lower Bann River into the north-east. In all cases, however, the grey squirrel has overcome these obstacles, e.g. crossed bridges as is the case in the Lower Bann River.

Background to the introduction
At the time of the introduction to Ireland there was less knowledge of the possible harm likely to result from releasing non-native mammals. At this time, the movement of plants and animals around the world was regarded favourably by many people. There was a perception that non-native species were welcome exotic enhancements to familiar native flora and fauna, rather than potential problem species.

Problems caused by the introduction
The grey squirrel is a long-established invasive non-native species which has impacted significantly on native wildlife and also causes economic damage. Grey squirrels can cause considerable damage to forests by stripping bark from a wide range of broadleaf and coniferous species. The spread of the grey squirrel throughout Ireland has been associated with a decline in red squirrel populations. They out-compete the native red squirrel and it has been proposed that they spread the parapox virus to red squirrels. The competitive advantage of the grey squirrel over the red squirrel is thought to be greatest in areas with a higher proportion of deciduous tree species. Currently control of the impacts of grey squirrels can only be achieved through by killing animals. Public acceptability needs to be considered in respect of methods of control of mammals and other techniques have been investigated. Experimentation with immuno-contraception has given disappointing results after a promising start.

How the introduction might have been prevented
It is unlikely that the introduction of grey squirrels could have been prevented given the mindset of the time and the number of similar introductions into Britain. If the spread of the grey squirrel were to have been halted a concerted effort would have been needed at a very early stage. Even so, once they spread from the estate at Castle Forbes it would have been nearly impossible and containment and control are now the best options.

Invasion dynamics outside Ireland
Grey squirrels are well established in most of England, Wales and southern Scotland, and have colonised many urban areas in these regions. As far as woodlands are concerned, the grey squirrel is probably the most damaging non-native species that Britain has had to contend with. The extinction of the red squirrel in England and Wales is a possibility in the foreseeable future, although they are more secure in Scotland. The grey squirrel is also causing problems in northern Italy.

References
Hayden, T. & Harrington, R., 2000. *Exploring Irish Mammals*. Townhouse, Dublin.

Case study 1.4 Giant hogweed *Heracleum mantegazzianum*

Category of introduction Intentional but subsequent spread has been accidental.

Reason for introduction Ornamental plant

Pathway for the introduction
Giant hogweed spreads mainly along river and canal corridors. Colonization and spread have been mainly in a downstream direction reflecting the dependence of the plant upon seed dispersal by flowing water. Other pathways for spread are railway lines and roadways where the plant can be abundant on areas of waste ground.

Background to the introduction
Hogweed was first recorded in Ireland in the late 19th century, although the exact date is not known. The plant was recorded as "naturalized" in the country in Blackrock Park in Dublin in 1902. In 1987 *H. mantegazzianum* was recorded in 23 vice-counties in the island of Ireland. By 1989 the species had extended its distribution to a further 7 vice-counties, a spread which had been primarily along river corridors (Caffrey, 1994). Figure 1.1 shows the distribution of giant hogweed in Northern Ireland and the Republic of Ireland up to 1989 and since 1989.

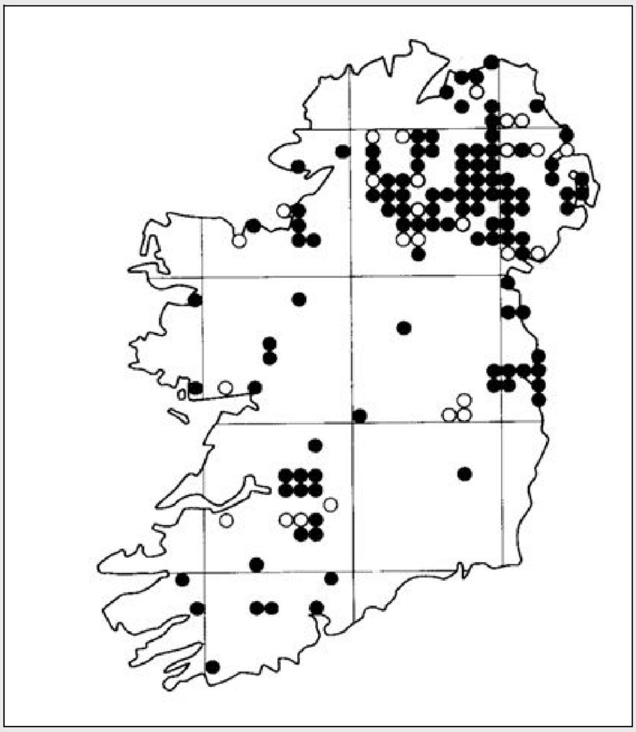


Figure 1.1. Distribution of *Heracleum mantegazzianum* in Ireland. Black circles are sites recorded prior to 1989. White circles are additional sites recorded since 1989. (Reproduced from Wade *et al.* 1997)

Problems caused by the introduction
Giant hogweed poses a health hazard to humans as skin contact with the sap of the plant causes irritation, particularly in direct sunlight. Symptoms include skin blisters and rashes which appear 24 - 48 hours after contact and often require hospital treatment. Post-inflammatory hyper-pigmentation can persist for 6 years after initial contact. On some sections of Ireland's more popular salmonid and coarse fishery rivers (e.g. Newport in County Tipperary, Mulkear in County Limmerick, Bride in County Cork and Dee in County Louth) dense bankside infestations have developed restricting access to the water. Financial and

social implications for angling clubs and local tourism are considerable. The plant also excludes indigenous herbaceous plants which are essential in maintaining riverbank stability. In winter *H. mantegazzianum* dies back, exposing the soil which is washed into rivers, altering substrate characteristics and providing favourable conditions for abundant aquatic plant growth, whilst rendering river substrates unsuitable for salmon spawning. In addition *H. mantegazzianum* hybridizes with the native *H. sphondylium*, although hybrids have low pollen fertility (Grace & Nelson, 1981).

How the introduction might have been prevented
In Northern Ireland the planting of *H. mantegazzianum* was made illegal under the 1985 Wildlife Order. In the Republic of Ireland the Office of Public Works undertook a recent 4-year control/eradication programme (1998-2002) in the Mulkear River catchment, devising a protocol which when applied over a 4-year period will deplete the seedbank and reduce the possibility of re-infestation of an area (Caffrey, 1994).

References

Caffrey, J.M., 1994. Spread and management of *Heracleum mantegazzianum* (Giant Hogweed) along Irish River Corridors. *Ecology and management of riverside plants*. De Waal, L.C., Child, L.E., Wade, M., Brock, J.H.(eds) England: John Wiley & Sons Ltd. pp. 67-76.

Lundstrom, H. & Darby, E., 1994. The *Heracleum mantegazzianum* (Giant Hogweed) problem in Sweden: suggestions for its management and control. *Ecology and management of riverside plants*. De Waal, L.C., Child, L.E., Wade, M., Brock, J.H.(eds) England: John Wiley & Sons Ltd. pp. 93-100.

Tiley, E.D. & Philip, B., 1994. *Heracleum mantegazzianum* (Giant Hogweed) and it control in Scotland. *Ecology and management of riverside plants*. De Waal, L.C., Child, L.E., Wade, M., Brock, J.H.(eds) England: John Wiley & Sons Ltd. pp. 101-110.

Case study 1.5 Sika deer *Cervus nippon*

Category of introduction Intentional.

Reasons for introduction Recreational and aesthetic.

Background to the introduction

One stag and three hinds were introduced from London into Ireland by Lord Powerscourt at his estate in County Wicklow. None of the original records exist and the stock of the original animals cannot, therefore, be confirmed. Lord Powerscourt bred these animals successfully and some were transported to other Irish counties including Limerick, Fermanagh, Tyrone and Kerry. The sika deer acclimatised very well, and there were at least 100 of them in the Powerscourt estate by 1884. Hybrids were also noticed in the same year (Hayden & Harrington, 2000). The sika (and sika/red hybrids) continued to flourish and eventually escaped from the deer park in 1922, during a period of political unrest. Since 1936 the sika deer have colonised large areas of land in Co. Wicklow, and have spread to counties Wexford, Kildare and Carlow. The main reason for the rapid colonisation of the Wicklow area by sika deer from the 1930s onwards was the extensive afforestation of upland areas of the Wicklow Mountains under the tree planting schemes of the state forestry board (1930-1950s), thereby creating large tracts of habitat suitable for sika deer. In 1865 one stag and two hinds were transported to the Killarney area (Muckross Lake), where Lord Kenmare released them into the wild for hunting purposes. Whitehead (1964) estimated that by 1935 the herd numbered between three and five thousand, with numbers decreasing to one thousand by 1948 with no reason cited.

The spread of sika deer, especially in Killarney, is in part due to the presence of woodland or forest in early successional vegetation state and also the presence of the invasive plant species *Rhododendron ponticum*. Sika deer exhibit preferences to these habitats and extensively use the *Rhododendron* for cover.

Problems caused by the introduction

Sika deer pose a threat to the genetic integrity of the native red deer (Hayden & Harrington, 2000). Sika deer and red deer hybridise and the hybrids are fertile and have no apparent competitive disadvantage compared to red or sika deer (Hayden & Harrington, 2000).

Sika deer can become a serious pest of commercial forestry and agriculture. They reduce timber production by browsing leader shoots of young trees, by scoring the bark with antlers and by stripping bark with the teeth. The major impact is the damage they cause to newly planted trees (Hayden & Harrington, 2000). The problems associated with sika deer lies in their destruction of saplings, which prevents regeneration within some tracts of woodlands which represent the last vestiges of primordial woodlands in Ireland. The native Yew wood (*Taxus baccata*) on Muckross peninsula is unique to Ireland and has been subjected to heavy grazing by sika deer. In upper regions of Looscaunagh wood there is effectively no regeneration, where the ground vegetation is heavily grazed and churned up by sika deer. In 1976 greater awareness of the importance of the natural woodlands in the area and the growing concern about their survival prompted the Office of Public Works and the Forestry and Wildlife Service to propose an annual cull of sika deer. The proposed cull was introduced in 1979 with the Forestry staff culling in areas leased to the Forestry dept and park staff culling within the park itself.

Invasion dynamics outside Ireland

Sika deer are highly adaptable in their feeding habits and show seasonal variation in habitat preferences in relation to food abundance. Their colonizing ability has resulted in the displacement of red deer and other cervid species in the USA.

References

Hayden, T. & Harrington, R., 2000. *Exploring Irish Mammals*. Townhouse, Dublin

Whitehead, G., 1964. Japanese sika deer in Ireland. *The Deer of Great Britain and Ireland*. Routledge and Keegan-Paul, London.

Case study 1.6 Roach *Rutilus rutilus* (Contributed by R. Rosell)

Category of introduction Intentional.

Reasons for introduction Recreational

Background to the introduction
Ireland's truly native freshwater fish fauna consists only of species able to colonise Inland waters from marine environments after the end of the last glaciation. Half of the current list of 22 freshwater species is considered to be postglacial introductions. In lowland waters, Roach are now Ireland's most abundant species, dominating biomass in many lakes. The history of roach introduction and subsequent, in many cases deliberate, spread has been documented by Fitzmaurice (1981) and others.

Roach were introduced into Ireland, along with dace, in 1889, when specimens brought from England as bait for pike accidentally escaped into the Co. Cork Blackwater (Went 1950). By 1940 the entire river Blackwater system was colonised by both roach and dace. In 1905, The Baronscourt lakes on the Foyle system were stocked with roach, to provide food for pike (Hale 1956). These fish are thought to have been transferred from the original introduction site in the Cork Blackwater. The roach subsequently disappeared from the Baronscourt lakes, but some must have moved downstream to the River Strule, giving rise to populations in the Rivers Strule and Fairywater.

The Cork Blackwater and Foyle system Strule/Fairywater populations remained isolated for some time, until in 1931 roach were deliberately transferred into Galbally Lake, on the Erne system. In 1960 dredging of the outflow of this lake allowed fish to escape to the River Erne. The first roach in the Erne river system were noted in coarse fishing competitions in 1963 and by 1966 roach were a common feature of anglers' catches (Mercer 1968, Kennedy and Fitzmaurice 1973). By 1973 they had colonised the entire upper Erne system, and rapidly became the dominant fish by biomass in the whole system (Cragg- Hine 1973, Rosell, 1994).

From the Upper Erne system roach passed, possibly via the (then semi-derelict) Ballyconnell canal to the Shannon system, then spreading throughout the 1970s to a wide range of sites, assisted by transport as anglers live bait for pike. By the early 1980s they were widespread throughout Ireland, including the Foyle, Shannon, L Neagh/River Bann, Boyne, Shannon, Corrib and Lee systems. (Fitzmaurice 1981). During the late 1980s and 1990s spread continued and by 2000 they had reached every major river catchment in Ireland, probably absent only from a few montane or small coastal systems without recreational pike fisheries. The latest new site is Lough Melvin, Co Leitrim, where Roach/rudd hybrids were noted in 2002 (Delanty & O'Grady, 2002)

Problems caused by the introduction
Initially, roach were not thought likely to have any major impact on other native or previously introduced fish (Went, 1950). This assessment proved, however, to be wrong. Following roach population explosion in Lower Lough Erne, rudd, a much earlier introduction to Ireland, disappeared (Cragg-Hine 1973), and this pattern has been repeated everywhere roach have been introduced to large lakes containing rudd. Rudd are now largely confined to small, isolated lakes without roach or to densely weeded sites where they are apparently more able to compete with Roach (Winfield, 1986).

Roach can have severe ecological consequences, particularly when lakes become enriched from mesotrophic to eutrophic conditions. Their ability to reach a large biomass and heavily graze zooplankton can exacerbate the algal blooms associated with nutrient enrichment in lakes. They can apparently accelerate the switch from clear water mesotrophy to a turbid water eutrophic state, effectively altering their environment to their own requirements. Biomanipulation experiments in Finland have shown significant water quality benefits following large-scale roach removal (Horppila et al 1994). It is probable that the high biomass reached by roach in Irish lakes has contributed to the effects of eutrophication. (Rosell and Gibson 1994)

The latest invasive introduction to Irish freshwater, the Zebra Mussel, may now act to control roach populations by removing some of its plankton food source. This may not, however come with any significant benefit to any of the native species affected by roach and/or eutrophication. In the long term, it is probable that the only viable roach (and Zebra mussel) control strategy likely to maintain elements of the affected native biodiversity is maintenance of low trophic status through effective control of nutrient loads to freshwater (Rosell et al 2003).

References

Cragg-Hine, 1973. Coarse fish and fishery management in Northern Ireland. Proceedings of the 6th British Freshwater fisheries conference, University of Liverpool.

Delanty, K., & O'Grady, M.F., 2002. Lough Melvin Fish survey report. Central Fisheries Board.

Fitzmaurice. P. 1981. The Spread of roach Rutilus rutilus in Irish waters. Proceedings of the second British Freshwater Fisheries Conference, University of Liverpool, 154-161.

Hale, P. A., 1958. Roach Rutilus rutilus occurring in Co Tyrone. Irish Naturalists Journal, 12. 160-169.

Horppila, J. 1994b. The diet and growth of roach in lake Vesijarvi and possible changes in the course of biomanipulation. Hydrobiologia, 294, 34-41.

Kennedy, M., & Fitzmaurice, P., 1973, Occurrence of Cyprinid Hybrids in Ireland. Irish naturalists Journal 17, 349 – 351.

Mercer, J.P., 1968. Roach *Rutilus rutilus* L., a new record from Co Fermanagh.

Rosell, R. S., 1994. Changes in fish populations in Lower Lough Erne: a comparison of 1972-3 and 1991-2 gill net survey data. *Biology and Environment: Proceedings of the Royal Irish academy*, **94B**, 275-283.

Rosell, R. S., & Gibson. C.E., 2000. Interlinked changes in fish populations and their environments in Lower Lough Erne, Northern Ireland. *Verhandlungen der Internationale Vereinigung fur Limnologie,* **27**, 2095-2099.

Rosell, R.S., Maguire, C., MacOscar, K., & Roberts, D. 2003. Changes in fish population of Lower Lough Erne, Ireland, following invasion by Zebra mussels. Abstracts of papers presented at the Society of European Freshwater Sciences conference, Edinburgh, July 2003.

Went, A.E.J., 1950. Notes on the Introduction of some freshwater fish into Ireland. *Journal of the Department of Agriculture, Dublin,* **47**, 119-124.

Winfield, I.J., 1986. The influence of simulated macrophytes on the zooplankton consumption rates of juvenile roach, rudd and perch. *Journal of fish biology* **29** (A) 37-48.

Table 1.1 Negative impacts of non-native species on Irish biodiversity: competition

Non-native species	Ecosystems or habitats affected	Impacts
a) Vascular plants		
Rhododendron ponticum	Woodland, grassland, heath	Invasions into natural broadleaf woodland in Killarney & Glenveagh National Parks and acidic soils in the west of Ireland. Plants form dense stands which cast deep shade and reduce native plant cover (Usher, 1987). Lowland heath vegetation and soils are changed enormously by invasion (Mitchell *et al.,* 1997). The plants also secrete toxins into the soil which reduces regeneration of native plants.
Australian swamp stonecrop *Crassula helmsii*	Native aquatic flora	All species form dense stands that shade out native flora, particularly Giant Hogweed (Wyse Jackson, 1989). Dense infestations of *Crassula helmsii* can choke native aquatic plants and deplete the waters of oxygen resulting in competition for limiting resources.
Giant hogweed *Heracleum mantegazzianum*	River banks	
Japanese knotweed *Fallopia japonica*		
Indian balsam *Impatiens glandulifera*	Range of habitats	
Entire leaved cotoneaster *Cotoneaster integrifolius*	Dense flowered orchid *Neotinea maculata*	*Cotoneaster integrifolius* is spreading in Knockninny and Balmore and reducing habitat availability at sites supporting the rare dense flowered orchid.
Salmonberry *Rubus spectabilis*	Native deciduous woodlands	This woody shrub produces dense stands preventing regeneration of native trees. It is spreading in plantations in Armagh and broadleaved plantations in Donegal and elsewhere.
b) Seaweed		
Japanese brown algae/wire weed *Sargassum muticum*	Native coastal marine habitats and plants	Spread in Strangford Lough where it is likely to compete with eelgrass (*Zostera* species) and indigenous algae, as it does on the French Atlantic coast. e.g. *Laminaria saccharina.* Fouling of ships, marinas, moorings, nets, shellfish and aquaculture structures also takes place.
c) Invertebrates		
Zebra mussels *Dreissena polymorpha*	Native fish populations *Anodonta* spp.	High densities of filter feeders like zebra mussels reduce phytoplankton and zooplankton levels which decreases food availability for juvenile fish. Zebra mussels also compete for resources such as space with native freshwater mussels and other benthic invertebrates such as chironomids and webspinning caddis flies in the littoral zone.
d) Vertebrates		
Grey squirrel *Sciurus carolinensis*	Red squirrel *Sciurus vulgaris*	Grey replacing red over much of its former range. Greys have a feeding advantage in deciduous woods (Gurnell, 1983, 1989), possibly due to better ability to tolerate phytotoxins in acorns (Kenwood & Holm, 1993).
Farmed Atlantic salmon *Salmo salar*	Native Atlantic salmon *Salmo salar*	Adult farmed salmon escapees are less successful at reproducing in the wild but their offspring are highly sexually precocious, outcompeting native salmon in river environments.
Introduced fish species e.g. roach *Rutilus rutilus*	Native fish populations	Either competitive replacement of native fish or formation of introduced × native hybrids
	Tufted duck *Aythya fuligula*	There is also evidence that roach compete for the same benthic food as tufted duck, with reductions in the populations of duck being causally linked to roach population increases (Winfield *et al.*, 1992; Winfield *et al.*, 1994)

Table 1.2 Negative impacts of non-native species on Irish biodiversity: herbivory

Non-native species	Ecosystem or species affected	Impacts
Japanese sika deer *Cervus nippon nippon*	Native woodlands and native red deer	Grazing damages coppice regrowth in woodlands (Kay, 1993). Numbers in County Wicklow are inflicting some damage to commercial forestry.
Canada geese *Branta canadensis*	Reed bed, saltmarsh and other vegetation	Damage by overgrazing, particularly in the Lough Erne area of County Fermanagh.
Feral goats *Capra hircus*	Native vegetation	Damage by overgrazing
Red lily beetle *Lilioceris lilii*	Lilies and fritillaries	Defoliation of plants, damage to flowers, seed capsules and stems during heavy infestations (Anderson *et al.,* 2002)
Grey squirrel *Sciurus carolinensis*	Native trees, reafforestation programmes and commercial plantations	Bark-stripping of trees by the grey squirrel causes extensive damage (Case Study 1.3).

Table 1.3 Negative impacts of non-native species on Irish biodiversity: predation

Non-native species	Ecosystems or species affected	Impacts
New Zealand flatworm *Arthurdendyus triangulatus*	Earthworms	Reduces earthworm populations to undetectable levels, thus impacting soil processes.
American mink *Mustela vison*	Native birds, mammals, fish and crustaceans along waterways	Impacts some waterbird species but the magnitude of the effects are unknown (Ferreras & Macdonald, 1999).
Freshwater shrimp *Gammarus pulex*	Native shrimp *Gammarus duebeni celticus*	Decline in native invertebrate community diversity through competition and predation mechanisms; which has a potential unknown effect on the diet of native fish species (Dick, 1996; MacNeil *et al.*, 2000).
Introduced piscivorous fish e.g. Pike *Esox lucius*	Native fish species e.g. salmon *Salmo salar*	Predation by piscivorous fish introduced as stocking fish in freshwater river systems

Table 1.4 Negative impacts of non-native species on Irish biodiversity: parasites and pathogens

Non-native species	**Ecosystems or species affected**	**Impacts**
Plant fungus *Phytophthora ramorum*	Native oak trees	This fungus, carried by *Rhododendron ponticum* is believed to have caused extensive problems in California as the causative agent of "Sudden Oak Death", although European oak species appear more resilient.
Bee ectoparasites *Varroa destructor* (formerly *V. jacobsoni*)	Native honey bees *Apis mellifera*	Causes large declines in commercial hives. Honey bees are generalists and rarely the sole pollinator of any plant. Due to the lack of knowledge about pollination in Ireland it is unclear whether this reduction in commercial honey bees will have a large or small impact on native plant species that rely on pollination (R. Paxton, pers. comm.)
Farmed Atlantic salmon *Salmo salar*	Native Atlantic salmon *Salmo salar* Native sea trout *Salmo trutta*	The increase in numbers of farmed salmon has increased the incidence of the copepod ectoparasites. The collapse of sea trout populations in the west of Ireland is due to increased infection by sea lice from salmon farms (Marine Work Group, ROI 2003).
Protistan *Bonamia ostrea*	Native flat oysters	Losses of flat oysters due to the disease may be in the region of 80% or more in the Republic of Ireland (Marine Work Group, ROI 2003). Northern Ireland currently has a disease free status regarding *B. ostrea*.
Parapox virus	Red squirrels *Sciurus vulgaris*	Grey squirrels are believed to act as a carrier to the disease which red squirrels are extremely susceptible to, although the prevalence of the disease in Ireland is unknown.
Dutch elm fungus *Ceratocystis ulmi*	Elm trees *Ulmus* spp.	Spread by beetles of the genus *Scolytus*, or through roots of adjacent trees. Indirectly affects invertebrates dependent on elm and many farmland birds (Osbourne, 1985)
Eel swimbladder nematode *Anguillicola crassus*	Freshwater eels *Anguilla anguilla*	First reported in Lower Lough Erne in 1998 this nematode considerably reduces eel fishery profits and is now widely distributed in Ireland (Evans *et al.*, 2001)
Crayfish plague *Aphanomyces astaci*	White-clawed crayfish *Austropotamobius pallipes*	Since the first confirmed outbreak of the plague fungus in Lough Lene, Co. Westmeath in 1987 (Reynolds, 1998) and its suspected recurrence elsewhere (Reynolds, 1988), repeated surveys have indicated the loss of stocks from several midland lakes (Matthews & Reynolds, 1992; Matthews *et al.*, 1993)

Table 1.5 Negative impacts of non-native species on Irish biodiversity: habitat alteration

Non-native species	**Ecosystem or species affected**	**Impacts**
Giant hogweed *Heracleum mantegazzianum* Japanese knotweed *Fallopia japonica* Indian balsam *Impatiens glandulifera*	Riparian habitats Aquatic freshwater habitats	As well as being aggressive colonists of river banks and shading local flora, in winter plants die back, exposing soil which is eroded into rivers, altering substrate characteristics, providing favourable conditions for abundant aquatic plant growth and rendering the river substrates unsuitable for salmon spawning (Caffrey, 1994; Lucey, 1994).
Non-native conifers/plantations	Aquatic freshwater biota	Planted on poorly buffered acid/acid-sensitive soils partly blamed for increased acidification of uplands. Subsequent felling generates more acid stream water (Neal *et al.*, 1992) which can have a consequent effect on fish populations.
Cordgrass *Spartina anglica*	Coastal floodplain environments Native bird species	Rapid colonization of *Spartina* over sites with large wintering population of waders and wildfowl reduces habitat availability for feeding and roosting. *Spartina* alters shallow estuaries to form badly drained marshes that commonly have steeply sloping seaward edges and deep, steep-sided channels. Results include increased flooding, blockage of navigational channels and reduced recreational amenity value of an area.
Zebra mussels *Dreissena polymorpha*	Aquatic freshwater habitats	Significant removal of material from the water column to the benthic environment by zebra mussels increases water clarity and thus increases macrophyte growth. The species also causes fouling in water pipes (Minchin & Moriarty 2002)
Tench *Tinca tinca*	Various native species	Bottom-feeding fish increase water turbidity by churning sediment while feeding. Declines in aquatic plants consequently cause reduction in invertebrate populations such as snails and dragonflies. De-oxygenated sediment disturbed through fish feeding activities can release nutrients, in particular phosphorus, which in turn increases crops of phytoplankton resulting in a more eutrophic habitat.
Sea buckthorn *Hippophae rhamnoides*	Sand dune ecosystems	Nutrient enrichment, increased stabilization and acceleration of succession occurs. Sea buckthorn also changes the composition of mesofauna and ground beetle communities (Binggeli *et al.*, 1992).

Table 1.6 Negative impacts of non-native species on Irish biodiversity: genetic

Non-native species	**Ecosystem or species affected**	**Impacts**
Farmed fish	Native fish populations	Experiments in NW Ireland demonstrate that farmed and hybrid progeny can survive in the wild, indicating that escaped farm salmon can produce long-term genetic changes in natural populations (McGinnity *et al.*, 2003).
Bumblebee *Bombus terrestris terrestris*	Bumblebee *Bombus terrestris audax*	*B. terrestris terrestris* was introduced from mainland Europe for commercial agriculture and hybridizes freely with the native Irish bumblebee *B. terrestris audax,* which could lead to a breakdown in local adaptation to the Irish environment (M. Brown, pers comm.)
Japanese sika deer *Cervus nippon nippon*	Native red deer *Cervus elaphus*	A potential threat to the genetic integrity of the native red deer herd present in Killarney National Park.
Spanish bluebell *Hyacinthoides hispanica*	Native bluebell *Hyacinthoides non-scripta*	*H. hispanica* hybridizes with the native *H. non-scripta* and the hybrid is widespread in County Down to the exclusion of the native bluebell. The hybrid is also common in County Cork (O' Mahony, 1991, 1996, 1997) and around Doldrum Bay (Reynolds, 2002).
Midland hawthorn *Crataegus laevigata*	Common Hawthorn *Crataegus monogyna*	Midland hawthorn hybridizes freely with native species of hawthorn, threatening the genetic integrity of the native species (Jones & Evans, 1994).

Section 2: Vectors for the introduction and spread of non-native species

2 Vectors for the introduction and spread of non-native species

2.1 Introduction

For millennia, the natural barriers of oceans, mountains, rivers and deserts provided the isolation essential for unique species and ecosystems to evolve (IUCN, 2000). Many of these natural barriers have been undermined by modern transportation, enabling species to travel large distances to regions where they are not native. The globalisation and growth in the volume of trade and tourism, along with the emphasis on free trade, provide more and continued opportunities for species to be spread accidentally or deliberately (IUCN, 2000). Customs and quarantine practices, developed to protect health and economic interests against diseases and pests, have often been found inadequate safeguards against species that threaten native biodiversity (IUCN, 2000).

Europe is a major trading bloc with many contiguous states that has highly-developed free trade arrangements. Live plants and animals are translocated, intentionally and unintentionally, in the course of routine trading activities within and between states. Potentially invasive alien species may easily reach neighbouring states or ecologically different parts of the same state (Genovesi & Shine, 2003).

Humans have introduced most of the non-native species in Ireland, intentionally or accidentally. Many artificial introductions are of such long standing, however, that they are generally accepted as part of the Irish countryside, e.g. sycamore *Acer pseudoplatanus* and rabbits *Oryctolagus cuniculus* (Bullock *et al.*, 1996).

By comparison with Britain and continental Europe, the terrestrial and freshwater fauna of Ireland is relatively impoverished reflecting Ireland's isolation by sea since the last glaciation (Costello, 1993). The lower diversity of species, the absence of particular groups, and the lack of a coevolutionary history with invaders, may influence the susceptibility of Ireland to invasive species (Minchin, 2000).

2.2 Vectors

A better understanding of how alien species are spread, together with the knowledge of the critical numbers needed to form new populations and when and where this is most likely to happen, will greatly aid the management of invasive species. The routes by which alien species enter new areas are known as *pathways* while the way they travel to new destinations are known as *vectors* (UNEP, 2001). Pathways and vectors for alien species are numerous (Table 2.1) and can be a result of a diverse array of human activities operating over a range of scales in time and space (UNEP, 2001).

Primary introductions result from the accidental transport of species such as on fouled hulls or in transported water including ballast. Shipping, activities and air transport of living organisms are the main modes of transmission for primary introductions (Minchin & Gollasch, 2002).

Secondary introductions result from the expansion of the alien species from its first location of establishment. This secondary spread will normally include a wider range of vectors that may act either separately or together (Minchin & Gollasch, 2002). Some vectors may transport fundamentally different sets of organisms; for example, mussels attached to hulls, species sheltering within the mussel clumps, species encrusting the mussels, species burrowing into the mussel shells, and pathogens or microalgae inside the mussels. Conversely, some species may be spread by several different vectors; for example, larval mussels may be transported amongst the plankton in ballast water; adult mussels as hull foulers, as species for aquaculture or as accidentally introduced species associated with stock for culture (ICES CM, 2003).

Some species have more than one possible vector. For example the seaweed *Codium fragile tomentosoides,* which was unintentionally introduced to Ireland, may have been introduced attached to shellfish such as oysters, attached to ships' hulls, as spores in ballast tanks or conceivably through natural rafting and floating (Eno *et al.,* 1997). Some species have been introduced via one vector and have spread via another vector/pathway. For example, *Codium fragile atlanticum*, was unintentionally introduced to southwest Ireland in association with shellfish, from where it has spread through rafting or floating (Eno *et al.,* 1997). Table 2.1 summarises the vectors for the introduction of non-native species.

Some vectors may be classed as both intentional and accidental. For example, in the case of aquaculture and mariculture, species are intentionally introduced for farming purposes. However, some of the animals may escape and result in the unintentional introduction of new species or their associated flora and fauna into a new environment. As a result of this potential risk, aquaculture and mariculture activities are strictly monitored and regulated to reduce the risk to an economically important industry in both Northern Ireland and the Republic of Ireland.

2.3 Biological control

Biological control involves the introduction of a predator, parasite or pathogen of a particular pest species in order to suppress the pest species population (Fasham & Trumper, 2001). The control agent should be host-specific and should not attack native species. Native species usually have natural enemies that appear to regulate the population at a lower density than the maximum possible. Natural enemies include predators, pathogens, parasites or herbivores (Bullock *et al.*, 1996).

Problems occur when a species is moved from its native range to an area where these enemies are not present. In this case a biological control programme may be initiated in order to remove the invasive species. One of the characteristics of a biologically controlled system of populations is that prey and predator, or host and parasite populations are often reciprocally density-dependent (Caltagirone & Huffaker, 1980). For all practical purposes these systems can be self-sustaining and permanent. In theory, biological control offers the ideal solution to the problems associated with invasive species. Pest species subjected to biological control programmes throughout the world include aquatic plants, terrestrial plants, herbivorous arthropods, predatory and parasitic arthropods, non-arthropod invertebrates and vertebrates. Non-native biological control agents have rarely been released into the wider environment in the British Isles; most applications are of biological control agents into glasshouses (Fasham & Trumper, 2001).

Biological control programs can be initiated to support species that have themselves been introduced. For example, the accidentally introduced eucalyptus psyllid *Ctenarytaina eucalypti*, has caused economic damage to a commercial eucalyptus plantation in County Kerry (Purvis *et al.*, 2002). In order to reduce this deleterious impact, an Australian parasitoid wasp *Psyllaephagus pilosus*, was introduced as a control agent (Chauzat *et al.*, 2002).

Table 2.1 Summary of the vectors for the intentional and accidental introduction of non-native species.

Intentional Introductions
1. Biological control
2. Wildfowl and game stocking
3. Horticulture, amenity and ornamental planting, stocking and collections
4. Pet shops, aquaria and scientific institutions
5. Fur farming
6. Forestry
7. Agriculture
8. Aquaculture and mariculture

Accidental Introductions
1. International freight, tourism and travel
2. Fishing equipment, angling and pleasure boats
3. Ports
4. Shipping
   a. hull fouling
   b. ballast water and its sediments
5. Parasites and pathogens carried by invasive species
6. Inland waterways
7. Aquaculture and mariculture
8. Horticulture, amenity and ornamental planting, stocking and collections
9. Pet shops, aquaria and scientific institutions

The grass carp *Ctenopharygdon idella* is used sometimes in the UK to control aquatic weeds but can bring about excessive reduction of beneficial aquatic plants (Stott, 1974; Crivelli, 1995). This may affect native invertebrate species that use areas of invasive aquatic plants. Thus biological control agents, although chosen to be host-specific, may switch to feed on other species and affect non-target organisms.

Howarth (1991) listed factors affecting the degree of risk to non-target organisms:

Permanency of the agent in the environment. The chances of a non-target organism being adversely affected increases with the length of time the control agent is in the environment. The more generations for which an agent persists, the greater is its potential to spread, and the greater is the risk of host and habitat shift.

Host range. Agents with narrow host ranges are less likely to affect other species and those with a broad host range have greater potential to affect non-target organisms.

Habitat range. Species with a greater habitat range can invade a greater number and variety of communities.

Genetic adaptability. The generation time of invertebrates is much shorter than that of higher organisms, and consequently they have a greater tendency for genetic change. The shift from ecological specialisation to generalisation in some rapidly reproducing short-lived species may have a relatively simple genetic basis.

Behaviour of the control agent. Dispersal ability, host-searching and host-handling abilities can enhance a control agent's chances of increasing habitat range and attacking non-target organisms.

Vulnerability of the target region. Most extinctions caused by biological control agents have occurred on islands or in freshwater habitats. In part this may be due to the greater use of biological control on islands, and to superior documentation of extinctions in these habitats.

Indirect effects on native organisms resulting from biocontrol programs. Indirect effects resulting from biocontrol programs in Ireland remain largely unstudied. However, comparative examples from elsewhere in Europe suggest that the potential for indirect influences upon native biota exists. Biocontrol of rabbits *Oryctolagus cuniculus* using *Myxoma* in the UK is believed to have resulted in the extirpation of the large blue butterfly *Maculina arion* through a series of indirect effects that fatally linked this species with rabbits (Moore, 1987). The large blue required nests of the ant *Myrmica sabuleti* for the development of their larvae. These ants in turn had become dependent on rabbit grazing to maintain open habitat for their nests, so biocontrol of the rabbits with the *Myxoma* virus initiated a cascade of interactions believed to have led to the extinction of the large blue in the UK in 1979 (Thomas, 1995).

Food-web interactions can also result from the introduction of biocontrol agents. For example, if an established biocontrol agent is ineffective at reducing its host densities, populations of the biocontrol agent are likely to remain abnormally high due to abundant food resources (Pearson & Callaway, 2003). High concentrations of a particular biocontrol agent can provide an increased source of food for native consumers. Many native organisms are food limited and food subsidies to key native organisms can serve to restructure community interactions, whether inputs come from native or exotic sources.

2.4 Wildfowl and game stocking

Ireland has a long history of introducing species for sport; past introductions included pheasant *Phasianus colchicus*, red-legged partridge *Alectoris rufa*, fallow deer *Dama dama* and rainbow trout *Oncorhynchus mykiss*. All of these species breed to some degree in the wild and compete with native species and alter their habitats. In addition, plant species were introduced as game cover (e.g. snowberry *Symphoricarpos albus*) (Fasham & Trumper, 2001).

Bait organisms used for angling may be exported beyond their normal range and may be discarded alive to the wild to form new populations. An example of a bait organism brought into Northern Ireland is the freshwater shrimp *Gammarus pulex* (Case Study 2.2). This species was introduced as prey for the native Brown trout in the Ballinderry River system in Northern Ireland. Since its introduction this species has spread in Northern Ireland and more recently in the Republic of Ireland (Kelly *et al.*, 2003).

Numerous bird species have established wild populations either through deliberate releases or accidental escapes. Examples include the ruddy duck *Oxyura jamaicensis* and the mandarin duck *Aix galericulata.* The ruddy duck is thought to be an uncommon breeding resident in Ireland, with populations found in Lough Neagh (approximately 89 birds), Portmore Lough (approximately 54 birds) and in Limerick and northeast of Limerick. The presence of ruddy ducks in Ireland has been linked to the expansion of the English feral population (NI Bird Report, 1999). Mandarin ducks are found in Tollymore, County Down where there is an estimated population of 20-30 pairs (NI Bird Report, 1999).

Mammal introductions include deer species such as sika deer *Cervus nippon*, which were introduced to deer parks, subsequently invading woodlands and hybridising with the native red deer *Cervus elaphus* (Hayden & Harrington, 2000).

2.5 Horticulture, amenity and ornamental planting, stocking and collections

Many animal and plant species have been introduced into Ireland solely for their decorative qualities (Bullock *et al.*, 1996). Ornamental gardening began in Ireland during the medieval period with specimens coming from Europe and West Asia, then later Africa, the Far East and the Americas as trade routes opened across the world. Many of these ornamental species have escaped from private gardens, parks and garden centres and have established wild populations. Some of these species have then become invasive by spreading to natural habitats, particularly along river corridors. Examples of invasive terrestrial plants introduced to Ireland in this manner include Rhododendron *Rhododendron ponticum*, giant hogweed *Heracleum mantegazzianum*, Japanese knotweed *Fallopia japonica* and Himalayan balsam *Impatiens glandulifera*. Invasive ornamental aquatic plant species introductions include stonecrop, *Crassula helmsii*.

In addition, large-scale planting of public areas such as road verges has not only commonly included non-native species, but also non-native strains of native species (Fasham & Trumper, 2001). Examples of the latter include hybrids of bird's-foot trefoil *Lotus corniculatus*, oxeye daisy *Leucanthemum vulgare* and red clover *Trifolium pratense*.

2.6 Pet shops, aquaria and scientific institutions

Animals imported as pets and domestic animals can find their way into the wild, either by deliberate release or accidental escape, where they may subsequently breed. Examples include feral and domestic cats (which have been known to hybridise with wild cats *Felis silvestris* in Scotland).

The valuable trade in ornamental fish presents an interesting case. In Northern Ireland, import of ornamental fish and plants is allowed subject to the granting of an Import Licence and compliance with EU requirements (DARD, 2003). Voluntary trade organisations have taken the lead in reducing illicit trade and associated spread of invasive species and vectors of disease. It has been suggested that the international trade in tropical and ornamental fish has been responsible for the direct spread of diseases such as Epizootic Ulcerative Syndrome in (caused by the bacteria *Yersinia ruckeri*) in a number of European countries. However, most ornamental fish are introduced to closed systems where they present little threat. Escapes and deliberate releases do occur but trade organisations have had a demonstrable role in encouraging responsible ownership.

In May 2003, The Department for Environment, Food and Rural Affairs (DEFRA) issued an Order under the Diseases of Fish Act 1937, prohibiting the movement of fish to and from two fish farms in Worcestershire, following an outbreak of Spring Viraemia of Carp (SVC). SVC is a serious viral disease affecting common and ornamental carp as well as a variety of other wild species including tench, roach, rudd and pike. SVC is widespread in many European and Asian countries from where fish are imported, legally and illegally, into the United Kingdom (E-Fish Business, 2003a). Again, legitimate trade will present less of a problem than illicit activities.

In the case of scientific institutions, zoological gardens and aquaria, there are many exotic organisms held. Unfortunately, the secondary spread of such organisms is apparently common-place (Bullock *et al.*, 1996).

By way of indicating the variety of non-native species being introduced, Table 2.2 lists 30 species of aquatic plant that were imported into the Republic of Ireland in 2002. These imports were licensed for sale in aquarium and garden centres. As yet, no invasive properties have been identified in these species.

2.7 Fur farming

The farming of animals for their pelts is another long-standing reason for the introduction of non-native species (Bullock *et al.*, 1996). In Ireland, the American mink *Mustela vison* was first introduced in the early 1950s for fur farming, and soon escaped and established feral populations. The population densities of American mink in Ireland are believed to be at, or near, the carrying capacity of the environment and in all cases appear self regulating (Smal, 1991). Availability of the crayfish *Austropotamobius pallipes* appears to be a major factor in determining mink numbers and stability within populations in Ireland (Bullock *et al.*, 1996).

Legislation for the regulation of fur farms does exist in Ireland. The Department of Agriculture and Food in the Republic of Ireland brought in a licensing scheme in 1966 and similar regulations were introduced for Northern Ireland in 1968. From the 1st January, 2003 the Fur Farming (Prohibition) (Northern Ireland) Order 2002 made it illegal to conduct fur farming in Northern Ireland. The Government in the Republic of Ireland has not made plans to ban fur farming in the Republic of Ireland. Currently there are six mink and two fox fur farms in the Republic of Ireland (Compassion in World Farming, 2003).

2.8 Forestry

Many native trees are slow growing and site-sensitive species. In the past the land available for afforestation was often on exposed marginal agricultural land. This resulted formerly in little economic justification for the planting of native trees for commercial forestry. Faster growing, non-native conifer species were widely planted in Ireland on these marginal soils. Furthermore, the commercial basis of the forestry industry in the UK relies greatly on introduced tree species, particularly Sitka spruce from North America (Forestry Authority, 1998).

These faster growing non-native species have been known to invade some semi-natural and disturbed habitats beyond areas where they have been planted (Bullock *et al.*, 1996). In addition, planting of species beyond their native habitats and the use of non-local provenance stock is common in the commercial, amenity and ornamental forestry sectors. However, forestry departments increasingly recognise the importance of broadleaf native woodland. In recent years land of higher fertility has become available for forestry in Ireland thereby enabling the establishment of commercial native broadleaved plantations. In the Republic of Ireland the Forest Service national target is 30% of annual afforestation by 2006. The Forest Service also grant aids the protection of native woodlands and the establishment of new native woodland through its Native Woodland Scheme. UK Forestry Guidelines highlight the need to plant at least 5% of the area of any new conifer woodland with broadleaved trees or shrubs (Forestry Authority, 1998).

2.9 Agriculture

Since humans first moved from one region to another, crop species have been moved with them. Agriculture has been responsible for many plant introductions over the years (Fasham & Trumper, 2001). Many long-established species were originally introduced for their utility value, e.g. most agricultural crops like maize, wheat, tomatoes, herbs, medicinal plants and also species introduced for pasture improvement (Bullock *et al.*, 1996). Long-established species also include archeophytes and more recently established (post 1700) neophytes (Preston *et al.*, 2002). Seeds of other plant species have also been accidentally imported with crop seeds, and some crop species themselves have become established in the wild. Examples include wild oat *Avena fatua*, and fodder crops such as Alsike clover *Trifolium hybridum*. Oil seed rape *Brassica rapa* is now a common sight on roadsides, field margins and disturbed ground adjacent to areas where the crop has been planted. Agriculture is a main secondary vector for the spread of invasive non-native species.

2.10 Aquaculture and Mariculture

Aquaculture and mariculture have long been recognised as important vectors for introductions of non-native species, both deliberate and accidental.

Both aquaculture and mariculture are particularly important for the rural economy. In Ireland, aquaculture is a particularly important industry; the volume of production in 2001 was 60,935 tonnes, worth €107 million (M. Mathies, BIM, pers. comm.). In general, introductions arising from aquaculture and mariculture are intentional and are regulated, approved and positively in line with government regulations. Aquaculture facilities are strictly licensed in the Republic of Ireland by the Department of Communications, Marine and Natural Resources (DCMNR) and by the Department of Agriculture and Rural Development (DARD) in Northern Ireland.

The international trade in live fish, shellfish and eggs for aquaculture, fisheries and the exotic food market has increased in recent years (Fasham & Trumper, 2001). A variety of non-native species are farmed in Ireland, including Pacific oysters *Crassostrea gigas,* the manila clam *Tapes semidecussatus*, the Japanese abalone *Haliotis discus hannai* and the European abalone *Haliotis tuberculata.*

Bord Iascaigh Mhara (BIM), an agency with responsibility for developing the Irish sea fishing and aquaculture industries has actively promoted the development of new opportunity species under its aquaculture diversification programme. This aims to increase aquacultural output from novel species in line with the more traditionally produced species such as salmon and mussels. This programme is vitally important in helping sustain rural employment and wealth creation in these communities.

The global market in seafood results in the long distance transport of live organisms for immediate consumption and these non-native organisms can be accidentally released into new environments where they can establish reproducing populations (Chapman *et al.*, 2003).

Table 2.2. Licensed imports of aquatic plants to the Republic of Ireland in 2002 (ICES CM 2003/ ACME:041)

Species	Number	Country of Origin
Alternantherna bettzicklana	20	Indonesia
Alternantherna lilacina	10	Indonesia
Alternantherna ocipus	20	Indonesia
Alternantherna reinckii	10	Indonesia
Ammannia gracilis	20	Indonesia
Bacoma amplexicaulis	10	Indonesia
Bacopa monnieri	10	Indonesia
Caboma aquatica	10	Indonesia
Echinodorus latifolius	10	Indonesia
Echinodorus pervensis-amazonicus	20	Indonesia
Elodea densa (Egeria densa)	10	Indonesia
Eustralis stellata	10	Indonesia
Hemigropsis sp.	10	Indonesia
Hydrocotyle leucocephala	20	Indonesia
Hygrophila lacustris	10	Indonesia
Hygrophila polysperma	40	Indonesia
Hygrophila corymbosa	20	Indonesia
Hygrophila salicifolia	10	Indonesia
Hygrophila siamensis	20	Indonesia
Lilaeopsis novae-zelandiae	10	Indonesia
Limnophila aromatica	30	Indonesia
Limnophila sessiflora	10	Indonesia
Ludwegia arcuata	10	Indonesia
Ludwegia repens-palustris	20	Indonesia
Micranthemum umbrosum	10	Indonesia
Nomaphila angustifolia	10	Indonesia
Nomaphila sp.	10	Indonesia
Physostegia purpurea	20	Indonesia
Rotala nanjenshan	20	Indonesia
Rotala wallichif	10	Indonesia

Holcik (1991) estimated that in Europe over 30% of introduced inland fish species originated from aquaculture. In the Republic of Ireland, BIM has been involved in supporting trials with Icelandic, Swedish and Canadian Arctic charr, *Salvelinus alpinus*. Arctic charr is native to Ireland. However, the Irish strain matures at a small size and is not well suited to culture, therefore more suitable strains have been imported (M. Mathies, BIM, pers. comm.). Furthermore, novel species aquaculture has been going on for years in Ireland supported by DCMNR, BIM, UnaG, TMT, the SRA and some of the Universities.

During the 1940s and 1950s the native oyster was imported as spat from areas in France with dense natural settlements. Oyster production increased in Ireland following trials with the Pacific oyster *Crassostrea gigas* which started in the late 1960s (Utting & Spencer, 1992). In the following years various species of exotic molluscs were used in trials with the intention of increasing aquaculture production. These were subject to periods of quarantine so as to ensure a disease-free stock (Minchin & Eno, 2002). An example was the introduction of the Japanese scallop *Patinopecten yessoensis*, from Japan to Ireland in 1990 (Minchin, 2003). The original introduced stock was not released into the wild, and only the F1 generation of scallops was released in 1990 and were held in hanging culture near Carnsore Point on the south-east coast, alongside the native scallop *Pecten maximus*.

In Ireland, the Pacific oyster *Crassostrea gigas* is produced in Irish hatcheries but is also imported from hatcheries in Britain and the Channel Islands and France. Cultivation takes place on all Irish coasts with the main production in Carlingford Lough and Dungarvan Bay. Following the 1993 European Free-Trade Agreement, the trade in half-grown Pacific oysters from France has resulted in the oyster-gut parasite *Mytilicola orientalis* being introduced to Ireland. In 1993 samples taken from Carlingford Lough, Dungarvan, Cork Harbour, and Oysterhaven revealed the presence of this organism (Holmes & Minchin 1995).

Irish oyster growers continue to be advised against bringing in half-grown oysters because of the high risk of importing unwanted biota. Movements of Pacific oysters have also been implicated in the spread of the Japanese brown alga *Sargassum muticum*.

Most marine salmon farms are liable to infestations of parasites and pathogens, probably originating from local wild salmon stock. Since the late 1980s it has been suggested that infection of wild post-smolt sea trout *Salmo trutta* by sea lice from non-native fish in fish farms has caused serious population reductions in the west of Ireland (Marine Work Group, Marine Institute, 2003). The collapse of sea trout populations from Galway Bay to Clew Bay has coincided with areas of intensive salmon farming and there is a widespread perception that increased infection by sea lice from salmon farms is an important factor (Marine Work Group, Marine Institute, 2003). However, there is now legislation in place in the Republic of Ireland to regulate and control sea lice and this regulation is part of every salmon farmer's licence conditions (M. Mathies, BIM, pers. comm.).

It has been the policy in the Republic of Ireland, since the 1960s, to refuse requests for shellfish and fish imports from unapproved areas, including oysters grown in France (Minchin & Rosenthal, 2002). However, EU free trade agreements did not take ecological matters fully into account and non-native species have been spread with species destined for aquaculture or mariculture (Minchin & Rosenthal, 2002).

A list of invertebrate species and fish species imported into the Republic of Ireland in 2002 is presented in Tables 2.4 & 2.5. All of these imports were licensed and regulated under the Fisheries (Amendment) Act, 1997. Under this Act any import of fish or shellfish has to be accompanied by the relevant movement documents and health certification requires that they be proven disease free before they are imported (M. Mathies, BIM pers. comm.). These tables highlight the diversity of species being imported from a range of areas.

2.11 Accidental introductions

The intentional import and release of species can give rise to unintentional introductions of species through vectors linked to the international trade in organisms (Fasham & Trumper, 2001). Species may also be introduced through activities not directly concerned with the transport of and trade in live organisms.

2.12 International freight, tourism and travel

Non-native species are commonly transported via freight and tourism, e.g. with the import of plants and plant products. For example, the New Zealand flatworm *Arthurdendyus triangulatus* was accidentally introduced to Northern Ireland in growing media (e.g. soil) traded in pots, trays and root-balled plants (Case Study 2.1). In addition, pathogenic organisms can be introduced via imports of live or dead animals or plants.

2.13 Fishing equipment, angling and pleasure boats

Movements of infested fishing gear or boats may allow species to colonise new regions (Wallentinus, 1999). Small boats may also be carried on trailers and are well understood as being important in overland species transmissions. Animals may be either carried in bait wells as larvae or attached to hulls, with re-immersion leading to the fouling biota being rubbed off (Minchin, Lucey & Sullivan, 2002). The trailer itself may also transmit species.

A threat that has already been recorded in Ireland is crayfish plague, caused by the fungus *Aphanomyces astaci.* The plague is usually introduced with the North American signal crayfish *Pacifastacus leniusculus* (Palmer, 1994). In October, 1987 the plague was recorded in Ireland in Lough Lene (Mathews & Reynolds, 1990) and destroyed most of the stock of native crayfish in one lake system. Outbreaks of the disease have not been noted since. The North American signal crayfish is not yet present in Ireland and, therefore, was not the vector responsible for the introduction of the plague to Ireland. Crayfish plague can be introduced into a water-body by water, fish or equipment that has been in contact with signal crayfish and these may have been the vectors in the case of crayfish plague in Ireland (Mathews & Reynolds, 1990). The spores of the fungus are able to survive in moist conditions such as on muddy boots and fishing gear (Holdich & Reeve, 1991). The spread of crayfish plague is difficult to control because it could be carried from one population to another by many different vectors (Holdich & Reeve, 1991).

2.14 Ports

A large number of organisms can be carried in a viable state to ports and waterways where shipping is the principal activity. A large variety of activities take place in ports (Rosenthal, 1997) and so ports may act both as donor and recipient for invasive species. In ports, vectors are likely to overlap because many people normally live in these regions and engage in a wide range of relevant activities. Many aquaculture activities are near ports or within natural bays due to the shelter and the proximity to markets. However, there is a risk that organisms carried with ships may impact on survival, compromise growth of the culture species or result in a product being unmarketable (Minchin & Gollasch, 2003). Because exotic species are likely to be present in ports, there are opportunities for the spread of these species with smaller boats (Minchin & Gollasch, 2003). Furthermore, marinas are frequently found in port regions and many boats may remain here for some time, allowing a build up of fouling biota (Minchin & Gollasch, 2003). Managing the overlap of vectors in such regions may lead to hard decisions regarding whether some activities should be restricted so as to reduce risk. Ports will benefit from studies of the exotic species present, particularly when there is a risk of that port acting as a donor to other regions. Irish harbours have been the recipient for invasive species. For example, an oyster gill condition was noted in about 22% of Pacific oysters *Crassostrea gigas* and 12% of native oysters *Ostrea edulis* in Cork Harbour in the autumn of 2000 and in 15% of Pacific oysters in Waterford Harbour in October, 2001 (Minchin, 2002). However, cryptogenic species may be responsible for this condition.

Table 2.3 Examples of vectors of intentional or accidental introductions that have resulted in the spread of non-native species to either Northern Ireland or the Republic of Ireland. It is important to note that some of the vectors can be classified as being both intentional and accidental vectors.

Intentional Introduction Vectors	**Non-native species**
Biological control	*Myxoma* virus, Psyllid parasitoid wasp *Psyllaephagus pilosus*
Wildfowl and recreational fishing stocking	Pheasant *Phasianus colchicus* Rainbow trout *Oncorhynchus mykiss* Freshwater shrimp *Gammarus pulex*
Horticulture, amenity and ornamental planting and stocking	Himalayan balsam *Impatiens glandulifera*
Pet shops and aquaria	Spring viraemia of carp
Fur farming	American mink *Mustela vison*
Forestry	Sitka spruce *Picea sitchensis*
Agriculture	Wild oat *Avena fatua* Oil seed rape *Brassica rapa*
Aquaculture and mariculture	Canadian Arctic charr, *Salvelinus alpinus* Pacific oyster *Crassostrea gigas*
Accidental Introduction Vectors	**Non-native species**
International freight, tourism and travel	New Zealand flatworm *Arthurdendyus triangulatus*
Fishing equipment, angling and pleasure boats	Crayfish plague fungus *Aphanomyces astac* Zebra mussel *Dreissena polymorpha* *Wire weed Sargassum muticum*
Ships' hull fouling	Possibly Red Algae *Antithamnionella ternifolia* Tubeworm *Ficopomatus enigmaticus* Tunicate *Styela clava*
Ships' ballast water and its sediments	Tubeworm *Ficopomatus enigmaticus* *Codium fragile* subsp. tomentosoides
Parasites and pathogens	Nematode bladder parasite *Anguillicola crassus*
Horticulture, amenity and ornamental planting and stocking	New Zealand flatworm *Arthurdendyus triangulatus*
Agriculture	Bearded Darnel *Lolium temulentum*
Aquaculture	Red seaweed *Polysiphonia subtilissima* Wire weed *Sargassum muticum* Oyster-gut parasite *Mytilicola orientalis*

Case study 2.1 New Zealand flatworm *Arthurdendyus triangulatus*

Category of introduction Accidental.

Reasons for introduction Economic trade. Through lack of precautionary measures to prevent the introduction of non-native invertebrates and other organisms in soil imported as a growing medium for living plants.

Pathway for the introduction
It was first discovered in Belfast in 1963. There is anecdotal evidence of earlier infestations. The introduction was associated with the plant trade. New Zealand flatworms arrived into Northern Ireland in association with potted plants of *Narcissus*.

Background to the introduction
UK plant trade with New Zealand because it is part of the Commonwealth.

Problems caused by the introduction
The problem caused by the New Zealand flatworm is the impact it has on earthworm biodiversity possibly resulting in their local extirpation. The New Zealand flatworm is a predator of the earthworms which keep our soils in good condition and are a source of food for many animals. The flatworm has been known to reduce earthworms to below detectable levels and hence poses a threat to native earthworms and the ecosystems dependent on earthworms, including agricultural production.

How the introduction might have been prevented
Stricter phytosanitary measures. Had there been knowledge of the species and the risk of its introduction, some trade measures may have been deemed appropriate to prevent the introduction from New Zealand in planting material, e.g. by only allowing bare rooted plants or requiring growing media accompanying plants to be sterile. Additionally a good level of awareness of the risk of moving it in plant material could have limited its spread once the introduction had taken place.

Research
The effect of the New Zealand flatworm on earthworm species diversity and the effect on the food chain is currently being undertaken (Moore *et al.*, 1998).

Invasion dynamics outside Ireland
Limited largely to the British Isles – Scotland, Ireland and Northern England. There is evidence that the New Zealand flatworm has limited tolerance of climatic variation and may only be a problem in areas that have a similar climate to its native habitat.

References
Moore, J.P., Dynes, C. & Murchie, A.K., 1998. The status and public perception of the New Zealand flatworm, *Artioposthia triangulata* (Dendy) in Northern Ireland. *Pedobiologia*, 2;563-571.

Case study 2.2 Fresh water shrimp *Gammarus pulex*

Category of introduction
Intentional

Reasons for introduction Recreational and economic.

Pathway for the introduction
Human vector. Introduced to several rivers in connection with fish farming practices, spreading rapidly in the North of Ireland and more recently in the Republic of Ireland.

Background to the introduction
Gammarus pulex was introduced in the 1950's by humans to provide additional feeding for native brown trout in the Ballinderry River system in Northern Ireland.

Problems caused by the introduction
The amphipod community has changed dramatically, from a single species to a patchwork of mixed species communities. *Gammarus pulex* displaces the native *Gammarus duebeni celticus*. The reduction and decline of the native invertebrate community distribution and diversity occurs through both competitive and predation mechanisms. The change in the diet of the native trout to that dominated by the introduced *G. pulex* has unknown effects on the population biology of trout.

How the introduction might have been prevented
Increased community awareness of the consequences of invasive species. Legislation preventing the introduction of non-native species as bait for angling.

Invasion dynamics outside Ireland
G. pulex is native to mainland Great Britain and to parts of Europe. *G. pulex* is also invasive in the Isle of Man and in Brittany in Northern France. In both areas it has displaced the native *G. d. celticus* in large areas of the natives distribution.

References
Kelly, D.W., Dick, J.T.A., Montgomery, W.I. & Macneil, C., 2003. Differences in composition of macroinvertebrate communities with invasive and native *Gammarus* spp. (Crustacea: Amphipoda). *Freshwater Biology*, 48; 306-315.

2.15 Shipping

Over millennia, marine species have dispersed throughout the oceans by natural means, carried on currents and attached to floating logs and debris. Shipping activities are believed to be primarily responsible for the majority of modern species introductions in the marine environment (ICES CM, 2003). Shipping transports over 80% of the world's commodities and transfers approximately 3 to 5 billion tonnes of ballast water internationally each year. The majority of introduced invertebrates have arrived in association with shipping either as fouling organisms or in ballast water. The spread of already established non-native marine species can be exacerbated by ships travelling along the coast.

2.16 Hull fouling

The phenomenon of ships and boats carrying exotic species on their hulls has been occurring for many centuries (Minchin & Eno, 2002). This is because when ships are in dry-dock they are supported on wooden blocks, the hull beneath does not get painted with antifoulants and at this point fouling may freely develop once the ship is reimmersed (Bullock *et al.,* 1996). Ships may have well developed fouling communities including mussels and oysters (Minchin & Eno, 2002). Serpulid and spirorbid polychaetes have spread extensively as fouling organisms both on ships and oysters (Zibrowius & Thorp, 1989). Furthermore, several invertebrates spread to new areas as a result of hull fouling could spawn when exposed to temperature fluctuations while entering the new ports and leave behind a viable inoculum of zygotes that could form a founder population (Minchin & Gollasch, 2003). One species, the 'shipworm', a boring bivalve, *Teredo navalis*, became extensively distributed as a result of hull fouling. This species has been recorded in Cork Harbour but no recent records exist (Minchin & Sheehan, 1999), perhaps as a result of reduced habitat availability. The Australasian barnacle *Elminius modestus* became established on the south coast of Britain carried on warships returning from the Pacific during the Second World War (Crisp, 1958). It has since spread and become abundant in many sheltered estuaries in Britain, Ireland and northern Europe.

Studies on species introductions in Europe suggest that hull fouling is an important vector of invasive species (Gollasch, 2002) and fouling organisms can occur in great numbers. However, since the use of tributyltin (TBT) as a toxic ingredient in hull paint coatings in the early 1970s, no further exotic species that can be attributed to hull fouling have occurred in Cork Harbour (Minchin & Sheehan, 1999). The deleterious effects of TBT, however, include altering of embryonic development, metamorphosis, 'imposex' (superimposed male features on female neogastropods leading to sexual impairment in some species) in neogastropods and the disappearance of some species in areas with high contamination both in water and in sediments (Mansueto *et al.*, 2003). In Cork Harbour the poor recruitment and decline of the scallop fishery is consistent with the relative levels of TBT contamination (Minchin *et al.,* 1987). There are also known impacts of TBT on the culture of molluscs (Alzieu & Heral, 1984) and salmonids (Short & Thrower, 1987).

2.17 Ballast water and its sediments

Ballast water is usually carried in segregated ballast water tanks or in emptied cargo holds and is taken on board in ports, waterways and the open ocean (IMO, 2000). Ballast water is essential to the safe and efficient operation of modern shipping, providing balance and stability to unladen and partly laden ships. Ships usually carry ballast water when no cargo is carried. However, even when the ship has a full load of cargo, some ballast water will remain in ballast tanks (Minchin & Gollasch, 2002). Ballast water may pose a serious ecological, economic and health threat because alongside the intake of ballast water, organisms, suspended solids and chemicals, including industrial and human wastes, are also pumped onboard (IMO, 2000). As the tanks will be filled and drained in different sequences either singly or collectively, the ballast water in one tank may be composed of water and sediments from several ports (Gollasch, 1996).

There are thousands of marine species that may be carried in ballast water; constituting those that are small enough to pass through ballast water intake ports and pumps. These include bacteria and other microbes, small invertebrates and the eggs, cysts and larvae of various species (IUCN, 2001). Discharge of ballast water or sediment into the waters at ports may result in the establishment of harmful aquatic organisms and pathogens which may pose threats to indigenous human, animal and plant life, and the marine environment (IMO, 2000). In 14 recent European ballast studies approximately 990 species were recorded from ballast tanks (water and sediment), ranging from bacteria to 15 cm long fishes (Gollasch *et al.,* 2003). The problem is compounded by the fact that virtually all marine species have life cycles that include a planktonic stage or stages (IMO, 2000). Thus, even species in which the adults are unlikely to be taken on board in ballast water because they may be too large or live attached to the seabed, may be transferred in ballast during their planktonic phase (IMO, 2000).

The ballast water discharged into Ireland mainly originates from British and other European ports (Minchin, 1996a; Minchin & Eno, 2002). Species that expand their ranges and colonise greater numbers of ports will subsequently increase the risk of their spread to Britain and Ireland on established trading routes. A study on ballast discharges in Ireland in 1994/5 showed that the greatest volumes were discharged in Cork Harbour and the Shannon Estuary (Minchin, 1996a). Trade with Baltic Sea ports to Irish estuaries could result in introductions of some Ponto-Caspian species that have colonised parts of the Baltic Sea (Minchin & Eno, 2002). The amount of ballast water discharged into Irish waters has been calculated to be 1.5 million cubic metres per year (Minchin, 1996a). This is likely to increase, however, with the expansion of port facilities (Minchin, 1996a).

In response to the threats posed by invasive marine species, the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, in its Agenda 21 called on the International Maritime Organization (IMO) and other international bodies to take action to address the transfer of harmful organisms by ships. The IMO has been addressing this issue and a number of remedies are being investigated including ballast water exchange by ships at sea. This method might well be the best practical option but does have shortcomings, in that it is not fully effective in removing organisms from ballast and may be subject to ship safety limits (Topfer, 2002). Ships that empty ballast tanks in bad weather can be structurally compromised which could lead to the loss of the vessel and its crew (Minchin, 2001).

2.18 Parasites and pathogens carried by invasive species

Parasites or pathogens may be carried by invasive species and transmitted to native species. The native species may be detrimentally affected by the new parasite or pathogen. In Ireland a potential threat is the spread of the parapox virus to the native red squirrel species by the invasive grey squirrel species. The origins of parapox virus are unknown, but antibodies of the virus have been found in grey squirrel populations in Northern Ireland (Northern Ireland Forest Service, 2003). Recent outbreaks of the virus in England have almost wiped out local populations (National Farmers Union, 2003). It has been found that the parapox virus is endemic in some grey squirrel populations, but rarely results in death in the grey squirrels (Gurnell *et al.*, 2003). It would appear that Grey Squirrels act as a reservoir host for the virus, which if passed on to red squirrels, results in death (Gurnell *et al.*, 2003).

One further example is that of imported stocks of the oriental eel *Anguilla japonica*, in which the lack of proper quarantine procedures ultimately led to the spread of the nematode bladder parasite *Anguillicola crassus* arriving into Germany and spreading from there. It has since become established in Ireland. This nematode parasite surrounds the airbladder of the freshwater common eel *Anguilla anguilla*. This parasite was first discovered in Ireland in Waterford in 1997. In 1999 it was recorded in the Lower Shannon River in Lough Derg and in the Erne catchment. This parasite was probably introduced by its infective stage being released in water used to refresh eels in a truck fitted with tanks with consignments eels captured in Britain before arriving in Ireland (Minchin, 2003). However, it is possible that the infective stage could be carried with copepods released with ships' ballast water or with water associated with imported fish for stocking rivers (Minchin, 2003). The introduction of this parasite may have long-term consequences for not only Irish eel populations, but also the North Atlantic stock which is declining for other reasons (Dekker, ICES WG reports).

2.19 Inland waterways: a pathway for the movement of invasive species

The existence of old canal systems and new waterways has allowed for the ready transmission of species, either by moving on their own accord or by inadvertently being carried by boats (ICES, 2003). The opening up of new waterways and restoration of canals creates corridors which allow the spread of non-native species by natural dispersal and via water crafts. An example of inland waterways aiding the spread of an invasive species in Ireland is the spread of the zebra mussel *Dreissena polymorpha* from the River Shannon to Lough Erne via the Shannon-Erne Waterway which was opened in 1994 (Case Study 2.3). A further example of invasive species being spread through inland waterways on small boats is the case of the tubeworm, *Ficopomatus enigmaticus*, which was noted in 1995 at a small boat marina in a shallow artificial lagoon on the Shannon Estuary and it is likely that it was carried on the hulls of pleasure boats from the only other known population in Cork Harbour (first recorded there in 1971) (Minchin & Gollasch, 2003).

2.20 Conclusions - Irish priorities

This review highlights the variety of vectors and pathways for the introduction and spread of invasive species in Ireland. Some vectors are hard to identify and a better understanding of how invasive species are spread together with research and data on the critical numbers needed to form new populations, and when and where this is most likely to happen, will greatly aid the understanding of the vectors of non-native species.

There are many vectors responsible for the introduction of non-native species into Ireland and it is not always clear which vectors are responsible for some introductions. In many cases more than one vector may be responsible.

In terms of priorities, the vectors responsible for the majority of invasive species introductions into Ireland appear to be related to shipping, effecting both deliberate and accidental introductions, and to the import of plants and associated material via horticulture. In the case of shipping, forty marine and brackish water exotic species have been recorded in Ireland (Appendix 1).

It is extremely difficult to monitor and regulate vectors. It is likely that shipping will continue to be an important vector and the port regions with a complement of exotic species, such as Cork Harbour and the Shannon estuary, may expect to receive more invasive species due to their sheltered conditions. Furthermore, in the coming century, should predicted changes in climate occur, natural ranges of organisms native to northern Europe are likely to change providing new opportunities for exotic species to expand their ranges (Minchin & Gollasch 2002).

The horticulture trade is another important vector with little data available on the numbers of species being introduced via this vector. This particular vector will be difficult to monitor and campaigns aimed at trade sectors and the general public will be necessary to generate increased awareness.

Research is necessary to increase the frequency and utility of risk assessment exercises so that a precautionary approach may be adopted to prevent the introduction of new species rather than trying to remove them once they have become established and invasive. In the long-term proactive measures are likely to be more cost effective than reactive control measures in both economic and ecological terms.

Case study 2.3 Zebra mussel *Dreissena polymorpha*

Category of introduction Unintentional.

Pathway for the introduction
The zebra mussel were noted in Ireland around 1994 and became invasive over the later 1990s (Pollux *et al.,* 2003). The main vector for the primary introduction of the zebra mussel was boating, accidentally attached to the hulls of second hand boats imported from Britain or the Netherlands (Minchin *et al.*, 2003; Pollux *et al.*, 2003). These boats, imported for private use mainly on the Shannon Navigation system, were lifted from British waters onto trailers, transported to Ireland by ferry and lifted into Irish waters within a day. They were introduced to the Lower Shannon River in 1994 and were recorded in the Limerick docks at the top of the Shannon estuary in the spring of 1995.

Following the establishment of zebra mussels they became attached to leisure craft and were carried upstream via locks and swing bridges to the entire navigation on Loughs Derg (11,600 ha), Ree (10,500 ha), Key (900 ha) and several smaller lakes by 1996. From the River Shannon Waterway they were accidentally carried into the Erne on the bottom of boats. By 1996 zebra mussels had become established in Lower Lough Erne via the recently restored Shannon-Erne Waterway in 1994 (Figures 2.1).

Background to the introduction
Several events in 1993 may have created an invasion window: the abolition in January 1993 of VAT on second hand boats within the EU, the introduction of a certificate of competence for second hand boats in England and an exchange rate favouring exports from the UK to Ireland. This combination of events resulted in an increase in a dispersal vector for zebra mussels: second hand boats, moving from England to Ireland. Human activities enabled the expansion of the zebra mussel and its further spread was made possible by a combination of natural and human-mediated dispersal mechanisms (Minchin *et al.*, 2003).

Problems caused by the introduction
Economic: water treatment plants, fish hatcheries and hydroelectric power stations in the Erne and Shannon systems have had to be modified to exclude zebra mussels. Education and public awareness campaigns have had to be financed.
Ecological: There have been widespread ecological impacts in both the Erne and Shannon systems. There have been changes in the abiotic components of the ecosystem with alterations in some nutrient concentrations, a dramatic increase in water clarity. A substantial decrease in the abundance of the phytoplankton and zooplankton communities have been recorded and these alterations of the food web have had impacts on fish recruitment. Zebra mussels have impacts on fish populations through alterations of the food web. Heavy infestations of zebra mussels may interfere with the feeding, respiration and reproduction of freshwater mussels and may impede locomotion. In extreme cases, zebra mussels can cause sufficient freshwater mussel mortality to eliminate populations.

How the introduction might have been prevented
The zebra mussel invasion occurred as a result of the removal of an economic barrier. As this was an accidental introduction it would have been difficult to prevent, but key to prevention is awareness among those sectors and people engaged in practices that can spread invasive species, such as importing boats. A guiding policy or code of conduct would be a step in the right direction. In the zebra mussel management strategy codes of practice for boat importers, tourism sector, sand abstractors, fisheries managers, anglers, boaters, marina/ slipway managers, environmental agencies and researchers have been recommended. Initial steps include deciding which sectors need basic training and then deciding whether sectors require specific codes of practice for their activities or if legislation is needed.

Boats which are moved between different water systems should have been carefully cleaned and all aquatic plant material attached to the engine or trailer should have been removed.

Invasion dynamics outside Ireland

The zebra mussel has been expanding its range over the last 200 years from the Black Sea and Aral-Caspian Sea basins. This post-glacial range expansion throughout Europe was facilitated by the development of a canal network linking the major European river systems. Zebra mussels are continuing to expand their range in Europe with the associated economic and ecological impacts. However it is the invasion of the Great Lakes and subsequent rapid spread in North America that have resulted in major impacts such as shutting down the water supply to Detroit and cooling water supply to a nuclear power station. Economic impacts are massive with cumulative costs from 1998-2000 estimated at between $750 million and 1 billion. Major ecological change as a result of the zebra mussel invasion has been documented in North America, in particular the extinction of many endemic unionid species. Impacts noted have included severe fouling of man-made structures, of fish spawning grounds, changes in fish populations, increases in water clarity and alteration of plankton communities in North America

References

Minchin, D., Maguire, C.M. & Rossell, R., 2003. The zebra mussels (*Dreissena polymorpha.* Pallas) invades Ireland: human mediated vectors and the potential for rapid international dispersal. *Biology and Environment*, 103B (1); 23-30.

Pollux, B., Minchin, D., Van der Velde, G., Van Alen, T., Yeo, S., Der Staay, M. & Hackstein, J., 2003. Zebra mussels (*Dreissena polymorpha*) in Ireland, AFLP-fingerprinting and boat traffic both indicate an origin from Britain. *Freshwater Biology*, 48: 1127-1139.

Figure 2.1 The current distribution of Zebra mussels in Ireland (C. Maguire, pers. comm.).

Table 2.4 Licensed imports of fish to the Republic of Ireland in 2002 (ICES CM 2003/ ACME:041)

Species & stage	**Quantity (Consignments)**	**Country of Origin**
Oncorhynchus mykiss eggs	14,000 (6)	Isle of Man
Oncorhynchus mykiss eggs	1,700,000 (4)	Denmark
Oncorhynchus mykiss eggs	200,000 (1)	England
Oncorhynchus mykiss eggs	1,320,000 (5)	N. Ireland
Oncorhynchus mykiss	306,230 (13)	N. Ireland
Oncorhynchus mykiss	100,000 (1)	Wales
Salmo salar eggs	3,286,500 (6)	Scotland
Salmo salar juveniles	1,957,000 (2)	Scotland
Salmo salar	6,650,000 (5)	Iceland
Salmo trutta	1,800 (2)	N. Ireland
Hippoglossus hippoglossus	1,200 (1)	Isle of Man
Psetta maxima fry	50,000 (1)	France

Table 2.5 Licensed imports of invertebrates to the Republic of Ireland in 2002 (ICES CM 2003/ ACME:041)

Species & stage	**Quantity (Consignments)**	**Country of Origin**
Crassostrea gigas (hatchery)	17,400,000 (11)	France
Crassostrea gigas (hatchery)	36,665,000 (54)	England
Crassostrea gigas (hatchery)	10,185,000 (14)	Guernsey
Crassostrea gigas	2.75mt (3)	England
Nereis sp.	426kg	England

SECTION 3: Legislation pertaining to non-native species

3 Legislation pertaining to non-native species

3.1 Introduction

The problems created by invasive alien species in Ireland are similar to those in many European States. Some of the principal constraints acting on prevention and control may include outdated or inadequate legislation and poor co-ordination between government agencies, neighbouring States and other stakeholders (Genovesi & Shine, 2003). In Ireland, in both jurisdictions, several departments and agencies have responsibility for managing some aspect of the problems caused by invasive species and so several different legislative instruments and environments may be relevant (e.g. plant and animal health and quarantine; nature conservation; wildlife protection, etc.).

Beyond domestic legislature, the problems of non-native species are addressed by international and European legislation. Many international instruments or technical guidelines deal directly or indirectly with invasive alien species (Table 3.1). These binding or voluntary instruments often provide the baseline from which domestic legislatures develop policy, legislation and management frameworks to address invasive species issues (Genovesi & Shine, 2003).

European environmental law and policy exerts an enormous influence on the nature and direction of environmental regulation in both jurisdictions (Turner & Morrow, 1997). Over 200 pieces of environmental legislation have been adopted by the EC during the past two decades which have considerably strengthened the protection afforded to Ireland's environment as a whole (Turner & Morrow, 1997). The conservation of biodiversity in Ireland has been strengthened and expanded by EC law, most notably by the Birds and the Habitats Directives and also by the EIA Directive (Buckley, 1998) (Table 11).

There is currently no fully comprehensive national strategy for prevention and mitigation of both invasive plant and animal species in either jurisdiction, although the National Biodiversity Plan and Biodiversity in Northern Ireland both support the development of such a strategy. In this section we review the existing legislation affecting invasive alien species. The different instruments and legislations are reviewed in three sections, international, European and domestic. These three sections are summarised in Tables 3.1, 3.2 and 3.4.

3.2 International instruments

There are a number of international treaties or instruments which identify a common problem such as invasive alien species, they set overall goals and policies and general obligations and organise technical and financial cooperation. However, the responsibility for achieving the goals rests largely with the countries themselves. Not all the agreements are legally binding, therefore, although they can make recommendations to the member countries, they cannot affect the legislation of these countries. The international instruments are described in sections 3.2 to 3.18.

3.3 Biodiversity conservation

The main international instruments for nature conservation that specifically address invasive species include the Convention on Biological Diversity (Rio de Janeiro, 1992), The Convention on the Conservation of European Wildlife and Natural Habitats (The Bern Convention, Bern, 1979) and The Convention on the Conservation of migratory species of wild animals (The Bonn Convention, Bonn, 1980). There are also international instruments which relate to the protection of specific habitats including Convention on Wetlands of International Importance as Waterfowl Habitat (Ramsar Convention, Paris, 1994) and Ministerial Conference for the Protection of Forests in Europe (MCPFE, Vienna, 2003). Finally there is Agenda 21 which was adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, June, 1992. There are further international agreements which deal with maritime issues.

3.4 Convention on Biological Diversity

The Convention on Biological Diversity (CBD) of 5th June, 1992 requires its contracting parties, as far as is possible and appropriate, "to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".

This Convention also addresses liability for damage caused by introductions where insufficient or ineffective measures have been taken to eradicate the species once released. The responsibility to implement the Convention lies with the individual countries and, to a large extent, compliance will depend on informed self-interest and peer pressure from other countries and from public opinion.

Contracting parties to the Convention on Biological Diversity are committed under Article 8 to take action to:

"(k) develop or maintain necessary legislation and/or other regulatory provisions for the protection of threatened species or populations;

(l) where a significant adverse effect on biological diversity has been determined....regulate or manage the relevant process and categories of activities.

Furthermore, Article 13 of the Convention commits contracting parties to:

"(a) Promote and encourage understanding of the importance of, and the measures required for, the conservation of biological diversity, as well as its propagation through media, and the inclusions of these topics in education programmes...".

The implications of the CBD are that contracting parties have to take account of IAS and aim to prevent introductions, control invasive species and develop legislation. The contracting parties of the Convention have to report on what has been done to implement the Convention, and how effective this is in meeting the objectives of the Convention. These reports are submitted to the Conference of the Parties (COP) - the governing body that brings together all countries that have ratified the Convention.

3.5 The Bern Convention on the Conservation of European Wildlife and Natural Habitats

This Convention provides a regional framework for implementation of the CBD in Europe and brings together the majority of European States concerned with biodiversity conservation (Genovesi & Shine, 2003). It has given particular attention to invasions over the last twenty years and adopted a wide range of policy and technical recommendations.

Article 11(2) of the Bern Convention states that Contracting parties:

"(b) strictly control the introduction of non-native species," and "inform neighbouring States if accidental introductions have occurred."

It obliges Member States to ensure that the deliberate introduction to the wild of non-native species is regulated so as not to prejudice the implementation of national legislation directed at the preservation of species. The Convention also outlines how Contracting parties should set up mechanisms for inter-State co-operation, notification and consultation in order to co-ordinate precautionary and control measures for invasive species. There is potential in this Convention to facilitate and promote national and European co-operation on IAS issues. This is a vital issue as many non-native species in Ireland have been introduced either directly or via other EU countries, including Great Britain.

3.6 The Bonn Convention on the Conservation of migratory species of wild animals

This Convention highlights "the protection of (the) habitats (of migratory species) from disturbances, including strict control of the introduction of, or control of already introduced exotic species detrimental to the migratory species".

Article V(5)(e) of The Bonn Convention states that contracting parties should provide for strict control of the introduction of exotic species (or control those already introduced) which would be detrimental to native species.

Article III(4)(c) states that the Contracting parties agree "to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely to further endanger species, including strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species."

There is potential in this Convention for providing the basic instruments for contracting parties to address the issue of IAS.

3.7 Convention on Wetlands of International Importance as Waterfowl Habitat (Ramsar Convention)

In Resolution VII.14 on invasive species and wetlands The Ramsar Convention encourages Contracting Parties to address the environmental, economic and social impact of invasive species on wetlands within their jurisdictions. It also urges Contracting Parties to (adapted from Fasham & Trumper, 2001):

- prepare a list of alien species in wetlands and identify and prioritise those which pose a threat to wetlands and wetland species, and those which may be adequately controlled or eradicated;
- target priority invasive species with a view to control or eradicate and implement other related international programmes;
- assess the environmental, economic and social impact of the movement and transport of non-native species on the global spread of invasive wetland species;
- review existing legal and institutional measures and, where necessary, adapt legislation and measures to prevent the introduction of new and environmentally dangerous non-native species and the movement or trade of such species within their jurisdictions;
- develop capacity for the identification of new and environmentally dangerous alien species (including those being tested for agricultural and horticultural use) and the promotion and enforcement of legislation and best practice management;
- encourage education towards the identification and control of, new and environmentally dangerous alien species and
- co-operate with other Contracting Parties to exchange information and experience, increasing the overall capacity to deal with wetland invasive species and promote regional coordination of invasive species programmes. However, Ramsar is not legally binding.

3.8 World Conservation Union (IUCN) Guidelines for the prevention of Biodiversity loss caused by invasive alien species (2000)

These guidelines are a set of guiding principles and recommendations for preventing the introduction of, controlling and eradicating non-native species. The aim of these guidelines is to prevent further biodiversity loss through the effects of non-native species, and to assist government and management agencies to give effect to Article 8(h) of the CBD.

The objectives of these guidelines are:
1. to increase awareness of IAS affecting native biodiversity in all regions of the world;
2. to encourage prevention of IAS introductions as a priority issue requiring national and international action;
3. to minimise the number of unintentional introductions and to prevent unauthorised introductions of IAS;
4. to ensure that intentional introductions, including those for biological control purposes, are properly assessed in advance, with full regard to potential impacts on biodiversity;
5. to encourage the development and implementation of eradication and control programmes for IAS, and increase the effectiveness of these programmes;
6. to encourage the development of a comprehensive framework for national legislation and international cooperation to regulate the introduction of IAS and the eradication and control of IAS;
7. to encourage research and communication to address the problem of IAS worldwide.

IUCN have also produced a code of practice on the Translocation of Living Organisms (IUCN, 1987). This document outlines how the introduction of non-native species should only be considered if there are benefits to man or natural communities and if no native species is considered suitable. The code also states that no non-native species should be introduced into any natural habitat and not into any semi-natural habitat unless there are important reasons (Fasham & Trumper, 2001). The code sets out guidelines for the assessment of the potential effects of a proposed introduction.

The state members of IUCN from the Republic of Ireland are the National Parks and Wildlife Service and The Heritage Council. In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) is the State member of IUCN.

3.9 Agenda 21

Agenda 21 was adopted by the United Nations Conference on Environment and Development on 14th June 1992. Agenda 21 is a plan for global, national and local action in every area in which humans impact on the environment. The issues dealt with that are relevant to invasive alien species are the protection of forests from disease and the uncontrolled introduction of exotic plant and animal species; the adoption of appropriate rules on ballast water discharge to prevent the spread of exotic species; the strengthening of the legal and regulatory framework for mariculture and aquaculture; and the control of noxious aquatic species that may destroy other aquatic species.

The successful implementation of Agenda 21 is primarily the responsibility of Governments. National strategies, plans, policies and processes are crucial in achieving this and international co-operation should support and supplement such national efforts

3.10 Ministerial Conference for the Protection of Forests in Europe (MCPFE)

MCPFE is an ongoing initiative for the co-operation of approximately 40 European countries to address common threats and opportunities related to forests and forestry.

One of the guidelines addresses the conservation of native tree species and provenances. This states that "native species and provenances should be preferred where appropriate. The use of species, provenance, varieties or ecotypes outside their natural range should be discouraged where their introduction would endanger important or valuable indigenous ecosystems, flora and fauna. Introduced species may be used where their potential negative impacts have been assessed and evaluated over sufficient time, and where they provide more benefits than do indigenous ones in terms of wood production and other functions. Where introduced species are used to replace local ecosystems, sufficient action should be taken at the same time to conserve native flora and fauna."

3.11 International Maritime Organisation (IMO) Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens

Legislative developments on alien species at an international level have been in process in the United Nations IMO for nearly a decade. The IMO has produced guidelines (IMO Assembly Regulation A.868(20)) in response to the threat of ballast water introducing invasive species. These guidelines provide advice on the control and management of ship's ballast water to minimise the risk of unwanted organisms and pathogens from the ballast water and the sediment discharged.

These Guidelines provide tools which, if correctly applied, will help to minimize the risks associated with ballast water discharge.

3.12 International Council for the Exploration of the Sea (ICES) Code of Practice on the introduction and Transfer of Marine Organisms, 1994

This Code of Practice recommends procedures to decrease the risk of detrimental effects from the introduction and transfer of marine organisms. The code outlines the recommended actions to be undertaken prior to new intentional introductions.

Member countries contemplating a new introduction are expected to submit to the ICES Council a detailed evaluation of the introduction including:

- the stage in the life cycle proposed for the introduction,
- the native range,
- the donor location,
- the target areas for release,
- the biology and ecology of the species as these pertain to the introduction and
- information on the receiving environment.

A detailed analysis of the potential impacts on the aquatic ecosystem must be included reviewing;

- the ecological, genetic and disease impacts and relationships of the proposed introduction in its natural range and donor location;
- the expected ecological, genetic and disease impacts and relationships of the introduction in the proposed release site and projected range, as well as vectors for further distribution and
- economic assessment where appropriate.

Following approval the translocation procedure should involve the following.

- Establishment of a stock for artificial propagation (i.e. a brood stock) in quarantine.
- Sterilization of effluents from the quarantine premises.
- Evaluation of the health status of the stock. The translocation should proceed only with a healthy stock.
- A limited release into open waters of the first generation progeny to assess ecological interactions with native species.
- Continued study and monitoring of the outcome.
- Submission of progress reports to ICES.

Ongoing translocations that are part of commercial practice require periodic inspection of material prior to translocation. If any pathogens or pests are discovered the translocation must be discontinued and/or quarantine, inspection and control must be implemented. The genetic impacts of the pests/pathogens on the native species must be evaluated.

Both jurisdictions in Ireland are member countries of the International Council for Exploration of the Sea (ICES) and are consequently obliged to comply with the code. Unfortunately this Code of Practice has not always been closely adhered to (Reise *et al.*, 1998). Although there is an urgent need to strengthen quarantine regulations, no new EC legislation has been implemented.

3.13 United Nations Convention on the Law of the Sea (UNCLOS)

This Convention, in Article 196, requires Member States to take all necessary measures to prevent, reduce and control the intentional or accidental introduction of non-native species to a particular part of the marine environment, which may cause significant detrimental effects.

3.14 Food and Agriculture Organisation (FAO) Code of Conduct for Responsible Fisheries, 1995

This Code outlines guidelines on the precautionary approach for fisheries and species introductions. This FAO Code of Conduct also facilitates the setting up of legal and administrative frameworks for responsible aquaculture and sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity.

3.15 International Protection Plant Convention (IPPC)

The International Plant Protection Convention (IPPC) is an international treaty to which 117 governments currently adhere. The purpose of this Convention is to secure common and effective action to prevent the spread and introduction of pests of plants and plant products and to promote appropriate measures for their control. The Convention extends to the protection of natural flora and plant products. It also includes both direct and indirect damage by insects, including weeds. The provisions extend to cover conveyances, containers, storage places, soil and other objects or material capable of harbouring plant pests. National Plant Protection Organisations (NPPOs) and Regional Plant Protection Organisations (RPPOs) work together to help contracting parties meet their IPPC obligations. The regional plant protection organisation responsible for co-operation and plant protection in Europe is the European and Mediterranean Plant Protection Organisation (EPPO).

3.16 Food and Agriculture Organisation (FAO) Code of Conduct for the Import and Release of Exotic Biological Control Agents, 1995

In 1995, the FAO set out a Code of Conduct for the import and release of exotic biological control agents. This Code sets out the responsibilities of government authorities and importers and exporters of biological control agents capable of self-replication used for research and for environmental release. This code aims to facilitate the safe import, export and release of exotic biological control agents by introducing internationally acceptable procedures for all public and private bodies involved, particularly where national legislation does not exist (Fasham & Trumper, 2001).

3.17 World Trade Organisation (WTO) Agreement on Sanitary and Phytosanitary measures (SPS Agreement)

The WTO has an agreement on sanitary and phytosanitary measures in relation to trade (SPS agreement), which provides binding rules to ensure that governments extend free market access to each other's products and services. Countries can implement national regimes to protect human, animal and plant life from the problems arising from the entry, establishment or spread of pests, diseases and disease carrying organisms (Fasham & Trumper, 2001). Import restrictions put in place by countries must be based on scientific evidence. The Agreement requires that SPS measures are based on international standards, guidelines or recommendations, and should be based on scientific principles.

3.18 Convention on International Trade in Endangered Species of wild fauna and flora (CITES)

CITES is an international binding agreement between Governments. The aim of CITES is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Species covered by CITES are listed in three appendices. Trade between countries of live or dead specimens of the species in these appendices is strictly controlled; export and import licences are required, and can only be issued if certain conditions are met. CITES is implemented in EC law by the Wildlife Trade Regulation (EC Regulations 338/97 and 939/97).

1. Appendix I lists species threatened with extinction which are or may be affected by trade.
2. Appendix II lists species which 1) may become threatened with extinction unless trade is subject to strict control and 2) species which need to be regulated so that trade in species covered in 1) can be brought under effective control.
3. Appendix III lists species which any contracting party identifies as being subject to regulation within its jurisdiction and which requires the co-operation of other parties to control trade (Fasham & Trumper, 2001).

3.19 International Civil Aviation Organisation (ICAO) Resolution on Preventing the Introduction of Invasive Alien Species

Resolution A-32-9 of the ICAO encourages contracting states to use their civil aviation authorities to assist in reducing the risk of introducing potentially invasive species to areas outside their natural ranges through civil air transport.

Table 3.1 International instruments concerning non-native species relevant to Ireland (adapted from Fasham & Trumper, 2001)

Name	Year	Subject	Web address
Convention on Biological Diversity (CBD)	1993	Biodiversity Conservation	http://www.biodiv.org
Bern Convention on conservation of European wildlife and Natural Habitats.	1982	Biodiversity Conservation	http://conventions.coe.int/treaty/en/treaties/html/104.htm http://www.nature.coe.int/english/main/bern/texts/rec9757.htm
Bonn Convention on the Conservation of Migratory Species of Wild Animals	1983	Biodiversity Conservation	http://www.wcmc.org.uk/cms/
IUCN Guidelines for the prevention of Biodiversity loss caused by alien invasive species	2000	Biodiversity Conservation	http://www.iucn.org/themes/ssc/pubs/policy/invasivesEng.htm
Convention on Wetlands of International importance especially as Waterfowl Habitat (Ramsar Convention)	1975	Biodiversity Conservation	http://www.ramsar.org
Agenda 21	1992	Biodiversity Conservation	http://www.igc.org/habitat/agenda21
Ministerial Conference for the Protection of Forest in Europe	1993	Biodiversity Conservation	http://www.minconf-forests.net/
International Maritime Organisation (IMO) Guidelines for the control and management of ships' ballast water to minimise the transfer of harmful aquatic organisms and pathogens	1997	Aquatic environment	http://www.imo.org
International Council for Exploration of the Sea (ICES) Code of Practice on the Introductions and Transfers of Marine Organisms, 1994	1994	Aquatic environment	http://www.ices.dk/pubs/itmo.pdf
United Nations Convention on the Law of the Sea (UNCLOS)	1994	Aquatic environment	http://www.un.org/depts/los/losconv1.htm
Food and Agriculture Organisation (FAO) Code of Conduct for Responsible Fisheries	1995	Phytosanitary measures	http://www.fao.org/fi/agreem/codecond/ficonde.asp
International Plant Protection Convention (IPPC)	1951	Phytosanitary measures	http://www.fao.org/WAICENT/FAOINFOR/AGRICULT/agp/agpp/PQ/Default.htm
Food and Agriculture Organisation (FAO) Code for the Import and Release of Exotic Biological Control Agents.	1996	Phytosanitary measures	http://www.fao.org/
Convention on International Trade in Endangered species of wild fauna and flora (CITES)	1975	Trade-related agreements	http://www.cites.org
WTO Agreement on Sanitary and Phytosanitary measures (SPS Agreement)	1995	Trade-related agreements	http://www.wto.org/english/tratop_e/sps_e/spsagr.htm
International Civil Aviation Organisation (ICAO) Resolution on Preventing the Introduction of Invasive Alien Species	1998	Transport	http://www.icao.int/icao.int/icao/en/res/a32_9.htm

European legislation

3.20 Wildlife Trade Regulation

The Wildlife Trade Regulation 338/97/EC protects species of wild fauna and flora by regulating trade. Commission Regulation 939/97/EC provides detailed guidelines concerning the implementation of this Regulation. Together these two Regulations are termed the Wildlife Trade Regulation which implements CITES, and sets out rules for the import, export and re-export of species which are deemed an ecological threat to native EC flora and fauna, and provisions to restrict the internal movement of these species (Fasham & Trumper, 2001).

A species which has been recorded as a serious risk can be listed under Article 9.6 of CITES to prohibit their importation into the EU, and restrictions placed on the holding and/or movement of such animals within the community. This Regulation has the possibility, therefore, to restrict the trade and import of potential invasive alien species, such as the signal crayfish *Pacifastacus leniusculus* or the Chinese mitten crab *Eriocheir sinensis*. Restrictions should be instigated ideally with the voluntary compliance of industry bodies and imposition without consultation can lead to conflicts.

3.21 Habitats Directive

This Directive promotes the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, and to contribute to the general objective of sustainable development (Clerkin, 2002). The HD aims to protect bio-diversity through the conservation of natural habitats of wild fauna and flora throughout the EC (Turner & Morrow, 1997). The Directive gives full legal force, at EC level, to the actions laid down by the Bern Convention and the Bonn Convention. Although it contains provisions for the protection of specific species of wild animals and plants, the Directive is primarily concerned with the general issue of habitat protection and the creation of a network of European protected sites known as 'Natura 2000'.

Article 22 of the Directive requires member states 'to ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within the natural ranges or the wild native fauna and flora, and if they consider it necessary, prohibit such introductions.' Article 22 of the Directive also requires member states to study the desirability of reintroducing native animals and plants of European protected species where it might contribute to the conservation of such species. However, member states should only undertake the reintroduction of such species if the results of the study establish that such a reintroduction 'contributes effectively to re-establishing these species at a favourable conservation status'.

The Directive provides a legal basis that obliges Member States to protect Natura 2000 sites. Along with the Birds Directive, this Directive provides the main legislative framework and driver for the prevention of the introduction of non-native species by means of the potential threat they pose to protected areas. Member states must take measures to maintain in 'a favourable condition', the habitats and species for which the sites have been selected, or, where necessary, take action to restore them. Natura 2000 sites are Special Protection Areas (SPAs), classified under the Birds Directive, or Special Areas of Conservation (SAC), designated under the Habitats Directive.

An example of the legal status provided by the Directive is the Magheraveely Marl Loughs SAC in County Fermanagh, Northern Ireland. These four marl loughs have strong isolated populations of white-clawed crayfish *Austropotamobius pallipes* and have been selected as an SAC site because of the presence of these Annex II species and because of the hydrological isolation and the absence of crayfish plague from Northern Ireland. The white-clawed crayfish is the only species of crayfish found in Ireland, where it is protected under the 1976 Wildlife Act and the Wildlife Order (Northern Ireland) 1985. It is classified as a vulnerable and rare species in the World Conservation Union (ICUN) Red List of threatened animals, listed as a protected faunal species in Appendix III of the Bern Convention and is listed in Annex II of the EU Habitats Directive. The protection given to this site by the Directive is that the addition of e.g. signal crayfish, a potential competitor but also carrier of crayfish plague, would be in contravention of this Directive as it would be a direct threat to this SAC site. The Member State would then be obliged to undertake measures to remove the threat to the SAC site.

3.22 Birds Directive

The Birds Directive applies to birds, their eggs, nests and habitats. The Directive provides for the protection, management and control of all species of naturally occurring wild birds in the Member States and requires that Member States take measures to conserve a diversity of habitats for all species of wild birds naturally occurring within their territories in order to maintain populations at ecologically and scientifically sound levels. The Directive also requires that Member States take special measures to conserve the habitat of certain species of conservation concern and of migratory species. In particular it requires Member States to identify areas for special protection of the rare or vulnerable species listed in Annex I (Article 4.1) and for regularly occurring migratory species (Article 4.2) and for the protection of wetlands, especially wetlands of international importance. These areas are known as Special Protection Areas (SPAs). The Directive provides a legal basis that obliges Member States to protect the SPA sites.

Article 11 of the Birds Directive states that, "member states shall see that any introduction of species of bird which do not occur naturally in the wild state in the European territory of the member states does not prejudice the local flora and fauna".

3.23 Environmental Impact Assessment Directive

Although not directly relevant to IAS, the Environmental Impact Assessment Directive requires environmental assessments for development which could strengthen the conservation of biodiversity. The EIA procedure ensures that environmental consequences of projects are identified and assessed before authorisation is given. When developments include the use of non-native species, the potential effects on the environment needs to be determined and assessed (Fasham & Trumper, 2001) and this Directive facilitates this.

3.24 Water Framework Directive

The Water Framework Directive is a substantial EC legislation and principally addresses the anthropogenic effects on water from the source to coastal waters. The WFD requires that all inland and coastal waters reach a "good status" by 2015. This is to be undertaken by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters. When negative impacts on water quality are identified the WFD requires that steps be taken to improve water quality to return the water quality to as close a 'pristine' state as possible (Minchin & Gollasch, 2003). Perhaps ironically the regulations on the discharges of wastewater from industry and municipal water works may result in less toxic run-off from port areas which may provide more habitats suitable for exotic species invasion (Minchin & Gollasch, 2003).

This Directive has the power to protect river basins and Ireland would be in contravention of this Directive if these protected sites were affected by invasive alien species. The Directive requires that a river basin covering the territory of more than one Member State is assigned to an International River Basin District (IRBD). The issue of river basins in the island of Ireland has been addressed in a recent joint North/South consultation paper on international river basin districts and administrative arrangements for implementation of the Water Framework Directive. The Department of the

Environment for Northern Ireland and the Department of the Environment and Local Government in the Republic of Ireland have proposed the delineation of three international river basin districts within which appropriate administrative arrangements must be in place to ensure that water management is co-ordinated in accordance with the Directive. Each Member State must ensure that the environmental objectives of this Directive are met by 2015.

3.25 Fish Health Directive

The principle EU legislation governing fish health in aquaculture and the aquarium trade is The Fish Health Directive concerning the animal health conditions governing the placing on the market of aquaculture animals, including ornamentals, and products. This Directive prohibits the import of live or dead fish from zones within the EC not certified as free of certain diseases.

3.26 Forest Reproductive Material Directive

The EC Forest Reproductive Material Directive facilitates the restriction of the marketing of forest reproductive material of unsuitable origin in all or parts of the Member States where it could adversely affect biodiversity or genetic resources (Fasham & Trumper, 2001). This Directive can apply to 46 species, from which the Member States select the species they wish to regulate.

Permission to prohibit or restrict marketing of forest reproductive material will be granted only where there is reason to believe;

- that the reproductive material would, as a result of its phenotypic or genetic characteristics, have an adverse effect on forestry, environment, genetic resources or biodiversity on the basis of:
  I) evidence relating to the region of provenance or the origin of the material, or
  II) results of trials or scientific research carried out in appropriate locations, either within or outside the Community, or,
- that the use of the said reproductive material would, on account of its characteristics have an adverse effect on forestry, environment, genetic resources or biodiversity in all or part of that Member State, on the basis of trials, research, or results obtained from forestry practice concerning survival and development of planting stock in relation to morphological and physiological characteristics.

3.27 Plant Health Directive

This Directive has been amended and was consolidated into Directive 2000/29/EC (Fasham & Trumper, 2001). This Directive facilitates protective measures against the introduction of organisms harmful to plants or plant products and measures to prevent their spread within the Community. The Directive primarily protects agricultural, forestry and horticultural plant species, but can also be applied to wild species.

3.28 Animal Health Directives

The Animal Health Directives aim to prevent the spread of diseases. The Directives are primarily concerned with trade in agricultural animals, but can also be applied to wild species. They are implemented by Directives 90/42/EEC, 64/432/EEC, 91/496/EEC, Directive 92/65/EEC and 90/425/EEC.

Consignments of live animals have to be inspected by an official veterinarian prior to intra-community movement and certified free of infectious or contagious disease. As a further precaution against the spread of disease, destination countries are empowered to conduct spot checks on imported consignments at the point of destination, or at any point in the transport chain, including points of entry (Fasham & Trumper, 2001).

The removal of internal border controls has resulted in a situation where monitoring on live animals and animal products imported into the EC from outside the EC are required at the external border. The Directive requires that live animals and animal products may only be imported into the EC through an approved Border Inspection Post and require full documentation, identity and physical checks by an official veterinarian before being permitted to enter into free circulation within the Community.

3.29 Plant Protection Products Directive

This Directive concerns the placing of plant protection products on the market and provides an authorisation system where plant protection products cannot be sold or used in an EC country unless they have been authorised under the Directive of that Country.

Plant protection products are defined as active substances and preparations containing one or more active substances intended to protect plants against harmful organisms. "Active substance" means any substance or micro-organism, including viruses, which has a general or specific action against harmful organisms or on plants.

3.30 The importance of rapid response to emergency legislation

Legislative processes are often slow when rapid movement is necessary in order to consolidate defence against a specific pest species. The EU has been forced to pass a number of emergency amendments to previous Commission Decisions in order to safeguard against further spread of a pest species within the European Union (Table 3.3). In order to combat the threat of invasive species a flexible legal system is required which retains the ability to disseminate information rapidly when necessary.

Table 3.2 EU legislation relating to risk alerts regarding pest species

EU Legislation	Description
Commission Decision 2001/218/EC	Temporary emergency measures in respect of wood packing comprised in whole or in part of non-manufactured coniferous wood originating in Canada, China, Japan, and the United States. The legislation is aimed at preventing the introduction into Irish and EU forests of the pine wood nematode *Bursaphelenchus xylophilus* and other serious forest insect pests and diseases.
Amended 2003/127/EC	Non-conifer wood packing, originating in China only, under existing separate legislation aimed at preventing the introduction of Asian long horn beetle (*Anoplophora glabripennis*), shall be stripped of its bark and shall be free of insect holes greater than 3 mm across or shall be kiln dried to below 20 % moisture content.
Commission Directive 93/49/EEC	The schedule applies to the growing of crop and ornamental propagating material (including rootstocks), and ornamental plants derived there from, of all the genera and species referred to in Annex to Directive 91/682/EEC, and to rootstocks of other genera and species referred to in Article 4 (2). Material must be checked for viruses and shown to be derived from stock which is virus free.
Council Directive 2000/29/EC	Implements protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. Plant health checks for products originating in non-member countries. Bans of specific plant products, producers must be officially registered and subject to plant health checks, the satisfactory completion of which results in a plant passport for movement within the EU. Harmful organisms include pests of plants or of plant products which belong to the animal or plant kingdoms, or which are viruses, mycoplasmas, or other pathogens.
Commission Decision 2002/7/57/EC	To prevent the introduction and spread of *Phytothora ramorum* within the European community. This species is known to cause Sudden Oak Death in California.
Commission Decision 96/490/EC	Following a programme of intensive sampling to prove absence of *Gyrodactylus salaris* in the UK, special safeguard measures have been awarded to prevent movement of salmonid fish from areas that are, or may be, infected with *Gyrodactylus salaris*, to the UK.

Table 3.3 European legislation relevant to non-native species (after Fasham & Trumper, 2001)

Name	Year	Subject	Web address
Wildlife Trade Regulation: Council Regulation (EC) No 338/97 on the protection of species of wild fauna and flora by regulating trade therein Commission Regulation (EC) No 939/97 laying down detailed rules concerning the implementation of Council Regulation (EC) No 338/97 Commission Regulation (EC) NO 191/2001 suspending the introduction into the Community of specimens of certain species of wild fauna and flora	1997	Trade-related agreements/Biodiversity conservation	http://europa.eu.int/eur-lex/en/lif/dat/1997/en_397R0338.html http://europa.eu.int/eur-lex/en/lif/dat/1997/en_397R0939.html http://www.ukcites.gov.uk/pdf/20files/a191_2001.pdfl
Habitats Directive: Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora	1992	Biodiversity conservation	http://europa.eu.int/eur-lex/en/lif/dat/1992/en_392L0043.html
Birds Directive: Council Directive 79/409/EEC on the conservation of wild birds	1979	Biodiversity conservation	http://europa.eu.int/eur-lex/en/lif/dat/1979/en_379L0409.html
Environmental Impact Assessment Directive Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment Council Directive 97/11/EC amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment	1985 1997	Environmental protection	http://europa.eu.int/eur-lex/en/lif/dat/1985n_385L0337.html http://europa.eu.int/eur-lex/en/lif/dat/1997/en_397L0011.html
Water Framework Directive Council Directive 2000/60/EC	2000	Environmental protection	http://europa.eu.int/comm/environment/water/water-framework
Forest Reproductive Material Directive Council Directive 1999/105/EC on the marketing of forest reproductive material	1999	Phytosanitary & biodiversity	http://europa.eu.int/eur-lex/en/lif/dat/1999/en_399L0105.html
Plant Health Directive Council Directive 2000/29/EC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the community	2000	Phytosanitary measures	http://europa.eu.int/eur-lex/en/lif/dat/2000/en_300L0029.html
Plant Protection Products Directive Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market	1991	Phytosanitary measures	http://europa.eu.int/eur-lex/en/lif/dat/1991/en_391L0414.html
Fish Health Directive Council Directive 91/67/EEC concerning the animal health conditions governing the placing on the market of aquaculture animals and products	1991	Sanitary measures	http://europa.eu.int/eur-lex/en/lif/dat/1991/en_391L0067.html

Animal Health Directives Council Directive 90/425/EEC concerning veterinary and zootechnical checks applicable in intra-Community trade in certain live animals and products with a view to the completion of the internal market.	1990	Sanitary measures	http://europa.eu.int/eur-lex/en/lif/dat/1990/en_390L0425.html
Council Directive 91/496/EEC laying down the principles governing the organisation of veterinary checks on animals entering the Community from third countries	1991		http://europa.eu.int/eur-lex/en/lif/dat/1991/en_391L0496.html
Council Directive 64/432/EEC on animal health problems affecting intra-Community trade in bovine animals and swine	1964		http://europa.eu.int/eur-lex/en/lif/dat/1964/en_364L0432.html
Council Directive 92/65/EEC laying down animal health requirements governing trade in and imports into the Community of animals, semen, ova and embryos not subject to animal health requirements laid down in specific Community rules referred to in Annex A (I) to Directive 90/425/EEC.	1992		http://europa.eu.int/eur-lex/en/lif/dat/1992/en_392L0065.html

Case study 3.1 Conflicts between EC free trade agreements and national conservation policies (adapted from Fasham & Trumper, 2001)

A problem faced by many European Governments is the ability to restrict imports without violating trade agreements. A recent case concerned a ruling by the European Court of Justice (ECJ) in 1998 relating to the import of bees to a Danish island. The focus of this example is to establish principles concerning intra-EC trade and biodiversity conservation.

In 1993 the Danish Minister for Agriculture and Fisheries issued Decision No. 528 which prohibited the keeping of nectar-gathering bees on the island of Læsø, other than those of the subspecies *Apis mellifera mellifera*. Any existing swarms of other bees had to be destroyed, removed, or the queen replaced with an inseminated queen of the specific species. The aim was to conserve the population of Brown Bee subspecies from hybridization with other bee species.

Criminal proceedings were initiated by the Danish Government against a resident of Læsø for continuing to keep a swarm of another bee species after Decision No. 528 came into force. The defendant argued that the Decision constituted a measure having effect equivalent to a quantitative restriction on imports contrary to Article 30 of the Treaty of Rome. He further contended that the Læsø Brown Bee was not unique to the island and threatened with extinction, so that Article 36 could not be used to justify the restriction. The public prosecutor argued that the effects of the Decision were entirely internal to Denmark and thus Article 30 did not apply. The national court referred the case to the ECJ for a ruling.

The case raised questions about whether such restrictions come within the scope of Article 30 of the Treaty of Rome, and if so, whether such restrictions can be justified. The ECJ has consistently confirmed that all trading rules enacted by Member States which are capable of hindering (directly or indirectly, actually or potentially) intra-community trade are to be considered as measures having an effect equivalent to quantitative restrictions; such measures are prohibited under Article 30 of the Treaty of Rome, unless their application can be justified by a public-interest objective taking precedence over the movement of free goods. Article 36 allows for measures which would otherwise be prohibited under Article 30 if they can be justified on the grounds of "protection of health and life of animals". However the ECJ has described a prohibition on imports as the most extreme form of restriction.

The effect of the Decision on trade of each subspecies of bee was analyzed separately and concluded to discriminate in favour of the Danish (and in particular Læsø) production of the Brown Bee relative to non-Danish Brown Bee. However it is indistinctly applicable in respect of other bee species. In view of this the ECJ concluded that the Decision did fall under the scope of Article 30. However, the opinion of the Court's Advocate was that a legitimate aim of Article 36 would be protection below the subspecies level (for example subgroups within a subspecies) and the population in question need not be in immediate danger of eradication. It is also possible to justify indistinctly applicable restrictive measures by reference to the mandatory requirement of environmental protection as supported by the CBD. Therefore Decision No. 528 was justified by reference to both Article 36 and the CBD.

The ruling of the ECJ was that:

1. "A national legislative measure prohibiting the keeping on an island such as Læsø of any species of a bee other than the subspecies *Apis mellifera mellifera* constitutes a measure having an effect equivalent to a quantitative restriction within the meaning of Article 30 of the EC Treaty.
2. "A national legislative measure prohibiting the keeping on an island such as Læsø of any species of a bee other than the subspecies *Apis mellifera mellifera* must be regarded as justified, under Article 36 of the treaty, on the ground of the protection of the life and health of animals."

This ruling determines that national conservation law can over-ride trade regulations. However, this does not infer that any and every restrictive measure adopted by a Member State pursuant to the CBD is justified. The judgement itself is specific in that it refers only to Læsø and to the specific bee species in question. Restrictive measures cannot be justified if it is possible to achieve the same result by less stringent measures.

References

Judgement of the Court 03-12-1998. Anklagemyndighed v. Ditlev Bluhme. http://www.asser.nl/EEL/cases/HvJEG/697j0067.htm

Fasham, M. & Trumper, K., 2001. Review of non-native species legislation and guidance. DEFRA, Bristol, U.K

Domestic legislation

3.31 Wildlife (Northern Ireland) Order, 1985

A number of pieces of legislation in both jurisdictions directly concern the keeping, release and control of non-native species, reflecting EC legislation and international agreements, such as the EC Habitats Directive, the Convention on Biological Diversity and the Bern Convention. The most important relevant piece of legislation in Northern Ireland is the Wildlife (NI) Order, 1985. This Order was designed to implement the Bern Convention and also implement the species requirements of the Birds Directive. Article 15 of the Wildlife Order implements Article 22 of the Habitats Directive, which prohibits the introduction of foreign plant and animal species into the wild in Northern Ireland, the intention being to prevent further instances of the ecological damage caused by the introduction of non-native species (Turner & Morrow, 1997).

Article 15 makes it an offence to 'release or allow to escape into the wild' any animal that: (i) is not 'ordinarily resident in and is not a regular visitor to Northern Ireland in a wild state' or (ii) is listed in Part I of Schedule 9 of the Wildlife (NI) Order. Article 15 also states that if any person 'plants or otherwise causes to grow in the wild' any plant listed in Part II of Schedule 9 they will be guilty of an offence.

In addition, an introduced species of animal, once it is established in the wild, and any plant, established or not, that is known to have detrimental effects on the environment, may be added to Schedule 9. It is illegal to release, or allow to escape into the wild, any species listed in this Schedule.

Schedule 8 lists non-native plant and animal species that have become widely established in the UK (i.e. that are normally resident), that it is nevertheless illegal to release, or to allow escape in order to prevent increased numbers of these species in the wild. Related offences include digging up of Schedule 8 plants for relocation or for artificial propagation to provide stock for reintroduction, supplementation or introduction. Sale provisions cover material which is alive or dead, also any derivative (including seeds) from the plant. The legislation does not restrict the collection of seed from wild plants for sowing elsewhere unless it is seed of a Schedule 8 species.

This Order provides the basis for restricting the introduction and deliberate spread of alien species but does not allow for control efforts. This Order is currently under review.

3.32 Wildlife Act 1976

The Wildlife Act, 1976 in the Republic of Ireland covered many aspects of nature conservation but was enacted prior to most recent international instruments, as listed above. The Wildlife (Amendment) Act 2000 complements and strengthens the 1976 Act and provides a legal basis for Ireland to ratify CITES and implement the EC Wildlife Trade Regulations. It provides for control of international trade and holding, possession or domestic trade in specimens of species listed under those regulations (Shine, 2002) and includes "stronger protection for species and their habitats, including control of wildlife trade, introductions of alien species and a regulatory system for commercial shoot operations". The Wildlife Acts are the main basis for the protection of flora and fauna and the control of activities that may adversely affect their conservation.

With regard to non-native species: it is prohibited, without licence,

- to release, wilfully cause to escape or transfer within the State for the purpose of establishment in the

wild any species of wild animal or spawn and any wild bird or the eggs thereof;
- plant or otherwise cause to grow in a wild state in any place in the State any species of flora, or the flowers, roots, seeds or spores thereof.'

The Wildlife (Amendment) Act, 2000 also strengthens the legal basis for controlling the introduction of potentially invasive alien species. The Minister may issue regulations prohibiting possession or introduction of any species of wild bird, animal or flora, or part, product or derivative thereof that may be detrimental to native species (Shine, 2002). Where a non-native species has been introduced, measures can be taken, as far as feasible and appropriate under the Wildlife Act, to ensure that such introductions do not pose a potential hazard to native stocks.

Under the Regulation on the Control of Importation of Wild Animals and Wild Birds, 1989, the importation of live wild animals or birds is subject to licence by the Minister.

3.33 The Conservation (Nature Habitats, etc.) Regulations (Northern Ireland), 1995

These Regulations implement the European Habitats Directive in Northern Ireland and control the introduction of native plants and animals of European protected species into areas of Northern Ireland by means of the licensing system set out in regulation 39 (Turner & Morrow, 1997). The purpose of this licensing scheme is for:

- "conserving wild animals or wild plants or introducing them to particular areas;
- protecting any zoological or botanical collection;
- preserving public health or public safety or other imperative reasons of overriding public interest including those of a social or economic nature and beneficial consequences of primary importance for the environment;
- preventing the spread of disease;"

3.34 Environmental Protection Agency Act, 1992

The Environmental Protection Agency Act, 1992 in the Republic of Ireland provided for the establishment of the Environmental Protection Agency (Maguire *et al.,* 1999).

This is an independent body and was established in 1993. The functions of the Agency are:

1. the licensing, regulation and control of the activities for the purposes of environmental protection;
2. the monitoring of the quality of the environment, including the establishment and maintenance of data bases of information related to the environment and making arrangements for dissemination and availability to the public of such information;
3. the provision of support and advisory services for the purposes of environmental protection to local authorities and other public authorities;
4. the promotion and co-ordination of environmental research and the carrying out or arranging for such research;
5. liaising with the European Environment Agency; and
6. other functions in relation to environmental protection as may be assigned or transferred to it by the Minister under sections 53 or 54 of the Act, including functions arising from European Community obligations, or any other international convention or agreement to which the State is, or becomes a party.

3.35 Heritage Act, 1995

The purpose of the Heritage Act 1995 in the Republic of Ireland was to set up the Heritage Council and to give the Minister a number of powers and functions in relation to the national heritage. The Heritage Council, an independent State body established under the Heritage Act 1995, defines priorities for identification, protection and enhancement of wildlife, archaeology, architecture and inland waterways (Shine, 2002). It includes a statutory committee on wildlife.

Legislative approach to invasive plant species in Northern Ireland

In Northern Ireland the Department of Agriculture and Rural Development (DARD) has produced five major legislative documents which regulate against infestations of non-native plant pests and outbreaks of non-native plant diseases.

3.36 The Plant Health Order (PHO) (Northern Ireland), 1993

This legislation is in place to protect Northern Ireland against the introduction and spread of invasive species associated with plants and plant products. The legislation is enforced by DARD Quality Assurance Branch (QAB) and in principle covers the import of plants and plant products from two sources, 1) Non-European Union Countries and 2) Great Britain and other Member States.

1) Non-European Countries

All plant and plant products imported from non-EU countries have to be accompanied by a phytosanitary certificate, which is issued by the Plant Protection Service of the exporting country. This certificate confirms that the material meets the Plant Health requirements of the EU. Checks are carried out at border control points before the material is released into free circulation.

2) Great Britain and other Member States

Within the EU there is in principle free movement of all plant and plant products. This change took place (from Phytosanitary Certificates and border checks) in 1993, when the plant passport system was introduced. All plant material being moved as part of trade within or between Member States that has the potential to pose a major threat or carry a quarantine pest must be accompanied by a plant passport. In Northern Ireland businesses registered by DARD have the authority to issue plant passports. The same rules apply throughout the EU. Each registered business must have a nominated person who is given a list of responsibilities which include carrying out plant health checks. In essence the industry at large takes responsibility for ensuring that plant material moving in trade meets the legislative requirements of each Member State.

3.37 The Plant Health (Wood & Bark) Order (Northern Ireland), 1993

This Order describes the conditions to be met before wood, isolated bark and used forest machinery may be introduced into Northern Ireland. Wood used to wedge or support parts of cargo including packing material, spacers and pallets are also considered. Temporary emergency measures have been initiated several times and this order amended in relation to the tree pest *Anoplophora glabripennis* (Motschulsky) (Amendment S.I. 389, 1999), the pine wood nematode *Bursaphelenchus xylophilus* (Steiner et Bührer) (Amendment S.I. 401, 2001) and more recently against the introduction and spread of the pest, *Phytophthora ramorum*, a fungus identified as causing Sudden Oak Death Syndrome in species of oak in the USA and harm to other species of plants (Amendment S.I. 175, 2003). The latter imposes controls on wood of four species of forest tree, *Acer macrophyllum. Aesculus californica, Lithocarpus densiflorus* and *Quercus* spp.. Wood of this description which originates in the USA and is despatched to the EC after 12th April 2003 must be accompanied by a phytosanitary certificate issued in compliance with the various requirements of the Schedule. These amendments have not always been successful. Amendment S.I. 285, 2002 removed the protected zone in respect of the pest *Pissodes* spp. which was present in Great Britain and spread to Northern Ireland and Ireland in 2002.

DARD makes a six monthly review of their contingency plan measures and will continually amend the plan to accommodate all parties involved in contingency measures.

3.38 The Seed Potatoes Regulations (Northern Ireland), 2001 (S.I. No. 188)

Under Schedule 1 of these regulations seed potatoes must be grown, harvested, stored, prepared for marketing, transported, handled and graded so as to minimize the risk of contamination by such harmful diseases or pests as notified by the department (DARD). A certificate is issued by the Department once they are satisfied that the regulations have been upheld. For example, seed potatoes must be taken from a crop which is free from a number of outlined diseases and pests, e.g. Wart Disease (*Synchytrium endobioticum* (Schilb.) Perc.), Brown Rot (*Ralstonia solanacearum* (Smith) Yabuuchi *et al.*) and Colorado Beetle (*Leptinotarsa decemlineata* (Say));

Schedule 9 describes measures to prevent spread, by means of seed potatoes, of disease or pests and lists the individual tolerances to pest species on potatoes originating internally within the UK and outside of the UK. The majority of individual tolerances are nil for potato pest species.

The Potatoes Originating in Egypt (Amendment) Regulations (Northern Ireland) 2003 are implemented in Northern Ireland Commission Decision 2002/903/EC, which renews the framework within which potatoes may be imported from Egypt into the territory of the European Community for the 2002/2003 season. This authorizes Member States temporarily to take emergency measures against the dissemination of *Pseudomonas solanacearum* (now referred to as *Ralstonia solanacearum* Smith (Yabuuchi)) from Egypt. The importance of this Order is the mechanism it exemplifies for imposing emergency measures to prevent the introduction of a harmful alien species.

3.39 Marketing of ornamental plant propagating material, 1995 (Amended 1999)

These Regulations are implemented in Northern Ireland Council Directive 98/56/EC on the marketing of propagating material of ornamental plants. Commission Directive 1999/68/EC lists varieties of ornamental plants kept by suppliers under Directive 98/56; and Commission Directive 1999/66/EC sets out requirements regarding the labelling or documents required by the supplier pursuant to Council Directive 98/56.

The Regulations set quality standards to be met by ornamental plant propagating material of all species when marketed and set conditions to be satisfied by suppliers. Regulation of citrus propagating material is emphasized.

The past history of organisms is also taken into account. In addition to meeting the requirements of Regulation 4, flower bulbs shall have been derived directly from material which, at the time the crop of bulbs concerned was growing, was checked and found to be substantially free from any harmful organisms and diseases or any signs or symptoms of such organisms and diseases.

3.40 Noxious Weeds (Northern Ireland) Order, 1977

This Order enables authorised officers to enter any land for the purpose of ascertaining whether any noxious plant, as listed in schedule 1, or part of a plant which is a noxious weed is present. The Order gives the officers the power to ensure that landowners cut down and dispose of or otherwise destroy noxious weeds.

3.41 Legislative approach to invasive plant species in the Republic

All EU legislation necessarily applies to the Republic of Ireland also. Domestic legislation also exists. For example, producers and traders in plants and plant products covered by the plant passport system are required to officially register with the Department of Agriculture and Food. Each registered person or firm is allocated a registration number, which must be recorded on plant passports issued by the person or firm. The objective is to facilitate trace-back should a quarantine problem subsequently arise. Registered growers/traders are required to notify the Department of any outbreak of harmful organisms on their premises, to facilitate Department inspections of their crops and premises and to retain documentary records for inspection.

A variety of plant species require passports to enter Ireland under the Department of Agriculture and Food recommendations. These are listed in Table 3.4.

Plants of fireblight host, *Populus* spp and of the conifers, listed at (1) to (3) in Table 3.4, must be accompanied by plant passports valid for the protected zone of Ireland. The other plants, listed at (4) to (7), must be accompanied by plant passports valid for movement of such material within the European Union. Plants other than the above do not require plant health documentation when being moved for personal use within the European Union.

3.42 Forestry legislation

The Forest Service of the Department of Agriculture and Food in the Republic of Ireland, and the Forest Service of DARDNI are responsible for forest policy and management. The protection of the forest estate against the introduction of dangerous forest pests and diseases is the responsibility of the forestry body in each jurisdiction and is implemented under the provisions of the EU Plant Health Directive and enforced in Northern Ireland by the Forestry Inspectorate (Forest Service, 2002) and by the Forest Service in the Republic of Ireland.

<u>Northern Ireland</u>

The Forest Reproductive Material Regulations (Northern Ireland), 2002 controls the quality of seeds, plants and cuttings marketed for forestry purposes. These regulations extend the definitions and classifications that apply to forest reproductive material. The regulations require that forestry reproductive material at market is required to be clearly labelled and identified, to be well adapted to the site it was collected from, and is of high quality. The regulation also requires that people who market or import forest reproductive material, in the course of business or trade, place their name on the "Register of Suppliers of Forest Reproductive Material".

<u>Republic of Ireland</u>

Forestry in Ireland operates within a legal and regulatory framework. The Irish National Forest Standard outlines the basic criteria and indicators relating to the implementation of Sustainable Forest Management in Ireland (SFM). It lists a series of qualitative and quantitative measures by which progress towards the practice of SFM can be monitored under forest conditions. The Code of Best Forest Practice lists all forestry operations and the protocol by which these operations should be carried out to ensure the implementation of SFM in Ireland.

The Forestry Acts, 1946, 1956 and 1988 contain provisions for controlling felling. The Forestry Act, 1988 established Coillte and amended penalties relating to felling offences. The European Communities (Marketing of Forest Reproductive Material) Regulations 2002 (S.I. 2002/618) gives legal effect to Council Directive 1999/105/EC.

3.43 Animal health

Long-distance transport and non-localised centres for the processing of livestock have been implicated in the spread of several agricultural diseases through Europe, including foot and mouth disease (FMD), classical swine fever (CSF) and BSE (Elbers *et al.*, 1999; Adam, 2001, Alexandersen *et al.*, 2003).

Northern Ireland

The Animals and Animal Products (Import and Export) Regulations (Northern Ireland) 1995 (S.R. 1995 No. 52), as amended by the Animals and Animal Products (Import and Export) (Amendment) Regulations (Northern Ireland) 1997 (S.R. 1997 No. 87) refer mainly to the import and export of livestock. The recent amendments introduce new provisions affecting transporters, dealers and owners of assembly centres who handle cattle and pigs. These provisions are designed to further reduce the risk of disease being spread while cattle and pigs are being moved across the Community.

Republic of Ireland

A number of EU directives have been translated into Irish law at the instigation of the Department of Agriculture and Food. The European Trade in Animals and Animal Products Regulations was transposed into Irish law as S.I. No. 289, 1994. Persons importing animals, pets, semen, ova, embryos, poultry and hatching eggs and those accepting delivery as consignees, products of animal origin (e.g. meat, blood, bones, wool, and manure) must register 24 hours notice of intent with the Import Registration Section of the Department of Agriculture and Food, Dublin. Veterinary Checks on Products Imported from Third World Countries Regulations 2000 (S.I. No. 292 of 2000) require assessment of live animals. An importer must give at least 24 hours notice of intent to import Animals/Products from Third World Countries to the Department of Agriculture and Food.

In the Republic of Ireland a licence is required for the importation of hay, straw and peat moss litter from all countries (including Great Britain). No licence is required in respect of any hay, straw or peat moss litter of Northern Ireland origin. "Hay" includes grass, moss, clover, *lucerne, sainfoin*, rushes, ferns, reeds, bracken, heather, alfalfa meal and pieces of surface earth containing roots of the following: namely, grass and other small plants of whatsoever kind. Application for a licence is required 7 working days in advance of import and the completed form sent to Animal Health and Welfare Division. This legislation is documented under section 4 of the Foot and Mouth Disease (Hay, Straw and Peat Moss Litter) Order 2001 (S.I. No. 49, amended to S.I. No. 89 and subsequently S.I. No. 239).

3.44 Aquaculture and mariculture legislation

Aquaculture production is regulated by an extensive system of national and EU legislation, which includes provisions for the prevention of importation of diseased stock.

Northern Ireland

In Northern Ireland the introduction of non-native species of fish, eggs and gametes is regulated by the Fisheries Act (Northern Ireland), 1966, the Fish Health Regulations, 1992 and the Fish Health (Amendment) Regulations, 1993-1994.

The Fisheries Act (Northern Ireland) 1966 empowers the Department of Agriculture and Rural Development of Northern Ireland to introduce legislation to prohibit the introduction, unless under permit, into certain waters of fish species which would be detrimental to the fishery. The other regulations seek to prevent the introduction of certain disease species to the UK and prohibit the import of live or dead fish from zones not approved as free of these diseases. These apply to native and non-native fish species.

Republic of Ireland

In the Republic of Ireland, the Department of Communications, Marine and Natural Resources (DCMNR) develops and coordinates the management and conservation polices for sea and inland fisheries, aquaculture and fish processing. It is also responsible for harbour and foreshore development, dumping at sea, marine pollution, shipping and implementation of relevant conventions.

The Fisheries Act, 1980 provided for the establishment of the Central Fisheries Board (CFB) and regional fisheries boards. The CFB has operational responsibility for the management of inland fisheries and sea angling; conservation and protection of fish stocks and their habitat optimising the amenity value of fisheries, recreational and environmental values and some enforcement of pollution controls in accordance with any directions given by the Minister for the Marine and Natural Resources under section 8(1)(b) of the Fisheries Act 1980.

The Fish Health Directive 1991 was transposed into Irish Law as S.I. Number 253 of 1996. This instrument aims to prevent the distribution of contagious fish diseases whilst promoting trade in aquaculture animals. Important fish diseases are categorised into List 1, 11 and 111 diseases, together with their susceptible species.

Further to this, parts of the Irish aquaculture industry is adhering to voluntary quality control schemes, that have an impact on alien species control, namely through the EN 45011 third party independently accredited Bord Iascaigh Mhara (BIM) quality schemes for salmon, trout and mussels. A fourth quality scheme for oysters is currently under development. The management of stock health is part of these quality assurance schemes with provisions made for different species. Non-compliance with these schemes will have to be followed by corrective action or the producer will not receive the quality mark under the scheme. Provisions include that fish farmers adhere to Council Directive 91/67/EEC on the movement of eggs, gametes or fish to another member state. Veterinary certification and Fish Transfer Licences have to be obtained for movements of fish into and within Ireland, which are issued by DCMNR. Records of Health Certification and Fish Transfers Licences have to be maintained and made available on request (M., Mathies, BIM, pers. comm.).

Table 3.4 Plant species subject to the plant passport requirement

Restricted material	Latin name	Common name
(1) Fireblight (*Erwinia amylavora*) host material	*Amelanchier*	Serviceberry
	Chanomeles .	Quince
	Cydonia	Quince
	Cotoneaster	
	Crataegus	Whitethorn
	Cydonia	Rose family
	Eriobotrya	Loquat
	Malus	Crab apple
	Mespilus	Medlar
	Photinia davidiana	Chinese photinia
	Pyracantha	Firethorn
	Pyrus	Pear
	Sorbus	Rowan, Mountain Ash, Whitebeam
	Stranvaesia .	
(2) Plants of *Populus*	*Populus*	Poplars
(3) Plants of conifer species	*Abies*	Fir
	Laryx	Larch
	Pinus	Pine
	Picea	Spruce
	Pseudotsuga	Douglas Fir
(4) Plants of *Prunus,* other than *Prunus laurocerasus* and *Prunus lusitanica*	*Prunus*	Plums, cherries, almonds, apricots, laurel, blackthorn, damson etc.
(5) Plants of *Rhododendron* species (other than *Rhododendron simsii*) and *Virburum*	*Rhododendron* *Virburum*	
(6) Plants of *Fortunella*, *Poncirus* and *Citrus* spp. and their hybrids	*Fortunella* *Poncirus* *Citrus*	
(7) Plants of *Humulus lupulus* and *Vitis* spp.	*Humulus* *Vitis*	Golden Hop, Vine

Table 3.5 Domestic legislation relevant to non-native species

Name	Year	Jurisdiction	Subject	Web address
Wildlife (Northern Ireland) Order	1985	NI	Biodiversity conservation	http://www.northernirleand-legislation.hmso.gov.uk/legislation/northernireland/nisr/yeargroups/1980-1989/1985/198501c/aos/n017.htm
Wildlife Act Wildlife (Amendment) Act	1976 2000	ROI	Biodiversity conservation	http://www.irishstatutebook.ie/zza39y1976.htm http://www.irishstatutebook.ie/ZZA38Y2000.html
The Conservation (Nature Habitats, etc.) Regulations	1995	NI	Biodiversity conservation	http://www.hmso.gov.uk/sr/sr1995/Nisr_19950380_en_1.htm
Environmental Protection Agency Act	1992	ROI	Biodiversity conservation	http://www.irishstatutebook.ie/zza4y1992.htm
Heritage Act	1995	ROI	Biodiversity conservation	http://www.irishstatutebook.ie/zza4y1995.htm
The Plant Health Order (PHO)	1993	NI	Phytosanitary measures	http://hmso.gov.uk/si/si1993/uksi-19931320_en_1.htm
The Plant Health (Wood & Bark) Order	1993	NI	Phytosanitary measures	http://www.forestry.gov.uk/forestry/infd-5azlcat
The Seed Potatoes Regulations	2001	NI	Phytosanitary measures	http://hmso.gov.uk/si/i1991/uksi-19912206_en_1.htm
Marketing of ornamental plant propagating material (Amended 1999)	1995	ROI	Phytosanitary measures	http://www.irishstatutebook.ie/zzsI201i1999.htm
The Forest Reproductive Material Regulations	2002	NI	Forestry	http://www.legislation.hmso.gov.uk/si/si2002/20023026.htm
Marketing of Forest Reproductive Material Regulations S.I. 2002/618	2002	ROI	Forestry	http://www.irishstatutebook.ie/
The Foot and Mouth Disease (Hay, Straw and Peat Moss Litter) Order	2001	ROI	Sanitary measures	http://www.irishstatutebook.ie/8zsI49y2001.htm
Forestry Act	1988	ROI	Forestry	http://.laws.justice.gc.ca/en/f_30/
Plant Health Act	1967	NI	Phytosanitary measures	http://www.forestry.gov.uk/forestry/Lcou-4usgdn
Animals and Animal Products (Import and Export) (Amendment) Regulations	1997	NI	Sanitary measures	http://www.hmso.gov.uk/sr/sr20010312.htm
Fisheries Act	1966	NI	Sanitary measures	http://www.dardni.gov.uk/consultations/can03022.htm
Fish Health Regulations(Amendment)	1993-1994	NI	Sanitary measures	http://www.hmso.gov.uk/si/si1992/uksi-19923300_en.1.htm
The Fisheries Act	1980	ROI	Fisheries	http://www.web2.gov.mb.ca/laws/statutes/ccsm/f090e.php
Dumping at Sea Act	1996	ROI	Marine	http://www.irishstatutebook.ie/zza8y1981.htm

3.45 Enforcement of domestic legislation

Interpreting existing legislation is not easy (for example, there is no definition of "the wild" – does it include gardens or semi-confined areas from which there is the possibility or probability of escape?) and partly because many introductions are unintentional or accidental and hence potentially covered by the defence. This lack of clarity has led to few prosecutions in both jurisdictions. Both the Wildlife (Northern Ireland) Order 1985 and the Wildlife (Amendment) Act 2000 require reviewing and updating to ensure that they are effective in the control of IAS.

A key problem is the lack of people with the power to enforce domestic legislation, increasing dependence on the support of key sectors, notably trade and transport, to establish codes of conduct that will be complied with and enforced by trade associations.

There are a number of problems regarding legislative matters within both jurisdictions. These concerns are outlined below (adapted from DEFRA, 2003)

1. Time delays are created by inflexible codes of practice for regulation of industries and trade sectors. There is a need to adopt codes of practice that are more flexible and gain the support of the trade sectors which they involve.

2. Fines for criminal offences are very low in comparison to the potentially huge costs of damage, control and repair and do not, therefore, constitute an effective deterrent.

3. There is unequal treatment of plants and animals in law.

4. There is a general lack of power to prohibit the sale of non-native species, especially where this involves sale via the internet and possibly import.

5. Lists of relevant species need to be updated.

6. There is a lack of duty of care placed on any particular sector.

7. There is no consideration of threats from unintentional introductions via new developments (for example by soil contaminated with Japanese knotweed, or use of non-native plants or genotypes).

8. There is a lack of enforcement powers, for example, a right of entry to check for species or to undertake control and the need to ensure that agencies and local authorities are accountable for taking action with respect to relevant named species.

3.46 Escapes from private collections

There are a large number of illegal releases or escapes from private collections of non-native species. It is difficult to police legislation in countries where the keeping of exotic animals in captivity is common in zoos, aquaria etc. and the accidental or deliberate release of non-native species may occur. Most established zoos have representative collections of non-native species and records of these are kept in a system known as the International Species Information System (ISIS). Both Northern Ireland and the Republic of Ireland failed to transpose the EU Zoos Directive, intended to improve the conservation role of zoos, by the deadline of April 10th 2002. However, the Zoos Directive was finally implemented in 2003; zoos must now hold a licence to operate and are subject to strict inspections by national competent authorities.

3.47 Biological control

There is no specific legislation in either jurisdiction regarding the import of non-native species for the purpose of biological control. The Department of Environment, Heritage and Local Government grant licences for importing animals under the Wildlife Act, 1976 – Section 52 (Control of Importation of Wild Animals and Birds Regulations, 1989). The Wildlife (Northern Ireland) Order grants similar licences in Northern Ireland.

The necessary legislative control systems for biological control are not very clear in either jurisdiction. Research is required to access biological control practise. Risk Assessments should be mandatory for such introductions.

The European FAO Code of Conduct for the import and release of exotic biological control agents facilitates the safe import, export and release of exotic biological control agents. This Code introduces internationally acceptable procedures for all public and private bodies involved, particularly where national legislation does not exist. Both jurisdictions need to implement this Code to monitor biological control agents.

3.48 Escapees and genetic pollution of wild populations

Efficient monitoring of fish farm escapees requires co-ordinated regional effort. Responsibility for the management of the Irish Salmon Fishery lies with the Department of Communications, Marine and Natural Resources (DCMNR) and is administered through the seven Regional Fisheries Boards (East, South, South West, Shannon, West, North West and North). The boards enforce fisheries legislation and carry out inspection at sea and on inland waters. This surveillance is further enhanced by naval surveillance co-ordinated through the Central Fisheries Board. Each region is further sub-divided into districts for administrative and management purposes, of which there are 17 in Ireland.

Enforced legislation preventing salmon escapees appears weak. In July 2003, Bord Iascaigh Mhara introduced its *Environmental Code of Practice for Aquaculture Companies and Trades* (ECOPACT). This code concerns stock health management. It is a recommended action under the code to implement the Irish Salmon Growers' Association (ISGA) *Code of Practice for the prevention of stock escapes of Irish farmed salmonids.* Yet enforcement of this procedure appears non-existent.

The importance of freshwater habitat quality and stocks of wild salmon populations is highly prioritized in Ireland. Under the EU supported Tourism Angling Measure (TAM, 1995-1999):

- € 15.6 million was spent on freshwater habitat improvements;
- 2000 km of freshwater habitats were resurveyed and rehabilitation was carried out on 400 km and
- 22 fish counters have been installed on significant salmon rivers over the past 6 years.

3.49 Discussion and conclusions

As outlined in this section, there are many international instruments and European Directives and Codes which are relevant to invasive alien species (Tables 3.1, 3.3 & 3.4). Whether these instruments are legally binding is of great importance to how they effect legislation in both jurisdictions. Many of the European Directives have been transposed into Irish and Northern Irish Law. However, it would appear that this has little effect, with the exception of the protection afforded to protected sites. Although there are many Acts and Orders in both jurisdictions which relate to some extent to non-native species, there does not appear to be the legislative power to act and either prevent or control invasive species.

A major problem is the lack of access to private land, which in itself can prevent a potentially invasive species being removed before it spreads to a wider area. In the case of animal health Government officials have the power to gain access to private lands to remove a potential hazard. However, this does not seem to be the case for invasive species.

A good model which currently exists in Northern Ireland and the Republic is the legislation which exists for plant health. The Department of Agriculture and Rural Development (DARD) produced four legislative documents which regulate against infestations of non-native plant pests and outbreaks of non-native plant diseases. This system could be applied to different sectors of legislation and could be used as a basic model for invasive species legislation. Although legislation does exist in both jurisdictions it urgently needs to be reviewed and updated. Box 3.1 highlights some key recommendations for IAS legislation. These recommendations are dealt with in more detail in sections four and five.

3.50 Cross border cooperation

Co-operation between the Republic of Ireland and Northern Ireland was formalised under the Belfast agreement on the 10th April, 1998. This established a North/South Ministerial Council with power to develop common policies on topics with a cross-border and all-Ireland benefit (including animal and plant health, environment, inland waterways, inland fisheries and marine matters) (Shine, 2002). The role of this Council is consultation between those with executive responsibilities in Northern Ireland and the Irish Government and to develop co-operation and action within the island of Ireland. The Council will implement this through an all-island and cross-border basis

The Council's Environment Sector has initiated cooperative work on environmental research, an environmental information database and the development of catchment strategies for water quality (Shine, 2002).

The International Designations Group (IDG) is a more informal arrangement which has operated for many years and involves representatives of Ireland through NPW, Northern Ireland, JNCC and DEFRA. This group meets to discuss and co-operate on biodiversity issues of mutual concern (Shine, 2002). The group is primarily concerned with environmental designation issues but also addresses other issues as the need or interest arises.

These groups have potential to provide support for a cross-border invasive species forum. A cross-border group, forum or agency could lead and coordinate the efforts of responsible agencies and government departments dealing with IAS in both jurisdictions. At present these issues and the different government departments responsible for invasive species issues are unclear. A forum/agency would provide one centralised group responsible for IAS issues.

The agency would become the primary point of reference and guidance for the management of all issues pertaining to non-native species and should be financed by the two jurisdictions and an interdepartmental budget, which incorporates contingency measures, should be agreed upon in advance of an issue arising.

The agency should be co-chaired by the most relevant government departments, most probably the Department of Environment (N.I.) and the Department of the Environment, Heritage and Local Government (R.O.I), though key inputs will be required from other departments, most notably agriculture, trade and transport. Linkages should also be fostered with public health departments for guidance in the construction of contingency plans in the event of an invasive species becoming a public health hazard.

The agency would:

1. Engage with stakeholders and relevant sectors to raise awareness to develop and encourage best practices to avoid unwanted introductions and to assist education and awareness measures.
2. Lead the development and implementation of a national strategy on invasive alien species.
3. Provide a focus for high-level decision making.
4. Consult with scientific authorities to obtain technical advice on decision-making related to IAS
5. Establish contingency plans including framework agreements to for plan implementation.
6. Lead the policy and legal review process.
7. Co-ordinate input from different agencies to national and European policy making and programmes.

Box 3.1 Recommendations for legislative approach to prevention of problems caused by invasive and alien species (adapted from De Klemm, 1994; Eno *et al.*, 1997).

The effects of invasive species may be impossible or extremely costly to control once the introduced species has become established. Prevention is consequently vital.

- Any legislation should be based on the precautionary principle which is gradually becoming an accepted basis for the development of environmental law. This means that the rule for deliberate introductions should be that permits are in principle denied, unless it can be shown that there are at least good scientific reasons to believe that the proposed introduction will be harmless.
- Quarantine procedures should be given legal force and become binding upon permit-issuing authorities. This could be achieved within the European Community.
- To prevent escapes from captivity or deliberate releases etc. the implementation of the precautionary principle requires strict controls on imports of live specimens of those species which may survive in the European environment. Import controls should be accompanied by prohibitions or restrictions on the possession, sale and transport of exotic species.
- Special precautions need to be taken to avoid accidental introductions into particularly sensitive areas.
- All legislation regulating the introduction of alien species should empower enforcement personnel to inspect premises and to seize and destroy specimens of introduced species which are illegally imported or possessed.
- An integrated holistic approach should be adopted. All these rules should be applicable to all species, whether terrestrial, freshwater or marine.

When prevention has failed and an introduced species has become established, there is clearly a need to try to eradicate it as quickly as possible before it is too late.

Section 4: Risk assessment and practical management of invasive species

4. Risk assessment and practical management of invasive species

4.1 Detection and capacity for mitigation measures

The three stage hierarchical approach to invasive species, adopted by the CBD, stresses that prevention is generally far more cost-effective and environmentally desirable than measures taken following the establishment of a non-native species. Therefore prevention should be given priority. However, prevention measures will sometimes fail and if an invasive non-native species has already been introduced then further measures will be necessary. A key issue to contend with is justification of resource allocation between preventive measures and actions in mitigation of existing problems.

The second and third stages of the CBD approach are addressed in this chapter. These are 1) the monitoring and surveillance and 2) the capacity to take mitigation measures for non-native species. While the nature of biogeographical processes ensures that sealing a land mass against invading wildlife is impossible, much can be achieved to reduce the number of future invasions and the damage created by those that slip through the safety net.

A key step in the management of biological invasions is an understanding of the frequency with which a species is introduced into a specific area, the size of each introduction and the subsequent pattern of spread across the natural landscape, all of which emphasise the need for regular surveillance. Likewise, ill-informed and/or poorly constructed control regimes are expensive and often fail to yield sustainable results.

The development of a structured approach to assess the impact and management of individual non-native species is highly desirable. Control attempts should not be the only response to the identification of non-native species; as such a policy would be prohibitively expensive. The DEFRA review (2003) recommends that a targeted response should be able to accommodate a range of management options, from acceptance of the presence of a species with ongoing review of their changing status, through to mitigation measures such as containment or control.

4.2 Monitoring and surveillance

Surveillance is the act of undertaking repeated surveys and monitoring is surveying against a standard, to determine subsequent changes (DEFRA, 2003). To be efficient a monitoring scheme must incorporate a number of different elements including:

- recording of all invasive/native species across taxa, including proactive recording of key invasive species of concern

- changes in numbers and distribution of invasive/native species over time and analysis within and among taxa

- changes in phenology (the seasonal activity) of native/invasive species within and among taxa

- maintaining lists of species which have not yet been recorded in Northern Ireland or the Republic of Ireland but are known to have been accorded pest status elsewhere in north-west Europe and in regions of similar climatic regime.

It may be advisable to sample areas at different spatial scales. In order to maximise information for a given cost it could be necessary to combine extensive, inexpensive sampling with intensive, expensive sampling of smaller sub-samples. The value of sampling at finer scales may often be predicted in advance of an investigation, though this would benefit from tools for predictive economic analysis.

Additional monitoring concerns include the importance of temporal and spatial scale with respect to new and established invaders and the limitations of extrapolating across scales set in the context of the apparent urgency of advice based on results. Within the scientific community, concerns have been raised regarding the prevalence of anecdotal evidence, inconsistency in documentation and metrics used; dominance of single trophic-level studies and the emphasis on ecological (theoretical) outcomes rather than mechanisms of control or mitigation. Management efforts should attempt to co-ordinate monitoring strategies across geographic regions.

Comparison of the availability of databases between the north and south indicates at a glance that the frameworks for monitoring and the associated availability of data appear better developed in Northern Ireland (Box 4.1, Table 4.1). However, this is not necessarily the case; it is merely that the consolidation of relevant records under one central agency increases ease of access to a larger group of people. It is recommended that such a recording framework is adopted in the Republic, although the need for individual organizations to maintain a specialist interest in identifying certain taxa remains high.

The Northern Ireland Biodiversity Group (2002) identified gaps in knowledge of regional biodiversity: not all species inhabiting Northern Ireland have yet been identified; some groups such as fungi, lichens and most invertebrates are poorly described. Records are frequently out-of date and this has partially been attributed to a lack of enthusiastic and competent field recorders and inadequate or difficult identification keys for certain groups (Northern Ireland Biodiversity Group 2002).

4.3 The decline of trained taxonomists

Taxonomic research has a large input from non-professional or amateur researchers, in addition to professionals working at museums or universities. The decline of taxonomy and the number of taxonomists within the professional community has been widely publicized but trends in the activities of amateur taxonomists are unclear. Because amateurs contribute many valuable species records this may have a disproportionate impact upon the information available for conservation planning and therefore represents an under-appreciated threat to developing policies on invasive species (Hopkins & Freckleton 2002).

A study evaluating the changing role of both amateur and professional taxonomists was conducted by Hopkins and Freckleton (2002). Contributions by British-based authors to Entomologist's Monthly Magazine over the past century were reviewed. Results showed that both amateur and professional taxonomy have undergone a long and persistent decline since the 1950s, in terms of both the number of contributors and the number of papers contributed.

A useful innovation would be to consolidate information so that the public is provided with clearly defined access routes for information on identifying non-native species. Currently key personnel tend to be inundated with queries on identification from the general public. This work load tends to peak during the summer months when people spend an increasing proportion of time outdoors and also during the breeding seasons of particularly conspicuous and attractive species.

Box 4.1. Biological Recording in Northern Ireland

The Centre for Environmental Data and Recording (CEDaR) was established in 1995 at the Ulster Museum supported by grant aid from the Environment and Heritage Service (EHS). The CEDaR project is a partnership between Ulster Museum, EHS and the recording community throughout Northern Ireland. The core objectives of CEDaR are: to store information related to the geology and distribution of the flora and fauna within Northern Ireland and its coastal waters and make these data available.

Computerised datasets held by CEDaR include:

- NI Vascular Plants Database/BSBI Atlas 2000 Project
- NI Mammal Survey data
- NI Littoral and Sublittoral data
- Butterflies and Moths data
- Birds data (RSPB data, Raptor Study Group and Northern Ireland Birdwatchers' Association)
- A range of invertebrate datasets

CEDaR is increasingly accepted as the focal point for the collation and storage of environmental records related to Northern Ireland. The achievements of the project have been recognized recently by the consortium developing the National Biodiversity Network (NBN) in the United Kingdom. The NBN will be a partnership of local and national custodians of wildlife information proving access to all within a framework of standards. The essence of NBN is the importance of co-ordinating information on a national basis. Within the framework, CEDaR has been described as a suitable model for developing Local Records Centres.

Table 4.1 Organizations holding databases on native and exotic flora and fauna in the Republic of Ireland

Organization	Type of organization	Holdings
Research Section of the National Parks and Wildlife Service designated as the National Reference Centre for Biodiversity (formerly the Irish Biological Records Centre until 1988)	Government	Irish flora and fauna
The National Museum	Government	Irish flora and fauna
The National Botanic Gardens at Glasnevin	Government	Irish flora
Department of Communications, Marine and Natural Resources (Marine Division)	Government	Inland and marine fish species
Department of Agriculture and Food (Forest Service)	Government	Native/imported tree species
Central Fisheries Board	Government	Aquatic vegetation and fish
The Marine Institute	Statutory body	Fish species/inshore species
Coillte Teoranta	Semi-state body	Native/imported tree species
Teagasc (Irish Agriculture and Food Development Authority)	State forest body	Plants and invertebrates (see also REPS scheme)
Birdwatch Ireland	Conservation NGO	Countryside/garden bird surveys
Irish Peatland Conservation Council	Conservation NGO	Wetland plants/amphibian surveys
The Irish Wildlife Trust	Conservation NGO	Irish Mammals
The Vincent Wildlife Trust	Conservation NGO	British and Irish mammals
The Cork County Bat Group	Conservation NGO	Bat surveys
The Botanical Society of the British Isles (Ireland)	Conservation NGO	Local flora/butterfly surveys
The Dublin Naturalists' Fieldclub	Conservation NGO	Local flora and fauna
The Irish Seedsavers Association	Conservation NGO	Native grains and fruits
National Association of Regional Game Councils	Hunting and conservation NGO	Local predator information (local fauna)
Universities		Various
Commercial consultancies (Environmental Impact Statements)		Various
Private individuals		Various

4.4 Access to private land

A large proportion of land within Northern Ireland and the Republic of Ireland is privately owned. However, the sequence of events following the discovery of an invasive species on private land remains unclear. Additionally, the difficulties of conducting research on privately owned parcels of land may result in a bias towards a restricted set of community types (Hilty & Merenlender 2003). Another pitfall of not conducting research on private land is the potential, particularly in landscape-scale studies, for unrepresentative sampling because public and private lands may differ in biodiversity and productivity. Such trends could lead to erroneous conclusions (Hilty & Merenlender 2003). There may also be a dearth of information relating to prevalence of a particular species on private land.

One of the reasons for which landowners might be reluctant to allow research being carried out on their land is concerns over liability and property damage. Interrelated factors identified by Hilty & Merenlender (2003) that may indicate an increased or decreased probability of a landowner being receptive include property size, average income, past experience with agencies or researchers, education level, political affiliations and geographic location. In rural communities, an individual's interest in and knowledge of biodiversity can be predicted at least partly on the basis of membership in hunting and environmental organizations, age and education level (Clements 1996, Macdonald & Johnson 2000). If representatives of these local organizations contact landowners about the research before the researcher does, participation and access to sites is much more probable.

Alternatively, researchers can be discouraged from using private land due to concerns regarding the transfer of property and alterations in site usage part way through a study. Therefore continuing participation of the landowner cannot be guaranteed. Researchers may perceive limitations to the research design resulting from the restrictions imposed by landowners. For example, studies that require a random-sampling design may present problems if the rejection rate for land access is high or biased in some way. Additional constraints may be placed on the researcher's ability to disseminate the results.

4.5 Risk assessment

As the range of IAS continues to grow, science and management are forced to predict and manage only the most serious species. This requires the adoption of a management framework that can encompass ecosystem change and pragmatic acceptance of invasive species as part of ecosystem dynamics. Such a management system must allow change within a range of predefined limits of acceptable change, identified by bioeconomic tools such as "aesthetic injury levels", while also effectively highlighting areas where these limits are broken and action is required. A suitable framework requires the flexibility to incorporate new research and thinking in a manner that is fundamentally pro-active in approach.

A variety of public agencies, organizations and individuals have compiled lists of the invasive species regarded as the most detrimental within their respective regions of interest. Unfortunately, the factors used to determine which species are included on many of these lists are not explicit, making it difficult or impossible to compare or compile different lists and leaving these lists open to concerns that they were produced on a subjective or *ad hoc* basis. To address this problem, a standard set of criteria for categorizing and listing non-native invasive species according to their overall impacts on biodiversity in a large area, such as a particular habitat or ecological region, is required. Use of these criteria can make the process of listing invasive species more objective and equitable, rendering the resultant lists more useful to researchers, land managers, regulators, consumers and commercial interests, such as the horticultural sector. An example would be criteria which are designed to distinguish between species that are capable of causing high, medium, low or negligible impacts to native biodiversity within a specified region.

In 2001 the Global Invasive Species Programme (GISP) proposed a 'pied list' for governing the trade of species, which contains:

- A 'black list': species whose importation is prohibited;
- A 'white list': species classified as beneficial or low risk, whose importation is allowed under conditions restricting the use of the species to specific purposes (research, public education, others) or with approved holding facilities. 'White lists' may be developed at national or sub-national level and should only include species that have undergone risk assessment.
- A 'grey list': any species not yet known to be harmful or harmless. Any species not included on either the 'black' or 'white' list.

To evaluate the potential risk it is necessary to have monitored the spread of invasive species and any trends in their distribution and abundance over rapid time scales. This could enable forecasting of the potential time frame in which a population will begin to expand in size.

4.6 Risk assessment of species and habitats in Ireland under threat from non-native invasive species

In addition to the species mentioned in Section 1: Tables 1.1 to 1.6 there are a number of species which have not yet been recorded in Ireland but could cause significant problems if they became established here, as demonstrated in Great Britain and elsewhere in Europe. Examples include non-native crayfish species, such as Turkish crayfish, *Astacus leptodactylus* and North American signal crayfish, *Pacifastacus leniusculus*, which can both host the crayfish plague responsible for decimating native crayfish and freshwater fish populations in both Great Britain and Europe. Northern Ireland currently has legislation in place to prevent the importation of non-native crayfish for aquaculture purposes. However, there is currently no legislation preventing the importation of live crayfish as food items. Restaurants and fish and wholesale markets are advised to follow the Crayfish Code of Practice, although no legal enforcement exists. The one diagnosed outbreak of crayfish plague in Ireland is believed to be the result of fungal spores introduced by fishermen on wet gear (Reynolds, 1998). The reintroduction of native crayfish to Lough Lene sometime after the eradication of infected native crayfish appears to have been successful.

A second example of serious concern is *Gyrodactylus salaris*, a parasite which infects the skins and fins of salmon and can both kill and cause serious harm. This parasite is native to waters of the Baltic in Russia, where its impact upon native fish populations is small. However *G. salaris* is thought to have been introduced to Norway by stocking with resistant Swedish stock in the mid-1970s. The only known means of eliminating the parasite is to poison the whole river system and re-stock. By 1984 the Norwegian salmon fisheries had sustained losses of between 250-500 tonnes per year (Johnsen & Jensen 1986).

The high frequency of traffic between Great Britain and Ireland and their close proximity renders each susceptible to detrimental species introductions from the other. A prominent invasive species present in Great Britain is zander *Stizostedion lucioperca*, a fish introduced for sport. Other fish species present in Great Britain that could become invasive in Ireland are chub, *Leucisus cephalus* and ruffe, *Gymnocephalus cernua*. Species not found in Ireland which are native to Great Britain, such as the muntjac deer *Muntiacus reevesi* could considerably reduce grazing and pasture quality. A notable invasive of rivers in Great Britain is the Chinese mitten crab *Eriocheir sinensis*, which causes erosion to soft sediment banks of the Thames and consequently concern in terms of flood defence measures. For these species it is important that action is undertaken to assess the risk of their introduction. If a particular species does pose a significant risk, efforts to reduce the risk of introductions and, if the species is found in the wild, control/eradication programmes should be urgently considered.

Several attempts have been made to predict the characteristics of a successful invader (Williamson, 1996). Morphological, physiological and life-history traits might predict the probability of a non-native species becoming more or less invasive when introduced to a new region. Crawley *et al.* (1996) conducted an analysis to compare native and non-native British plants, but found only that the latter were taller, had larger seeds and more protracted seed dormancy. Such an analysis compares native with successful non-native species. Rejamanek & Richardson (1996) conducted a comparative analysis of invasive and non-invasive non-native pine species (in the genus *Pinus*) in the USA, and found that the former had greater seed mass, faster growth and more frequent seeding. Ehrlich (1986) reported that successful invertebrate invaders are likely to be mobile species, generalist in their feeding habits, with short generation times, high population genetic variation and the ability to function in a wide range of physical conditions. Simberloff (1989) could make no generalizations about the invasive potential of insect species. A recent review of previous studies reported that it is not possible to arrive at general conclusions between species' attributes and invasive ability (Manchester & Bullock, 2000).

It has been suggested that an invasion will only be successful where the climate of a region being invaded is similar to that of a species' native region. However, both Williamson (1996) and Mack (1996) found as many exceptions to this rule as there are supporting cases. It is also possible that genetic and breeding characters, such as inbreeding, asexuality, polyploidy or heterozygosity are related to invasiveness. Invaders of the British flora are not characterized by particular genetic characteristics (Gray, 1986). Williamson (1996) concluded that genetic studies offered no generalities of predictive use.

Species that are more abundant and have a larger range in their native region might be expected to be more invasive, because these parameters can be seen as a surrogate for wide ecological amplitude or good dispersal (Manchester & Bullock, 2000). Williamson (1996) reported some evidence to support this hypothesis, but concluded that it does not have good predictive potential.

Certain families (e.g. the Poaceae and Asteraceae in plants) and genera (e.g. *Bromus, Cirsium, Poa*) contain a majority of the world's problem plant species (Mack, 1996). Because related species share traits, species from these taxa might be expected to be more invasive than species from other taxa. A similar idea is that if a species has been a successful invader of a region then its congenerics might be invasive as well. However, Mack (1996) and Williamson (1996) reported that there are too many exceptions for these to be useful rules. Therefore, it is vital to make case-specific studies of those species which are potentially invasive in Ireland.

It is accepted that disturbed habitats such as urban wasteland, arable fields and riverbanks are generally more readily invaded (Smallwood, 1994). Conversely, undisturbed natural and semi-natural communities tend to contain few, if any, recently introduced non-native species. Thus plant communities may be ranked in terms of their 'invasibility', based upon the proportion of bare ground and on the frequency and intensity of soil disturbance (Crawley, 1987). Therefore, whilst there is some information on the susceptibility of different habitat types to invasions, predictions of precisely which habitats will be invaded by which species, and which of those habitats will be most affected by such invasions, cannot be made with any degree of certainty (Manchester & Bullock, 2000). This suggests that only a detailed ecological study of a species and its potential habitats can allow accurate prediction of the invasiveness of an introduced species. This was the general conclusion of the SCOPE (Scientific Committee on Problems of the Environment of the International Council of Scientific Unions) programme on biological invasions (Kornberg & Williamson 1987; Drake & Mooney, 1989).

The presence of an invasive alien species in an ecosystem thus depends on the survival and invasion rate of the invasive alien and ecosystem resilience (Figure 4.1). The speed of establishment is susceptible to various factors, in particular human intervention. The unpredictable nature of species invasions means that fully quantitative and economic assessments can rarely be prepared. The quantifications which are usually attempted are calculations of the area endangered by a non-native species and costs to individual enterprises whose gross margin budgets can be readily obtained.

4.7 Vulnerable habitats in Ireland

A variety of habitats within Northern Ireland and the Republic of Ireland are designated for protection at national or European level. A number of these habitats (Table 4.2) are under threat from invasive non-native species; for example freshwater river systems are being degraded due to the introduction and spread of ornamental plants (Case study 1.4) and freshwater fish species. Old oak woodlands and dry and wet heath sites are threatened by rhododendron, sea buckthorn is infiltrating sand dune systems and coastal habitats are being degraded by Canada geese *Branta canadensis* and common cordgrass *Spartina anglica*.

Habitats in Ireland listed on the Habitats Directive are protected as Special Areas of Conservation (SACs), while sites that are important for birds are protected as Special Protection Areas (SPAs). Additional priority sites receive local protection as Natural Heritage Areas, National Nature Reserves or Areas of Special Scientific Interest (ASSIs). he breakdown of protected areas is shown in Table 4.3. In the Republic of Ireland SACs cover a land area of 1.1 million ha. The land area covered by SPAs and NHAs is

258061 ha and 907672 ha respectively. In Northern Ireland SACs cover a region of 65100 ha and SPAs (designated as SPAs only) cover an additional area of 70700 ha (Source: http://www.jncc.gov.uk/idt/spa/default.htm).

Reserve creation is a primary line of defence in the conservation of native species. Unfortunately, this leads to the concept of "full protection versus no protection" and recent research has shown that maintenance of the intervening matrix is also of considerable importance, especially for species which regularly disperse between different habitats (Baillie *et al.*, 2000; Ray *et al.*, 2002, Selonen & Hanski, 2003). Furthermore, for species to be maintained (rather than just represented) we must conserve ecological and evolutionary processes beyond, as well as within, reserves (Balmford *et al.*, 2000). Unfortunately there are currently limitations in quantifying how far these additional conservation objectives are met. Species representation tends to be the most widely used metric of conservation performance, and it is hoped that insights gained from comparative performance between regions can be used to predict geographical areas where the need for more sophisticated measures of conservation performance is high.

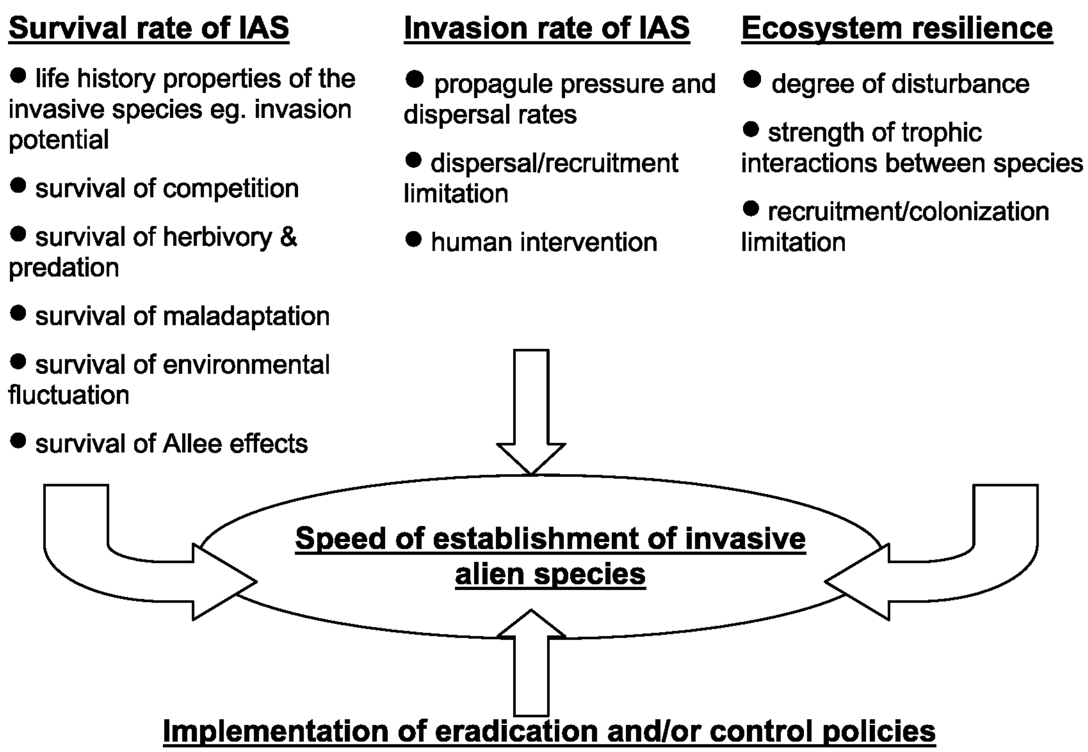


Figure 4.1 Processes influencing ecosystem resilience and the potential speed of establishment of invasive alien species.

Article 8 of the Convention on Biological Diversity obliges contracting parties to establish protected areas for conservation. Balmford and Gaston (1999) hypothesize that this can be achieved in networks of smaller reserves, provided their design is based on how well different sites complement one another biologically, rather than on more commonly used criteria, such as species richness or the availability of site acquisition. This hypothesis is based on the scenario that an inefficient reserve design, whose cumulative representation of biodiversity rises only slowly with increasing area is inferior to a network chosen using a complementarity-based algorithm, which reduces the area needed to achieve a particular conservation goal. This increase in efficiency requires species lists for each candidate site which can be expensive to obtain, yet can still ultimately result in economic saving.

4.8 Vulnerable species: the need for conservation

A number of species are selected as priorities for conservation in both the UK and, more specifically, in Northern Ireland (Northern Ireland Biodiversity Group 2002). Maintenance of these species is important to conserve both natural ranges and genetic diversity. A number of Northern Ireland species which do not have UK action plans were identified as requiring Northern Ireland action plans. Action plans for the Irish hare, chough and curlew have since been drafted (Northern Ireland Biodiversity Group 2000). Ireland's National Biodiversity Plan (2002) promotes similar actions for species of conservation concern. Both national reports additionally recommended that the lists should be viewed as provisional, pending further biodiversity research.

Genetic threats to native species can arise either as a consequence of declining population size, the introduction of invasive species, or even the introduction of native species of non-local provenance, with different genetic composition from local stock. An example of the latter would be the importation of forest trees from sources on the continent. Despite being the same species, genetic differences might result in a different capacity of the stock to survive in the Irish environment, or a different palatability to native insects. We endorse the suggestion made by the DEFRA Review Group (2003) that native plants of local provenance should be stipulated for use in commercial, conservation or amenity planting schemes, particularly within or near areas of conservation interest.

A second example outlining the dangers of introducing non-native genotypes is the introduction of non-native salmon for brood stock. Interbreeding between introduced fish and local wild populations has resulted in detrimental impacts in wild populations (Case study 4.1).

One of the most seriously affected sectors to suffer from the importation of different genetic strains of a species is the glasshouse industry. The introduction of strains of previously established insect species which are resistant to an array of insecticides is an increasing concern (Dunne 2003). An example is the cotton-melon aphid *Aphis gossypii* Glover which, until recent years, was a rarely encountered pest of certain glasshouse crops. However, in recent years a strain has been occurring on chrysanthemums and cucumbers that is resistant to all the usual organophosphate, carbamate and synthetic pyrethroid aphicides and is susceptible only to nicotine spray (Dunne 2003). The increased use of insecticides on populations of insect species with short generation times has serious implications for pesticide resistance in wild insect species.

Table 4.2 Examples of priority habitats and invasive and potentially invasive species that threaten their favourable status

Priority Habitat	Invasive threats
Upland mixed ashwoods	*Sciurus carolinensis*
Upland oakwood	*Rhododendron ponticum*
Wet woodland	*Impatiens glandulifera*
Lowland woodland pasture and parkland	*Prunus laurocerasus*
Lowland heathland	*Rhododendron ponticum*
Limestone pavement	*Fagus sylvatica*
Aquifer-fed naturally fluctuating waterbodies	*Heracleum mantegazzianum*
Ancient and/or species-rich hedgerows	*Crataegus laevigata*
Cereal field margins	*Arthurdendyus triangulates*
Eutrophic standing waters	*Heracleum mantegazzianum*
Mesotrophic lakes	*Rutilus rutilus*
Marl lakes	*Pacifastacus leniusculus*
Rivers	*Gammarus pulex*
Mud habitats in deep water	*Dreissena polymorpha*
Blanket bog	*Picea sitchensis*
Coastal sand dunes	*Hippophae rhamnoides*
Coastal saltmarsh	*Spartina anglica*
Saline lagoons	*Spartina anglica*
Seagrass beds	*Spartina anglica*
Tidal rapids	*Sargassum muticum*

Table 4.3. Designated nature protection areas in Ireland. These designations include marine areas.

Designation	Approximate land area ('000 ha)	
	Northern Ireland	**Republic of Ireland**
Special Areas of Conservation (SACs)*	65	1,100
Natural Heritage Areas (NHAs)	n/a	907
Special Protection Areas (SPAs)	70.7	258

*In the Republic of Ireland, terrestrial SACs are a subset of NHAs.

Case Study 4.1 Atlantic salmon *Salmo salar*

Category of introduction: Atlantic Salmon are native Irish species protected under Annex II of the Habitats Directive. However, non-native salmon are introduced to fish farms that benefit economically from their superior growth rates.

Reasons for introduction: Commercial production of farmed fish for sale.

Pathway for introduction: Growing salmon and other fin fish in sea pens exposes the farm operation to certain risks that can lead to escapes. The pens can be damaged due to weather (storms), persistent predators such as seals that try to get at the fish, industrial accidents (human error or equipment malfunction) and vandalism.

Problems caused by the introduction: Adult farmed salmon are competitively and reproductively inferior in the wild and their escape and subsequent interbreeding with wild salmon disrupts local adaptations and reduces the genetic diversity of wild salmon populations (Fleming *et al.*, 2000). Interbreeding can potentially change the genetic make-up, fitness (i.e. recruitment in subsequent generations) and life history characteristics of wild salmon. In order to assess the impact of such genetic changes on wild stocks, experimental simulations of escapees were carried out in a 10 year, 2 generation project on a tributary of the River Burrishoole in Western Ireland (McGinnity *et al.*, 2003). Farm salmon were found to be larger and competitively displaced wild parr, thus reducing wild smolt output, which is equivalent to a loss of part of the freshwater habitat (McGinnity *et al.*, 2003). The hybrids were intermediate in survival. Even modest numbers of farm escapees and modest levels of stocking can result in <5% to 30% declines in fitness, stocking with non-native salmon is likely to have similar effects (McGinnity *et al.*, 2003). Farmed salmon may also be carriers of diseases and parasites unknown in the wild that have the potential to reduce wild populations. Therefore increased emphasis needs to be placed on preventing escaped farm salmon from entering rivers. From an economic perspective farm salmon escapees may also pose a threat to producers seeking to brand their products as organic.

How the introduction may have been prevented: Stock records are essential to accurately quantify the potential scale of a problem should an incident occur, notify appropriate legislative departments and initiate attempts to recapture the fish.

Invasion dynamics outside of Ireland: Farmed salmon populations appear to threaten wild salmon populations throughout the North Atlantic (Fleming *et al.*, 2000).

References

Fleming, I.A., Hindar, K., Mjolnerod, I.B., Jonsson, B., Balstad, T. & Lamberg, A. (2000) Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London Series B*, 267, 1517-1523.

McGinnity P., Prodohl P., Ferguson K., Hynes R., O' Maoileidigh N., Baker N., Cotter D., O' Hea B., Cooke D., Rogan G., Taggart J., & Cross T. (2003) Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London, Series B*: **270**, 2443-2450.

4.9 Research needs for risk assessment

The effects of alien species on native biodiversity, the rate at which effects proceed, and the time scales over which negative impacts can be detected are still not fully understood. "Just Ecology" consultants were commissioned to undertake a report to the UKBAP invasive group (Callaghan 2003), which recommends a variety of potential research areas, some of which we consider merit inclusion here. Further research should aim to incorporate:

1. *Basic biology, database and monitoring*. Improved knowledge of the basic biology of introduced species: compilation of a database of current information about actual and potential problem species, improved monitoring and surveillance of invasives/natives.
2. *Indirect impacts on species*. Assessment of indirect impacts on native species, e.g. on dependent/specialist herbivores, by altering competitive interactions, disease/pathogens etc. Determination of functional and performance consequences for the population.
3. *Functional impacts*. Assessing the ecological impacts of functional/performance consequences on affected species, on habitats, ecological processes and ecosystems.
4. *Genetic impacts*. Assessment of direct impacts through gene flow and introgression within-species and gene flow between introduced and native species and hybridization. Determination of functional/ performance consequences for the population.
5. *Genetic conservation*. Improve current knowledge of the range of genetic variation represented in priority, native species, assessing the potential impacts of introduced genes and grouping of species according to their vulnerability to genetic change and the need for genetic conservation.
6. *Decision support system*. Identify direct/indirect impacts, ranking species according to threat posed. Understand different agents of change. Develop a decision support system for defining thresholds of unacceptable change, determining when to take action and what action to take.
7. *Removal of aliens*. Experiments to determine which invasive species can be effectively removed. Considerations include recruitment potential, landscape patterns/dynamics and cost-benefit analyses.
8. *Scientific basis for management*. Developing the scientific rationale for management techniques, tools and measures, run from a decision support system as a precursor to taking action. Research to inform appropriate responses to observed /predicted effects and to evaluate management options, including operational responses, educational and economic policy and legislation.
9. *Risk assessment*. Develop biodiversity risk assessment for screening imports of exploited species or related commercial products, in order to identify the role of different vectors/pathways for introduced species .
10. *Cost-benefit analysis* of introductions. Produce environmental accounts for introduced species and evaluate the economics of new proposals to commercially exploit species. Consider loss of biodiversity benefits and services and costs to industry.
11. *Impacts of controlling diseases/parasites*. Investigate the effects of controlling introduced disease/parasites on other species at all relevant scales (individual, sub-population or population).

12. *Long-term forecasting*. Investigate long-term adaptive changes of non-native species in relation to climate change, through monitoring genetic change and phenotypic indicators.

Risk reduction

4.10 The importance of social and economic stability in risk reduction

The most influential conservation priority-setting approaches emphasize biodiversity and threats to it when deciding where to focus investment. However, the socio-economic and political attributes of nations clearly influence the uptake and delivery of conservation actions. An analysis by O'Connor *et al.*, (2003) examined a combination of biological and sociological variables in the context of a "return on investment" framework for establishing conservation priorities. Only a few countries emerged as high priorities irrespective of which factors were included in the analysis (O'Connor *et al.*, 2003). Some countries that ranked highly as priorities for conservation when focusing solely on biological metrics, did not rank highly when governance, population pressure, economic costs and conservation need were considered (e.g. Columbia, Ecuador, Indonesia and Venezuela). Whilst considerations within Ireland differ from these examples, priority-setting is rarely divorced from political agendas. The need for cross-border policies is particularly poignant in Ireland.

4.11 Risk Analysis

By way of a model for organising risk analysis, the management of plant pests provides guidance. Specific organizations such as the EPPO, the European Plant Protection Organization have specific Risk Assessment Schemes. Such schemes incorporate an initiation stage and a quantitative and qualitative risk assessment (http://www.eppo.org/QUARANTINE/PRA/prassess_figures.html).

In the Irish case it is difficult to predict how a cross-border situation would be addressed, both in terms of legislative procedures and financial responsibility for ecosystem restoration. For example, if a threat arose within or near to a particular SAC which spans Northern Ireland and the Republic of Ireland (Table 4.4) there may be additional barriers to rapid action. For example, Lough Melvin is an important resource for tourism due to the high level of recreational fishing. The infiltration of an invasive alien species resulting in a detrimental impact on the fishing industry would be of serious economic concern to both countries. Identification of the jurisdictional and legislative barriers to immediate action is required. It is recommended that a standard protocol is designed to combat the complications of cross-border invasions.

Table 4.4 cSACs in Northern Ireland that adjoin cSACs in the Republic of Ireland (Source: http://www.jncc.gov.uk/ProtectedSites/SACselection/adjoining_csacs.htm)

UK cSAC		**Republic of Ireland cSAC**	
Site code	Site name	Site code	Site name
UK0016603	Cuicagh Mountain	IE0000584	Cuilkcagh-Anieran Uplands
UK0030047	Lough Melvin	IE0000428	Lough Melvin
UK0016621	Magheraveely Marl Loughs	IE0001786	Kilrooskey Lough Cluster
UK0016607	Pettigo Plateau	IE0001992	Tamur Bog
UK0016607	Pettigo Plateau	IE0002164	Lough Golagh

An example of a cross-border scenario is illustrated by the sequence of events depicted in Figure 4.2. In this hypothetical situation a member of the public is brought into contact with an "unusual species", which we shall consider to be American signal crayfish, discovered in Dawson's Lough (H365165), in the north of the Republic close to the border. This individual may then take one of several options, they may choose not to act or they could dispatch the item to a local conservation office in Belturbet, a local fisheries officer, or a museum in Dublin. The choice of destination will influence the length of time to arrive at a positive identification of the species. Once the species has been identified, by one of a limited number of capable individuals, National Parks and Wildlife Service may be informed of a potential threat. Authorization to conduct survey sampling of Dawson's Lough would reveal the presence of American signal crayfish at low abundance. The threat to the site south of the border could be perceived as low, as this area is not a designated SAC. However, it must be remembered that signal crayfish are highly mobile and can move over land (Alderman & Wickins, 1996). North of the border lies Lough Erne, the whole of which is a designated SAC and Magheraveely Marl Loughs, for which native freshwater crayfish are a designating feature. Therefore a differential exists in the prioritization of the threat between the north and south.

No formal mechanism exists for transfer of information and cross-border communication in this matter, yet it is probable that NPWS staff would personally inform their counterparts at EHS in the north. Senior level authorization will be required to authorize surveying of sites north of the border in order to determine the extent of the local threat. Access to private land may be restricted and trained personnel may be scarce. Thus there may be a requirement to train staff at short notice. Species-specific information may also be lacking, increasing the difficulty in ascertaining the degree of threat and possibility of eradication. Nonetheless it is probable that attempts will be made to evaluate the extent of the distribution and the probability of success of control or eradication methods. Co-ordination of any eradication policy between north and south will be essential due to the connectivity of this ecosystem. It is possible that either EHS or NPWS may lack the scope or manpower to act on this matter and may advertise a contract to tender, leading to initial feasibility studies and eventually eradication, evaluation and post-evaluation. The time scale of this process is delayed by the lack of pre-defined pathways, resulting in the initiation of an eradication policy after a considerable delay of up to several years, by which time the crayfish will have reproduced and increased their numbers.

The alternative scenario considers a situation whereby the unusual species is dispatched direct to a cross-border invasive species agency, where identification takes place and a specific contingency plan is set in motion. This would necessarily require a broad advertising campaign targeted at the general public and possibly the maintenance of a web-based invasive species site, all of which would come under the general remit of the invasive species agency. In this case an eradication campaign could be initiated in 3 months or less, based on framework agreements with contractors working to an established plan. This rapid response would considerably reduce the possibility of the crayfish completing its reproductive cycle before eradication, increasing ease of eradication and reducing cost.

4.12 Forecasting future introductions

Long term consideration of the potential future introductions of invasive alien species in relation to changing climatic regimes is of importance for predicting the kind of organism that could become more invasive in Ireland in the future. The potential for synergistic effects, two processes acting concurrently to accelerating rates of change is likely to increase in the future, due to the increasing pressures of habitat fragmentation, climatic alteration and increased disturbance. A case study of the role of climate in predicting species invasions of invertebrate fauna into Ireland is documented below (Case Study 4.2).

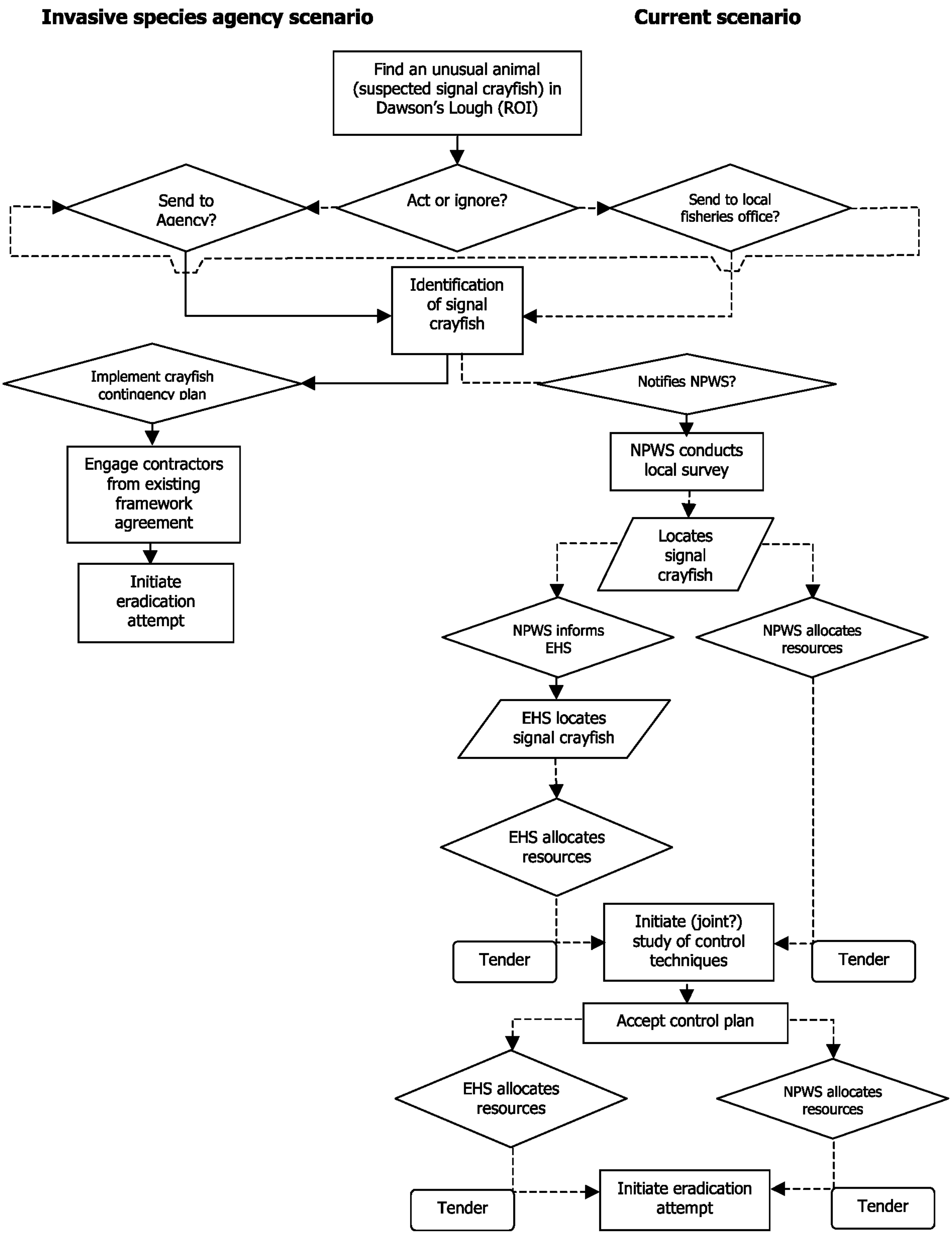


Figure 4.2 Hypothetical scenario of decisions and processes affecting the cross-border response to finding a potential new invasive species near the border. Dotted lines indicate risk prone stages. The key factor is the development of a contingency plan, comprising the detailed processes and decisions, lead by a cross-border body in advance of the discovery of the invasive. Thus the potential delays occur before the invasion occurs. As delays arise from a post-hoc response the chances of success rapidly diminish.

Case Study 4.2 The role of climate change in predicting species invasions

Climate change means that the ranges of many insects, including those that are not native to Ireland, are likely also to change. This may be accelerated by alterations in land-use. In Ireland, alien invertebrate species have been recorded originating from Australia, Asia, America and mainland Europe (Figure 4.3, Anderson, 2003). The proportion of alien species represented within the different invertebrate groups differs; alien species comprise a high proportion of the total fauna within the flatworms and, to a lesser extent, within groups such as slugs, snails, isopods and millipedes (Figure 4.4, Anderson, 2003). Recent rapid climatic trends have been observed within Northern Ireland including: increases in winter precipitation and night temperatures, increased cloudiness and reduced sunshine hours and milder winters with significant increases in minimum and maximum temperatures. Increases in temperature are likely to favour both cryptozoic and thermophilic fauna while increased precipitation and cloudiness will favour cryptozoic and hygrophilous fauna.

One example of a recent species invasion believed to be attributable to climate is that of the Lily Beetle *Lilioceris lilii*, a garden pest discovered in Belfast in 2002 (Anderson & Bell, 2002). This species is native to Eurasia and occurs across the north Palaearctic land mass and became established in the British Isles during the nineteenth century (Cox, 2001). Despite being erratically resident in southern Britain for many years, marked expansion northwards from the south-east counties of England appears to have occurred only within the last 20 years or so. The appearance of *L. lilii* in Northern Ireland is by far its most northerly and westerly site, a significant step in range expansion believed to have been facilitated by climate change (Anderson & Bell, 2002).

If current trends continue we can predict increases in the flux of damp loving organisms with a reduced influx of diurnal thermophilic organisms. This will result initially in a greater range of non-native slugs, snails, millipedes and flatworms and fewer new beetles, dragonflies, bees or butterflies. The potential economic consequences are difficult to evaluate but slugs are considered garden pests and create horticultural damage. The impact of flatworms is likely to cause serious long-term damage to earthworm populations in Ireland (see Case Study 2.1). This will have a consequent long-term effect on soil quality, such as increased surface litter accumulation, a lack of bypass flow for surface drainage, widespread increasing surface compaction and increased soil acidity.

References

Anderson, R. 2003. Workshop Presentation, "Patterns of terrestrial invertebrate invasions as a guide to future trends". All-Ireland Invasive Alien Species Workshop, Dublin, 26th November 2003.

Anderson, R. & Bell, A.C. 2002. A first record of the Lily Beetle Lilioceris lilii (Scopoli) in Ireland (Chrysomelidae: Criocerinae). *The Coleopterist*, **11**, 90.

Cox, M.L. 2001. The status of the Lily Beetle Lilioceris lilii (Scopoli, 1763) in Britain (Chrysomelidae: Criocerinae). *The Coleopterist*, **10**, 5-20.

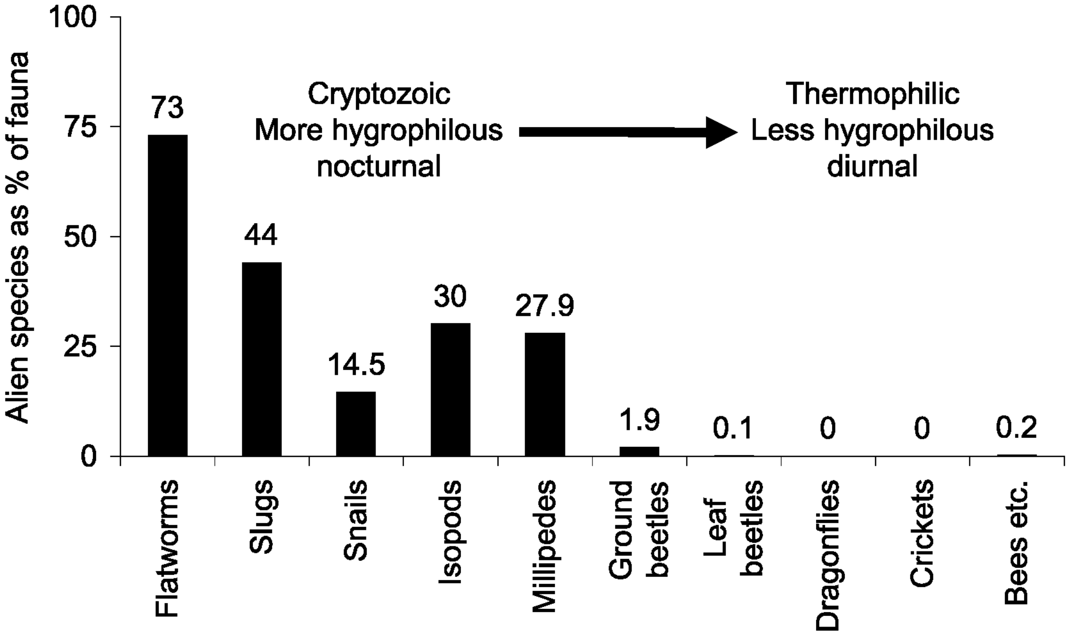


Figure 4.3 Representation of non-native species among invertebrate taxa in Ireland (Reproduced by courtesy of R. Anderson).

4.13 Public awareness and education issues

The fact that management and eradication programs are likely to be more successful if supported by an informed and co-operative public is frequently stated. An awareness of the community benefits arising from co-operative policies on IAS can increase the willingness of the public to contribute (occasionally even financially) to any attempts to rectify the problems. The DEFRA review group (2003) point out that reducing the number of inadvertent offenders also allows enforcement agencies to concentrate on persistent criminal offenders.

Public use of the internet has the dual potential to both increase the risk of invasive species imports (through the acquisition of rare and unusual plant and animal species) and it is an efficient tool to disseminate precautionary information to the public on the correct protocols to follow to reduce risks to native biodiversity.

The DEFRA review (2003) identifies key target audiences for improving awareness in relation to the problems of non-native species.

4.14 Target audiences and key issues

Issues which must be addressed to the general public, such as the risks of unwanted introductions through the dumping of garden waste. Educated naturalists within the general public who are able to contribute a wealth of information on the distribution and spread of invasive species

Professional groups with important roles to play, including policy makers, civil servants and ministers. Operational professionals, (e.g. agriculture, forestry, landscape or planning professionals) and other groups of professionals such as horticulturists or pet-trade professionals. The activities of each of these groups and the guidance and advice they provide to the public will be instrumental in raising awareness or alternatively causing problems.

4.15 Developing the culture

"Thinking green" has been on the increase for many years. However, many European countries still lag behind the custodial mindset prevalent within countries such as New Zealand, although the policies of such countries do benefit from the advantage of lower population densities. New Zealand has a heightened sense of responsibility regarding its native species due to the decimation during European colonization of a number of natives. For example the kiwi, kaka and other endemic birds declined in New Zealand as a direct result of the invasion of Eurasian rats (King, 1984). The approach to invasive species issues within Ireland is currently rather negative, based upon restrictive measures rather than encouraging an ethos of custodial care in the national psyche. Ireland also has the distinct disadvantage of having a car-based, ferry-driven tourist economy, placing high responsibility on both the local public and incoming tourists to safeguard against invasive species. Therefore it is recommended that considerable efforts are made towards public education regarding invasive species issues, in particular at points of entry into the country but also to raise the generalized level of awareness. As a means of promoting such a culture the DEFRA Review Group (2003) suggest a number of key basic messages are propagated, which we have adapted for the Irish situation.

- awareness of the potential risks of releases and escapes into the environment
- understanding of the consequences of moving plants and animals around N. Ireland and the Republic of Ireland
- understanding of the risks and consequences of introductions, especially to islands, remote areas and freshwaters
- understanding of the concepts of the values of native biodiversity and the term "native"
- awareness of the potential risks of what is brought back from abroad
- understanding of the need for the control and management of invasive non-natives and understanding of the risks of failure
- also understanding that only a minority of non-native species cause problems and that many have and will continue to enrich people's lives

In developing the means to achieve these ends the DEFRA Review Group advance several key considerations.

- ensuring the simplicity of the message to build up understanding
- avoiding the use of the words that have had negative associations with human activities, thus using, for example, the term "non-native" rather than "alien"
- advance planning to address concerns about animal welfare ahead of any control measures, recognizing that control measures should be undertaken to high standards that ensure the welfare of animals
- developing an awareness culture where the risk of invasive non-native species is considered a legitimate concern, ensuring that those undertaking any actions have a "licence to operate"
- dealing with any public assumption that reporting the presence of individuals of a non-native species will automatically lead to their death or removal
- overcoming professional and scientific concerns about scientific accuracy to convey a message

effectively: it is important to strike the right balance

The way in which the information is delivered needs to be targeted for each specific group. For example, it has been suggested that ferry and aeroplane tickets should carry information regarding instructions on what not to bring into the country. Specialist press should be used to target naturalists and the more informed members of the public, such as gardeners and anglers.

A key step will be the introduction or increase of information regarding invasive species in core curricula in primary and secondary education. Tertiary education tends to specialize in this area to a greater extent; yet improvements could be made regarding the specific concerns of non-native species to agriculture, forestry, ecology and land management. Some universities run courses in risk management, generally targeted towards providing short and long term relief in the aftermath of a disaster. Training in the management of invasive species could be included within such courses as a form of risk analysis.

4.16 Cost analysis: decision-making under uncertainty

The information necessary to conduct traditional cost-benefit analysis and risk assessment is largely inadequate and much of the existing ecological risk assessments are based on subjective information. The technology of risk assessments for introduced species is still at an early stage. Confidence limits about estimates of likelihood that a species will become a pest are large, increasing the probability of making a highly costly false hypothesis of no negative effect (Simberloff & Alexander, 1998).

A large proportion of management relating to invasive species is steeped in a "search-and destroy" mentality. In the case of rapid action against a species which is detected early a large amount of information on population biology of the particular species is not necessarily essential to eliminate the problem. Because of their rapid population growth and high dispersal abilities introduced species are one target at which it is better to "shoot first and ask questions later" (Simberloff, 2003). One concern is that successful eradication of the invasive species could feasibly be attributed to good luck rather than the particular management strategy used. For example, severe drought or a prolonged period of below average temperature may actually have had a greater detrimental effect upon the population than the control strategy did. Therefore, unless application of the same eradication procedure during a second invasion is initiated very rapidly, it will not necessarily be successful. It is recommended that where economically viable, efforts are made to identify the quantitative effects of a specific management treatment in contributing to a successful eradication. Certainly, attempts to eradicate long-standing invasions will require substantial biological knowledge of both the ecosystem and the population biology of the species. This will allow a better estimate of the probability of a successful campaign, avoiding wastage of time and public money (Simberloff, 2003), and enabling the prediction of situations where sudden removal of an alien species may generate a further disequilibrium, resulting in greater damage to the ecosystem.

Uncertainty is inherent in ecological systems and this can be countered by developing effective management options that adjust for different levels of risk and uncertainty. The use of mathematical models is fundamental to this procedure. However modelling can only play a role in this process if there is close interaction between modellers and resource managers. Some of the most successful management tools have been applied using an economically-based system of cost, risk and benefit measures applied in a location-specific manner.

Location-specific indicators of "damage" may be structured to represent economic concepts of capacity to produce a service, differential value of services at different locations, scarcity and replaceability of services and risk of service flow disruptions (Wainger & King 2003). The use of computer programs (such as Geographical Information Systems GIS), can allow these factors to be quantified at multiple scales. For example, different potential benefits from a treatment come into play over the extent of a park, aquifer recharge zone, or county.

4.17 The Polluter Pays Principle

The costs of damage, control and repair work are typically met by the taxpayer, or industrial sectors whose economic interests are affected. The DEFRA Review (2003) considered that the level of those fines available do not constitute a deterrent. It was recommended that, where such releases constituted a criminal offence or wilful negligence, then the "polluter pays" principle should be invoked, allowing the courts to have the option of imposing fines bearing some relation to the cost of reparation. The costs of inspection, monitoring or management are open to the "polluter pays" principle and consideration needs to be given to the legal framework for imposing and collecting fines, or imposing an insurance requirement (DEFRA, 2003). In different circumstances these might include imposing the cost of management on those responsible for the release or introduction of damaging invasive non-native species. The potential costs of control may provide the basis for determining financial costs. However, insurance companies could experience difficulty in identifying potential underwriters, due to the complexity of assessing the financial risk posed by invasive species.

4.18 Priority setting in conservation: trade related conflicts

The need to conserve biological diversity and landscape quality often conflicts with social, economic and political motivations. In the past the general perception has been that trade-led economic growth will naturally lead to better environmental quality because economic growth increases public demand for stricter environmental standards. However this is most probable for reversible and local environmental damage that directly lowers living standards, such as polluted drinking water, and, notoriously, has not functioned for cumulative and difficult-to-reverse forms of environmental damage, such as primary forest destruction, greenhouse gas build up and increasing infiltration of invasive species (Yu *et al.*, 2002). Geographical differences in market pressure and population density result in differing accessibility levels to markets, which influences the potential for serious invasive species problems.

Promoting moves towards increasing consumption of local produce may be beneficial in reducing the impact of invasive species through a reduction in imports, but the outcome is not straightforward. For many consumers discriminating between products on the basis of provenance rather than price remains a luxury they cannot afford (Stephens *et al.*, 2003). One obvious mechanism for promoting the competitiveness of local produce is to tax long-distance transport of goods in a realistic way, taking into account the damage caused to the environment, the economy, human health and national infrastructure (Stephens *et al.*, 2003). Congestion charging is now accepted in several countries in northern Europe and the Far East, suggesting that the public might be prepared to accept realistic charging of transport for the environmental costs that it incurs.

4.19 Incorporation of protection schemes into existing agri-environment schemes

Under the General Agreement on Tariffs and Trades (GATT) administered by the World Trade Organization (WTO) subsidies from the government to specific industries or companies are disallowed if they deter imports or boost exports, and thereby distort trade. Subsidies are considered perverse when they cause not only economic but also environmental harm in contributing to resource degradation (Yu *et al.*, 2002); examples include subsidies within the farming and fishing industries. Increasing concern over the environmental impact of agriculture in Europe has led to the introduction of Agri-Environment schemes. These schemes compensate farmers financially for any loss of income associated with measures that aim to benefit the environment or biodiversity. Environmentally Sensitive Areas (ESAs) were the first agri-environmental initiative provided for in European legislation, under the Farm Structure Regulation 797/85 of 1985. In 1992 the CAP reforms were accompanied by Regulation 2078/92 which required member states to establish tailored Agri-environment schemes. There are currently Agri-Environment schemes in 26 out of 44 European countries (Kleijn & Sutherland 2003).

Inclusion of measures for the prevention and eradication of IAS could feasibly be incorporated into the Irish Rural Environmental Protection Scheme (REPS) as outlined below. This scheme would have the additional benefit of utilizing existing legislation.

Box 4.2 The Irish Rural Environmental Protection Scheme (REPS)

The Irish Rural Environmental Protection Scheme (REPS) consists of one scheme with only 11 compulsory measures and a further 6 "Supplementary Measures". The basic scheme is comprehensive and addresses biodiversity and environmental protection, training courses and keeping of farm and environmental records. The REPS aims to conserve wildlife habitats and endangered species of flora and fauna as well as address environmental problems.

REPS measures

1. Waste management, liming and fertilization plan
2. Grassland management plan
3. Protection of water courses and wells
4. Retention of wildlife habitats
5. Maintenance of farm and field boundaries
6. Ban on chemicals near hedgerows and waterbodies
7. Protection of historical and archaeological features
8. Maintenance and improvement of the visual appearance of the farm and farmyard
9. Production of tillage crops without growth regulators
10. Familiarity with environmentally friendly farming practices
11. Keeping of farm and environmental records

Five compulsory measures are particularly relevant to biodiversity conservation. All Supplementary Measures are primarily aimed at conservation aspects and only apply in designated areas.

REPS Supplementary Measures

1. National Heritage Areas
2. Rejuvenation of degraded areas
3. Local breeds in danger of extinction
4. Long-term set-aside
5. Public access and leisure activities
6. Organic farming

The inclusion of an additional REPS measure aimed at preventing the infiltration and spread of invasive alien species would be beneficial as the scheme has been widely taken up. The value of the REPS scheme has been attributed to its universal geographic availability, voluntary nature, comprehensiveness, tailoring to individual farm limited payments (which control the extent to which larger farms can benefit proportionately from the scheme) and financial training incentives (Emerson & Gilmour, 1999). The REPS budget for 2004 is €260 million and 45, 000 farmers are currently involved, which constitutes one third of the utilizable agricultural land (2004 Estimates for Public Service, Department of Finance).

Box 4.3 ESA Schemes in Northern Ireland

For the whole of the UK 9 different schemes exist of which only one, the "Organic Aid Scheme" is truly horizontal. Others can be applied in certain regions or address specific biotopes. Overall, there is a strong emphasis on wildlife conservation in UK AEP schemes. The concept of Environmentally Sensitive Areas (ESA) was originally developed in the UK and first implemented under regulation 797/85. Wildlife conservation in the wider countryside is addressed by the Countryside Stewardship Scheme. Hart and Wilson (2000) record that the highest uptake is the ESA scheme, accounting for 58% of the AEP budget and 74% of the area, followed by the Countryside Stewardship Scheme, allocated 21% of the budget and 7% of the area.

The Department of Agriculture in Northern Ireland launched the Countryside Management Scheme (CMS) in 1999. This scheme has a tiered approach, Tier 1 focusing on a general set of measures aimed at the maintenance of more extensive farming systems and Tier 2 and 3, which adopt measures that exceed the baseline management practice and are aimed at habitats or features where specific management prescriptions must be instigated. Tier 2 focuses on priority habitats in Northern Ireland, which if present on a farm must be brought under agreement, whilst Tier 3 offers the potential to create optional habitats on a farm, for example buffer zones.

Current expenditure in Northern Ireland on agri-environment schemes amounts to about £7.5 million or just over 3 per cent up take. This compares with spending on similar schemes in the Republic of Ireland of over £200 million (Session 2001-02, Northern Ireland Affairs Committee Publications - Appendices to the Minutes of Evidence, Appendix 13, Supplementary Memorandum submitted by Friends of the Earth Northern Ireland).

4.20 Accessibility of scientific results to policy makers

Although a considerable amount of research has been carried out on the relationships between agricultural practices and biodiversity in Ireland the results are often unpublished or in journals that are hard to access. In order to influence the relevant policy makers it is essential that the existing science is inventoried, reviewed and presented in a non-technical and easily accessible way. A mechanism to promote effective information exchange and technology transfer between researchers would help to prevent wastage in terms of repetition, and to focus new projects on policy-relevant issues.

Control of IAS

4.21 Containment and Eradication vs. Sustainable Control through Biological and Integrated Methods

In the long-term if the eradication of an IAS is not feasible or resources are not available for its eradication, containment and long-term control measures should be implemented (UNEP 2003). The aim of control is to reduce the density and abundance of an IAS in order to keep its impact to an acceptable level in the long term. Before starting a control programme, ideally a cost/benefit analysis should be carried out, desired outcomes should be clearly defined and appropriate monitoring of the results should be planned (Genovesi & Shine, 2003). Control methods should be selected with regard to their efficiency, and selectivity, with due consideration of the negative effects they may cause (Genovesi & Shine, 2003).

A variety of different techniques may be utilized to control or eradicate a species.

- physical/mechanical e.g. trapping, shooting
- chemical e.g. poisoning
- biological e.g. directed use of specific disease, use of immuno-contraceptives

Whatever the strategy used its long-term success is critically dependent on support from different areas, including financial support, staff commitment and the support of the public.

4.22 Comparisons with disease epidemics

Some successful examples of control can be found in the Public Health Sector. For example, rabies, once prevalent has been virtually eliminated in the UK and Ireland due to a successful control program.

During the last century rabies was rife throughout parts of Central and Western Europe. Foxes have been the main host but other mammals have also been infected, including not only dogs and cats, but also cattle, horses, badgers, martens, sheep, deer, goats and racoon dogs, providing a large host range. However, non-carnivores pose a low risk of transmitting the virus to humans. The Kennedy Report (2000), states that during the last 10 years the incidence of endemic, fox-adapted rabies in Western Europe has fallen dramatically and it appears to have been virtually eliminated from the EU. However, in November 2002 one death occurred in Scotland from European Bat Lyssavirus, contracted by a bat conservationist from Daubenton's Bat. The virtual eradication of rabies in Western Europe has been largely due to the success of co-ordinated wildlife vaccination programs, together with the availability of effective commercial vaccination for domestic animals. Some EU member states have continued to report occasional cases of rabies in domestic animals imported from non rabies-free countries.

More recent legislation has relaxed the 6-monthly quarantine procedure for pets, an alteration that the public are willing to pay for. From December 11th 2002 pets no longer have to be caged for 6-months in quarantine prior to entering the UK. Animals entering Britain through the EU pet passport scheme will be eligible for onward travel to the Republic of Ireland. The passport scheme means that pets must be fitted with an identifying microchip after getting a rabies vaccination, blood tests and extensive veterinary checks, all at the cost of the individual owner.

DEFRA acknowledge the benefit of research relating to the containment of disease epidemics, a recent job advertisement (5/2/04) based at the University of Oxford and funded by DEFRA seeks to analyse foot and mouth disease control strategies.

4.23 Willingness to pay

Consumer preference surveys amongst urban and suburban residents have provided further evidence of the high value placed on aesthetic environmental quality. A study conducted by Jetter and Paine (2004) attempted to quantify the comparative public value of chemical, biorational (bacterial) and biological control options for management of an introduced urban forest pest. This is one of the first attempts to evaluate public perception and willingness to pay a tax to support landscape biological control.

Differing combinations of control options were allocated fluctuating prices. When the price of all options was low residents preferred the biological control option. As the allocated price for all options rose an increase in preference was seen for the bacterial and chemical options. However, when prices became high preferences shifted again to the natural enemy option (Jetter & Paine, 2004). The social characteristics of respondents were also evaluated, with the conclusion that it may be possible to generate social and financial support from urban residents for classical biological control options (Jetter & Paine, 2004).

Case study 4.3 The eradication of the muskrat *Ondatra zibethica*

Category of introduction: Muskrats are rodents native to North America that were intentionally introduced to Great Britain for fur farming in the 1920s.

Background to the introduction: Muskrats are generalist herbivores which damage native plants and crops (Warwick, 1940). Additionally these rodents cause damage to drainage systems by burrowing. Escapees soon established populations in the wild so that by 1932 there were feral colonies in 14 different counties in Britain (Fairley, 2001). Further imports were halted due to the Destructive Imported Animals Act (1932). An eradication scheme was initiated by the Ministry of Agriculture. The muskrat was a known pest in Europe (Sheail, 1988), therefore information was available in order to assess the effort required, the costs involved and the probability of success which justified government funding (Gosling & Baker, 1989). The relatively mild climate in Britain and an abundant food supply ensured an extended breeding season for *O. zibethica* from February to November, facilitating a potential of 6 to 7 litters of 8 young per female per year (Warwick, 1940). By 1936 the animals were eradicated in England after a total of 4,500 had been killed.

Muskrat was first imported into Ireland in 1929 into County Tipperary and it is likely that 3 individuals were imported (Fairley, 2001). A further two were imported into County Wicklow. Escaped animals quickly spread to the River Nenagh, Black Lough, Annagh Lough and Lough Nagelane (Fairley, 2001). Muskrats built up in number unnoticed for a time due to their elusive behaviour and nocturnal habits (Fairley, 2001). The Department of Agriculture became increasingly concerned, not only about the undermining of riverbanks but more especially over the possibility of the rats reaching the new hydroelectric installation at Ardnacrusha on the River Shannon, below Killaloe at the southern end of Lough Derg.

Eradication methods: During 1931 and in 1933 the *Foot and Mouth Disease (Importation of Rodents and Insectivora) Order* prevented the further import of muskrats, after a slight delay resulting from uncertainty as to whether muskrats could actually transmit the disease (Fairley 2001). This Act was followed by the *Destructive Imported Animals Bill*, in February 1933 and the *Destructive Imported Animals Act (Northern Ireland)*, March 1933 which dealt primarily with muskrats. Finally, the *Musk Rats Act* (1933) in the Republic of Ireland initiated an intensive trapping programme which ran from September, 1933 until April, 1935 when the muskrat was believed to have been eradicated. The success of the scheme was partly attributable to the commendable short time interval between the discovery of the infestation and the commencement of destruction (Fairley, 2001). The unavoidable delay required to draw up and enact the necessary legislation was partially offset by an exceptional dry summer of 1933, which had detrimental effects on the muskrat population and continued into the winter of 1933; thus trapping was unhindered by flooding (Fairley, 2001).

References

Fairley, J. (2001) *A Basket of Weasels. The weasel family in Ireland and other furred Irish beasts : bats, the rabbit, hares and some rodents*. Published privately, Belfast, Northern Ireland.

Gosling, L.M. & Baker, S.J. (1989) The eradication of the muskrats and coypus from Britain. *Botanical Journal of the Linnean Society*, 38, 39-51.

Sheail, J. (1988) The extermination of the muskrat (*Ondatra zibethicus*) in inter-war Britain. *Archives of Natural History*, 15, 155-170.

Warwick, T. (1940) A contribution to the ecology of the musk-rat (*Ondatra zibethica*) in the British Isles. *Proceedings of the Zoological Society of London, Series A*, 110: 165-201.

Case study 4.4 Control of Giant Hogweed in Ireland

Background to the introduction: As mentioned in Section 1 Giant Hogweed was an accidental introduction, is detrimental to vulnerable habitats and requires a control strategy. Studies on the distribution of *H. mantegazzianum* in Ireland and the UK show that the plant is still in an expansive mode and that "further expansion into new ecologically and socially sensitive areas is likely" (Caffrey, 1999). These studies have further revealed that ten years ago there were still a number of large catchments in Ireland which were free from the plant (Wade *et al.*, 1997). It is recommended that efforts are made to effectively curtail the spread of the plant in regions that are already infested to maintain areas free from invasion.

Table 4.3 Incidence and extent (estimated area in m^2) of *Heracleum mantegazzianum* sites in Northern Ireland, 1993 (Reproduced from Wade *et al.*, 1997).

	Infestation level							
	Low		Common		Dominant		Total	
County	Area m^2	No. sites	Area m^2	No. sites	Area m^2	No. sites	Area m^2	No. sites
Armagh	17	4	722	11	20	1	759	16
Down	1,052	4	6,400	7	12,050	8	19,502	19
Fermanagh	28	3	12,035	2	150	1	12,213	6
Londonderry	0	0	122	3	60	3	182	6
Tyrone	23	0	395	9	20,110	13	20,528	25
TOTAL	1,120	14	19,674	32	32,390	26	53,184	72

Eradication methods: It was recognized that long term control and ultimate eradication can only be achieved through the implementation of a national, co-ordinated and comprehensive management strategy that involves all interested groups (Wade *et al.*, 1997). Giant hogweed populations can only be perpetuated via seeds and control measures applied before flowering and seed set will limit recruitment to subsequent generations, and, if applied systematically over a number of years, will ultimately deplete the seed bank reserve. The longevity of seeds in the soil is unknown, although there are indications that the vast majority of viable seeds germinate within one year (Tiley *et al.*, 1996).

Success of eradication methods: Results from extensive trials have demonstrated the susceptibility of *H. mantegazzianum* to glyphosate (Williamson & Forbes, 1982; Powell, 1988; Caffrey, 1994; Tiley & Philip, 1997). These studies have resulted in the creation of a step-by-step protocol for the long-term control of *H. mantegazzianum*, using glyphosate (Caffrey, 1999). This methodology, if strictly adhered to could lead to successful eradication of the plant if the areas are not reinfested from external sources.

Eradication program on the Mulkear Catchment

Praeger (1939) reported large localized populations of *H. mantegazzianum* in the Mulkear Catchment. The level of infestation increased dramatically from 1970 to 1990, affecting practically all beneficial use of the water-course (Caffrey, 1994). In 1997 the Office of Public Works compiled maps detailing the distribution of the plant in the catchment, which indicated that an area of 35 km^2 was overgrown by the plant. A contractor was commissioned to undertake a 4-year control/eradication program with follow up monitoring on the entire catchment using the protocol described above. This programme commenced in 1998 and ran until 2002.

References

Caffrey, J.M. 1999. Phenology and long-term control of *Heracleum mantegazzianum*. *Hydrobiologia*, 415, 223-228.

Caffrey, J.M. 1994. The spread and management of Giant Hogweed *Heracleum mantegazzianum* (Somm. and Levier) along Irish River corridors. In de Waal, L.C. et al. (eds) *Ecology and Management of Invasive Riverside Plants*. John Wiley & Sons: 67-76.

Powell, F. 1988. Giant Hogweed control in NE Scotland. Plant Press Nr; 4.

Praeger (1939) A further contribution to the flora of Ireland. *Proceedings Royal Irish Academy* 45B: 231-254.

Tiley, G.E.D., Dodd, F.S. & Wade, P.M. 1996. *Heracleum mantegazzianum* Sommier & Levier. Biological Flora of the British Isles. *Journal of Ecology*, 84, 297-319.

Tiley, G.E.D. & Philip, B. 1997. Observations on the flowering and seed production of *Heracleum mantegazzianum* in relation to control. In Brock, J.H. et al. (eds) *Plant Invasions*. Backhuys Publishers, Leiden, 123-138.

Wade, M., Darby, E.J., Courtney, A.D. & Caffrey, J.M. 1997. *Heracleum mantegazzianum*: a problem for river managers in the Republic of Ireland and the United Kingdom. Brock, J.H. *et al*. (eds) *Plant Invasions*. Backhuys Publishers, Leiden, pp. 139-151.

Williamson, J.A. & Forbes, J.C. 1982. Giant Hogweed: *Heracleum mantegazzianum*: its spread and control with glyphosate in amenity areas. *Proc. 1982 British Crop Protection Conference – Weeds*: 967-972.

Case study 4.5 Biological control of the eucalyptus psyllid

Category of introduction: Intentional as a biological control agent.

Background to the introduction: The potential for using a biological control agent within Ireland has been investigated in relation to economic maintenance of a commercial eucalyptus plantation. In Ireland commercial production of eucalyptus species started in 1993. Approximately 28 hectares are devoted to the production of eucalyptus forest. In 1998 approximately 4 million eucalyptus stems (worth 1.5 million Irish pounds = 2 million Euro) were exported to European and American markets (Forest, 2000). Accidental introduction of eucalyptus psyllid (*Ctenarytaina eucalypti*) in Ireland coincided with the start of this new industry and eventually proved disastrous. Despite a high chemical usage (5 to 7 pesticide applications per season) insecticides proved ineffective because the insects eggs were found to be resistant to damage (Chauzat *et al.*, 2002) and the terrain in many eucalyptus plantations is unsuitable for applying sprays (Dunne *et al.*, 2001). No previous attempt had been made to control an outdoor pest in Ireland using classical biological control. However, Teagasc and University College Dublin initiated a trial project to explore the potential of a natural predator, a parasitic wasp, *Psyllaephagus pilosus* as a control agent. An import licence was obtained from the Department of Environment, Heritage and Local Government.

Eradication methodology: Documentation regarding the previous importation and release of *P. pilosus* in California and Europe was sufficient to enable the Irish Department for Arts, Heritage, Gaeltacht and the Islands to grant an import licence. In May 1998 approximately 2,000 parasitized psyllid nymphs and 200 adult wasps were collected from a commercial plantation in south-east France and released on a eucalyptus plantation near Kilgarvan in County Kerry (Dunne *et al.*, 2001). The extent of psyllid parasitism and the dispersal of the wasp were studied at different geographical levels: within the release site, in the greater Kerry area and eventually in other Irish regions (Chauzat *et al.*, 2002). At the end of the 1999 growing season 100% parasitism of psyllid populations was reached in all commercial plantations in Kerry. Signs of establishment were evident elsewhere in County Dublin and County Waterford.

Success of the scheme: No insecticides have been used at the release site since the introduction of the wasp and chemical applications have been reduced substantially or eliminated at other commercial eucalyptus plantations in the County Kerry area, with the dual benefit of reduced production costs and increased environmental acceptability in continental European markets (Dunne *et al.*, 2001) In Ireland the spread of the wasp to other commercial plantations was less rapid than that observed in France and this has been attributed both to a lack of host plant within the natural environment and climatic differences between the two countries (Chauzat *et al.*, 2001). Dunne *et al.*, (2001) consider this case to be a successful example of biological control in a climate which differs substantially from that of the parasite's native range in Australia and attribute its success to the efficiency of the parasite in finding the host insect to which it is naturally adapted. It is important to emphasize that all the species in this case study are not native to Ireland and the introduced wasp is specific to the target organism, creating a low risk inexpensive solution to an economically damaging problem.

References

Chauzat, M-P., Purvis, G. & Dunne, R. 2001. A foreigner in Ireland. *Biologist*, 48, 133-135.

Chauzat, M-P., Purvis, G. & Dunne, R. 2002. Release and establishment of a biological control agent, *Psyllaephagus pilosus* for eucalyptus psyllid (*Ctenarytaina eucalypti*) in Ireland. *Annals of Applied Biology*, 141, 293-304.

Dunne, R., Chauzat, M-P, Fitters, P., Purvis, G. & Donovan, M. 2001. *Biology and control of some pests of hardy nursery stock, ornamentals and soft fruit. Teagasc* End of Project Report 4464, Horticulture and Farm Forestry Series No. 25, Kinsealy Research Centre, Dublin.

Forest, M. 2000. A valuable tree – by gum. *Biologist*, **47,** 139 – 142.

Case study 4.6 Eradication of the Roe Deer in County Sligo during 1901.

Category of introduction: Roe deer (*Capreolus capreolus*) were successfully introduced in the early 1870s to Lissadell, Co. Sligo, which was the seat of the Gore-Booth family.

Background to the introduction: Information on this introduction was compiled by J. Fairley from previously unpublished records in the Gore-Booth Archive (Public Record Office of Northern Ireland) and from examination and measurement of all trophy material in Lissadell House. It is usually assumed that in the late 1900s deer were shot only for sport or the pot. However descriptions by Thomas Killagon, a butler in service, mention migration of individuals from the original site of entry, Lissadell, a general indication that the population had reached the carrying capacity of the area (Fairley *et al.* 2002). An eyewitness account composed by Killagon describes the migration of deer within a 20km radius from the original source. Killagon records,

"as years went by they became so numerous that they became a pest to the new plantations by nipping off the leading shoots of young trees. It was decided to have a big drive and weed them out."

In the late 1890s compensation for damage was being paid to at least one neighbour, a Mr Young Warren of "Cooladrummon", although continued compensation was obviously a point for argument, as recorded in a letter dated 12th June 1901 which reads,

"you were notified of last year that I did not intend giving any compensation for damage caused by harts and rabbits. I am also informed that it was for damage caused by these animals that you were compensated in past years."

Eradication methods: Extensive culling is believed to have taken place between 1896 and 1898 and records show that the last of the roe deer were shot around 1905 (Fairley *et al.* 2002). The population density of deer was calculated retrospectively by Fairley *et al.* (2002) using the 1885 revision of the 6 inch ordnance survey map and game-keepers accounts of the number of deer shot. A minimum population density of 0.31 per ha was derived for 1901. Fairley considers that the population exceeded this value for at least a period of time around the turn of the century, as the estimate does not consider probable culling before 1900 which may already have considerably reduced population density. Comparison with values of population density for Roe deer derived in British forests (Staines & Ratcliffe, 1991) to those at Lissadell were high, emphasizing the superior conditions there for Roe deer (Fairley *et al.* 2002).

This account demonstrates that the problems of invasive species are not new. However, they have increased in prevalence and speed within the last century due to increased global trade and migration.

References

Fairley, J., Gore-Booth, J. & Shiel, C., 2002. The Roe deer of Lissadell. *Deer*, **12**; 243-249.

Staines, B.W. & Ratcliffe, P.R. 1991. Roe Deer. In: *The Handbook of British Mammals*. Eds Corbet, G.B. & Harris, S. pp518-525. 3rd Edition, Blackwell, Oxford.

4.24 Lessons learned from other countries

Ireland suffers from the unusual situation of containing two jurisdictions within a relatively small land mass surrounded by sea. Benefit can be gained from analysis and evaluation of comparative, island and cross-border situations. We have chosen to focus firstly upon New Zealand, an island which structures its invasive species policy within an umbrella organization known as the Biosecurity Council. A second case study considers the United States, which operates high level trading across a landmass encompassing a wide variety of different climates and more than 12000 km of internal land boundary.

A) New Zealand

New Zealand is adversely affected by non-native invasive species; approximately 40% of the flora, 76% of the fish species and nearly 20% of the bird species are exotic in origin (Vitousek *et al.*, 1997). A large proportion of the country's economy is derived from ecological tourism and therefore this resource is considered worth protecting. The country as a whole has developed a highly-integrated approach to dealing with invasive species issues which involves high-level cabinet responsibility.

A hierarchical approach has been adopted, as recommended in the CBD Interim Guiding Principles for non-native species:

1) keeping unwanted non-native species out of the country;

2) eradicating any unwanted non-native species which are not yet widespread; and,

3) where eradication is impractical, controlling the impacts of non-native species.

The legal framework is based on two main items of legislation: the Biosecurity Act (1993), which deals with unwanted organisms and accidental releases; and the Hazardous Substances and New Organisms Act (1996), which deals with licensing intentional imports of new organisms. Administration of these Acts is principally the responsibility of the Ministry of the Environment, the Ministry of Agriculture and Forestry and the specially created Environmental Risk Management Authority (ERMA). Non-native species issues also have cabinet representation in the portfolio of the Minister of Food, Fibre, Biosecurity and Border Control. However, criticisms of the current legislation include a lack of explicit objectives for biosecurity, a strong emphasis on maintaining trade relationships, perhaps at the cost of the precautionary principle embedded in the CBD, and the high compliance cost and complexity associated with the approval process for importing new plant material (Fasham & Trumper, 2001). In addition, the issue of non-native species management on private land has not been fully addressed (Christenson, 2000).

Domestic legislation

Hazardous Substances and New Organisms Act 1996 (HSNO)

This Act deals with the assessment of applications to import new organisms and to release them from containment. It established the Environmental Risk Management Authority (EMRA) to conduct such assessments and judge applications. The Act is administered by the Ministry for the Environment. However, the implementation of the Act is the responsibility of ERMA.

Enforcement of the introduction of new organisms into New Zealand occurs at the border and is carried out by Customs and the Ministry of Agriculture and Forestry (MAF). MAF also ensures compliance with controls placed by ERMA on experiments and restricted field trials of new organisms. ERMA oversees the enforcement activity of the other agencies to avoid duplication or gaps in the system.

Provisions are made for ensuring compliance which include Infringement Notices and Compliance Orders. Fines for breaching HSNO regulations include up to $NZ 500, 000 for an offence and an additional $NZ 50, 000 a day for a continuing offence. Imprisonment can occur for up to 3 months. In addition a court can order a convicted offender to remedy or mitigate the effects of non-compliance at their own cost, or to pay the costs of such action, and can also require a new organism to be destroyed.

The enforcement agencies include:

• ERMA New Zealand – monitoring of enforcement performance and inquiries;
• Maritime Safety Authority – issues on board any ship
• Civil Aviation Authority – issues with aircraft and airports
• Land Transport Safety Authority (LTSA) – powers to deal with issues on road and rail
• Police – deal with vehicles and rail
• City and district councils (territorial local authorities) – cover public places.

Allied enforcement agencies are:

• Ministry of Agriculture and Forestry – powers under the Biosecurity Act
• Customs Department – deals with border controls

Biosecurity Act 1993

This Act has 2 major components: prevention of the introduction on unwanted organisms not already established in New Zealand (i.e. border controls) and management of unwanted organisms that are already, or will become, established.

It is an "empowering" rather than a "requiring" Act in that there is no requirement on any particular agency to take action in relation to the presence of a harmful organism (Fasham & Trumper, 2001). It provides for an integrated system of biosecurity risk management, comprising border controls, monitoring and pest management strategies and allows for the declaration of a "biosecurity emergency" in the event of an introduction of a new organism that has the potential to cause significant economic or environmental loss.

One distinction between these two Acts is whilst the Biosecurity Act sets up a process for ongoing management and monitoring of unwanted organisms, HSNO makes no provision for managing or monitoring the effect of alien organisms once they have been approved for release from containment (Fasham & Trumper, 2001).

Four government departments have operational powers under the Biosecurity Act: the Ministry of Agriculture and Forestry (MAF), the Ministry of Fisheries (MFish), the Minister of Health (MoH) and the Department of Conservation (DoC). These departments all report on their activities under the Act to the Minister of Food, Fibre, Biosecurity and Border Control, a specific cabinet portfolio, created in 1997.

A Biosecurity Council was established at the same time to co-ordinate biosecurity policy and implementation, comprising 4 chief executives of the Departments involved, the Chief Executives of the Ministry for Research, Science and Technology (MoRST), the Ministry for the Environment (MfE) and the Environmental Risk Management Agency (ERMA), a representative of local government and an independent chairperson. The four main departments take operational responsibility for different aspects of biosecurity. A Biosecurity Technical Forum provides the Council with technical and policy advice.

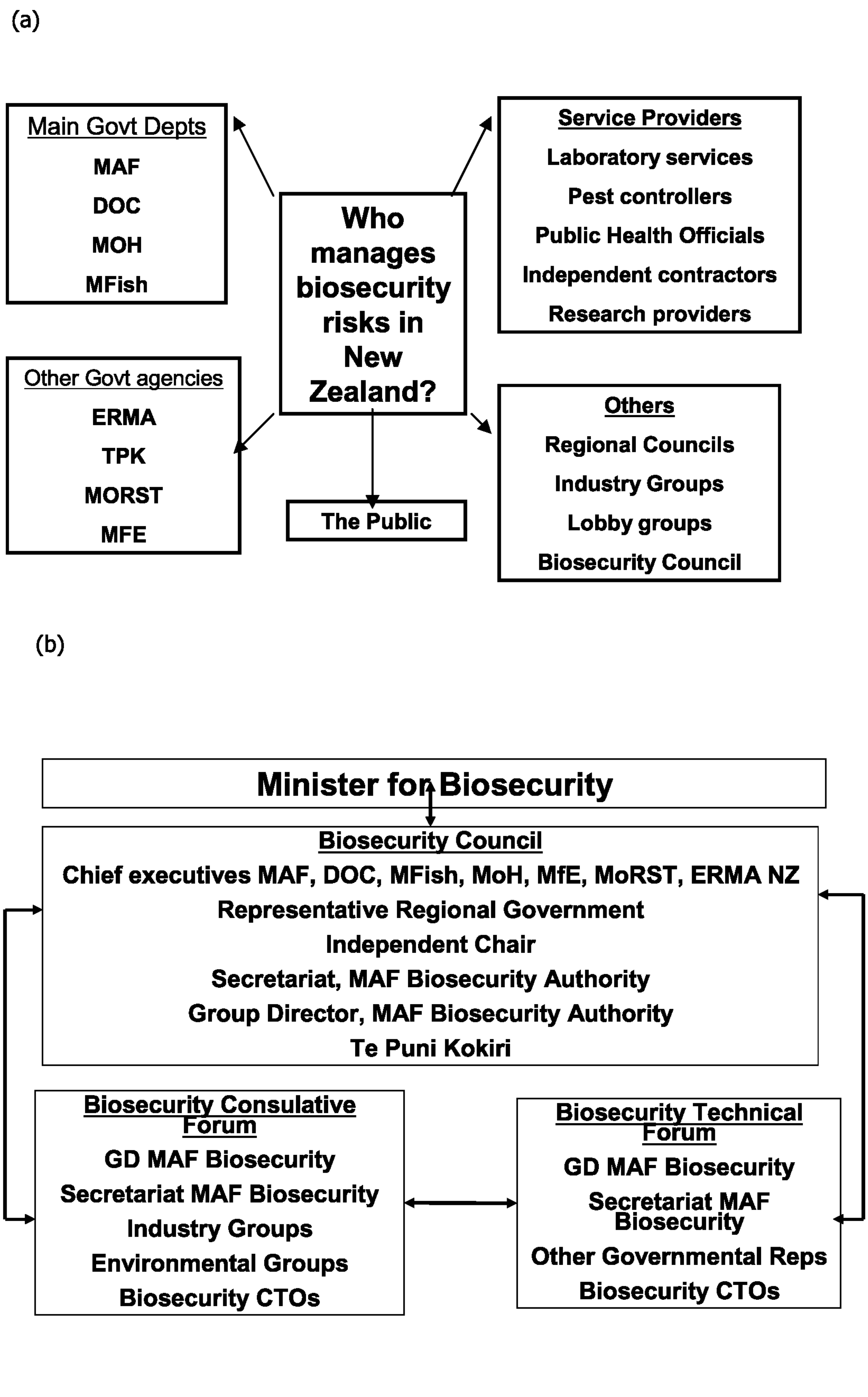


Figure 4.4 a) Relationships between the different biocontrol agencies in New Zealand and b) structure of the Biosecurity Council.

Box 4.5 Authorized procedures under New Zealand's Biosecurity Act 1993
(Source: Fasham & Trumper, 2001)

The Biosecurity Act 1933 grants the following powers to inspectors and other authorized persons appointed under the Act:

- request any person to assist in carrying out the provisions of the Act
- detain people in a biosecurity control area
- search people (police only)
- enter a place and inspect
- apply for a warrant to inspect a dwelling house or a marae
- enter in respect of offences
- following entry, record information and take actions necessary to eradicate pests or unwanted organisms
- apply articles or substances from aircraft above a place
- use dogs and devices to assist in exercising a power
- seize and dispose of unauthorized goods
- search and seize evidence
- seize abandoned goods
- intercept baggage
- examine organisms
- apply an article or substance to a place
- prohibit or control certain tests (power through Order in Council)
- give direction
- vaccinate or treat, etc.
- destroy organisms on non-payment of fees
- give a quarantine direction
- destroy imported organisms
- act in default where legal directions have not been complied with
- declare a restricted place
- declare a controlled area
- apply roadblocks, cordons, checkpoints etc. on application to a District Court Judge

A number of other acts have been devised to conserve biodiversity. These are:

- **Resource Management Act 1991 (RMA)**, covers land use planning controls
- **Conservation Act 1987**, covers the management of trout and salmon
- **Wild Animal Control Act 1977**, controls harmful species of non-native wild animals and regulates the operation of recreational and commercial hunters
- **Wildlife Act 1953**, protects all native and naturalized vertebrates by default but may be withdrawn if the animal becomes a problem
- **Forests Act 1949**, prohibits the import into or export from New Zealand of any tree, seed, timber or timber product which may be injurious to any tree

Control of entry

Intentional introductions

Any individual wishing to import a new organism (as defined by the HSNO) must apply for permission from ERMA.

An initial assessment places the application into one of four categories.

1. Certain organisms are prohibited from even passing through New Zealand
2. Section 36 of the Act sets out minimum standards that the organism must meet to be allowed entry. These involve predictions relating to the potential effects of the organism on native species and habitats.
3. If ERMA is satisfied that the organism is not an unwanted organism under the Biosecurity Act, that it is highly improbable that it will form a self-sustaining population anywhere in New Zealand and that it meets the conditions set out in Section 36, the application may be approved without controls.
4. If the organism does not fall clearly into one of these categories the application is assessed under the full application process.

The full application process involves advertising the application, receiving submissions and holding a hearing. Potential scenarios that must be considered include the ability of the organism to establish a self-sustaining population, the ease with which the organism could be eradicated and whether the positive effects of the organism outweigh its negative effects. In addition the ERMA must have particular regard to the views of the Department of Conservation.

The ERMA can then approve the application without conditions, approve for introduction into containment or decline the application. There is no right of appeal on the decision except on points of law. If new information suggests that an organism in containment should have its approval withdrawn, ERMA may reassess the approval and if necessary require the organisms to be destroyed at the owner's expense. There are provisions in the Act that allow the use of new organisms without approval where this is necessary to deal with an emergency, for example, the import of a live vaccine to deal with a disease outbreak.

Control of unwanted introductions

New Zealand has the advantage of being surrounded by sea, rather than a land-locked country, which allows for greater security at its borders. All vessels and aircraft must enter at a registered port or airport, all of which have suitable facilities for border control operations. Biosecurity border control is separate from the main customs and immigration control but is carried out alongside CITES control.

Before shipping any "risk good" to New Zealand the sender must ensure that it complies with the relevant Import Health Standard and the goods cannot be imported if no such standard exists (Fasham & Trumper, 2001).

Control and eradication
The Risk Management System is hierarchical, involving import controls (via import health standards as above), border control, monitoring within borders, pest management strategies (PMS) and a provision for emergency measures. Within New Zealand PMS can be either National or Regional, each of which must be subjected to a review process every 5 years. Once a strategy has been approved, the management authority has considerable control over implementation, such that land owners may be required to conduct pest control work at their own expense (see Box 4.3).

Evaluation
The Office of the Parliamentary Commissioner for the Environment published a review of New Zealand's biosecurity strategy in December 2000, with assessment of strengths and weaknesses. The key findings were as follows:

- the Biosecurity Council provides good co-ordination of strategic and policy advice; and
- the Ministry of Agriculture and Forestry had received international recognition in managing biosecurity risks to agriculture and trade;

However the review also states that:

- biosecurity emergency management funding and strategies need clarification to ensure that responsibilities are met
- the role, functions and responsibilities of the Biosecurity Council need to be revised to ensure that the Minister for Biosecurity receives timely and appropriate advice; and
- the proposed Biosecurity Strategy needs to explicitly state the government's outcomes and objectives for biosecurity.

The report recommends that in the light of New Zealand's vulnerability to non-native species, biosecurity issues should be treated with the same concern as issues of national security.

Comparison with New Zealand raises awareness of the need for Ireland to develop a more structured form of risk assessment. Risk assessment protocols require legislative support and monitored enforcement in order to achieve their intended aims.

B) Cross-border co-operation: Canada/America/Mexico
North America is highly vulnerable to invasive species due to the high level of trade and the geographical and physical context of Canada, the United States and Mexico. The entire land mass encompasses enormous climatic and environmental variation and the physical structure by which species can be transferred between ecosystems is heightened by the developed infrastructure of the countries. This extremely diverse array of ecosystems is connected to each other and the rest of the globe by:

- 7.5 million km of roads (including 6.3 million in the United States)
- 46, 000 km of navigable inland waterways
- 390, 000 km of rail lines
- 18, 000+ airports (including 18 of the 30 busiest airports in the world)
- 580 water ports and facilities
- more than 12, 000 km of land boundaries crossed by 132 legal ports of entry along the U.S. – Canada

border and 25 legal ports of entry between the U.S. and Mexico

(Airports Council International 2003, U.S. CIA Worldfact Book 2003)

Therefore the level of connectivity in North America exceeds that found in many equivalent land masses (North American Commission for Environmental Co-operation 2003). The three North American Free Trade Agreement (NAFTA) countries account for more than half the world's airports and only Asia, with 49 countries and more than twice the total land area has comparable amounts of road and rail infrastructure (Fasham & Trumper 2001). The United States alone accounted for 10% of the world's port calls in 2000, with 48% of the active world fleet, nearly half of all vessels, calling at U.S. ports (U.S. DOT-MARAD 2001).

Canada is the largest and Mexico the second largest trading partner of the United States (International Trade Administration – Trade and Economy: Data and Analysis http://www.ita.doc.gov/td/industry/otea/).

Canada is Mexico's fourth largest trading partner and Mexico is Canada's fifth largest trading partner. The United States is the largest trading partner for each of the other two countries. Between the US and Canada over 200 million border crossings took place in 1999 and over 300 million border crossings took place between the U.S. and Mexico (US DOT-BTS-2003).

Each country has a range of national, regional and international regulations to which it subscribes. At a regional level the US and Canada participate in a wide variety of bilateral and multilateral efforts to co-ordinate their efforts to reduce the threat of invasive species and share information on eradication techniques. Efforts are focused towards common concerns such as agricultural concerns (e.g. bovine spongiform encephalopathy), shared boundary waters (e.g. ballast water management in the Great Lakes) and other mutual concerns (e.g. West Nile virus). Staff of the Animal Plant Health Inspection Service (APHIS) and the Canadian Food Inspection Agency (CFIA), frequently meet to discuss issues. The Canada-U.S. Consultative Committee on Agriculture, established in 1998, discusses phytosanitary issues with a primary motivation to strengthen trade relations. However the U.S. and Canada have not developed a comprehensive strategy for joint prevention and management of invasive species.

The U.S and Mexico Consultative Committee on Agriculture, established in 2002 also discusses phytosanitary issues, although again with a focus on improving trade relations.

Trilaterally, Canada, Mexico and the U.S. have also signed a memorandum to establish a North American Animal Health Committee which attempts to create a co-ordinated response to specific threats such as foot-and-mouth disease and started developing a standard for treating solid wood packaging materials (U.S. General Accounting Office 2002).

The Commission on Environmental Cooperation (CEC) addresses regional environmental concerns in North America, helps prevent potential trade and environmental conflicts and promotes the effective enforcement of environmental law, all as part of its mandate under the North American Agreement on Environmental Co-operation (NAAEC). The CEC has initiated a project that seeks to protect North America's marine and aquatic ecosystems from the effects of aquatic invasive species.

The North American Plant Protection Organization (NAPPO) develops regional phytosanitary standards for Canada, the United States and Mexico. The Inter-American Biodiversity Information Network (IABN) Invasive Species Network (13N) is an internet based forum for technical and scientific co-operation among Western Hemisphere countries to share and use biodiversity information relevant to decision-making and education. To more effectively address priorities of continental significance and boost the concerted efforts of the three countries of the North American bioregion, the Canada/Mexico/U.S. Trilateral Committee for Wildlife and Ecosystem Conservation and Management was established in 1996. The Trilateral Committee has a variety of functions:

- assist coordination, cooperation and development of partnerships among wildlife agencies of the three countries and other interested groups
- facilitate programs/projects for conservation and management of biological diversity and ecosystems of mutual interest
- implement the conservation priorities of each country
- develop, implement, review and coordinate specific cooperative actions
- facilitate communication on issues that span international boundaries

The Trilateral Committee is headed by:

a) directors of the Canadian Wildlife Service, the
b) U.S. Fish and Wildlife Service, and
c) The Coordinating Unit for International Affairs of the Mexican Ministry of Environment and Natural Resources (SEMARNAT)

An indication of the degree of attention invasive species issues receive is provided by the fact that the last annual plenary session chose to hold a day long meeting focused solely on this issue. (http://www.trilat.org/annual_meetings/viii_mtg/invasives_plenary/trilateral_invasivesplenary_report_11july03.htm.)

There is an obvious need for the establishment of a cross-border, inter-departmental invasive species forum in Ireland, both to reduce time delays in the initiation of control programs and to co-ordinate cross-border schemes effectively.

4.25 Summary

This chapter details the importance of monitoring and surveillance, risk assessment and risk reduction and control and eradication policies from a cost-efficient perspective. It appears advisable to maintain financial support for the acquisition of knowledge in certain areas, such as monitoring and surveillance. Flexibility of approach appears to be the key factor in co-ordinating a successful and sustainable control policy.

The collection of case studies presented here indicates that a beneficial outcome can be achieved, although the process usually requires the expenditure of substantial sums of money in order to reduce the potential of a more devastating financial impact at a later date. Increased investment in amalgamating research efforts and disseminating the results to targeted audiences will contribute to safeguarding Ireland's biodiversity in the future.

Funding research into risk analysis scenarios and models incorporating ecological processes is vital in enabling more accurate simulations of the probable events following a species introduction. Examination of literature relating to the forecasting of disease epidemics and containment policies should be incorporated into investigations of invasive alien species, enabling assessment of the actions required at different hierarchical levels within and between organizations.

Co-ordination of a response over the land mass of Northern Ireland and the Republic of Ireland is essential if a reduction or eradication policy is to succeed. Contingency plans should be formulated to establish an efficient protocol for cross-border cases. Examples exist within other countries of the formulation of cross-border councils, such as the Trilateral Council for Ecosystem Conservation and Management in the North American continent. The adoption of a cross-border, inter-departmental forum between Northern Ireland and the Republic of Ireland is suggested. Invasive species issues could then be addressed under one body, in a similar fashion to the legislative structure in New Zealand.

Serious consideration needs to be given to the financial support framework for rectifying damage to biological communities. Alternative sources of funding should be considered, for example the adoption of severe financial penalties payable by the individuals or companies responsible.

Continuing efforts to increase economic production will result in little abatement of the current problems. Inventing new methods of control may temporarily diminish population densities of invasive alien species, yet ultimately adaptation of species is likely to prevail. However, the application of forethought, combined with ecological knowledge, political willpower and improved forecasting of risk can have a substantial impact on reducing the damage caused by invasive alien species, both to biological diversity and government finances.

Section 5: Recommendations to the two jurisdictions

5 Recommendations to the two jurisdictions

REDUCING RISK

KEY ACTION 1: Detailed risk assessments and contingency plans should be urgently prepared for species that are likely to invade Ireland in advance of their arrival.

An immediate pro-active approach to invasive species policies is required. In the current absence of an over-arching body initial stopgap measures should be implemented by units that are linked into existing active departments. Senior level authorization within current departments should be used as an impetus to motivate preventative actions in advance of a species entering the country, to ensure a rapid and co-ordinated response from additional agencies before the species becomes established. Provision should be made for the inclusion of contingency plans to deal with the unexpected occurrence of species that cross existing sectoral responsibilities.

Action 1.1: In consultation with interested stakeholders a list of problem species, designated by risk level, should be developed immediately for priority action.

A "High Risk List" could be drafted which would require the licensing and even exclusion of species Ireland. A list of further species where more evidence is required regarding their potential to cause problems (a "Medium Risk List") and also a list of species whose potential impact is judged on present evidence to be minimal (a "Low Risk List") are developed. Lists should be flexible and subject to frequent evaluation, in order to safeguard against the potential for a rapid population explosion in an invasive species currently perceived as low risk.

Action 1.2: A catalogue of scientific research relating to invasive species issues should be established and made available.

Focus on identification and eradication/control methods will be of particular benefit. Scientific advances should be made available to policy makers, through categorizing research and presenting it in a non-technical and easily accessible manner.

Action 1.3: Lists of species which have become invasive in other parts of the world should be maintained.

Particular attention should be devoted to Great Britain, European neighbours and principal trading partners, which may play host to a range of species with a high potential for establishment in Ireland. In future a centralized reference point should be designated for the storage of this information.

Action 1.4: The full consequences of potential invasions by non-native species should be established by extending investigations of ecological impacts into a cost-based environmental impact assessment.

Environmental economic tools exist that allow evaluation of the aesthetic and economic injury caused by invasive species. Establishing a means whereby damage can be costed allows an assessment of the appropriate allocation of resources to prevent and mitigate the problem.

RESPONDING TO NEW INVASIONS

KEY ACTION 2: Barriers to a rapid and decisive response to new invasions should be minimized by high level cross-jurisdictional and inter-departmental support for and funding of contingency plans.

Immediate action often presents the only opportunity for cost-effective eradication. Therefore detailed assessment of the impact of a newly invasive species should be conducted concurrently if possible and should incorporate cost estimation and cost-benefit analyses to agreed criteria. Management aims should be agreed in advance and appropriate monitoring of the results should be conducted.

The effectiveness of control programmes should be evaluated from a population demography perspective, identifying the quantitative effects of a particular management treatment. This should continue beyond the end of management regimes to determine that further invasion does not occur and that the problem has been resolved.

Action 2.1: Engagement with specific industrial and trade and commerce sectors should be initiated at the outset in the creation of control schemes to clarify feasible management objectives.

Action 2.2: A budget should be made available to support the development of control techniques for putative invasive non-native species.

Action 2.3: Programmes should be developed that allow the restoration of native habitats and species following the removal of invasive species.

CONTROL AND MANAGEMENT OF ESTABLISHED INVASIVE SPECIES

KEY ACTION 3: The ecological and economic impact of long-standing alien species and technology for their control should be investigated in detail in order to plan and execute cost-effective strategies for control and eradication.

In the case of well established invasive species control efforts that are unsupported by ecological studies have the potential for significant wastage of resources. Management plans should be designed with a view to the population biology of the invasive species and models can be used to determine the necessary effort to realise conservation objectives.

LEGISLATIVE REQUIREMENTS

KEY ACTION 4: Legislative provisions should be analysed and new legal frameworks developed specifically for dealing with invasive species, while facilitating beneficial introductions.

Action 4.1: An analytical review of legislation pertaining to non-native species should be undertaken by environmental law specialists.

Assessment of the strengths and weaknesses of the present legislative framework have been made from an ecological/management perspective. However, an analysis from an academic legal perspective by an environmental lawyer would highlight specific areas for improvement. Particular attention should be paid to European and domestic legislation and on cross-border constitutional arrangements.

Action 4.2: Governments should work with industries and trade organisations to encourage the development of legal underpinning for codes of conduct that define and allocate duty of care.

Codes of practice are more rapid than the law to initiating flexible responses to changing circumstances but require legal underpinning for ultimate sanction. The aquaculture industry provides particularly useful models in this area, e.g. the Environmental Code of Practice for Irish Aquaculture Companies and Traders (ECOPACT), launched by the Department of Communications, Marine and Natural Resources on behalf of Bord Iascaigh Mhara (BIM). Profitable commercial organizations operate to high standards to generate the greatest amount of long term profit. It is proposed that the application of such codes of practice should be encouraged by a reward in addition to a sanction-based system.

Action 4.3: Consultation processes regarding codes of practice and legislative development should be initiated with stakeholders.

Stakeholders, particularly trade and commercial organisations, should be fully consulted and engaged in development of invasive non-native species policies and actions. It is especially important to encourage north-south co-operation in this matter.

Action 4.4: The scope for implementing "polluter pays" principle for preventing invasions should be investigated.

Consideration should be given to identifying circumstances where responsibility for costs should lie with those responsible for the illegal introduction of the non-native species.

Action 4.5: Licensing arrangements should remain in place whereby desirable non-native species can be introduced, for commercial reasons and/or for biological control.

It is important to retain the potential use of non-native species as biocontrol agents, as this is frequently a less costly form of control. Proposals to commercially exploit new species should require legally enforceable risk assessments, including cost-benefit analyses that consider the potential loss of ecosystem goods and services.

MONITORING RISKS AND PROBLEMS

KEY ACTION 5: A framework, including support for specialist identification skills, should be established for the collation and cross-border exchange of information on non-native species.

Action 5.1: A centralized biological recording unit should be developed in the Republic of Ireland.

This centre would be similar to the Centre for Environmental Data and Recording (CEDaR), currently based at the Ulster Museum and funded by the Environment & Heritage Service, in order to maintain data on native and non-native flora and fauna. In each jurisdiction a single organization should have lead responsibility for co-ordinating the collation of data on non-native species. Efforts should be made to store data in a manner that is transferable between the different BRCs.

Action 5.2: Recording schemes should be developed for species which possess invasive qualities, involving separate monitoring criteria for land of differing protection categories and vulnerability to species invasions.

The protocol for recording schemes should be subject to the approval of a centralized agency. Financial support should be provided by governments, where there is currently insufficient means to monitor establishment and spread, or through capacity building of appropriate NGOs or volunteers. Monitoring criteria should be developed with separate consideration for areas of protected land and land which is currently unprotected. An example of a stratified recording and protection scheme is provided by the Water Framework Directive (2000). A department in each jurisdiction needs to be identified with responsibility for monitoring and surveillance.

Action 5.3: Authority should be granted to a monitoring agency to require landowners to comply with monitoring of invasive species on private land.

Monitoring and surveillance of biodiversity on private land should be encouraged to maintain a true representative picture of biodiversity in Ireland. Such a procedure requires a high level of communication between researchers and landowners.

Action 5.4: Taxonomic experts should be engaged to train personnel for monitoring tasks and for deployment at key points of entry.

Monitoring of invasive species is inhibited by a lack of competent recorders and taxonomic expertise is not widely accessible. A full audit should be undertaken to determine the skills base in this field in Ireland and to identify potential barriers to its effective use. The production of identification keys for invasive species is a priority.

AGRI-ENVIRONMENT SCHEMES

KEY ACTION 6: Measures for the prevention and eradication of invasive species should be incorporated into agri-environment schemes.

Examples include the Rural Environmental Protection Scheme (REPS) in the Republic of Ireland and the Countryside Management Scheme (CMS) in Northern Ireland.

EDUCATION AND RAISING AWARENESS

KEY ACTION 7: The dissemination of information to the public and the engagement of stakeholders, particularly in the commercial sector, should be prioritised by developing online, educational and scientific resources, and by targeted public awareness campaigns.

Action 7.1: Establishment of websites, e-mail discussion groups, workshops and conferences, to disseminate information on invasive species, their prevention and control, both nationally and internationally should be developed.

Action 7.2: Awareness campaigns should be initiated to raise public consciousness of non-native invasive species problems.

The campaigns should be constructed around a small number of key concepts and should use simple, clear terminology and plan in advance to deal with controversial issues. Information should be deliverable through easily accessible media such as television, radio and the press and through media targeted to key areas, activities and locations, such as garden centres, angling clubs, pet shops and airports.

Action 7.3: Targeted information should be broadcast to specific groups such as specialist societies and professions.

This information should include detailed professional and scientific analysis of the issues associated with invasive non-native species and should focus on the particular information needs of specified sectors, such as recreational fisheries and horticultural industries. Material should be presented in a fashion that is appropriate both to non-scientists and the public as well as scientific and research communities.

Action 7.4: Education on invasive species and their implications should be retained and improved within school curricula and higher education centres.

COMMUNITY ACTIONS

KEY ACTION 8: The use of native species in amenity planting and stocking and related community actions to reduce the introduction and spread of non-native species should be encouraged.

Action 8.1: Native species of local provenance should be encouraged for use in conservation or amenity planting schemes and to stock freshwaters in situations where a choice exists.

Any proposed new introductions should be submitted to a centralized agency, stipulating the species or sub-species of proposed introduction. Proposed introductions located in the vicinity of areas of conservation interest should be subject to higher scrutiny.

Action 8.2: Promote public acceptance of moves towards increased consumption of local produce.

Increased efforts towards sustainability and reduction of unnecessary freight haulage could reduce the impact of invasive species through a reduction in imports. When considering this scenario the implications for trade would need to be carefully assessed in discussion with commercial organizations and the relevant government departments.

INTERNATIONAL ACTIONS

KEY ACTION 9: The two jurisdictions should continue to work through international mechanisms to improve the regulatory and policy framework for dealing with invasive non-native species.

Action 9.1: The two jurisdictions should continue to work through international mechanisms to improve the regulatory and policy framework for dealing with invasive non-native species issues.

This should include input to the Convention on Biological Diversity, the International Plant Protection Convention, the International Maritime Organization's work to address unintentional introductions of marine non-native species through ballast water transfer, the International Civil Aviation Organization's consideration of unintentional introduction of non-natives via aircraft, the Bern Convention's work on a European approach and also the European Commission's work to consider how the EC Wildlife Trade Regulations might best be utilized to address invasive non-native species issues.

Action 9.2: Northern Ireland and the Republic of Ireland should support the development of international trade agreements relating to invasive non-native species, in order to retain their reputation as a responsible trading partner.

Efforts should be made to reduce the accidental export of native Irish species which may become invasive in other countries.

CROSS-BORDER SPECIALIST GROUP AND AGENCY

KEY ACTION 10: A cross-border specialist group should establish a dedicated agency to lead on invasive species issues, beyond the immediate actions prioritised above.

Action 10.1: Establishment of a cross-border forum or NDPB to guide the establishment of a centralized invasive species agency.

The forum should include policy makers from relevant departments, scientists from statutory agencies, research institutions, NGOs and independent authorities and also representatives from industrial, trade and commerce sectors. This combined expertise should cover knowledge of species biology, introductory pathways and options for feasible eradication and containment. The forum should consist of three working groups to advise on terrestrial, freshwater and marine environments.

Action 10.2: Establishment of a cross-border, inter-departmental agency under the guidance of the cross-border forum.

The agency would become the primary point of reference and guidance for the management of all issues pertaining to non-native species. The agency should be financed by the two jurisdictions and an interdepartmental budget, which incorporates contingency measures, should be agreed upon in advance of an issue arising.

The North-South Ministerial Council may provide a suitable umbrella under which to form this agency, either as a new North/South Implementation Body analogous to the present six bodies, or by the Council's approval of collaboration between existing bodies under the present Area for Co-operation of 'Environment'.

The agency should be co-chaired by the most relevant government departments, most probably the Department of Environment (N.I.) and the Department of the Environment, Heritage and Local Government (R.O.I), though key inputs will be required from other departments, most notably agriculture, trade and transport, and agency representatives from Great Britain. Inclusion of trade and transport sectors is vital in establishing codes of conduct that will be complied with and enforced by trade associations.

Linkages should also be fostered with public health departments for guidance in the construction of contingency plans in the event of an invasive species becoming a public health hazard, as was the case for West Nile Virus in the United States.

The agency should be supported by a secretariat staff to fulfil its remit of research, advisory and communication services, constructed in such a way that urgent matters can be expedited rapidly.

Acknowledgements

It would have been impossible to produce this report without the help of numerous individuals and organizations. In particular we are grateful to:

R. Anderson, C. Aughey, S. Beasley, P. Bryson, J. Caffrey, R. Carden, CEDaR, T. Champ, J. Cross, T. Cross, G. Day, DAF, DARDNI, DOENI, J. Doyle, R. Dunne, J. Faulkner, R. Forbes, J. Furphy, S. Gollasch, E. Gosling, R. Govier, S. Jennings, B. Johnston, D. Kelly, C. Lawton, F. Lucy, J. Lucey, L. Lysaght, C. Maguire, J. Marks, F. Marnell, M. Mathies, J. McAdam, D. McFerran, I. McKee, I. McLean, N. McWhinnie, M. Meharg, C. Mellon, K. Millsopp, D. Minchin, B. Moloney, P. Moore, A. Murchie, R. Northridge, G. Purvis, S. Purvis, S. Reynolds, R. Rossell, C. Rumble, D. Schabile, A. Scollick, S. Simpkons, J. Stout, J. Strong, R. Weyl, J. Wilson

This list is far from exhaustive and we must apologise to those contributors not mentioned individually. All those who patiently volunteered time and/or information are thanked sincerely.

References

Adam, D., 2001. Fears arise over BSE infection in UK abattoirs. *Nature*, **411**; 728.
Airports Council International (ACI) 2003. The World's Busiest Airports. http://www.airports.org/traffic/yeartodate.asp
Alexandersen, S., Kitching, R.P., Mansley, L.M. & Donaldson, A.I., 2003. Clinical and laboratory investigations of five outbreaks of foot and mouth disease during the 2001 epidemic in the United Kingdom. *Veterinary Record*, **152**; 489-496.
Anderson, R., 2003. Workshop Presentation, "*Patterns of terrestrial invertebrate invasions as a guide to future trends*". All-Ireland Invasive Alien Species Workshop, Dublin, 26th November 2003.
Anderson, R. & Bell, A.C., 2002. A first record of the Lily Beetle *Lilioceris lilii* (Scopoli) in Ireland. *Coleopterist*; **11**; 90.
Alderman, D.J. & Wickins, J.F. 1996. Crayfish CULTURE, Laboratory Leaflet No. 76, CEFAS, Lowestoft, MAFF.
Alzieu, C. & Heral, M., 1984. Ecotoxicological effects of organotins compounds on oyster culture. In: Persoone, G., Jaspers, E. & Claus, C. (eds) *Ecotoxicological Testing for the Marine Environment*, Volume 2. State University of Ghent and Institute of Marine Scientific Research, Bredene, Belgium.
Baillie, S.R., Sutherland, W.J., Freeman, S.L., Gregory, R.D. & Paradis, E. 2000. Consequences of large-scale processes for the conservation of bird populations. *Journal of Applied Ecology*, **37**; Suppl. 1, 88-102.
Balmford, A. & Gaston, K.J., 1999. Why Biodiversity surveys are good value. *Nature*, **398**; 204-205.
Balmford, A., Gaston, K.J., Rodrigues, A.S.L. & Alexander, J., 2000. Integrating costs of conservation into international priority setting. *Biological Conservation*, **14**; 597-605.
Baretta-Becker, J.G., Duursma, E.K., & Kuipers, B.R., (eds), 1992. *Encyclopaedia of marine sciences*. Springer-Verlag, Berlin.
Binggeli P., Eakin, M., Macfadyen, A., Power J. & McConnell, J.,1992. Impact of the alien sea buckthorn (*Hippophae rhamnoides* L.) on sand dune ecosystems in Ireland. In Carter, R.W.G., Curtis, T.G.F. & Sheehy-Skeffington, M.J. (eds) *Coastal dunes. Geomorphology, ecology and management*; 325-337. Balkema, Rotterdam.
Bleakley, B. 1979. *Spartina* – an unwelcome immigrant. Irish Hare, 2, 10-12.
Bord Iascaigh Mhara, 2003. *Ecopact, Environmental code of practice for Irish aquaculture companies and traders*. Bord Iascaigh Mhara, Ireland.
Brown, K.C., 1986. *Animals, plants and micro-organisms introduced to the British Isles*. London, Department of the Environment.
Buckley, P., 1998. Legislation and protected areas for the conservation of biological diversity. In: *Irish heritage and environmental directory* 1999. Deevey, M.B (ed); 13-30. The Heritage Council and Archaeology, Bray, Ireland.
Bullock, J.M., Hodder, K.H., Manchester, S.J. & Stevenson, M.J., 1996. Review of information, policy and legislation on species translocations. JNCC Report No. 261. Joint Nature Conservation Committee, Peterborough, U.K.
Cade, T.J., 1983. Hybridisation and gene exchange among birds in relation to conservation. In: *Genetics and conservation*. Schonewald-Cox, C.M., Shambers, S.M., MacBryde, B. & Thomas, W.L. (eds); 288-309. Benjamin Cummings, London.
Caffrey, J.M., 1994. Spread and management of *Heracleum mantegazzianum* (Giant Hogweed) along Irish River Corridors. In: *Ecology and management of riverside*

plants. DeWaal, L.C., Child, L.E., Wade, M. & Brock, J.H. (eds); 67-76. John Wiley & Sons Ltd, England.

Caffrey, J.M. 1999. Phenology and long-term control of *Heracleum mantegazzianum*. *Hydrobiologia*, **415**; 223-228.

Callaghan, D., 2003. Alien species research requirements for delivery of the UK biodiversity Action Plan – Discussion Paper. Just Ecology. URL: www.justecology.co.uk

Carlton, J.T., 1987. Mechanism and patterns of transoceanic marine biological invasions in the Pacific Ocean. *Bulletin of Marine Science*, **41**; 452-465.

Chapman, J.W., Miller, T.W. & Coan, E.V., 2003. Live seafood species as recipes for invasion. *Conservation Biology*, **117** (5); 1386-1389.

Chauzat, M.P., Purvis, G. & Dunne, R., 2002. Release and establishment of a biological control agent, *Psyllaephagus pilosus* for eucalyptus psyllid (*Ctenarytaina eucalypti*) in Ireland. *Annals of Applied Biology*, **141**; 293-304.

Chauzat, M-P., Purvis, G. & Dunne, R. 2001. A foreigner in Ireland. Biologist, **48**; 133-135.

Christenson, M. 2000. Global Invasives Species Project: Country Report: New Zealand. http://iucn.org/themes/law/elp_invasives.NZ.htm

Clements, K.L., 1996. An assessment of rural landowners' attitudes and knowledge about beavers, biodiversity, and conservation. *Bulletin of the Ecological Society of America*, **77;** 84.

Clerkin, S. 2002. Incorporating biodiversity considerations in policy. Biology and Environment, *Proceedings of the Royal Irish Academy*, **102B**, (32); 177-182. Royal Irish Academy.

Compassion in World Farming, 2003.

Costello, M.J., 1993. Biogeography of alien amphipods occurring in Ireland, and interactions with native species. *Crustaceana*, **65**; 287-299.

Council of the European Communities, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities **L206/35, 22.7.92**; 7-50.

Cox, M.L., 2001. The status of the Lily Beetle *Lilioceris lilii* (Scopoli, 1763) in Britain (Chrysomelidae: Criocerinae). *The Coleopterist*, **10**; 5-20.

Cragg-Hine, D., 1973. Coarse fish and fisheries management in Northern Ireland. *Proceedings of the sixth British coarse fish conference*; 52-59. University of Liverpool, UK.

Crawley, M.J., 1997. What makes a community invasible? In: *Colonization, succession and stability*. Gray, A.J., Crawley, M.J. & Edwards, P.J. (eds); 429-453. Blackwell Scientific Publications, Oxford, UK.

Crawley, M.J., Harvey, P.H. & Purvis, A., 1996. Comparative ecology of the native and alien floras of the British Isles. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences*, **351**; 1251-1259.

Crivelli, A.J., 1995. Are fish introductions a threat to endemic freshwater fishes in the northern Mediterranean region? *Biological Conservation*, **72**; 311-319.

Cross, J.R., 1981. The establishment of *Rhododendron ponticum* in the Killarney oakwoods, SW Ireland. *Journal of Ecology*, **69**; 807-824.

Cross, J.R., 1982. The invasion and impact of *Rhododendron ponticum* in native Irish vegetation. *Journal of Life Sciences Royal Dublin Society*, **3**; 209-220

Daehler, C.C. & Strong, D.R., 1997. Reduced herbivore resistance in introduced smooth cordgrass (*Spartina alterniflora*) after a century of herbivore-free growth. *Oecologia*, **110**; 99-108.

Davison, D.M., 1996. *Sargassum muticum* in Strangford Lough, 1995-1998. A review of the introduction and colonization of Strangford Lough MNR and cSAC by the invasive brown algae *Sargassum muticum*. Report to the Environment & Heritage Service, D.O.E. (N.I.).

Department for Environment, Food and Rural Affairs (DEFRA), 2003. Review of non-native species policy. Report of the working group. DEFRA publications, London.

Department for Environment, Transport and Regions (DETR), 1997. The regulation and control of the release of non-native animals and plants into the wild in Great Britain. Department of the Environment, Transport and Regions, London.

Dick, J.T.A., 1996. Post-invasion amphipod communities of Lough Neagh, Northern Ireland: influences of habitat selection and mutual predation. *Journal of Animal Ecology*, **65**; 756-767.

Doogue, D., Kelly, D.L. & Wyse Jackson, P.S., 1985. The progress of *Epilobium ciliatum* Rafin. (E. adenocaulon Hausskn) in Ireland, with some notes on its hybrids. *Irish Naturalists Journal*, **21**; 444-446.

Drake, J.A. & Mooney, H.A., 1989. *Biological invasions: a global perspective*. John Wiley & Sons, Chichester.

Dunne, R., 2003. Some recent insect and mite introductions to Ireland. In *Biological Invaders: the impact of exotic species*. Moriarty, C. & Murray, D. (eds); 115-118. Royal Irish Academy, Dublin.

Dunne, R., Chauzat, M-P., Fitters, P., Purvis, G. & Donovan, M. 2001. Biology and control of some pests of hardy nursery stock, ornamentals and soft fruit. Teagasc End of Project Report 4464, Horticulture and Farm Forestry Series No. 25, Kinsealy Research Centre, Horticulture and Farm Forestry, Dublin, Ireland.

Edwards, C., Tracy D. & Morgan J., 1993. *Rhododendron* control by imazapyr. *Research Information Note* **233**; Forestry Commission, Edinburgh

Edwards, C. & Morgan, J.L., 1996. Control of *Rhododendron ponticum* by stump applications of herbicides following mechanical clearance. *Proceedings Crop Protection in Northern Britain II*:213-218

Edwards, C. & Morgan J., 1997. Cut stump applications with imazapyr. *Forestry Commission Research Information Note* **293**; Edinburgh

Edwards C., Clay D.V. & Dixon F.L., 2000. Stem treatment to control *Rhododendron ponticum* under woodland canopies. *Aspects of Applied Biology*, **58**; 39-46

Edwards C., 1999. Herbicide control of *Rhododendron ponticum* following mechanical clearance by hydraulic flail. *Proceedings Crop Protection in Northern Britain*

E-Fish Business, 2003a. Imports of fish from other parts of the European Union (EU). [URL: http://www.efishbusiness.co.uk/importinside/default.asp

Elbers, A.R.W., Stegeman, A., Moser H., Ekker, H.M., Smak, J.A. & Pluijmers, F.H., 1999. The classical swine fever epidemic 1997-1998 in the Netherlands: descriptive epidemiology. *Preventory Veterinary Medicine*, **42**; 157-184.

Ehrlich, P.R., 1986. Which animal will invade? Ecology of Biological Invasions of North America and Hawaii. In *Ecological Studies 58*. Mooney, H.A. & Drake, J.A. (eds); 79-95. Springer-Verlag, New York.

Emerson, H.J. & Gillmor, D.A., 1999. The Rural Environment Protection Scheme of the Republic of Ireland. *Land Use Policy*, **16**; 235-245.

Eno, N.C., 1996. Non-native marine species: their effects and controls. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**; 215-228.

Eno, N.C., 1998a. Non-native marine species in British waters: ballast water introductions. *International Council for the Exploration of the Sea Cooperative Report No.* **224**; 43- 49.

Eno, N.C., 1998b. The introduction to British waters of non-native marine molluscs and their implications for nature conservation interests. *Journal of Conchcology, Special Publication* No. **2**; 287-294.

Eno, N.C., Clark, R.A. & Sanderson, W.G., 1997. Non-native marine species in British waters: a review and directory. *Joint Nature Conservation Committee*, Peterborough, U.K.

European and Mediterranean Plant Protection Organisation (EPPO), 2001. *Pest risk assessment scheme* (decisions-making scheme). URL: http://www.eppo.org//QUARANTINE/PRA/prassess_scheme.html.

European Communities (Natural Habitats) Regulations, 1997. SI NO. 94/1997. Amended by the European Communities (Natural Habitats) (Amendment) Regulations 1998, SI No. 233/1998. *Acts of the Oireachtas and statutory instruments*. Dublin, Stationary Office.

Evans, D.W., Matthews, M.A. & McClintock, C.A., 2001. The spread of eel swim bladder nematode *Anguillicola crassus* through the Erne system, Ireland. *Journal of Fish Biology*, **59**; 1461-1420.

Fairley, J., 2001. *A basket of weasels*. Published privately, Belfast, Northern Ireland.

Fairley, J., Gore-Booth, J. & Shiel, C., 2002. The Roe deer of Lissadell. *Deer*, **12**; 243-249.

Fasham, M. & Trumper, K., 2001. *Review of non-native species legislation and guidance*. Ecoscope Applied Ecologists, Stocks Bridge Way

Ferreras, P. & Macdonald, D.W., 1999. The impact of American mink *Mustela vision* on water birds in the upper Thames. *Journal of Applied Ecology*, **36**; 701-708.

Fleming, I.A., Hindar, K., Mjolnerod, I.B., Jonsson, B., Balstad, T. & Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London Series B*, **267**; 1517-1523.

Forest, M. 2000. A valuable tree – by gum. *Biologist*, **47**; 139-142.

Forest Service, 2000. *Code of best forest practise – Ireland*. Forest Service, Department of Communications, Marine and Natural Resources.

Genovesi, P. & Shine, C., 2003. *European Strategy on Invasive Alien Species, third draft. Convention on the conservation of European wildlife and natural habitats*. Council of Europe, Strasbourg.

Gibbons, D.W., Reid, J.B. & Chapman, R.A., 1993. *The new atlas of breeding birds in Britain and Ireland, 1988-1991*. T. & A.D. Poyser, London.

Global Ballast Water Programme. International Maritime Organisation. URL: http://www.globallast.imo.org

Gollasch, S., 1999. The Asian decapod *Hemigrapsus penicillatus* (de Haan, 1835) (Grapsidae, Decapoda) introduced in European waters: status quo and future perspective. *Helgoländer Meeresunterschungen*, **52**; 359-366.

Gomulkiewicz, R. & Holt, R.D., 1995. When does evolution by natural selection prevent extinction? *Evolution*, **49**; 201-207.

Gosling, L.M. & Baker, S.J. 1989. The eradication of the muskrats and coypus from Britain. *Botanical Journal of the Linnean Society*, **38**; 39-51.

Grace, J. & Nelson, M., 1981. Insects and their pollen loads at a hybrid *Heracleum* site. *New Phytologist*, **87**; 413-423.

Gray, A.J., 1986. Do invading species have definable genetic characteristics. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, **314**; 655-674.

Gurnell, J., 1983. Squirrel numbers and the abundance of tree seeds. *Mammal Review*, **13**; 133-148.

Gurnell, J., 1989. Demographic implications for the control of grey squirrels. In: *Mammals as pests*. Putman R. (ed.); 131-143. Crook Helm, London, UK.

Hanski, I., Breuker, C.J., Schops, K., Setchfield, R. & Nieminen, M. 2002. Population history and life history influence the migration rate of female Granville fritillary butterflies. *Oikos*, 98; 87-97.
Hayden, T. & Harrington, R., 2000. *Exploring Irish Mammals*. Townhouse, Dublin.
Hilty, J. & Merenlender, A.M., 2003. Studying biodiversity on private lands. *Conservation Biology*, **17**; 132-137.
Holdich, D.M. & Reeve, I.D., 1991. Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **1**; 139-158.
Holmes, J.M.C. & Minchin, D. 1995. Two exotic copepods imported into Ireland with the Pacific oyster, *Crassostrea gigas*.
Holt, R.D. & Keitt, T.H., 2000. Alternative causes for range limits: a metapopulation perspective. *Ecology Letters*, **3**; 41-47.
Hopkins, G.W. & Freckleton, R.P., 2002. Declines in the numbers of amateur and professional taxonomists
Howarth, F.G., 1991. Environmental Impacts of Classical Biological Control. *Annual Review of Entomology*, **36**; 485-509.
Hubbard, J.C.E., 1965. *Spartina* marshes in southern England. VI. Pattern of invasion in Poole Harbour. *Journal of Ecology*, **53**; 799-813.
Hughes, B., 1996. The ruddy duck *Oxyura jamaicensis* in the Western Palearctic and the threat to the white-headed duck *Oxyura leucocephala*. In: *The Introduction and Naturalization of Birds*. Holmes, J.S. & Simons, J.R. (eds); 79-86. HMSO, London, UK.
ICES (International Council for the Exploration of the Sea). URL: http://www.ices.dk
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:08 2000. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Meeting ACME:07 2001. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:05 2002. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:03 2003. Study group on Ballast and other ship vectors (SGBOSV). Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Meeting ACME:07, 2000. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:08, 2001. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:06, 2002. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:04, 2003. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.
ICES (International Council for the Exploration of the Sea) Council Meeting ACME:07, 2000. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ACME:06, 2002. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ICES CM/ACME:03 2003. Study group on Ballast and other ship vectors (SGBOSV). Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ICES CM/ACME:05 2002. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ICES CM/ACME:07 2001. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ICES CM/ACME:08 2000. Study group on Ballast and other ship vectors. Advisory committee on the marine environment.

ICES (International Council for the Exploration of the Sea) Council Meeting ACME:08, 2001. Working group on introductions and transfers of marine organisms. Advisory committee on the marine environment.

IMO (International Maritime Organisation). Conventions in development. URL: http://www.imo.org/Conventions/contents.asp?topic_id=261&doc_id=690

IMO (International Maritime Organisation), 1997. Guidelines for the control and management of ships' ballast water to minimise the transfer of harmful aquatic organisms and pathogens. IMO Resolution A.868 (29)1997.

Invasive alien species and the International Plant Protection Convention, Braunschweig, Germany, 22-26 September, 2003.

IUCN (World Conservation Union), 2000. Guidelines for the prevention of biodiversity loss caused by alien invasive species. IUCN, Gland, Switzerland.

IUCN (World Conservation Union). URL: http://iucn.or/themes/law/Treatiestable.htm

IUCN (World Conservation Union). Species survival commission (SSC). URL: http://iucn.org/themes/ssc/pubs/policy/invasivesEng.htm.

Irish Tourism: responding to change, 2003. *Interim report of the Tourism Policy Review* Group to Mr John O Donaghue, Minister for Arts, Sport and Tourism.

IUCN, 2000. Guidelines for the prevention of biodiversity loss caused by alien invasive species. IUCN, Gland, Switzerland.

IUCN. URL: http://iucn.or/themes/law/Treatiestable.htm

Jetter, K. & Paine, T.D. 2004. Consumer preferences and willingness to pay for biological control in the urban landscape. *Biological Control* (in press)

Johannson, L. & Persson, L., 1986. Planktivorous fish. In *Carbon dynamics in eutrophic temperate lakes*. Riemann, B. & Sondergaard, M. (eds); 237-266. Elsevier Science, Amsterdam.

Johnsen, B.O. & Jensen, A.J. 1986. Infestations of Atlantic salmon, (*Salmo salar*), by *Gyrodactylus salaris* in Norweigan rivers. *Journal of Fish Biology*, **29**; 233-241

Joint North/South Consultation paper on International River Basin Districts and administrative arrangements for implementation of the EC Water Framework Directive (200/60/EC), 2003. Managing our shared waters.

Jones, A.T. & Evans, P.R., 1994. A comparison of the growth and morphology of native and commercially obtained European *Crataegus monogyna* Jacq. (Hawthorn) at an upland site. *Watsonia*, **20**; 97-103.

Kay, Q., 1993. Genetic differences between populations of rare plants, *BSBI News*, **64**; 54-56.

Kelly, D.L., 1981. The native forest vegetsation of Killarney, south-west Ireland: an ecological account. *Journal of Ecology*, **69**; 437-472.

Kelly, D.W., Dick, J.T.A., Montgomery, W.I. & Macneil, C. 2003. Differences in composition of macroinvertebrate communities with invasive and native Gammarus spp. (Crustacea: Amphipoda). *Freshwater Biology*, **48**; 306-315.

Kennedy, G.J.A. & Strange, C.D., 1978. Seven years on – a continuing investigation of salmonid stocks in Lough Erne tributaries. *Journal of Fish Biology*, **12**; 325-330.

Kennedy, G.J.A. & Greer, J.E., 1988. Predation by cormorants, *Phalacrocorax carbo* (L.), on the salmonid populations of an Irish river. *Aquaculture and Fisheries Manual*, **19**; 159-170.

Kenward, R.E. & Holm, J.L., 1993. On the replacement of the red squirrel in Britain - a phytotoxic explanation. *Proceedings of the Royal Society of London Series B-Biological Sciences*, **251**; 187-194.

King, C.M. 1984. *Immigrant Killers. Introduced predators and the conservation of birds in New Zealand,* Oxford University Press, Auckland.

Kleijn, D. & Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology*, **40**; 947-969.

Kluyver, H.N. & Tinbergen, L., 1953. Territory and the regulation of density in titmice. *Archives Neerlandaises de Zoologie,* **10**; 265-289.

Kornberg, H. & Williamson, M.H., 1987. *Quantitative Aspects of the Ecology of Biological Invasions. Proceedings of a Royal Society Discussion Meeting*. The Royal Society, London, UK.

Lehmkuhl, J.F. 1984. Determining size and dispersion of minimum viable populations for land management planning and species conservation. *Environmental Management*, 8, 167-176.

Levins, R., 1970. Extinction. *Lectures on Mathematics in the Life Sciences*, 2. Gerstenhaber, M. (ed.); 77-107. American Mathematics Society, Providence, RI.

Levins, R. & Culver, D., 1971. Regional coexistence of species and competition between rare species. *Proceedings of the National Academy of Sciences USA*, **68**; 1246-1248.

Lewis, M. & Kareiva, P., 1993. Allee dynamics and the spread of invading organisms. *Theoretical Population Biology*, **43**; 141-158.

Lucey, J., 1994. Records of the Giant Hogweed *Heracleum mantegazzianum* Somm. & Lev., along southern Irish rivers and streams with a revised distribution map for the region. *Bulletin of the Irish Biogeographical Society*, **17**; 2-6.

Lundstrom, H. & Darby, E., 1994. The *Heracleum mantegazzianum* (Giant Hogweed) problem in Sweden: suggestions for its management and control. *Ecology and management of riverside plants*. De Waal, L.C., Child, L.E., Wade, M., Brock, J.H.(eds) England: John Wiley & Sons Ltd. pp. 93-100.

Macdonald, D.W. & Johnson, P.J., 2000. Farmers and the custody of the countryside: trends in loss and conservation of non-productive habitats 1991-1998. *Conservation Biology*, **13**; 1262-1272.

Mack, R.N., 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation*, **78**; 107-121.

MacNeil, C., Elwood, R.W. & Dick, J.T.A., 2000. Factors influencing the importance of *Gammarus* spp. (Crustacea: Amphipoda) in riverine salmonid diets. *Archives fur Hydrobiologie*, **149**; 87-107.

Maguire, B., O'Reilly, M. & Roche, M.S., 1999. *Irish Environmental Legislation*. Round Hall Sweet & Maxwell, Dublin.

Manchester, S.J. & Bullock, J.M., 2000. The impacts of non-native species on UK biodiversity and the effectiveness of control. *Journal of Applied Ecology*, **37**; 845-864.

Mansueto, C., Villa, L., D'Agati, P., Marcianò, V., Pellerito, C., Fiore, T., Scopelliti, M., Nagy, L. & Pellerito, L., 2003. Effects of tributyltin (IV) chloride on fertilisation of *Styela plicata* (Ascidiacea: Tunicata): II. Scanning and transmission electron microscopy studies. *Applied Organometallic Chemistry*, **14**; 553-560.

Marine Conservation Society, 2001. Alien species Factsheet. URL: http://www.mcsuk.org/

Marine Work Group, 2003. Fish farming? Must be Mad! Ireland. URL: www.mwg.utvinternet.com/aquaculture

Mathews, M. & Reynods, J.D., 1990. Laboratory investigations of the pathogenicity of *Aphanomyces astaci* for Irish freshwater crayfish. *Hydrobiologia*, **203**;121-126.

Mathews, M. & Reynolds, J.D., 1992. Ecological impact of crayfish plague in Ireland. *Hydrobiologia*, **234**; 1-6.

Matthews, M.A., Reynolds, J.D. & Keatinge, M.J., 1993. Macrophyte reduction and benthic community alteration by the crayfish *Austropotamobius pallipes* (Lereboullet). *Freshwater Crayfish*, **9**; 289-299.

McAree, D., 2002. The forest service biodiversity plan. *Biology and Environment: Proceedings of the Royal Irish Academy*, **102B**, (3); 183-184. Royal Irish Academy.

McCorrey, M, Curtis, T.G.F. & Otte, M.L., 2003. Spartina in Ireland. In *Wetlands of Ireland, Distribution, Ecology, Uses and Economic Value*. Otte, M.L. (ed.) University College Press Dublin, 44-50.

McGinnity, P., Prodohl, P., Ferguson, K., Hynes, R., O' Maoileidigh, N., Baker, N., Cotter, D., O' Hea, B., Cooke, D., Rogan, G., Taggart, J., & Cross, T. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London, Series B*: **270**; 2443-2450.

Minchin, D. Duggan, C.B. & King, W. 1987. Possible influence of organotins on scallop recruitment. *Marine Pollution Bulletin*, **18**; 604-608.

Minchin, D. & Duggan, C.B., 1988. The distribution of the exotic ascidian, *Styela clava* Herdman, in Cork Harbour. *Irish Naturalists' Journal*, **22**(9); 388-393.

Minchin, D. & Sheehan, J., 1995. The significance of ballast water in the introduction of exotic marine organisms to Cork Harbour, Ireland. *International Council for the Exploration of the Sea* C.M. 1995/0:1 15pp.

Minchin, D., 1996a. Desk assessment of discharges of shipping ballast water in Ireland. C.M. 1996/E:11 Marine Environmental Quality Committee. *International Council for the Exploration of the Sea*, Reykjavík.

Minchin, D., 1996b. Management of the introduction and transfer of marine molluscs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**; 229-244.

Minchin, D. & Sheehan, J., 1999. Cork Harbour, Ireland, as a focal point for the introduction of exotic marine species. ICES Co-op Res Rept No **224**; 12-23.

Minchin, D., 2000a. Modes of introduction of exotic animals into Irish waters. In: *Biodiversity: The Irish Dimension*. Rushton, B.S. (ed.); 147-155. Royal Irish Academy, Dublin.

Minchin, D., 2000b. Dispersal of zebra mussels in Ireland. *Verhandlungen Internationale Vireinigung Limnologie*, **27**; 1576-1579.

Minchin, D., 2001. Introduction of Exotic Species. In *Encyclopedia of Ocean Sciences*. Steele, J., Thorpe, S. & Turekian, K. (eds.); 878-889. Harcourt Publishers Ltd., Kent.

Minchin, D. & Eno, C. 2002. Exotics of coastal and inland waters of Ireland and Britain. In: *Invasive Aquatic Species of Europe: Distribution impacts and management*. Leppäkoski, E., Gollasch, S. & Olenin S. (eds); 206-216. Kluwer Academic Publishers, Dordreicht, The Netherlands.

Minchin, D. & Gollasch, S. 2002. Vectors – how exotics get around. In: *Invasive Aquatic Species of Europe: Distribution impacts and management*. Leppäkoski, E., Gollasch, S. & Olenin S. (eds); 206-216. Kluwer Academic Publishers, Dordreicht, The Netherlands.
Minchin, D. & Moriarty, C. 2002. Zebra mussels and their impact in Ireland. In: C. Moriarty & D.A. Murray. *Biological Invaders: the impact of exotic species*. Royal Irish Academy, Dublin, pp. 72-78.
Minchin, D. & Rosenthal, H. 2002. Exotics for stocking and aquaculture, making correct decisions. In: *Invasive Aquatic Species of Europe: Distribution impacts and management*. Leppäkoski, E., Gollasch, S. & Olenin S. (eds); 206-216. Kluwer Academic Publishers, Dordreicht, The Netherlands.
Minchin, D., Maguire, C.M. & Rossell, R. 2003. The zebra mussels (*Dreissena polymorpha.* Pallas) invades Ireland: human mediated vectors and the potential for rapid international dispersal. *Biology and Environment*, **103B** (1); 23-30.
Minchin, D. & Gollasch, S. 2003. Fouling and Ships' Hulls, how changing circumstances and spawning events may result in the spread of exotic species. *Biofouling*, **19**; 11-112.
Mitchell, R.J., Marrs, R.H., LeDuc, M.G. & Auld, M.H.D., 1997. A study of succession on lowland heaths in Dorset, southern England: changes in vegetation and soil chemical properties. *Journal of Applied Ecology*, **34**; 1426-1444.
Moore, J.P., Dynes, C. & Murchie, A.K., 1998. The status and public perception of the New Zealand flatworm, *Artioposthia triangulata* (Dendy) in Northern Ireland. Pedobiologia, 2;563-571.
Moore, N.W., 1987. *The Bird of Time*, Cambridge University Press.
National Farmers Union Countryside. Rural News, Monday 17th March, 2003. URL: http://www.nfucountryside.org.uk/news/showarchivenews.asp?newsid=674
Neal, C., Reynolds, B., Smith, C.J., Hill, S., Neal, M., Conway, T., Ryland, G.P., Jeffrey, H., Robson, A.J. & Fisher, R., 1992. The impact of conifer harvesting on stream water pH, alkalinity and aluminium concentrations for the British uplands – an example for an acidic and acid sensitive catchment in mid-Wales. *Science of the Total Environment*, **126**; 75-87.
Northern Ireland Biodiversity Group, 2000. *Biodiversity in Northern Ireland. Recommendations to Government for a Biodiversity Strategy*. The Stationary Office, Norwich.
Northern Ireland Forest Service. *Red Squirrels: causes of red squirrel decline*. URL: http://www.nics.gov.uk/forestserviceni/environment/red_squirrels/causes_of_decli ne
O'Connor, C., Marvier, M. & Kareiva, P., 2003. Biological vs. social, economic and political priority-setting in conservation. *Ecology Letters*, **6**; 706-711.
Ó Críodáin, C., 2002. Incorporation of biodiversity conservation into the work of DÚCHAS. *Biology and Environment: Proceedings of the Royal Irish Academy*, **102B**, (3); 189-162.
O' Mahoney, T. (1991) A report on the flora of Cork (v.cc. H3-H5), 1990. *Irish Botanical News* **1**; 17-19.
O' Mahoney, T. (1996) A report on the flora of Cork (v.cc. H3-H5), 1995. *Irish Botanical News*, **6**; 35-40.
O' Mahoney, T. (1997) A report on the flora of Cork (v.cc. H3-H5), 1996. *Irish Botanical News*, **7**; 33-36.
Osborne, P., 1985. Some effects of Dutch Elm disease on the birds of a Dorset dairy farm. *Journal of Applied Ecology*, **22**; 681-691.
Owen, J., 2003. Salmon farm escapees threaten wild salmon stocks, *National Geographic*, June 2003.

Pearson, D.E. & Callaway, R.M., 2003. Indirect effects of host-specific biological control agents, *Trends in Ecology & Evolution*, **18**; 456-461.

Pollux, B., Minchin, D., Van der Velde, G., Van Alen, T., Yeo, S., Der Staay, M. & Hackstein, J. 2003. Zebra mussels (*Dreissena polymorpha*) in Ireland, AFLP-fingerprinting and boat traffic both indicate an origin from Britain. *Freshwater Biology*, **48**; 1127-1139.

Powell, F. 1988. Giant Hogweed control in NE Scotland. *Plant Press Nr*, **4**.

Praeger. 1939. A further contribution to the flora of Ireland. *Proceedings Royal Irish Academy* **45B**; 231-254.

Preston, C.D. & Croft, J.M., 1997. *Aquatic plants in Britain and Ireland*. Henley Books, Colchester, England.

Preston, C.D., Pearman, D.A. & Dines, T.D., 2002. *New Atlas of the British and Irish Flora - an atlas of the vascular plants of Britain, Ireland, the Isle of Man and the Channel Islands*. Oxford University Press, Oxford.

Pulliam, H.R., 1989. Source, sinks and population regulation. *American Naturalist*, **132**; 652-661.

Purvis, G., Chauzat, M.P., Segonds-Pichon, A. & Dunne, R., 2002. Life history and phenology of the eucalyptus psyllid, *Ctenarytaina eucalypti* in Ireland. *Annals of Applied Biology*, **141**; 283-292.

Ray, N., Lehmann, A. & Joly, P. 2002. Modelling spatial distribution of amphibian populations: a GIS approach based on habitat matrix permeability. *Biodiversity and Conservation*, **11**; 2143-2165.

Red Squirrels in South Scotland. *Information sheet 6: Disease in Squirrels*. URL: http://www.red-squirrels.org.uk/pdf/6DiseaseInSquirrels02.pdf

Reise, K., Gollasch, S. & Wolff, W.J., 1998. Introduced marine species of the North Sea coasts. *Helgolander meeresuntersuchungen*, **52** (3-4); 219-234

Rejmanek, M. & Richardson, D.M. 1996. What attributes make some plant species more invasive? *Ecology*, **77**; 1655-1661.

Reynolds, J.D., 1988. Crayfish extinctions and crayfish plague in Ireland. *Biological Conservation*, **45**; 279-285.

Reynolds, J.D., 1998. Conservation management of the white-clawed crayfish *Austropotamobius pallipes* Part 1. *Irish Wildlife Manuals*, No. 1, Dúchas, The Heritage Service, Dublin.

Reynolds, S.C.P., 2002. *A catalogue of Alien Plants in Ireland*, National Botanic Gardens, Glasnevin, Ireland.

Rosell, R.S., Maguire, C.M. & McCarthy, T.K. 1999. First reported settlement of zebra mussels *Dreissena polymorpha* in the Erne system, County Fermanagh, Northern Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy*, **98B** (3); 191-193.

Rotherham, I.D. & Read, D.J. 1988. Aspects of ecology of Rhododendron ponticum L. with special reference to its competitive and invasive properties. *Aspects of Applied Biology*, **16**; 327-335.

Selonen, V. & Hanski, I. 2003. Movements of flying squirrel *Pteromys volans* in corridors and matrix habitat. *Ecography*, 26; 641-651.

Sheail, J. 1988. The extermination of the muskrat (*Ondatra zibethicus*) in inter-war Britain. *Archives of Natural History*, **15**; 155-170.

Shine, C. 2002. *Report on the implementation of the Bern Convention in Ireland (Draft). Convention on the conservation of European wildlife and natural habitats*. Council of Europe, Strasbourg.

Short, J.W. & Thrower, F.P., 1987. Toxicity of tri-n-butyl-tin to Chinook salmon *Onchorhynchus tshawytscha*, adapted to seawater. *Aquaculture*, **61**; 193-200.

Simberloff, D., 1989. Which insect introductions suceed and which fail. In: *Biological Invasions*. Drake, J.A., Mooney, H.A., diCastri, F., Groves, R.H., Kruger, F.J. Rejmanek, M. & Williamson, M. (eds); 61-75. John Wiley & Sons, Chichester, UK.

Simberloff, D. & Alexander, M., 1998. Assessing risks to ecological systems from biological introductions (excluding genetically modified organisms). In: *Handbook of environmental risk assessment and management*. Calow, P. (ed). Blackwell, Oxford, UK.

Simberloff, D., 2003. How much information on population biology is needed to manage introduced species? *Conservation Biology*, **17**; 83-92.

Smallwood, K.S., 1994. Site invasibility by exotic birds and mammals. *Biological Conservation*, **69**; 251-259.

Smith, A.P. & Quinn, D.E., 1996. Patterns and causes of extinction and decline in Australian conilurine rodents. *Biological Conservation*, **77**; 243-267.

Staines, B.W. & Ratcliffe, P.R. 1991. Roe deer. In: *The Handbook of British Mammals*. Eds Corbet, G.B. & Harris, S. PP. 518-525. 3RD Edition, Blackwell, Oxford.

Stephens, P.A., Jules, N.P. & Sutherland, W.J., 2003. Agriculture, transport policy and landscape heterogeneity. *Trends in Ecology and Evolution*, **18**, 555-556.

Stephens, P.A. & Sutherland, W.J., 1999. Consequences of the Allee effect for behaviour, ecology and conservation. *Trends in Ecology, Evolution and Conservation*, **14**; 401-405.

Stephens, P.A., Sutherland, W.J. & Freckleton, R.P., 1999. What is the Allee effect? *Oikos*, **87**; 185-190.

Stott, B., 1974. Biological control of water weeds. In: *Biology in pest and disease control*. Price Jones, D. & Solomon, M.E. (eds); 233-238. Blackwell Scientific Publications, London, UK.

Strasser, M., 1999. *Mya arenaria* – an ancient invader of the North Sea coast. *Helgoländer Meeresunterschungen*, **52**; 309-324.

Strong, J.A., 2003. *The environmental impact of* Sargassum muticum *around the coastline of Northern Ireland*. PhD Thesis, Queens University of Belfast.

Telfer, S., Holt, A., Donaldson, R. & Lambin, X. 2001. Metapopulation processs and persistence in remnant water vole populations. *Oikos*, 95; 31-42.

The Forestry Authority, 1998. The UK Forestry Standard. *The Government's approach to sustainable forestry*. Department of Agricultrue for Northern Ireland, Forestry Commission, Edinburgh.

The Kennedy Report, 2000. *Memorandum on Rabies Prevention and control*. Department of Health. URL: www.doh.gov.uk/memorandumonrabies/

The Tourism Policy Review 2003. *Final report – New Horizons for Irish Tourism: An agenda for Action*, Tourism Policy Review Group.

Thomas, J.A., 1995. The ecology and conservation of *Maculinea arion* and other European species of large blue butterfly. In: *Ecology and Conservation of Butterflies*. Pullin, A.S. (ed); 181-197. Chapman and Hall, London.

Tiley, E.D. & Philip, B., 1994. *Hercaleum mantegazzianum* (Giant Hogweed) and it control in Scotland. *Ecology and management of riverside plants*. De Waal, L.C., Child, L.E., Wade, M., Brock, J.H.(eds) England: John Wiley & Sons Ltd. pp. 101-110.

Tiley, G.E.D., Dodd, F.S. & Wade, P.M. (1996) *Heracleum mantegazzianum* Sommier & Levier. Biological Flora of the British Isles. *Journal of Ecology*, **84**; 297-319.

Tiley, G.E.D. & Philip, B. (1997) Observations on the flowering and seed production of *Heracleum mantegazzianum* in relation to control. In Brock, J.H.et al. (eds) *Plant Invasions*. Backhuys Publishers, Leiden, 123-138.

TRAFFIC, 1998. *European Community Wildlife Trade Regulations: Reference Guide*. URL: http://www.europa.eu.int/comm/environment/cites/legislation_en.htm

Turner, S. & Morrow, K., 1997. *Northern Ireland Environmental Law*. Gill & Macmillan, Dublin.

UNEP (United Nations Environment Programme), AEWA/TC 4.16, 2003. *Guidelines on avoidance of introduction of non-native migratory waterbird species*. African-European migratory water bird agreement. Tahskent, Uzbekistan.

UNEP/CBD/SBSTTA/6/INF/3 2001. Invasive alien species: A comprehensive review of activities for the prevention, early detection. Convention on biological diversity.

UNEP/CBD/SBSTTA/6/INF/11 2001. Invasive alien species: Status, impacts and trends of alien species that threaten ecosystems, habitats and species. Convention on biological diversity.

United States Central Intelligence Agency (CIA) 2002. *World Factbook*. Washington, D.C: CIA

United States Department of Transportation – Bureau of transportation statistics (USDOT/BTS) 1997. *North American Transportation Highlights*, Washington, DC: USDOT. 1997. World Transportation Directory <http.//www.bts.gov/programs/tt/wtd/>

United States Department of Maritime Administration (USDOT/MA) 2002. Marad Statistics. http://www.marad.dot.gov/MARAD_statistics/sheet003.htm 2001 Vessel calls at U.S. Ports. 2000 Washington, DC, gao.

United States General Accounting Office (GAO). October 2002. *Invasive species*. Report to Executive Agency Officials. Washington, DC: gao.

Usher, M.B., 1987. Scope-international synthesis symposium on the ecology of biological invasions, held at the East-West Center, Honolulu, Hawaii, USA. *Environmental Conservation*, **14**; 84-85.

Utting, S.D. & Spencer, B.E., 1992. Introductions of marine bivalve molluscs into the United Kingdom for commercial culture – case histories. *International Council for the Exploration of the Sea*.

Vitousek, P.M., D'Antonio, C.M., Loope, L.L., Rejmanek, M. & Westbrooks, R. 1997. Introduced species: a significant component of human caused global chhange. *New Zealand Journal of Ecology*, **21**; 1-16.

Wade, M., Darby, E.J., Courtney, A.D. & Caffrey, J.M. (1997) *Heracleum mantegazzianum*: a problem for river managers in the Republic of Ireland and the United Kingdom. Brock, J.H. *et al.* (eds) *Plant Invasions*. Backhuys Publishers, Leiden, pp. 139-151.

Wainger, L.A. & King, D.A., 2003. Decision-making under uncertainty: how much risk reduction can we afford? Conference presentation. Invasive Plants in Natural and Managed Systems, November 5-7, Ft. Lauderdale, Florida.

Warren, M.S., Hill, J.K., Thomas, J.A., Asher, J., Fox, R., Huntley, B., Roy, D.B., Telfer, M.G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S.G., Greatorex-Davies, J.N., Moss, D. & Thomas, C.D., 2001. Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, **414**; 65-69.

Warwick, T. 1940. A contribution to the ecology of the musk-rat (*Ondatra zibethica*) in the British Isles. *Proceedings of the Zoological Society of London, Series A*, **110**; 165-201.

Watkinson, A.R. & Sutherland, W.J., 1995. Sources, sinks and pseudo-sinks. *Journal of Animal Ecology*, **64**; 126-130.

Watkinson, A.R., Gill, J.A. & Freckleton, R.P., 2003. *Macroecology and microecology: linking large-scale patterns of abundance to population processes*. British Ecological Society Annual Symposium, 2002. Blackwell Scientific Publishing, Oxford.

Watt, H.B., 1923. The American Grey Squirrel in Ireland, *Irish Naturalist*, **32**; 95.
Whitehead, G., 1964. Japanese sika deer in Ireland. *The Deer of Great Britain and Ireland*. Routledge and Keegan-Paul, London.
Wielgus, R.B. 2002. Minimum viable populations and reserve sizes for naturally regulated grizzly bears in British Columbia. *Biological Conservation*; 381-388.
Wildlife (Amendment) Act 2000 NO. 38/2000. *Acts of the Orieachtas and Statutory Instruments*. Dublin, Stationary Office.
Wildlife (Northern Ireland) Order, 1985. HMSO SI 1985/171(NI 2)
Williamson, J.A. & Forbes, J.C. 1982. Giant Hogweed: *Heracleum mantegazzianum*: its spread and control with glyphosate in amenity areas. *Proc. 1982 British Crop Protection Conference – Weeds*: 967-972.
Williamson, M., 1992. Environmental risk from the release of genetically modified organisms (GMOs) - the need for molecular ecology. *Molecular Ecology*, **1**; 3-8.
Williamson, M., 1993. Risks from the release of GMOs - ecological and evolutionary considerations. *Evolutionary Trends in Plants*, **1**; 5-9.
Williamson, M., 1996. *Biological Invasions*. Chapman & Hall, London, UK.
Winfield, I.J., Winfield, D.K. & Tobin, C.M., 1992. Interactions between the roach *Rutulis-rutulis* and waterfowl populations of Lough Neagh, Northern Ireland. *Environmental Biology of Fishes*, **33**; 207-214.
Winfield, I.J., Tobin, C.M. & Montgomery, C.R., 1994. The fish of Lough Neagh. Part E. Ecological studies of a fish community. In: *Lough Neagh: The ecology of a multipurpose water resource*. Wood, R.B. & Smith, R.V. (eds); 451-471. Kluwer, The Netherlands.
Wyse Jackson, M., 1989. Observations on the Irish distribution of a plant with serious public health implications: Giant Hogweed (*Heracleum mantegazzianum*). *Bulletin of the Irish Biogeographical Society*, **12**; 94-112.
Yu, D.W., Sutherland, W.J. & Clark, C., 2002. Trade versus environment. *Trends in Ecology and Evolution*, **17**; 353

Appendix 1. Non-native estuarine and marine species that are known to be established in Ireland. (after Minchin & Eno, 2002)

	Species
Algae	*Heterosigma akashiwo*
	Gyrodinium aureolum
	Antithamnionella ternifolia
	Antithamnion densum
	Asparagopsis armata
	Laurencia brongiartii
	Polysiphonia subtilissima
	Colpomenia peregrina
	Alexandrium tamarense
	Sargassum muticum
	Codium fragile ssp. *atlanticum*
	Codium fragile ssp. *tomentosoides*
	Antithamnionella spirographidis
	Bonnemaisonia hamifera
	Polysiphonia harveyi
	Cryptonemia hibernica
Angiosperma	*Spartina anglica*
Cnidaria	*Gonionemus vertens*
Nematoda	*Anguillicola crassus*
Annelida	*Ficopomatus enigmaticus*
Crustacea	*Balanus amphitrite*
	Elminius modestus
	Limnoria tripunctata
	Porcellidium ovatum
	Balanus improvisus
	Myicola ostraea
	Mytilicola orientalis
	Mytilicola intestinalis
	Corophium sextonae
	Herrmannella duggani
Tunicata	*Phallusia mammilata*
	Styela clava

Appendix 2. Non-native marine and estuarine species that may become established in Irish and British coastal waters, invasive species in bold. (Sourced from Minchin & Eno, 2002)

Species	Taxon	Likely Vector	Nature of Impact
Coscinodiscus wailesii	diatom	ships, naturally	covers nets with mucilage
Pfiesteria piscicida	dinoflagellate	ships ballast water	fish mortalities, toxins
Gymnodinium catenatum	dinoflagellate	ships ballast water	paralytic shellfish poisoning
Undaria pinnatifida	brown alga	fouling ships/ boats	competition
'*Dasysiphonia* sp'	red alga	fouling ships/boats	Fouling cage netting
Grateloupia doryphora	red alga	natural spread	may have commercial use
Gyrodactylus salaris	monogenean	salmonids	reduced salmonid stocks
Corbula flammula	bivalve	aquatic plants?	extensive fouling
Nuttalia obscurata	bivalve	aquaculture	productive species
Mytilopsis leucophaeta	bivalve	hull fouling	extensive fouling
Ensis americanus	bivalve	natural spread	high biomass, fishery
Ocinebrellus inornatus	gastropod	oysters	eolluscan predator
Rapana venosa	gastropod	ballast, oysters	molluscan predator
Crepidula fornicata	gastropod	oysters	competition, habitat changes
Pseudostylochus ostreae	flatworm	oysters	molluscan predator
Marenzellaria viridis	polychaete	ships or naturally	high biomass
Cercopagus pengoi	ostracod	ships ballast	high biomass in estuaries/ lakes
Caprella mutica	caprellid	ship fouling	fouling fish culture nets
Hemimysis anomala	mysid	ships ballast	high biomass in estuaries
Paralithodes camtschaticus	crab	ships ballast	bivalve mortality, fishery
Hemigrapsus penicillatus	crab	ships, oysters	omniverous, habitat changes
Homarus americanus	lobster	trade, releases	hybridisation with *H. gammarus*
Rithropanopeus harrisi	crab	ships	high biomass locally
Eriocheir sinensis	crab	ships ballast	predator, habitat changes

Appendix 3. Alien plants considered established in natural and semi-natural habitats in Ireland. Some of the alien plants listed below are quite localized or rare and many are also established in artificial habitats. Semi-natural habitats include hedgerows but not road verges. Invasive species are highlighted in bold (adapted from Reynolds 2002).

Acaena novae-zelandiae	*Cotoneaster simonsii*	*Lolium multiflorum*	*Ribes nigrum*
Acaena ovalifolia	*Crepis vesicaria*	*Lupinus arboreus*	*Ribes rubrum*
Acer pseudoplatanus	*Crocosmia × crocosmiiflora*	*Lysichiton americanus*	*Ribes uva-crispa*
Adoxa moschatellina	*Cymbalaria muralis*	*Malus domestica*	*Rubus spectabilis*
Allium carinatum	*Elodea canadensis*	*Matricaria discoidea*	*Rumex pulcher*
Allium triquetrum	*Elodea nuttallii*	*Matteuccia struthiopteris*	*Salix fragilis*
Alnus incana	*Epilobium brunnescens*	*Mentha × gracilis*	*Salix viminalis*
Anisantha diandra	*Erica cilaris*	*Mentha × piperita*	*Sarracenia purpurea*
Aster spp. & hybrids	*Erica terminalis*	*Mentha requienii*	*Saxifraga × urbium*
Azolla filiculoides	*Fagus sylvatica*	*Mimulus guttatus*	*Sedum album*
Berberis vulgaris	***Fallopia japonica***	*Mimulus × robertsii*	*Sedum dasyphyllum*
Bryonia dioica	*Fuchsia magellanica*	*Mycelis muralis*	*Selaginella kraussiana*
Calystegia pulchra	*Gaultheria mucronata*	*Nymphoides peltata*	*Senecio cineraria*
Calystegia silvatica	*Geranium pyrenaicum*	*Oenothera glazioviana*	*Sisyrinchium californicum*
Carpobrotus edulis	*Gunnera tinctoria*	*Oenothera stricta*	***Spartina anglica***
Chenopodium murale	*Haloragis micrantha*	*Orobanche minor*	*Stratiotes aloides*
Chenopodium polyspermum	*Hebe × franciscana*	*Pastinaca sativa*	*Symphoricarpos albus*
Cirsium oleraceum	***Heracleum mantegazzianum***	*Petasites fragrans*	*Tamus communis*
Claytonia sibirica	***Hippophae rhamnoides***	*Picea sitchensis*	*Tellima grandiflora*
Clematis vitalba	***Impatiens glandulifera***	*Pinus contorta*	*Tolmiea menziesii*
Cornus sericea	*Juncus planifolius*	*Pinus sylvestris**	*Verbena officinalis*
Cotoneaster franchetii	*Lagarus ovatus*	*Poa palustris*	
Coptoneaster horizontalis	*Leycesteria formosa*	*Populus nigra†*	
Cotoneaster integrifolius	*Libertia formosa*	***Rhododendron ponticum***	

*now considered native in ROI. †Native status uncertain

Appendix 4. Alien plants considered established mainly in artifical habitats in Ireland. Artificial habitats include cultivated, managed and waste ground, walls, pavements, road verges and railways. Some of the alien plants listed below are rare and some are also established in natural and semi-natural habitats e.g. *Erysimum cheiri*, *Rosa rugosa* and *Veronica filiformis* (adapted from Reynolds 2002).

Aegopodium podagraria	*Erysimum cheiranthoides*	*Medicago sativa subsp. Varia*	*Sambucus rupestre*
Althaea officinalis	*Erysimum cheiri*	*Melilotus albus*	*Senecio fluviatilis*
Antirrhinum majus	*Fallopia sachalinensis*	*Melilotus officinalis*	*Senecio squalidus*
Armoracia rusticana	*Festuca heterophylla*	*Mentha spicata*	*Senecio viscosus*
Avena fatua	*Fumaria bastardii*	*Mentha suaveolens*	*Silybum marianum*
Avena strigosa	*Fumaria muralis*	*Mentha × villosa*	*Sinapis alba*
Barbarea intermedia	*Geranium phaeum*	*Mercurialis annua*	*Sisymbrium orientale*
Brassica napus	*Hesperis matronalis*	*Misopates orontium*	*Smyrnium olusatrum*
Buddleja davidii	*Hieracium gougetianum*	*Myrrhis odorata*	*Soleirolia soleiroloo*
Centranthus rubber	*Hieracium grandidens*	*Papaver hybridum*	*Spartina pectinata*
Chaenorhinum minus	***Hieracium maculatum***	*Papaver somniferum*	*Stachys arvensis*
Chelidonium majus	*Hirschfeldia incana*	*Pentaglottis sempervirens*	*Symphytum tuberosum*
Chenopodium bonus-henricus	*Hordeum murinum*	*Persicaria amplexicaulis*	*Symphytum × uplandicum*
Chrysanthemum segetum	*Hyacinthoides hispanica*	*Persicaria bistorata*	*Tanacetum parthenium*
Cicerbita macrophylla	*Hyacinthoides non-scripta × hispanica*	*Persicaria campanulata*	***Tanacetum vulgare***
Cichorium intybus	*Hydrocotyle moschata*	*Persicaria wallichii*	*Thlaspi arvense*
Conyza bilbaoana	*Hypericum calycinum*	*Petroselinum crispum*	*Trifolium hybridum*
Conyza canadensis	***Hypericum hircinum***	*Peucedanum ostruthium*	*Urtica urens*
Coronopus didymus	***Inula helenium***	*Pilosella aurantiaca*	*Valerianella carinata*
Cruciata laevipes	***Juncus tenuis***	*Plantago media*	*Verbascum vigatum*
Diplotaxis muralis	*Kickxia elatine*	*Poa compressa*	*Veronica crista-galli*
Draba muralis	*Lamiastrum galeobdolon subsp.argentatum*	***Prunus domesticus***	*Veronica filiformis*
Epilobium ciliatum	*Lamium album*	***Prunus laurocerasus***	*Veronica peregrine*
Epilobium pedunculare	*Lepidium draba*	***Raphanus raphanisttrum subsp. raphanistrum***	*Veronica persica*
Epilobium tetragonum	*Linaria purpurea*	***Rapistrum rugosum***	*Vicia sativa subsp. segetalis*
Erigeron karvinskianus	*Malva neglecta*	***Reseda alba***	
Erinus alpinus	*Medicago arabica*	***Rosa rugosa***	

Appendix 5. Non-native animal species known to be present in Ireland

Common name	**Latin name**
MAMMALS	
Hedgehog	*Erinaceus europaeus*
Bank vole	*Clethrionomys glareolus*
Grey Squirrel	*Sciurus carolinensis*
Brown rat	*Rattus norvegicus*
Ship rat (probably restricted to islands and docks)	*Rattus rattus*
Brown hare	*Lepus europaeus*
Rabbit	*Oryctolagus cuniculus*
Fallow deer	*Dama dama*
Sika deer	*Cervus nippon*
American mink	*Mustela vison*
BIRDS	
Canada goose	*Branta canadensis*
Mandarin duck	*Aix galericulata*
Ruddy duck	*Oxyura jamaicensis*
Red-legged partridge	*Alectoris rufa*
Pheasant	*Phasianus colchicus*
Greylag goose	*Anser anser*
Collared dove	*Streptopelia decaocto*
FRESHWATER FISH (not postglacially native)	
Rainbow trout	*Oncorhynchus mykiss*
Rudd	*Scardinius erythropthalmus*
Tench	*Tinca tinca*
Roach	*Rutilus rutilus*
Pike	*Esox lucius*
Perch	*Perca fluviatilis*
Bream	*Abramis brama*
Carp	*Cyprinus carpio*
Dace	*Leucisus leucisus*
Gudgeon	*Gobio gobio*
Minnow	*Phoxinus phoxinus*
INVERTEBRATES	
New Zealand flatworm	*Artioposthia triangulata*
Flatworms – 8 species	Tricladida
Slugs – 14 species	Mollusca
Millipedes – 11 species	Diplopoda
Terrestrial isopods/hoppers – 10 species	Crustacea
Freshwater shrimp	*Gammarus tigrinus*
Freshwater shrimp	*Gammarus pulex*
Freshwater shrimp	*Crangonyx pseudogracilis*
Zebra mussel	*Dreissena polymorpha*
Beetles – 14 species	Coleoptera
Bees, ants, ichneumons etc. – several gall wasps	Hymenoptera
Honeybee parasite	*Varroa jacobsoni*
Florida leafminer	*Liriomyza trifolii*
South American leafminer	*Huidobrensis*
Western flower thrips	*Frankliniella occidentalis*
Sweet-potato whitefly	*Bemisia tabaci*
Aphid	*Echinothrips americanus*
Lupin aphid	*Macrosiphum albifrons*
Colorado beetle	*Leptinotarsa decemlineata*

Glossary

Alien species: A species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce.
Aquaculture: The cultivation of aquatic organisms by human effort for commercial purposes. For the cultivation of marine organisms, often molluscs and crustaceans, in seawater the term 'mariculture' is also used.
Archaeophytes: Long established members of the local flora (before 1700).
Bern Convention: Convention on the Conservation of European Wildlife and Natural Resources.
Biological diversity (biodiversity): The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.
BIP: Border Inspection Posts.
BRC: Biological Records Centre.
CBD: Convention on Biological Diversity.
CBD Guiding Principles: Guiding Principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species (annexed to Decision VI/23 adopted by the Conference of the Parties to the CBD, The Hague, April, 2002).
CFB: Central Fisheries Board.
CITES: Convention on International Trade in Endangered Species.
Complementarity: A property of sets of species that exists when at least some of the species in one set differ from the species in a second set.
Cryptogenic species: A species of unknown origin.
Cryptozoic species: Invertebrates which have an affinity for dark places.
EC: European Community
ECOPACT: Environmental Code of Practise for Aquaculture Companies and Traders
EPA: Environmental Protection Agency.
EPPO: European and Mediterranean Plant Protection Organisation.
Establishment: The process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival.
EU: European Union
FAO: Food and Agriculture Organisation of the United Nations
FMD: Foot and mouth disease
Fouling: (biological) Growth of sessile algae and animals, especially on a ship's bottom or other artificial underwater structures, or in water-intake apparatus, also termed 'biofouling'.
GISP: Global Invasive Species Programme
Hygrophilous: Insects with an affinity for wet places.
ICES: International Council for the Exploration of the Sea.
IDG: The International Designations Group.
IMO: International Maritime Organisation.
Introduced species: Any species introduced by human agency into a geographical region outside its natural range. The term includes non-established ('alien') species and established non-natives, but excludes hybrid taxa derived from introductions ('derivatives').
Introduction: The movement by human agency, indirect or direct, of an alien species outside of its natural range (past or present). This movement can be either within a country or between countries or areas beyond national jurisdiction.

Intentional introduction: The deliberate movement and/or release by humans of an alien species outside its natural range.

Invasive species: A non-native species which becomes established in natural or semi-natural ecosystems or habitats, is an agent of changes, and threatens native biological diversity (or has the potential to do so). An alien species whose introduction and/or spread threaten biological diversity.

IRBD: International River Basin District.

ISGA: Irish Salmon Growers Association.

ISIS: International Species Information System.

IUCN: World Conservation Union.

Natural range: The geographical range of a species in historical times (i.e. since the beginning of the Neolithic Age (ca 3,500 BC), prior to any changes to that range as a result of human agency.

Neophytes: a plant which was introduced to our area by man (or animal naturally from an area in which it was present as an introduction) and became naturalised after AD1500.

NGO: Non-Government Organisation.

Non-established introductions: Species that are introduced through the agency of man but have not become established and are incapable of establishing self-sustaining or self-propagating populations without deliberate intervention by man.

Non-native species: A species that has been introduced directly by human agency (deliberately or otherwise) to an area where it has not occurred in historical times and which is separate from, and lies outside, the area where natural range extension could be expected. The species has become established in the wild and has self-maintaining populations.

NPPO: National Plant Protection Organisation.

NPWS: National Parks and Wildlife Service.

OIE: Office International des Epizooties.

Pathway: The routes by which invasive alien species enter new habitats.

PHO: Plant Health Order.

QAB: Quality Assurance Branch.

Risk analysis: (1) the assessment of the consequences of the introduction and of the likelihood of establishment of an alien species using science-based information (i.e., risk assessment), and (2) to the identification of measures that can be implemented to reduce or manage these risks (i.e., risk management), taking into account socio-economic and cultural considerations.

Thermophilic: Species with an affinity for high temperatures.

UNCED: United Nations Conference on Environment and Development

UNEP: United Nations Environment Programme.

Unintentional introduction: An unintended introduction made as a result of a species utilising humans or human delivery systems as vectors for dispersal outside its natural range.

Vagrant (species): Individuals of a species which, by natural means, move from one geographical region to another outside their usual range, or away from usual migratory routes, and which do not establish a self-maintaining, self-regenerating populations in the new region.

Vector: The means by which invasive alien species travel to new destinations.

Vice-county: The standard geographical area for county-based botanical recording, this approximates to administrative counties in most cases.

WFD: Water Framework Directive.