BACI monitoring for the effects of hydraulic dredging for cockles on the intertidal benthic habitats of Dundalk Bay

Sarah Clarke and Oliver Tully

Fisheries Science Services, Marine Institute

May 2011

Contents

Contents ... 2
Summary ... 3
Introduction ... 4
Methods ... 9
- 2008 survey ... 9
- 2009-2010 Survey ... 10
- 2011 Survey ... 15
- ANOVA of the data ... 16
- Multivariate analysis of the 2009-2010 data ... 17

Results ... 18
- 2008 survey ... 18
  - Sediments in fished and unfished areas ... 18
  - Fauna in fished and unfished areas ... 18
- 2009-2010 survey ... 20
- Univariate summary statistics and ANOVA in relation to BACI ... 21
  - Sediment data ... 21
  - Benthic core data ... 22
  - Benthic quadrat data ... 24
- Univariate summary statistics and ANOVA in relation to CI effects: March 2010 transects ... 25
- Distribution and abundance of characterising bivalves in May 2011. ... 26
- Multivariate statistical assessment of effects on benthic communities ... 29
  - Benthic quadrat data ... 29
  - Benthic core data ... 35
    - September – November 2009 ... 35
    - March 2010 south ... 44

Discussion ... 47
References (incomplete) ... 48

Summary

- Control impact monitoring of sediments and benthic invertebrates was undertaken in August 2008 10 months following the closure of the cockle fishery in October 2007 to assess the impact on sediments or benthic fauna
- A before after control impact study of the effects of hydraulic dredging for cockles on benthic invertebrates in Dundalk Bay was also undertaken in 2009-2010
- In 2008 68 quadrat samples for fauna and 110 sediment core samples were taken
- In 2009-2010 quadrat and replicate benthic core and sediment samples were taken at up to 66 stations on each of 3 sampling periods immediately before, immediately after and 4 months after closure of the fishery
- Data were analysed using ANOVA for Before After (BA), Control Impact (CI) and Spatial effects. In 2008 spatial effects were based on 5 areas that had been open to fishing. In 2009-2010 spatial effects were isolated by creating a blocking variable which, *a posteriori*, grouped control and impact stations close together. Multivariate analysis was used to detect changes in the species assemblage in relation to main BACI effects.
- In total 33 species were recorded; 7 crustaceans, 10 molluscs, one nemertean and 15 polychaetes
- In 2008 analysis of sediments showed that mean grain size was significantly higher in one fished area compared to nearby controls but not significantly different in 4 other locations. Sorting coefficients were similar in all 5 locations across control and fished areas.
- In 2009-2010 analysis of sediments showed that the average % of particles <125um in control and impact sites (F-ratio 0.08, p=0.77) were similar before and after (F-ratio 0.03, p=0.86) the fishery
- In 2008 abundance and diversity of fauna were similar in control and fished areas in all locations
- In 2009-2010 ANOVA of the **benthic core** data indicated significant BA effects in the case of bivalves, polychaetes and crustaceans. The CI effect was significant only in the case of crustaceans and occurred in March 2010 when the number of crustaceans was higher in control sites but not in impact sites. Abundance of crustaceans in impact and control sites immediately after the fishery in November 2009 was similar. The mean abundance of cockles was slightly higher in impact stations after the fishery closed in November 2009. BA, CI, the BA*CI interaction term and Block effects were all significant in the case of *A. tenuis* suggesting fishery and seasonal effects that varied spatially. The fishery effect was short lived and by March 2010 abundance in areas fished in October 2009 was higher than in controls.
- In March 2010, in core samples taken in transects at different shore levels in control and previously fished areas the number of bivalves was higher at impact stations than at control stations in upper, middle and lower shore samples. Polychaetes were more common in the control samples and the number of crustaceans per sample showed no consistent pattern across control and impact transects at different shore levels.

- In 2009-2010 ANOVA of **benthic quadrat** data for bivalves showed significant BA and block (spatial) but not CI effects. BA, CI and all interaction effects were significant in the case of *A. tenuis* which declined from 24 per sample, before the fishery, to 3 per sample after the fishery in the impact areas and declined from 14 per sample before to 10 per sample after the fishery in the control areas. *A. tenuis* was more abundant in March 2010 than November 2009 in impact areas and approximately 6 times higher in impact than control areas at this time. The overall seasonal (Sept 2009-March 2010) decline was higher in control areas. The abundance of *M. balthica* was higher in control areas than in impact areas before and after the fishery. The abundance of polychaetes and crustaceans was lower after the fishery in both control and impact areas. BA and block (spatial) factors were significant but the CI effect was not.
- Analysis of the sample similarity matrix indicated a divergence in the community structure for CI, location (north south) and season. This was mainly due to difference in the faunal communities between the northern CI sites for all three sampling periods including September 2009 before the fishery and where community divergence increased over time
- No significant difference was found for communities of the southern CI sites sampled in September 2009. A slightly elevated R-value (divergence) in CI sites in November 2009. However, this was still very close to zero, suggesting little divergence between the CI communities before and after the fishery.
- Seasonal and spatial variability are dominant factors determining the abundance of benthic invertebrates in Dundalk Bay. There were indications of short lived (<4 months) fishery effects on *A. tenuis* (core and quadrat samples) and the target species *C. edule* (quadrat samples only) which spatially overlap. The community assemblages diverged in time mainly due to the seasonal effects of recruitment and mortality. The dominant species in this community, *A. tenuis, M. balthica, C. edule* and a number of polychaete species have low sensitivity (high resilience and high recoverability) to disturbance.

Introduction

Dundalk Bay is a large exposed, east facing bay opening into the Irish Sea. The Bay is designated as a Special Area of Conservation (SAC, Habitats Directive) and a Special Protection Area (SPA, Birds Directive). These designations indicate the importance of the extensive intertidal and sub-tidal habitats within the Bay and the large populations of over wintering waterbirds which the site supports. There are internationally important (i.e. it regularly supports greater than 1% of the flyway populations of) populations of Light-bellied Brent Geese, Golden Plover, Knot, Black-tailed Godwit and Bar-tailed Godwit at the site. It also regularly holds over 20,000 waterbirds (which is an additional criteria for defining sites of international importance). It is nationally important for a further 18 species and has proven to be the most important site in Ireland for four species, namely Great Crested Grebe, Oystercatcher, Knot and Bar-tailed Godwit (Crowe 2008).

A dredge fishery for cockles (*Cerastoderma edule*) has taken place in Dundalk Bay intermittently since 2001 (Fahy et al. 2005). Since 2007 the fishery has been regulated by a fishery management plan which includes a range of fishery controls and harvest control rules. The annual out take is based on an annual biomass survey and a 33% harvest rate. Prior to 2001 cockles were harvested by hand gathering and raking, but landings data were not recorded (Fahy, 2005). In 2001 three suction dredgers took almost 9 tonnes of cockles from the Bay and the following year 2 to 3 boats, along with hand rakers, were responsible for landing 169 tonnes (Fahy, 2005). In 2007 approximately 800 tonnes were removed mainly by dredging and in 2009 approximately 120 tonnes were taken. The fishery was closed in 2008 because an appropriate assessment of the impact of the fishery had not been undertaken as required under article 6 of the Habitats Directive and in 2010 because biomass and density were below commercially viable levels.

Cockles are generally found in clean sand, muddy sand, mud or muddy gravel from the middle to the lower intertidal and sometimes occur subtidally (Tyler-Walters, 2003). They have been found to contribute to the accumulation of fine sediments by filtering fine particles from the water column which are deposited as faeces and pseudofaeces (Elliot *et al*., 1998). The annual assessment for cockles in Dundalk Bay recorded the most abundant cockle densities in clean sand sediments in the middle shore area. High numbers of cockles have also been found in finer muddy sediment along the upper shore, however the majority of these cockles are usually below commercial size (<18 mm in width). Cockle larvae settle in March usually on the upper and middle shores and growth tends to be rapid especially in Dundalk Bay where densities are lower than in many cockle fishing sites in the UK for instance. Commercial sized cockles are approximately 1.5 years old and are distributed primarily in the middle and lower shores (Tully and Clarke, 2010). The link between stock and recruitment is unknown but is likely to be affected significantly by local environmental conditions such as wind direction and hydrodynamics which controls the degree to which larvae are retained over the sand flat.

Suction and non-suction hydraulic dredging are currently the main methods of fishing for cockles in Dundalk Bay. There is a small scale hand gathering fishery for cockles. These dredges generate hydraulic jets of water to fluidise sediments in front of the dredge to displace bivalves from the sediments. The suction dredge pumps the fauna and associated sediments onto the deck where the catch is graded and sediments and associated fauna (apart from the target species above the minimum landing size) are returned to the seabed. Non-suction dredges fluidise the sediment but the catch is graded in situ in the dredge. In Dundalk the operational minimum size has, since 2007, been 22mm shell width although the legal size is 17mm shell width. There is, therefore, a high level of discarding and dredging effort, to take the annual quota, is higher than it would be if the minimum size was lower. This raises concerns about discard mortality of cockles and other non-commercial by-catch which is captured by the suction gear or at the dredge head in the case of non-suction gear.

The impact of hydraulic dredging on the benthic environment has not been investigated in Dundalk. Information from other sites, reviewed in Bell and Walker (2006), gives cause for some concern and the hypothesis that the fishery could be having significant detrimental effects on the benthos and on the prey base for overwintering waterbirds is reasonable. The significance of such effects and recovery from them, however, depend on the nature of the substrate which in turn reflects underlying physical hydrodynamic processes.

Studies have shown that the practice of suction dredging for cockles in certain areas can have an adverse impact on the sediment and its associated fauna and contribute to declines in shorebirds (Ens *et al*., 2004). Findings from a study carried out on suction dredging for cockles in the Wadden Sea led to the closure of the fishery due to concerns for habitats (Ens *et al*., 2004). In contrast Bell and Walker (2005) found that the biota and environment of much of The Wash appear to be naturally dynamic and are therefore fast to recover from the impacts of suction dredging and other perturbations. Dundalk Bay is very exposed and is often subjected to high winds and strong wave action from easterly storms, making this habitat highly dynamic. Previous studies have found that the scale and duration of impacts of suction dredging on benthic communities are specific to individual sites and occasions, but as a general rule greater impacts are observed on communities in fine sediments in sheltered locations than on coarser sediments in more exposed areas (Bell and Walker, 2005). It is important, therefore, to investigate effects at a site specific level to have high confidence that no on going cumulative changes to benthic environments are brought about by cockle dredging.

Evidence of impact (Table 1) and recovery (Table 2) of benthic communities from the effects of dredging and handraking for cockles is very site specific. This probably reflects the different physical and biological dynamics and variability at each site, the spatial resolution of the impact study and the capacity of studies to detect significant effects against background variability.

Table 1. Impacts of dredging and hand raking on invertebrate fauna in soft sediments

Source of impact	Species	Impact	Reference
Cockle harvesting	*Macoma balthica*	reduced densities	De Vlas 1982
	Cerastoderma edule	reduced densities	De Vlas 1982
	Mya arenaria	reduced densities	De Vlas 1982
	Nereis diversicolor	reduced densities	De Vlas 1982
	Hediste filiformis	reduced densities	De Vlas 1982
Cockle dredging	*Macoma balthica*	decreased recruitment	Piersma et al 2001
	Cerastoderma edule	decreased recruitment	Piersma et al 2001
Suction dredging	*Mytilus edulis*	densities (not evaluated statistically)	Hiddink 2003
	various	reduced densities	Hiddink 2003
	C. edule, Hydrobia ulvae	no sig diff in densities in tracks vs between tracks	Hiddink 2003

	N/A	trenches	Spencer et al 1998
	Species Number	Reduction by 30%	Hall & Harding 1998
	Mean # of individuals	Reduction by 50%	Hall & Harding 1998
	Pygospio elegans	Reduction by 85%	Moore 1991
	Macoma balthica	Reduction by 82%	Cook 1991
	Zostera marina	complete disappearance	Perkins 1988
	sediment	reduction from 30% silt to 8-13%	Perkins 1988
	sediment	decrease in silt content	Piersma et al 2001
Hand raking	N/S	exposure	Hancock & Urquhart 1966
Bait digging	sediment	increase in C & N levels in sediments	McLusky 1983

As the variability in the rate and degree of impact and recovery of habitats from dredging activity varies across sites it is difficult to have a high degree of confidence in extrapolating the results of such studies into Dundalk Bay. A specific study in Dundalk Bay was therefore undertaken to determine the degree and scale of impact and recovery of benthic communities as a result of hydraulic suction and non-suction dredging for cockles.

This report presents data from a before after control impact (BACI) study on the effects of cockle suction and non-suction dredging on the sediments and benthos of Dundalk Bay. Surveys were undertaken immediately before, immediately after and 4 months after the closure of the fishery in 2009 to monitor the impacts of dredging activities and, if effects occurred, to determine recovery rates once dredging activities ceased.

Table 2. Recovery of invertebrate fauna in soft sediments from fishing activity

Disturbance	Index of Recovery	Length of Recovery	Factors affecting recovery	Reference
Hand raking	Filling of trenches and depressions		Sediment bed-load transport	Kaiser et al 2001
			Suspended sediment load in water column	
			Exposure to wave action	
			Harvesting technique	
Bait digging	Faunal density	22 days	Back-filling of accelerated habitat restoration and faunal recolonisation	McLusky et al 1983
Lugworm dredgers	biomass of *Mya arenaria*	more than 2 yrs		Beukema 1995
	biomass of infaunal community	6 months post-harvesting		

Harvesting in general	Sediment habitat and it's associated fauna	Highly variable	Sediment type, Local environmental conditions, Type and frequency of harvesting process	Kaiser et al 2001
Harvesting in general	Faunal density	Variable	Size of animal	
Suction dredging	Dominance - partial dominance curves	after 56 days some effects remain	seasonal decline in fauna	Hall & Harding 1997
Suction dredging	Infauna in dredged tracks	within 3 months	regular disturbance by water movement	Moore 1990
Dredging	Abundance	2-3 months	Active/passive migration of individuals from overlying water column or undredged areas into harvested region	Dyrynda & Lewis, 1995; Hall & Harding, 1997,1998; Rees 1996
Suction dredging	Sediment characteristics - median grain size, silt content	8 years	benthic animals can alter properties of sediment	Piersma et al 2001
Suction dredging	spatfall of *Cerastoderma* and *Macoma*	10 yrs		Piersma et al 2001
Suction & Tractor	Hill's N1	Progressive recovery against a background of normal seasonal increases (suction dredge impact) and recovery against a background of seasonal decline (tractor dredge). Analysis suggests that effects do not persist		Hall & Harding 1997
Suction & Tractor	Hill's N2			Hall & Harding 1997

Methods

2008 survey

A dredge and hand rake fishery for cockles occurred in Dundalk in autumn of 2007 between July 16th and October 12th. An estimated 652 tonnes of cockles were landed by dredgers and up to 200 tonnes by handrakers. The fishery operated in restricted areas (Figure 1). Up to thirty two vessels fished a maximum of 5 days per week over 1 high tide period for an average duration of 3 hours per day.

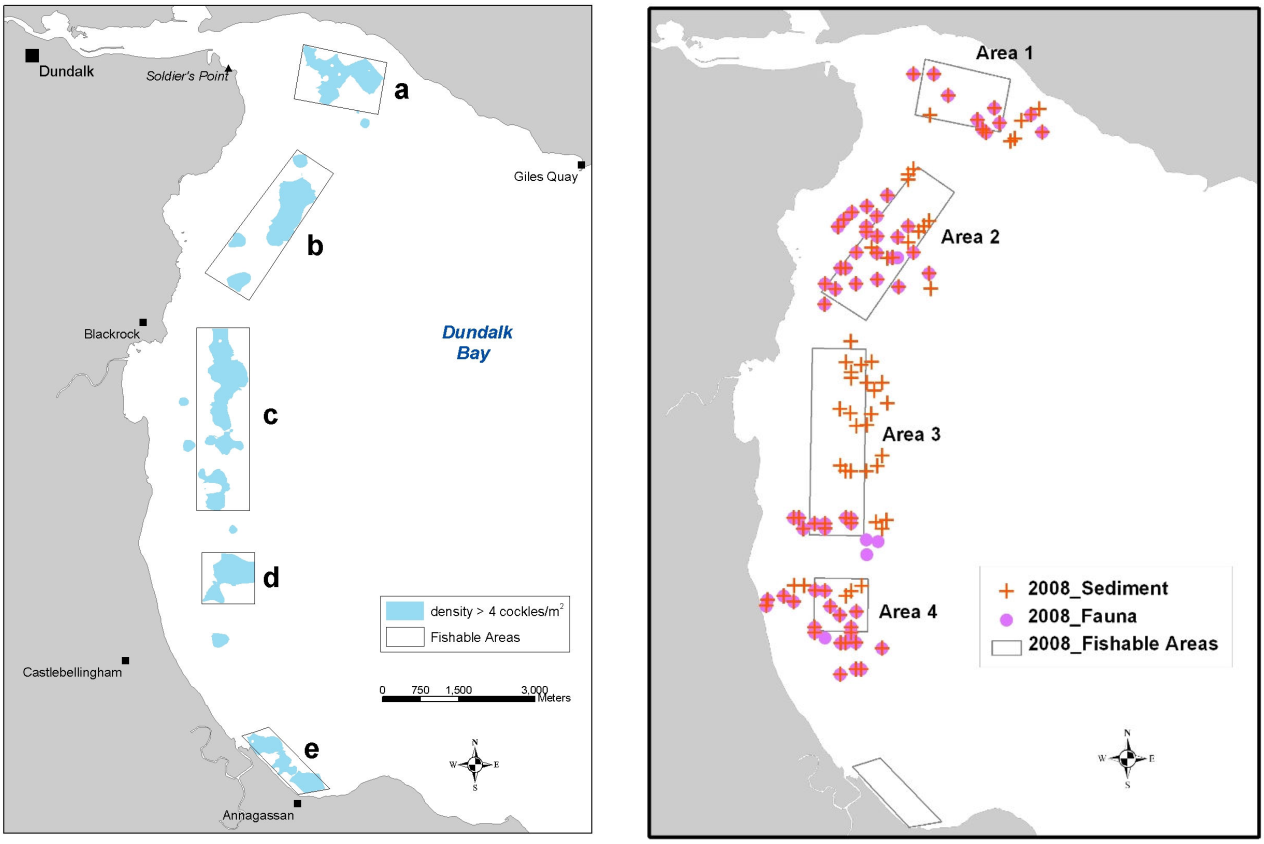

Figure 1 Areas (a-e) opened to cockle fishing in Dundalk Bay in 2007 and (right) locations of benthic monitoring stations for effects on benthic invertebrates in August 2008.

To assess recovery from the 2007 fishery 110 sediment (core) and 68 faunal samples (fauna retained on a 5mm grid) were taken in August 2008 from areas that were open to fishing and areas that were closed to fishing in 2007 (Figure 1).

In the field quadrat benthic samples were washed through a 4 mm sieve. All fauna remaining on the sieves were fixed in a 4% formalin solution. The faunal samples were sorted and preserved in 70% ethanol, prior to taxonomic identification to species level, where possible.

2009-2010 Survey

A total area of 14 km^2 was designated for fishing activities in September –October 2009 based on biomass estimates determined from an assessment of the cockle stocks carried out in May 2009 (Figure 1). A total of 66 sampling stations were then selected, 33 as control sites outside the designated fishing areas and 33 as impact sites within the designated fishing areas, for the BACI study. One quadrat (0.25m^2) and three core samples were collected at each sampling station. Sediment samples were taken.

Fishing locations were extrapolated from VMS data by converting the VMS data to vessel speed using location and time information in the data and deleting records where speed was >2knots given that dredging does not occur at higher speeds. Some vessels also fished for Razor clams during the cockle fishery. The location of this fishery is discrete and separate from the cockle fishery and showed up clearly in the VMS map of activity (Figure 4). Generally cockle fishing occurred only within the allowed areas and control sites sampled in September 2009 were not compromised by fishing. Fishing, however, did not occur at or close to a number of monitoring stations chosen as impact sites in the south of the area. These were reassigned as controls. Details are described below.

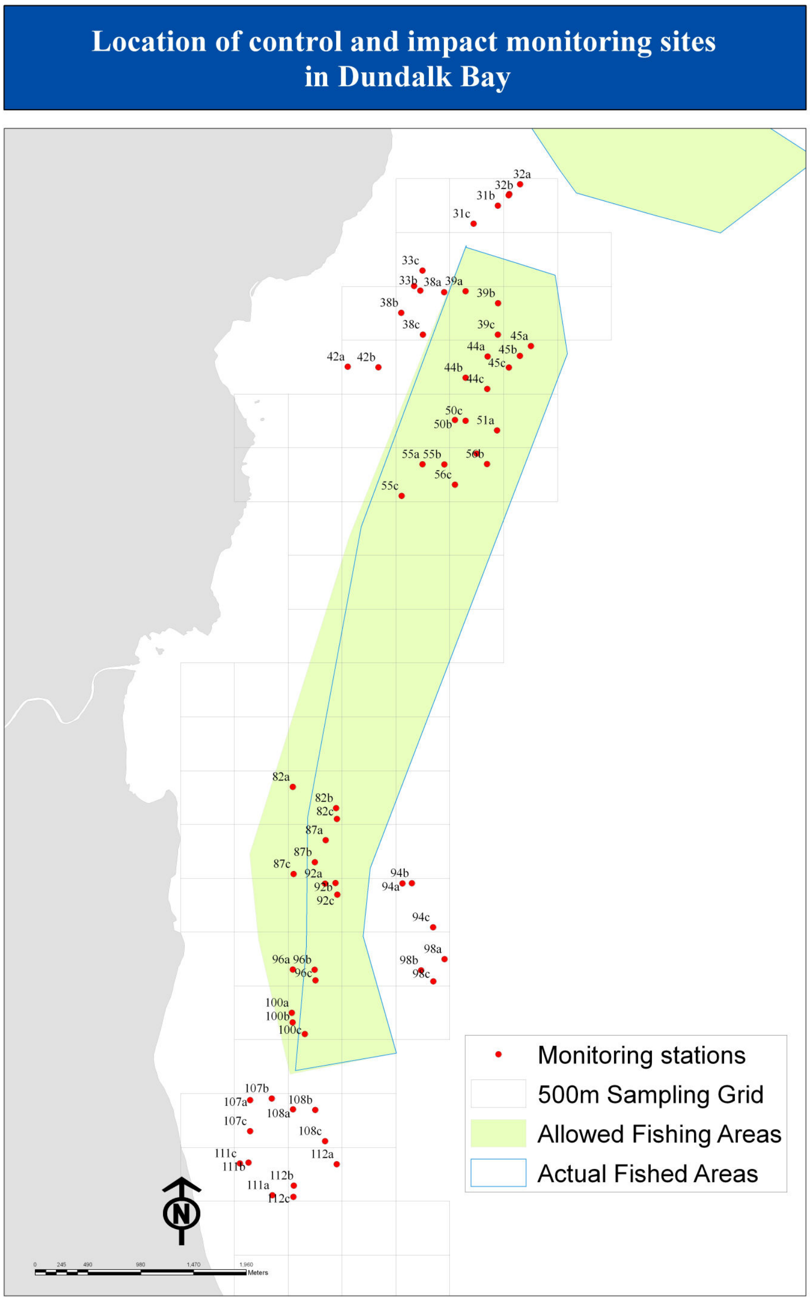

Figure 2 Location of control and impact sites and sampling locations in two areas of Dundalk Bay. Each square is 500x500m. Green = areas fished during October 2009. Blue dots are locations of sampling for the June 2009 cockle biomass survey. Red dots are locations of sampling for BACI monitoring. Red dots in green areas = Impact, Red dots in white areas = Controls. Pre-fishery sampling in September. Fishing occurred during October. Post fishery monitoring in November (10-11th) 2009 and in March (8-9th) 2010. The majority of control and impact sampling points are in a littoral sand (*Angulus tenuis, Cerastoderma edule*) community.

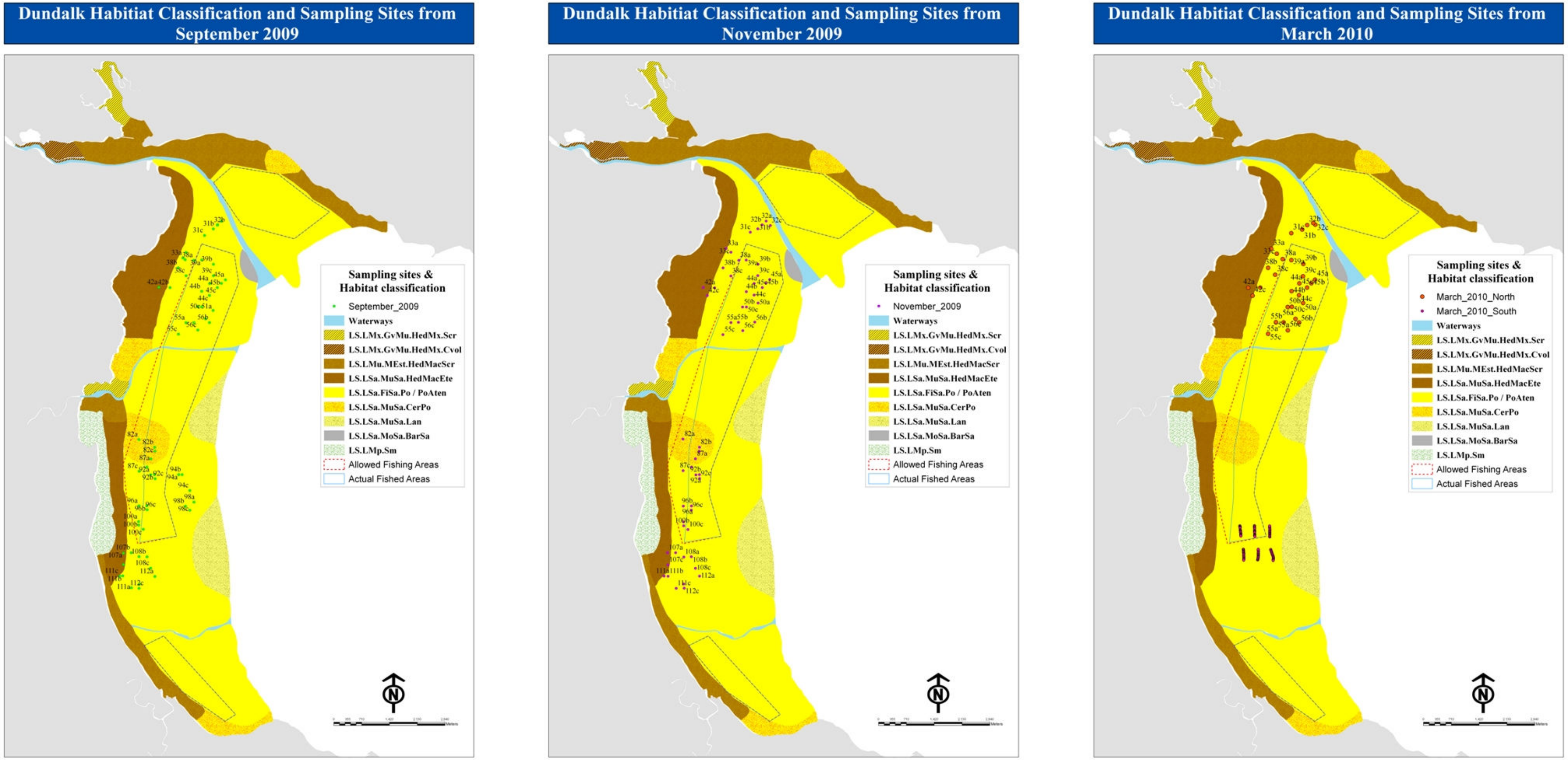

Figure 1. Distribution of control and impact sites in Dundalk Bay sampled in September 2009, November 2009 and March 2010 in relation to distribution of habitats (ASU 2008)

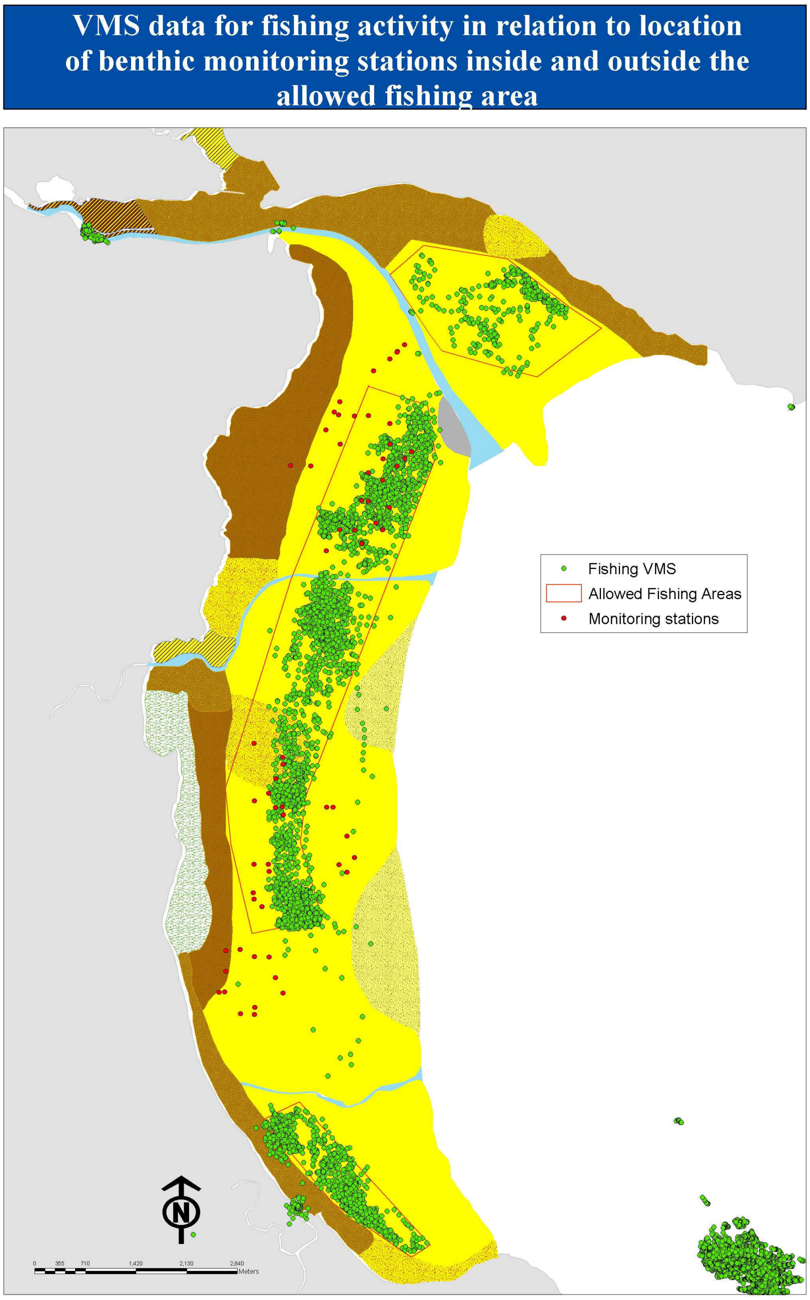

Figure 4. Distribution of fishing activity (sample from VMS data) in relation to distribution of benthic monitoring stations. The outline of the allowed fishing area is shown. The activity on the bottom right of the map is a fishery for razor clams (Ensis siliqua).

On the 17th and 18th September 2009, prior to the opening of the Dundalk Bay cockle fishery, 63 sites were sampled (three of the planned sites were omitted from the survey due to inaccessibility). The cockle fishery closed on the 1st November 2009 and further sampling was undertaken on the 10th and 11th November 2009 at the majority of the previously sampled control and impact sites. Nine sites were omitted due to inaccessibility caused by tidal conditions and time constraints.

To ensure dredging vessels remained within the designated fishing areas each vessel participating in the cockle fishery carried a GPS tracking system. The GPS monitoring system data compiled during November 2009 indicated that the vessels had not used the full extent of the designated fishing area and 5 of the original impact sites were re-classed, *a posteriori*, as control sites as they were unlikely to have been disturbed by fishing. The actual area fished was 12 km^2 (Figure 4).

In the field core and quadrat benthic samples were washed through 1 mm and 4 mm sieves, respectively. All fauna remaining on the sieves were fixed in a 4% formalin solution. The faunal samples were sorted and preserved in 70% ethanol, prior to taxonomic identification to species level, where possible. Sediment samples were collected from 22 control sites and 27 impact sites before the fishery in September 2009 and after the fishery in November 2009, for particle size analysis.

Four months later on the 8^{th} and 9^{th} March 2010 samples were collected from 31 of the sites (13 control and 18 impact) located in the northern sampling area. The original southern sites sampled in September and November 2009 were not re-sampled in March 2010. These sampling sites were re-located in order to overlap with bird count transects, which were established separately to monitor the number of birds using the habitat in the control and fished sites in this area of the bay. Differences in bird use of these areas could be related to changes in the abundance and diversity of benthic fauna resulting from fishing activity. The March 2010 southern sites were positioned along 6 cross shore transects situated at three different shore levels (in order to control for spatial effects). Fifteen core samples were collected along each transect at approximately 20m intervals. Ninety samples were taken in total, 30 within the impacted area and 60 in control areas (Figure 5). The location of these transects was informed by the GPS data from the fishing vessels. In the case of fishing impact, transects along the mid shore received higher fishing pressure than the upper and especially the lower transect, which was located 60-120m outside the allowed fishing area. The control transects were on average 320-500m south of the fishing area.

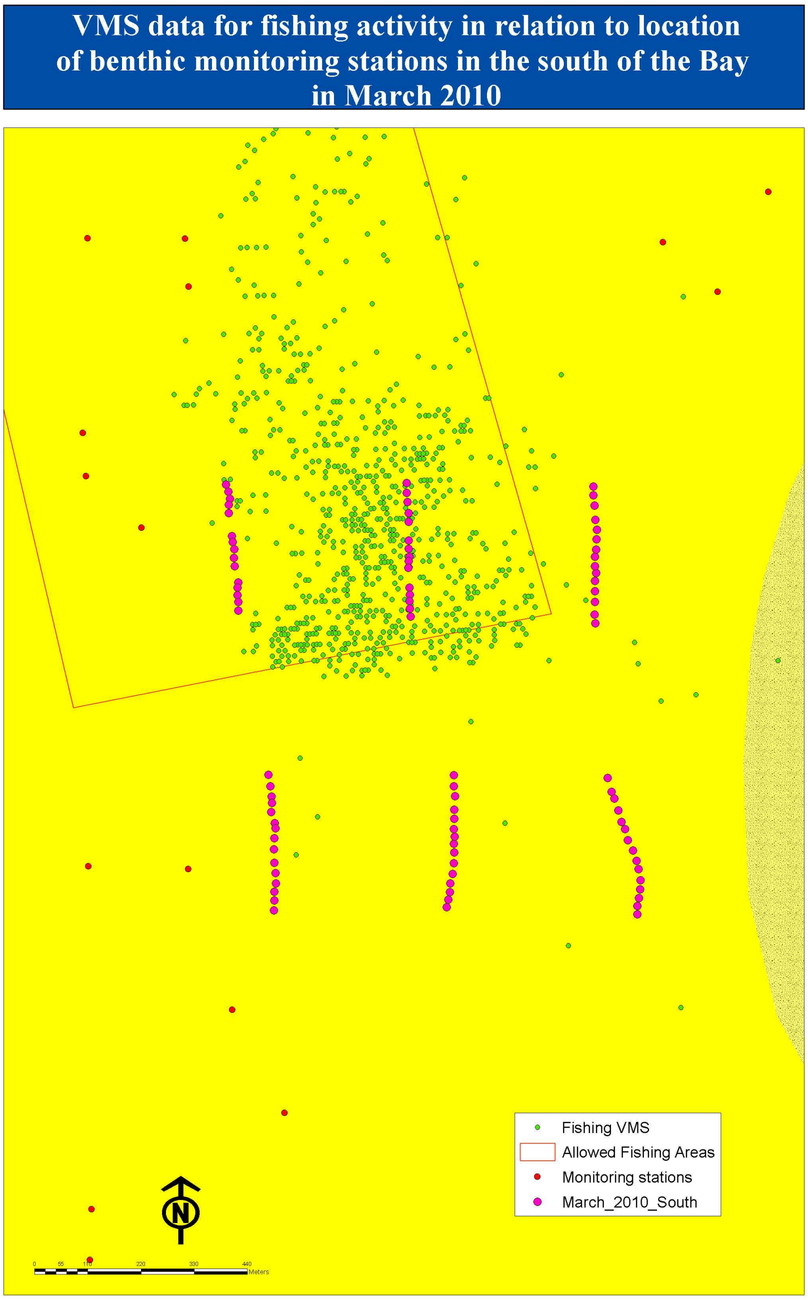

Figure 5. Distribution of benthic monitoring transects in relation to VMS data for cockle fishing vessels in March 2010.

2011 Survey

During the annual cockle biomass survey in May 2011 the two common bivalves species *Angulus tenuis* and *Macoma balthica* were also surveyed using a 4mm 0.25m^2 quadrat (see sampling plan). Their distribution and abundance were mapped.

ANOVA of the data

Two way ANOVA for location and fishery effects was undertaken on the 2008 sediment and fauna abundance and diversity data.

Prior to analysis of variance of the 2009-2010 data for BACI effects on individual species and taxonomic groups, sampling stations proximal to each other, and including control and impact sites, were grouped (Blocked) in order to isolate, as far as possible, spatial effects from the BACI effects in the analysis. The raw data and mapping of *C. edule, A. tenuis* and *M. balthica* distributions in 2008 showed strong spatial patterns in the abundance of these species justifying the *a posteriori* spatial grouping of sites. Stations 31 and 32 were excluded from analysis as their species composition was atypical and could not reasonably be blocked with other stations. These sites were close to the Dundalk River channel.

Control-Impact, Before-After and Block were the main factors included in an ANOVA of Ln (abundance+1) transformed data for bivalves, polychaetes and crustaceans. Effects on 3 common bivalves *Cerastoderma edule* (cockle), *Angulus tenuis* and *Macoma balthica* were also investigated. Second order interactions for CI *BA, CI*Block and BA*Block were retained in the analysis.

The before-after factor in the ANOVA had 3 levels; September 2009 (before the fishery), November 2009 (immediately after the fishery) and March 2010 (four months after the fishery). Stations were blocked in 3 groups, excluding stations 31 and 32. The output of the analysis can be interpreted as follows;

- significant control – impact effects suggest an impact of the fishery provided that the differences in abundance are in concordance with the hypothesis of impact i.e. abundance should be lower in the impact than in the control sites
- significant before – after effects in the absence of CI effects indicates significant seasonal changes in abundance independent of the fishery
- significant Block effects indicates spatial variability in the abundance of benthic fauna independent of fishery or seasonal effects. In this case the variability would be along shore as the stations were blocked in a north south direction
- significant interaction terms indicate that main effects on one factor do not occur to the same degree or in the same direction as effects on another main factor i.e. seasonal effects may vary between blocks, CI effects may depend on time or spatial variability etc.

Multivariate analysis of the 2009-2010 data

Data were square root transformed and subjected to Bray-Curtis similarity analysis using hierarchial agglomerative group-average clustering with the PRIMER program (Version 6.1.13). A similarity profile permutation test (using SIMPROF) was undertaken, to determine whether the null hypothesis that a single set of samples, which are not *a priori* divided into groups, do not differ from each other in multivariate structure. ANOSIM analysis was also applied to assess significant differences between pre-defined group structures, (such as CI (Control or Impact), 'location' (north or south sampling areas) and 'time periods' (Pre or post fishery)) against a series of random simulations, resulting in the calculation of a test statistic (R). R ranges from -1 to 1 and will be close to 1 when replicates are very dissimilar and approach 0 as when they are similar. Two of the three factors (type or site, time period and location) used to analyse the data were combined to undertake two-way ANOSIM analysis. SIMPER analysis was used to determine the contribution of each species to the average Bray-Curtis dissimilarity between samples in impacted and control areas, in different sampling locations and across time periods. Stations 31 and 32 were not excluded from the data for the purpose of the multivariate analysis and potential spatial effects were isolated by using 'location' as a factor in the ANOSIM analysis.

Results

2008 survey

Sediments in fished and unfished areas

Two way ANOVA showed that sediments in fished and unfished areas of Areas 2, 3 and 4 were similar in mean grain size but that mean grain size in Area 1 was higher in the fished area compared to the unfished area. Sorting coefficients were similar in all areas and in fished and unfished areas.

Table 3. Mean particle size in sediments in fished and unfished positions in Areas 1 – 4.

			Particle size		
Area	**Fished**	**N**	**Mean**	**S.d.**	**p<0.05**
Area 1	Yes	9	168.85	20.91	**
Area 1	No	6	147.40	3.83	
Area 2	Yes	27	150.88	11.74	
Area 2	No	6	146.22	18.80	
Area 3	Yes	13	139.61	2.64	
Area 3	No	12	144.01	7.72	
Area 4	Yes	18	157.53	10.65	
Area 4	No	19	148.69	21.22	

Fauna in fished and unfished areas

Two way ANOVA showed that there was no significant differences between the total abundance or diversity (H) of fauna between Areas 1 to 4 or in fished and unfished locations within each area (Table 4) although the mean abundance was generally higher in areas that were fished.

Table 4. Abundance and diversity of invertebrate fauna in fished and unfished locations in Areas 1 to 4.

			Abundance		Diversity (H)	
Area	**Fished**	**N**	**Mean**	**S.d.**	**Mean**	**S.d.**
Area 1	Yes	8	45.8	35.0	0.54	0.11
Area 1	No	2	36.0	29.7	0.55	0.05
Area 2	Yes	23	66.2	36.2	0.36	0.13
Area 2	No	2	46.5	7.8	0.55	0.13
Area 4	Yes	16	87.3	57.0	0.45	0.09
Area 4	No	17	60.7	63.8	0.41	0.13

Density distributions of the bivalves *Angulus tenuis* and *Macoma balthica* were not related to areas that were open and closed to fishing. Densities of these species were in accordance with expected zonation patterns on the shore. Densities of *Macoma balthica* were higher on the upper shore in muddy sand sediments while densities of *Angulus tenuis* was higher on the mid shore on sand in association with cockles and in the areas fished for cockles in 2007 (Figure 6).

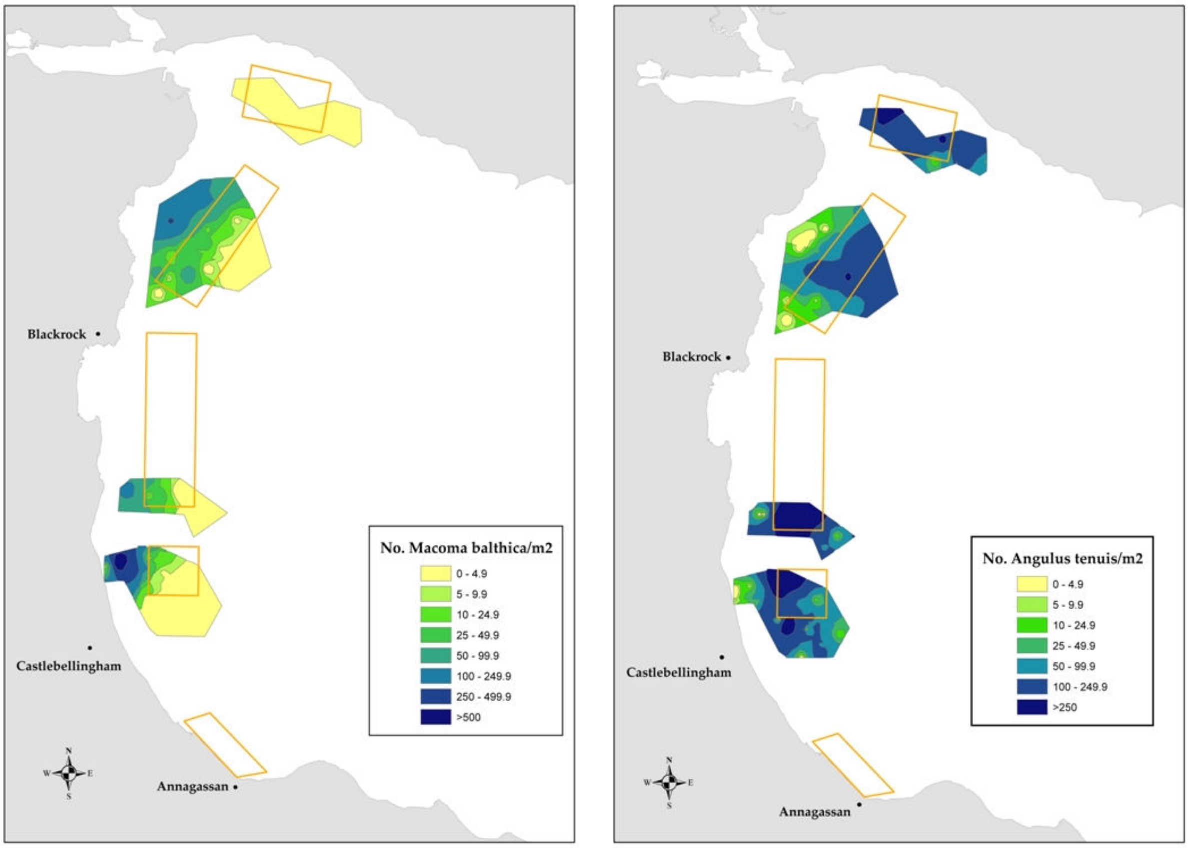

Figure 6. Distribution of the bivalves *Macoma* and *Angulus* in Dundalk Bay in August 2008 10 months following the closure of the fishery in October 2007. The areas fished in 2007 are overlain. Blank areas indicates no data.

Abundance of newly recruited (0+) cockles and total biomass of cockles was higher in 2008 (3,588±1,905 tonnes) than in 2007 (2,277±172 tonnes) although the fishery in 2007 removed up to over 700 tonnes compared with no dredge fishery in 2006. On the other hand cockle biomass in 2009 was lower (2158±721 tonnes) than in 2008 although no fishery occurred in 2008. Recruitment of cockles and probably other short lived bivalves is controlled primarily by environmental conditions during larval settlement and over wintering conditions for spawning stock. The distribution of recruitment of cockles is consistently along the mid shore level in sand with high densities also on the upper shore towards blackrock in sandy mud sediments.

2009-2010 survey

In total 33 species were recorded, 7 crustaceans, 10 molluscs, one nemertean and 15 polychaetes (Table 5). Three of the polychaetes were only recorded in low numbers from the southern sites in March 2010. The majority of species from both the core and quadrat data decreased in number from September to November 2009. An increase was observed in the number of individuals recorded for three species of crustacean (*Bathyporeia guilliamsoniana*, *Corophium volutator* and *Gammarus locusta*) and two species of polychaete (*Owenia fusiformis, Phyllodoce mucosa*) from September 2009 to March 2010. Numbers of the gastropod mollusc *Hydrobia ulvae* doubled over the same period.

Table 5. List of species recorded from Dundalk Bay benthic sampling for the different sampling regimes, undertaken in September 2009, November 2009 and March 2010 (Y=Yes species was recorded).

Pylum	Species	Core	Quadrat	March S (Core)
Annelida	*Capitella capitata*	Y	Y	
Annelida	*Eteone longa*	Y	Y	Y
Annelida	*Euclymene lumbricoides*			Y
Annelida	*Glycera cf tridactyla*	Y	Y	
Annelida	*Lanice conchilega*	Y	Y	
Annelida	*Magelona cf filiformis*	Y	Y	
Annelida	*Nepthys hombergii*	Y	Y	Y
Annelida	*Nereis diversicolor*	Y	Y	
Annelida	*Owenia fusiformis*	Y	Y	Y
Annelida	*Phyllodoce maculata*			Y
Annelida	*Phyllodoce mucosa*	Y	Y	
Annelida	*Pygospio elegans*	Y	Y	Y
Annelida	*Scoloplos armiger*	Y	Y	Y
Annelida	*Sigalion mathildae*			Y
Annelida	*Spio martinensis*		Y	
Crustacean	*Bathyporeia guilliamsoniana*	Y	Y	Y
Crustacean	*Carcinus maenas*	Y	Y	
Crustacean	*Corophium volutator*	Y		
Crustacean	*Crangon crangon*	Y	Y	Y
Crustacean	*Gammarus locusta*	Y	Y	
Crustacean	*Semibalanus balanoides*	Y	Y	
Crustacean	*Sphaeroma serratum*	Y		
Mollusca	*Angulus tenuis*	Y	Y	Y
Mollusca	*Cerastoderma edule*	Y	Y	Y
Mollusca	*Donax vittatus*	Y	Y	Y
Mollusca	*Hydrobia ulvae*	Y		Y
Mollusca	*Macoma balthica*	Y	Y	Y
Mollusca	*Mya arenaria*	Y	Y	
Mollusca	*Mytilus edulis*	Y		
Mollusca	*Scrobicularia plana*	Y	Y	
Mollusca	*Tellina fabula*		Y	
Mollusca	*Thracia phaseolina*	Y		
Nemertea	*Nemertea* indet	Y	Y	

The highest numbers of individuals recorded belonged to the Phlyum Mollusca from both the quadrat (86%) and core (53%) samples. A further 12% of the fauna identified from the quadrat samples and 41% from the core samples consisted of polychaete worms.

Univariate summary statistics and ANOVA in relation to BACI

Sediment data

Sediment samples were taken before the fishery in September 2009 and after the fishery in November 2009 at control and impact sites. The main concern regarding impact of cockle fisheries is the loss of fine material due to sediment fluidisation and disturbance. Sediment samples collected pre and post fishery showed no significant difference in the percentage of gravel, sand and mud with Mann-Whitney tests resulting in p values of p=1.0; p=0.3623; p=0.3825, respectively. Sand made up the largest proportion of all sediment samples, ranging from 82% to 99% in September and 86% to 99% in November 2009.

The average % of particles <125um in control and impact sites (F-ratio 0.08, p=0.77) were similar before and after (F-ratio 0.03, p=0.86) the fishery (Table 6, Figure 5).

Table 6. Average ±s.d % of particles <125um in sediments in control and impact sites before and after the cockle fishery in 2009.

Before/After	Control/Impact	N	Mean	S.d.
B	C	37	50.50	16.78
B	I	28	51.88	17.58
A	C	30	50.47	17.02
A	I	26	50.78	16.12

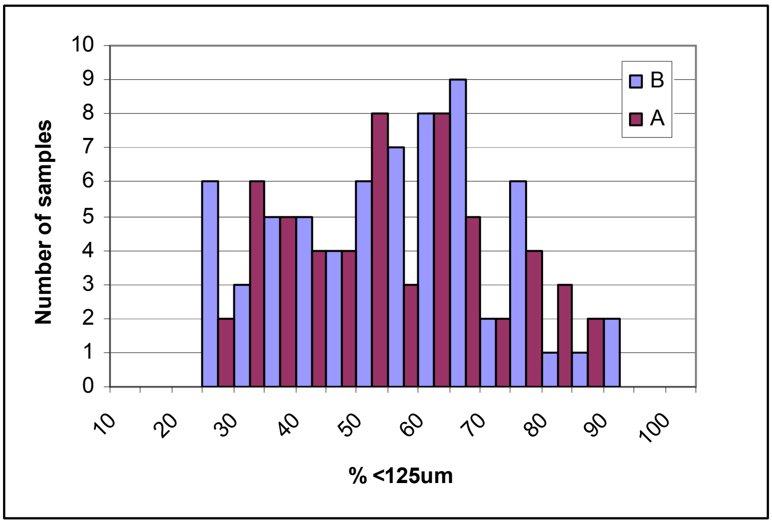

Figure 7. Distribution of % particles <125um in sediments before and after the fishery in Dundalk Bay in 2009.

Benthic core data

The mean abundance of bivalves in control and impacted (fished) sites declined during the period September 2009 to March 2010 (Table 7). The level of decline was similar in control and impacted areas. Polychaetes were more abundant in control sites before the fishery and were more abundant in March 2010 than in September 2009 in these sites. In impacted sites polychaetes were similar in abundance in September 2009 and March 2010. Crustaceans were more abundant in control and impact sites in March 2010 than in 2009. Abundance of cockles (*Cerastoderma edule*) was similar in control and impacted sites before and after the fishery although abundance was lower in March 2010 than in Sept-Nov 2009. The bivalve, *Macoma balthica* was more common in control than impact sites before the fishery and this difference was maintained after the fishery in November 2009 and March 2010. *Angulus tenuis* was more common in impact sites than control sites before the fishery but was more common in control sites post fishery in November 2009. In March 2010 numbers of *A. tenuis* in impact sites were higher than in control sites.

Table 7. ***Mean±s.d. abundance of faunal groups and selected bivalves in core samples taken in control and impacted sites before (Sept 2009) and after (Nov 2009, Mar 2010) the cockle fishery.***

			N	Mean	S.d		N	Mean	S.d
			Bivalves				***Cerastoderma***		
Sep-09	Before	Control	107	7.12	6.26		107	1.10	1.95
Sep-09	Before	Impact	82	5.22	3.77		82	1.15	1.29
Nov-09	After	Control	90	4.84	3.69		90	0.87	1.19
Nov-09	After	Impact	81	3.40	2.52		81	1.31	1.52
Mar-10	After 2	Control	39	3.10	2.02		39	0.41	0.68
Mar-10	After 2	Impact	53	3.21	2.03		53	0.25	0.52
			Polychaetes				***Macoma***		
Sep-09	Before	Control	107	6.50	12.66		107	2.46	3.83
Sep-09	Before	Impact	82	3.30	4.00		82	0.34	0.71
Nov-09	After	Control	90	4.87	15.64		90	1.70	2.61
Nov-09	After	Impact	81	1.96	1.90		81	0.33	0.71
Mar-10	After 2	Control	39	9.33	26.75		39	2.31	2.05
Mar-10	After 2	Impact	53	2.94	2.37		53	0.49	0.85
			Crustaceans				***Angulus***		
Sep-09	Before	Control	107	0.32	0.59		107	2.51	3.50
Sep-09	Before	Impact	82	0.37	0.76		82	3.72	3.35
Nov-09	After	Control	90	0.27	1.04		90	2.06	2.83
Nov-09	After	Impact	81	0.23	0.55		81	1.72	2.14
Mar-10	After 2	Control	39	2.54	3.95		39	0.26	0.55
Mar-10	After 2	Impact	53	1.28	2.97		53	2.45	1.97

ANOVA of the benthic core data indicated significant BA effects in the case of bivalves, polychaetes and crustaceans (Table 8). The CI effect was significant only in the case of crustaceans and occurred in March 2010 when the number of crustaceans had increased in control sites but not in impact sites (Table 7). However, abundance of crustaceans in impact and control sites immediately after the fishery in November 2009 was similar. The CI effect was only marginally significant for cockles. The mean abundance of cockles was in fact slightly higher in impact stations after the fishery closed in November 2009. BACI, the BA*CI interaction term and Block effects were all significant in the case of *Angulus tenuis*. However, abundance was higher in impact stations in September 2009 and March 2010.

Table 8. ANOVA of BACI benthic core data and including a spatial grouping variable (Block) to isolate spatial from BACI effects in the analysis.

Source	df	SS	MS	F-ratio	P	SS	MS	F-ratio	P
Bivalves						***Cerastoderma edule***			
Before(B)-After(A)	2	5.33	2.67	6.72	0.0014	1.65	0.82	2.92	0.0549
Control-Impact(I)	1	0.01	0.01	0.03	0.8668	1.14	1.14	4.04	**0.0452**
BA*CI	2	0.19	0.09	0.24	0.7898	0.76	0.38	1.35	0.26
Block(Blk)	2	13.07	6.54	16.46	0.0001	0.02	0.01	0.03	0.9719
BA*Blk	2	0.21	0.11	0.27	0.7665	0.08	0.04	0.14	0.8731
CI*Blk	2	1.63	0.81	2.05	0.1301	3.53	1.77	6.27	**0.0021**
Error	395	156.83	0.40			111.24	0.28		
Total	406	203.77				127.82			
Polychaetes						***Macoma balthica***			
Before(B)-After(A)	2	6.81	3.41	8.46	0.0003	0.21	0.10	0.27	0.7614
Control-Impact(I)	1	0.64	0.64	1.60	0.2064	7.47	7.47	19.82	**0.0001**
BA*CI	2	4.57	2.29	5.68	0.0037	0.85	0.42	1.13	0.3252
Block(Blk)	2	8.49	4.24	10.55	0.0001	6.00	3.00	7.95	**0.0004**
BA*Blk	2	3.49	1.74	4.33	0.0138	0.99	0.50	1.32	0.2687
CI*Blk	2	0.89	0.45	1.11	0.3301	7.26	3.63	9.62	**0.0001**
Error	395	158.97	0.40			148.99	0.38		
Total	406	175.27				199.88			
Crustaceans						***Angulus tenuis***			
Before(B)-After(A)	2	8.27	4.13	18.85	0.0001	354.39	354.39	797.67	**0.0001**
Control-Impact(I)	1	1.67	1.67	7.62	0.006	5.51	2.75	6.20	**0.0022**
BA*CI	2	6.19	3.09	14.10	0.0001	11.60	11.60	26.10	**0.0001**
Block(Blk)	2	0.50	0.25	1.14	0.3204	7.47	3.73	8.40	**0.0003**
BA*Blk	2	0.44	0.22	1.01	0.3669	36.03	18.02	40.55	**0.0001**
CI*Blk	2	0.28	0.14	0.63	0.531	0.58	0.29	0.66	0.5186
Error	395	86.62	0.22			1.96	0.98	2.21	0.1109
Total	406	115.41				175.49	0.44		
						264.25			

Benthic quadrat data

The mean abundance of bivalves declined in control and fished areas during the sampling period (Table 9). CI effects for bivalves (all species) was not significant although the BA and block (spatial) effects were. CI effects were significant for individual bivalves *C. edulis* and *A. tenuis* but not for *M. balthica*. The abundance of polychaetes and crustaceans was lower after the fishery in both control and impact areas. Here the BA and block (spatial) factors were also significant but the CI effect was not. *A. tenuis* declined from 24 per sample, before the fishery, to 3 per sample after the fishery in the impact areas although there was very high variability between samples within treatments. *A. tenuis* also declined from 14 before to 10 per sample after the fishery in the control areas. In March 2010 *A. tenuis* densities in impact areas were higher than in November 2009 and were approximately 6 times higher in impact areas than in controls at this time. The abundance of *M. balthica* was higher in control areas than in impact areas before and after the fishery.

Table 9. ***Mean±s.d. abundance of faunal groups and selected bivalves in quadrat samples taken in control and impacted sites before (Sept 2009) and after (November 2009) the cockle fishery. March 2010 samples not included.***

			N	Mean	S.d		N	Mean	S.d
			Bivalves				***Cerastoderma***		
Sep-09	Before	Control	33	29.12	19.58		33	4.15	3.98
Sep-09	Before	Impact	34	34.97	30.67		34	7.32	6.62
Nov-09	After	Control	25	26.44	21.72		25	5.76	5.93
Nov-09	After	Impact	32	10.19	5.93		32	4.97	4.13
Mar-10	After 2	Control	13	16.23	6.61		13	1.46	1.94
Mar-10	After 2	Impact	18	10.17	4.64		18	0.94	1.35
			Polychaetes				***Macoma***		
Sep-09	Before	Control	33	3.55	6.07		33	11.55	15.02
Sep-09	Before	Impact	34	5.91	8.04		34	3.32	4.02
Nov-09	After	Control	25	1.60	1.89		25	11.00	9.90
Nov-09	After	Impact	32	2.31	2.79		32	2.09	2.52
Mar-10	After 2	Control	13	0.85	0.99		13	12.92	7.93
Mar-10	After 2	Impact	18	3.89	3.05		18	1.83	2.75
			Crustaceans				***Angulus***		
Sep-09	Before	Control	33	0.39	0.61		33	12.18	17.87
Sep-09	Before	Impact	34	0.85	1.21		34	24.18	26.37
Nov-09	After	Control	25	0.40	1.22		25	8.80	21.21
Nov-09	After	Impact	32	0.44	1.08		32	3.13	4.09
Mar-10	After 2	Control	13	0.08	0.28		13	1.77	2.77
Mar-10	After 2	Impact	18	0.17	0.38		18	7.39	4.15

Table 10 ANOVA of BACI benthic quadrat data and including a spatial grouping variable (Block) to isolate spatial from BACI effects in the analysis.

Source	df	SS	MS	F-ratio	P	SS	MS	F-ratio	P
Bivalves						***Cerastoderma edule***			
Before(B)-After(A)	2	13.07	6.54	18.51	**0.0001**	5.33	2.66	5.52	**0.005**
Control-Impact(I)	1	0.50	0.50	1.43	0.2341	6.86	6.86	14.20	**0.0003**
BA*CI	2	2.48	1.24	3.51	0.0328	0.15	0.07	0.15	0.8589
Block(Blk)	2	16.35	8.18	23.16	**0.0001**	0.15	0.08	0.16	0.8533
BA*Blk	2	7.06	3.53	10.00	**0.0001**	2.08	1.04	2.16	0.1198
CI*Blk	2	10.88	5.44	15.40	**0.0001**	13.21	6.61	13.68	**0.0001**
Error	127	44.84	0.35			61.30	0.48		
Total	138	101.35				107.13			
Polychaetes						***Macoma balthica***			
Before(B)-After(A)	2	5.73	2.86	5.09	**0.0075**	0.67	0.33	0.41	0.6672
Control-Impact(I)	1	1.14	1.14	2.02	0.1581	1.73	1.73	2.11	0.1491
BA*CI	2	0.85	0.43	0.76	0.4721	1.86	0.93	1.13	0.3261
Block(Blk)	2	8.00	4.00	7.10	**0.0012**	11.22	5.61	6.82	**0.0015**
BA*Blk	2	1.34	0.67	1.19	0.3069	0.39	0.19	0.23	0.7915
CI*Blk	2	2.93	1.46	2.60	0.0782	25.43	12.72	15.45	**0.0001**
Error	127	71.52	0.56			104.54	0.82		
Total	138	104.68				178.58			
Crustaceans						***Angulus tenuis***			
Before(B)-After(A)	2	2.35	1.17	6.89	**0.0014**	414.31	414.31	459.34	**0.0001**
Control-Impact(I)	1	0.32	0.32	1.89	0.1713	39.39	19.70	21.84	**0.0001**
BA*CI	2	0.01	0.00	0.02	0.9821	14.17	14.17	15.72	**0.0001**
Block(Blk)	2	0.90	0.45	2.63	0.0762	6.31	3.15	3.50	**0.0333**
BA*Blk	2	0.67	0.34	1.97	0.1434	56.35	28.17	31.24	**0.0001**
CI*Blk	2	0.25	0.13	0.74	0.4792	15.89	7.94	8.81	**0.0003**
Error	127	21.64	0.17			0.68	0.34	0.38	0.6871
Total	138	25.52				114.55	0.90		
						231.54			

Univariate summary statistics and ANOVA in relation to CI effects: March 2010 transects

The number of bivalves per core sample was higher at impact stations than at control stations in upper, middle and lower shore samples. Polychaetes were more common in the control samples and the number of crustaceans per sample showed no consistent pattern across control and impact transects at different shore levels (Table 11).

Table 11. Summary statistics for the abundance of bivalves, polychaetes and crustaceans in core samples on upper, middle and lower shore control and impact transects in Dundalk Bay in March 2010.

	Upper			Middle			Lower		
	N	**Mean**	**S.d.**	**N**	**Mean**	**S.d.**	**N**	**Mean**	**S.d.**
Bivalves									
Control	15	6.5	2.1	15	7.0	1.5	15.0	4.1	3.0
Impact	15	7.8	2.9	14	9.4	3.5	13.0	5.9	2.8
Polychaetes									
Control	15	1.8	1.1	15	4.1	1.8	15.0	7.5	4.0
Impact	15	1.5	1.6	14	3.5	1.9	13.0	3.6	2.6
Crustaceans									
Control	15	0.1	0.3	15	0.6	0.7	15.0	0.1	0.3
Impact	15	0.3	1.0	14	0.3	0.6	13.0	0.2	0.4

ANOVA of mean abundance of bivalves and polychaetes indicated significant CI and Shore level effects. However, as the summary statistics show (Table 11) the abundance pattern was contrary to that expected from a fishing impact and suggests spatial variation independent of fishing. ANOVA of the crustacean data indicated no shore level or CI effects.

Distribution and abundance of characterising bivalves in May 2011.

As part of the annual cockle survey in May 2011 the distribution and abundance of 3 characterising species of bivalve, *A. tenuis, M. balthica* and *C. edule*, in the intertidal area of Dundalk Bay was mapped. The May 2011 survey was approximately 18 months after the closure of the fishery in November 2009.

The distribution of the 3 species in May 2011 shows a vertical zonation in distribution. *M. balthica* occurs in finer sediments in the upper shore, *C. edule* and *A. tenuis* are common in the mid shore and *A. tenuis* also extends to the lower intertidal area. The distribution patterns do not indicate any evidence of disturbance from previous fishing events i.e. they are not absent or in lower abundance in areas where fishing was concentrated in 2009 (Figure 8).

Table 12. ANOVA for Control-Impact and Shore level effects on abundance of Bivalves, polychaetes and crustaceans in Dundalk Bay in March 2010.

Source	df	SS	MS	F-ratio	Prob
Bivalves					
Control(C)_Impact(I)	1	1.52	1.52	8.28	**0.0051**
Shore level	2	4.57	2.28	12.41	**0.0001**
CI*Shore level	2	0.26	0.13	0.72	0.4903
Error	81	14.91	0.18		
Total	86	21.47			
Polychaetes					
Control(C)_Impact(I)	1	2.40	2.40	8.92	**0.0037**
Shore level	2	11.83	5.91	22.02	**0.0001**
CI*Shore level	2	1.03	0.52	1.93	0.1523
Error	81	21.75	0.27		
Total	86	37.45			
Crustaceans					
Control(C)_Impact(I)	1	0.01	0.01	0.11	0.7432
Shore level	2	0.60	0.30	2.63	0.0781
CI*Shore level	2	0.37	0.18	1.62	0.2048
Error	81	9.21	0.11		
Total	86	10.23			

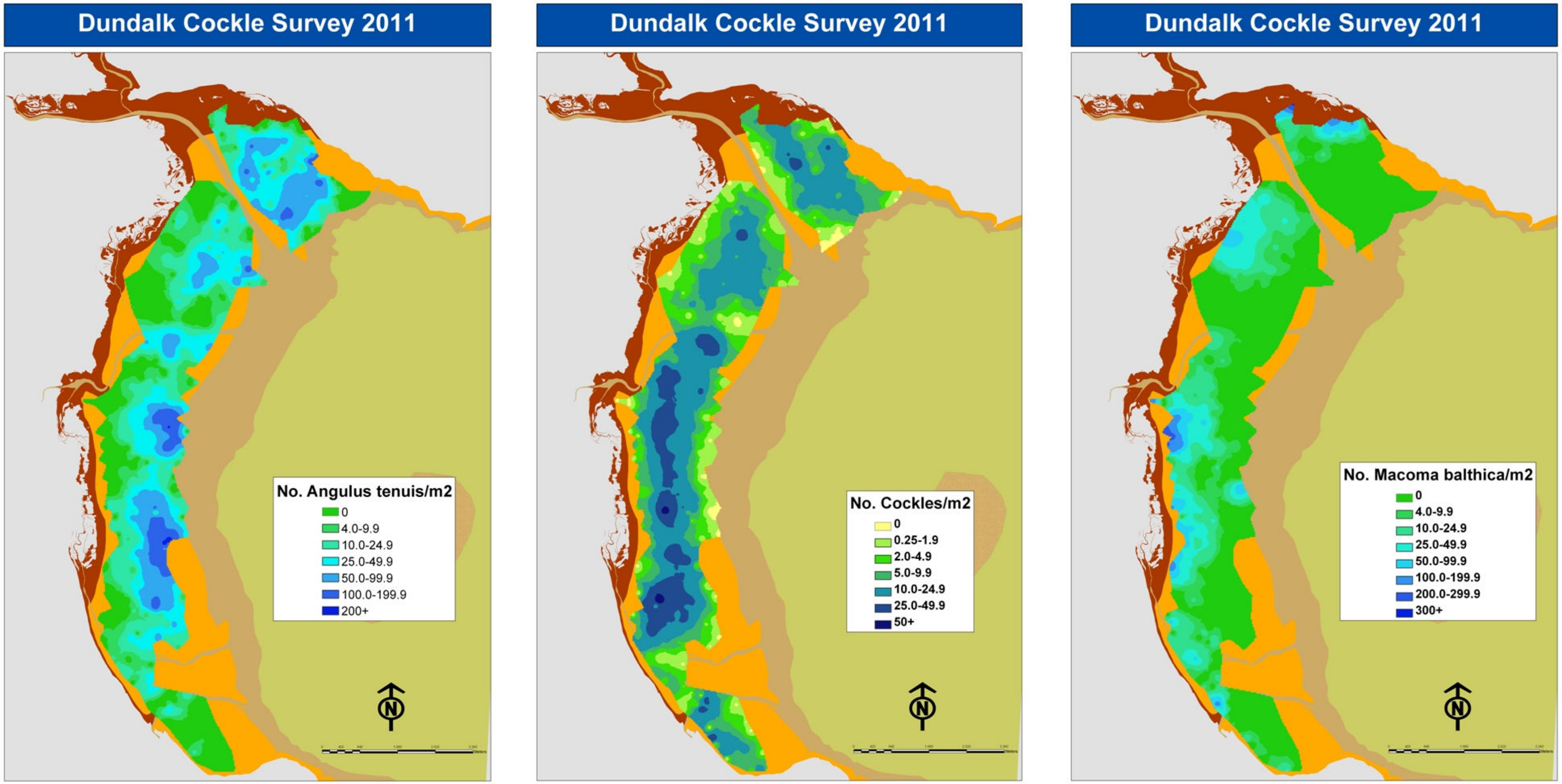

Figure 8. Distribution and density of *Angulus tenuis*, *Cerastoderma edule* (Cockle) and *Macoma balthica* in the intertidal area of Dundalk Bay, in May 2011.

Multivariate statistical assessment of effects on benthic communities

Benthic quadrat data

The SIMPROF (similarity profile) permutation tests carried out in conjunction with the hierarchial agglomerative clustering determined three significantly different site clusters (Figure 9). The smallest cluster consists of only 5 samples (two from control and three from impact sites). The two control samples are from the southern sampling area collected in September 2009, while all three impact samples are from the northern sampling area (1 from September and 2 from November 2009). The second cluster comprises of 26 control samples and 1 impact sample. The control sites are from both the northern and southern sampling areas and include samples from all three time periods. Group 3 is made up of 120 samples, 51 control and 69 impact. There are samples from all three time periods represented within this group.

SIMPER analysis on the three clusters determined the main contributing species to the similarity within each group. The polychaete *Owenia fusiformis* was the dominant contributor (80%) within Group 1. In Group 2, the bivalve *Macoma balthica* contributed 73% to the within group similarity, with *Cerastoderma edule* comprising a further 17%. Bivalves were also the main contributing species to the similarity within Group 3, *A. tenuis* (40%), *C. edule* (29%) and *M. balthica* (19%). The main contributor to the dissimilarity between Group 2 and the other two groups was *M. balthica*, which was recorded in higher abundances in Group 2 stations. The stations within Group 2 were located along the upper shore. Both *A. tenuis* and *C. edule* were the key species responsible for the dissimilarities between Group 1 and Group3. Group 3 was made up of stations along the lower intertidal area, which had higher abundances of *A. tenuis*, while Group 1 had higher abundances of *C. edule* and included stations predominantly found in the mid shore.

The R values from the two-way ANOSIM analysis on the quadrat data indicate a divergence in the community structure for CI, 'location' and to a lesser extent the BA (Table 13). Further one-way ANOSIM analysis was conducted to determine which of the three factors had the greatest influence on the diverging benthic community structure and the results are shown in Table 14. A significant difference in the faunal communities between the northern control and impact sites was found for all three sampling periods, with R-values increasing over time i.e. they were different in September 2009 before the fishery and this divergence increased until March 2010.

Comparing communities of the northern impact sites alone, over time, revealed an effect of BA (Table 15). A higher R-value was determined between November 2009 and March 2010 than between September 2009 and November 2009. Increasing R-values over time, were also indicated in comparison of the control site community structure, however these values were lower overall. No significant difference was found between the control and impact communities of the southern sites sampled in September 2009. A slightly elevated R-value was determined when comparing the impact and control sites for November 2009 (Table 14), however it is still very close to zero, suggesting little divergence between the impact and control communities over time.

Southern impact sites were significantly different in September (Before fishery) and November (After fishery) 2009 returning an R-value =0.63 (p=0.01%) (Table 15). The corresponding control sites were not divergent (R=0.096).

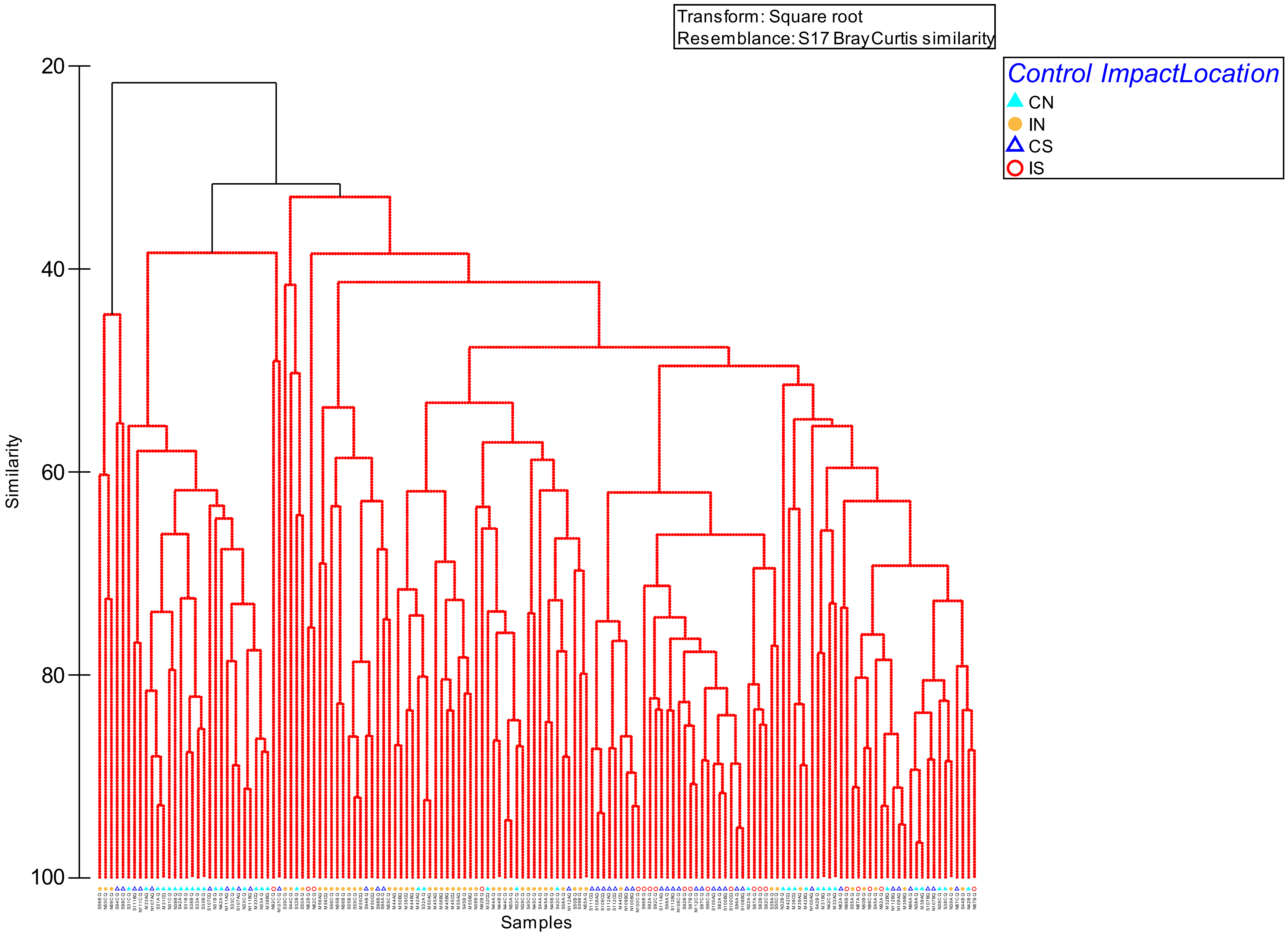

Figure 9 Dendrogram of hierarchial agglomerative clustering output to classify macrobenthic quadrat data from Dundalk Bay. A SIMPROF significance test has been used to assess the clusters indicating three significant groups joined by black lines.

Table 13. Matrix of Global R statistics from two-way ANOSIM analysis for both quadrat and core samples collected over three time periods, at control and impact sites in northern and southern sampling areas (Type of site = Control or Impact; Location = North or South; Time period = September 2009, November 2009 or March 2010). Global R-values close to 0 indicate no difference and close to 1 indicate significant differences.

		Time period_Location	Time period_Type of site	Location_Type of site
Quadrat	Type of site	0.261 (p=0.01%)		
	Location		0.217 (p=0.01%)	
	Time period			0.188 (p=0.01%)
Core	Type of site	0.316 (p=0.01%)		
	Location		0.276 (p=0.01%)	
	Time period			0.143 (p=0.01%)

Table 14. Matrix of Global R statistics from one-way ANOSIM analysis for quadrat and core samples collected in September 2009, November 2009 and March 2010 (N=North, S=South; C=Control, I=Impact).

		Sep_NC	Nov_NC	Mar_NC	Sep_SC	Nov_SC
Quadrat	Sep_NI	0.346 (p=0.02%)				
	Nov_NI		0.438 (p=0.01%)			
	Mar_NI			0.671 (p=0.01%)		
	Sep_SI				-0.098 (p=85.6%)	
	Nov_SI					0.085 (p=13.1%)
Core	Sep_NI	0.653 (p=0.01%)				
	Nov_NI		0.593 (p=0.01%)			
	Mar_NI			0.646 (p=0.01%)		
	Sep_SI				-0.165 (p=99.5%)	
	Nov_SI					0.01 (p=36.4%)

Table 15. Matrix of Global R statistics from one-way ANOSIM analysis for quadrat and core samples collected in September 2009, November 2009 and March 2010, at control and impact sites in northern and southern sampling areas (N=North, S=South; C=Control, I=Impact).

		Nov_NI	Mar_NI	Nov_SI
Quadrat	Sep_NI	0.117 (p=0.5)	0.218 (p=0.02)	
	Nov_NI		0.324 (p=0.01)	
	Sep_SI			0.63 (p=0.01%)
Core	Sep_NI	0.238 (p=0.03%)	0.28 (p=0.28%)	
	Nov_NI		0.317 (p=0.01%)	
	Sep_SI			0.196 (p=0.6%)
		Nov_NC	**Mar_NC**	**Nov_SC**
Quadrat	Sep_NC	0.088 (p=4.4%)	0.177 (p=0.6%)	
	Nov_NC		0.11 (p=4%)	
	Sep_SC			0.096 (3.2%)
Core	Sep_NC	-0.028 (p=69.7%)	0.124 (p=2.5%)	
	Nov_NC		0.108 (p=4.4%)	
	Sep_SC			-0.015 (p=56.4%)

SIMPER analysis conducted on the quadrat data, to determine the species responsible for the dissimilarities between the northern control and impact sites, found the tellin bivalve *M. balthica* to be the main contributing species (29.34%) (Table 16). *Angulus tenuis* also contributed (17.64%), along with, the polychaete, *Owenia fusiformis* (13.67%) and *C. edule* (12.31)%. Higher abundances of *M. balthica* were recorded within the control sites, while higher abundances of *A. tenuis* were recorded from the impact sites. These differences are probably due to spatial zonation of these species on the sand flat.

Table 16. Results of SIMPER analysis on quadrat data for between group dissimilarities for control and impact sites from both northern and southern sampling areas

Northern Sites	Average dissimilarity = 63.73					
Species	**Av.Abund C**	**Av.Abund I**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Macoma balthica	3.52	0.96	18.7	1.65	29.34	29.34
Angulus tenuis	0.78	2.01	11.24	1.37	17.64	46.98
Owenia fusiformis	0.26	1.37	8.71	1.22	13.67	60.66
Cerastoderma edule	1.64	1.54	7.85	1.17	12.31	72.97
Nepthys hombergii	0.19	0.81	5.02	1	7.88	80.85
Pygospio elegans	0.64	0.21	4.33	0.7	6.79	87.64
Crangon crangon	0.2	0.25	1.63	0.57	2.55	90.19
Southern Sites	Average dissimilarity = 46.28					
Species	**Av.Abund C**	**Av.Abund I**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	3.72	3.96	13.58	1.26	29.34	29.34
Macoma balthica	2.01	1.41	9.6	1.07	20.75	50.09
Cerastoderma edule	1.81	2.8	8.06	1.22	17.42	67.51
Nepthys hombergii	0.62	0.78	3.78	1.06	8.18	75.68
Owenia fusiformis	0.3	0.42	2.66	0.8	5.75	81.43
Crangon crangon	0.18	0.42	2.29	0.93	4.95	86.39
Mya arenaria	0.4	0	2.16	0.41	4.68	91.07

The bivalve species, *M. balthica* (66.43%) and *C. edule* (21.18%) were the main contributing species to the northern control within-group community similarities (Table 17). While *A. tenuis* (40.51%), *C. edule* (22.27%) and *O. fusiformis* (16.63%), were the three main contributors to the within-group similarities of the northern impact site communities (Table 17).

Table 17. Results of SIMPER analysis on quadrat data for within group similarities for northern and southern Control and Impact sites

Northern Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Control	Average similarity: 55.28				
Macoma balthica	3.52	36.72	2.24	66.43	66.43
Cerastoderma edule	1.64	11.71	1.03	21.18	87.61
Angulus tenuis	0.78	2.72	0.36	4.91	92.52
Impact	Average similarity: 53.48				
Angulus tenuis	2.01	21.66	1.44	40.51	40.51
Cerastoderma edule	1.54	11.91	1.04	22.27	62.78
Owenia fusiformis	1.37	8.89	0.79	16.63	79.41
Macoma balthica	0.96	5.43	0.7	10.15	89.56
Nepthys hombergii	0.81	4.53	0.61	8.47	98.03
Southern Sites					
Control	Average similarity: 48.91				
Angulus tenuis	3.72	23.51	1.16	48.06	48.06
Cerastoderma edule	1.81	12.28	1.31	25.1	73.16
Macoma balthica	2.01	9.56	0.81	19.55	92.71
Impact	Average similarity: 62.42				
Cerastoderma edule	2.8	24.96	1.85	39.99	39.99
Angulus tenuis	3.96	23.09	1.47	37	76.98
Macoma balthica	1.41	8.27	0.88	13.25	90.23

Angulus tenuis and *C. edule,* were the two key species contributing to more than 60% of the within group similarities for the northern impact sites in both September and November 2009, although they reversed in order (Table 18). *Angulus tenuis* (56.82) was the main contributor in March 2010, it declined in abundance from September to November 2009 but increased again by March 2010.

Table 18. Results of SIMPER analysis on quadrat data for within group similarities for northern Impact and Control sites determined from data collected in September 2009, November 2009 and March 2010

Northern Impact Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 44.92				
Angulus tenuis	2.14	15.82	1.2	35.21	35.21
Cerastoderma edule	1.96	12.97	1.56	28.87	64.08
Nepthys hombergii	1.21	6.88	0.92	15.31	79.4
Macoma balthica	0.98	3.6	0.59	8	87.4
Owenia fusiformis	1.34	3.34	0.43	7.43	94.83
November 2009	Average similarity: 55.35				
Cerastoderma edule	2.02	19.91	1.6	35.98	35.98
Angulus tenuis	1.24	14.01	1.48	25.31	61.29
Owenia fusiformis	1.3	11.71	1.06	21.16	82.45
Nepthys hombergii	0.78	4.76	0.56	8.59	91.04
March 2010	Average similarity: 60.39				
Angulus tenuis	2.61	34.31	2.73	56.82	56.82
Owenia fusiformis	1.45	11.95	0.97	19.78	76.6
Macoma balthica	1.05	8.2	0.96	13.58	90.18
Northern Control Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 52.68				
Macoma balthica	3.91	30.08	1.75	57.1	57.1
Cerastoderma edule	1.88	12.64	1.43	24	81.1
Pygospio elegans	1.27	4.66	0.59	8.84	89.94
Crangon crangon	0.6	2.61	0.6	4.95	94.89
November 2009	Average similarity: 55.39				
Macoma balthica	3.13	30.79	2.17	55.59	55.59
Cerastoderma edule	2.17	19.01	1.88	34.31	89.9
Angulus tenuis	0.89	3.53	0.46	6.37	96.27
March 2010	Average similarity: 58.39				
Macoma balthica	3.45	47.72	3.97	81.72	81.72
Cerastoderma edule	0.84	5.63	0.56	9.63	91.36

Table 19 shows that the same three bivalve species contribute over 90% to the within group similarity for both the control and impact communities of the southern sites, in differing orders. *Angulus tenuis* is the main contributor (48.06%) to the control sites while *C. edule* is the key contributor (39.99) in the impact sites. In September 2009 *A. tenuis* (48.85%) was the chief contributor to the within group similarity of the southern impact sites, with *C. edule* being responsible for a further 26.04% (Table 19) In November 2009, the reverse was determined, with *C. edule* being the main contributing species (59.35%) while *A. tenuis* only contributed 20.54%. This shift in key contributing speices resulted from a decline in the abundances of *A. tenuis* from September 2009 to November 2009. The polychaete worm, *Nephthys hombergii*, was the third contributor (9.8%) in September, however no polychaetes were listed as contributing species in November (Table 19). A similar change to the main contributing bivalve species occurred within the southern control sites.

Table 19. Results of SIMPER analysis on quadrat data for within group similarities for southern Impact and Control sites determined from data collected in September 2009 and November 2009

Southern Impact Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 72.56				
Angulus tenuis	6.52	35.45	5.44	48.85	48.85
Cerastoderma edule	3.41	18.89	2.67	26.04	74.89
Nepthys hombergii	1.46	7.11	1.59	9.8	84.69
Macoma balthica	1.69	6.03	1.18	8.31	93
November 2009	Average similarity: 52.28				
Cerastoderma edule	2.18	31.02	1.99	59.35	59.35
Angulus tenuis	1.39	10.74	0.89	20.54	79.89
Macoma balthica	1.13	10.51	0.88	20.11	100
Southern Control Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 47.55				
Angulus tenuis	4.5	28.31	1.32	59.53	59.53
Cerastoderma edule	1.76	9.58	0.98	20.14	79.67
Macoma balthica	1.73	5.42	0.61	11.4	91.06
November 2009	Average similarity: 51.44				
Cerastoderma edule	1.88	17.3	2.95	33.63	33.63
Macoma balthica	2.38	17.27	1.37	33.58	67.21
Angulus tenuis	2.66	14.58	1.03	28.34	95.55

Benthic core data

September – November 2009

Fourteen significantly different groups were determined from the hierarchial agglomerative cluster analysis on the core data (Figure 10). Details of the groups/clusters are summarised inTable 20. Group 1 consists of two samples from control sites collected in September 2009, both containing *Scoloplos armiger*. Group 2 includes only one sample from a northern impact site collected in November 2009. The faunal assemblage at this site consisted predominantly of the cockle *Cerastoderma edule*. *Bathyporeia guilliamsoniana* was the main contributing species to the similarity within Group 3, while the polychaetes *P. elegans* and *Scoloplos armiger* were the two main contributors within Group 4. Group 5 contains 21 control sites from both the northern and southern sampling areas over all three sampling times. The seventh group consists of 11 sites, 6 impacts and 5 controls, all from the northern sampling area over the three surveys. Group 8 is a mixture of control (10) and impact (3) sites surveyed in September and November 2009 of which several species contribute to the similarity within the group. *Nephthys hombergii* (47.4%) and *A. tenuis* (31.7%) combined contribute 79% to the similarity within Group 9. Group 10 is dominated by *C. edule*. Group 11 consits of two sites sampled prior to the fishery, while Group 12 contains four sites (one impact and three controls). The largest cluster, Group 13, includes 38 impact sites and 23 controls, the majority from the southern sampling area. Group 14 is made up of nine impact sites sampled in March 2010. Again the bivalve *A. tenuis* is predominant (37.1%

contribution to within group similarity) within the group, as are *N. hombergii* (23.9%) and *B. guilliamsoniana* (14.9%).

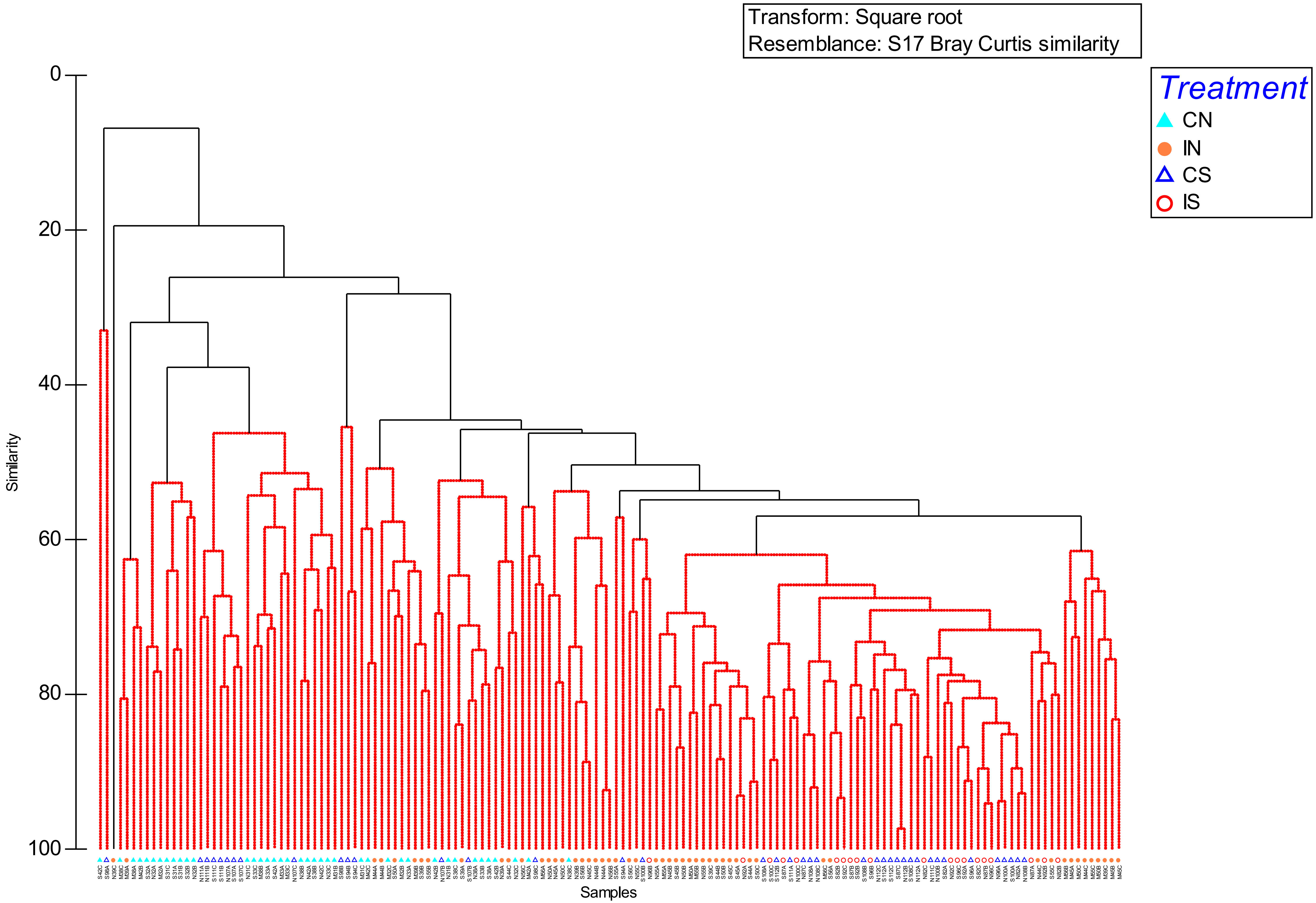

Figure 10. Dendrogram of hierarchial agglomerative clustering output to classify macrobenthic core data from Dundalk Bay. A SIMPROF significance test has been used to assess the clusters indicating fourteen significant groups joined by black lines.

Table 20. Summary of clusters determined from the hierarchial agglomerative clustering analysis carried out on the core macrofaunal data from Dundalk Bay (2009-2010).

Group/Cluster	No. of Sites	Control North	Impact North	Control South	Impact South	Main contributing species to within group similarity
1	2	S42C		S98A		*Scoloplos armiger* (100%)
2	1		N39C			Cerastoderma edule (Less than two samples in group)
3	4	M38C, M38A, M42B	M39A			*Bathyporeia guilliamsoniana* (50.8%)
4	8	S32A, N32A, M32A, S31C, S31A, S31B, S32B, N32B				*Pygospio elegans* (49.1%), *Scoloplos armiger* (17.6%)
5	21	N31C, S33C, M38B, S33A, S42A, M33A, M33C, N38B, N42C, S38B, N42C, N33C, M31B		N111A, N111B, S111C, S111B N107A, S107A, S107C, N107C		*Macoma balthica* (35.2%), *Pygospio elegans* (25.2%), *Hydrobia ulvae* (19.4%)
6	3			S98B, S94B, S94C		*Donax vittatus* (50.1%)
7	11	M31C, M42C, M32C, M32B N33A, N42B	M44A, M44B, S50A, M39B, S39B, S55B			*Pygospio elegans* (33.8%), *Angulus tenuis* (20.9%), *Macoma balthica* (16.9%)
8	13	N42B, N31B, S38C, N38A, S33B, S38A, S42B, N32C	S39A, N39A, S44C	N107B, S107B		Macoma balthica (25.4%)
9	4	M42A	N56C, M56A	S98C		Nephthys hombergii (47.4%), Angulus tenuis (31.7%)
10	10	N38C	N50A, N45A, N50C, N39B, S56B, N45C, N44B, N44A, N56B			*Cerastoderma edule* (43.73%)
11	2		S55A	S94A		*Angulus tenuis* (60.9%)
12	4		S56C, N55C	S100B	N96B	*Angulus tenuis* (38.04%), *Nephthys hombergii* (26.35%)
13	61		N55A, M55A, N45B, S45B, N50B, M50A, M55B, N55B, S39C, S44B, S50B, S45C, S45A, S44A, S50C, M56C, S56A, N44C, S55C	S108A, S112B, S111A, N87C, N108A, N108C, S108B, N112C, S112A, S112C, S87C, N112B, S108C, N112A, N111C, N100B, S82A, S96A, N96A, N100A, S100A, N82A, N108B	N92A, S100C, S87A, N100C, S82B, S92C, S87B, S92B, S96B, N82C, N92C, S96C, S92A, S82C, N87B, N96C, N87A, N92B, N82B	*Angulus tenuis* (41.9%), *Nephthys hombergii* (27.4%), *Cerastoderma edule* (19%)
14	9		M56B, M45A, M50C, M44C, M55C, M50B, M39C, M45B, M45C			*Angulus tenuis* (37.1%), *Nephthys hombergii* (23.9%), *Bathyporeia. guilliamsoniana* (14.9%).

Similar to the quadrat data the majority of the core sample clusters have grouped together in relation to their location along the shore.

Analysis of similarities of the core data also indicated diverging communities due mainly (highest R-values) to control-impact (fishery) and north-south (location). Community divergence was significant for all 3 sampling periods in the northern area (including pre-fishery September 2009 data)

ANOSIM analysis of the core data also indicated diverging communities, with the factors, CI and 'location' returning the highest R values (Table 13). One-way analysis on the northern and southern sampling areas was carried out separately for the CI and BA and the results are shown in Table 14. A divergence in community structure was determined between the control and impact sites for all three sampling periods in the northern sampling area. R values were fairly consistent over time. No significant differences were found between control and impact sites within the southern sampling area.

Comparing the core data from impact sites alone, resulted in increasing R-values between sampling periods (Table 15). However increases in R-values were also determined when comparing the northern control site communities over time.

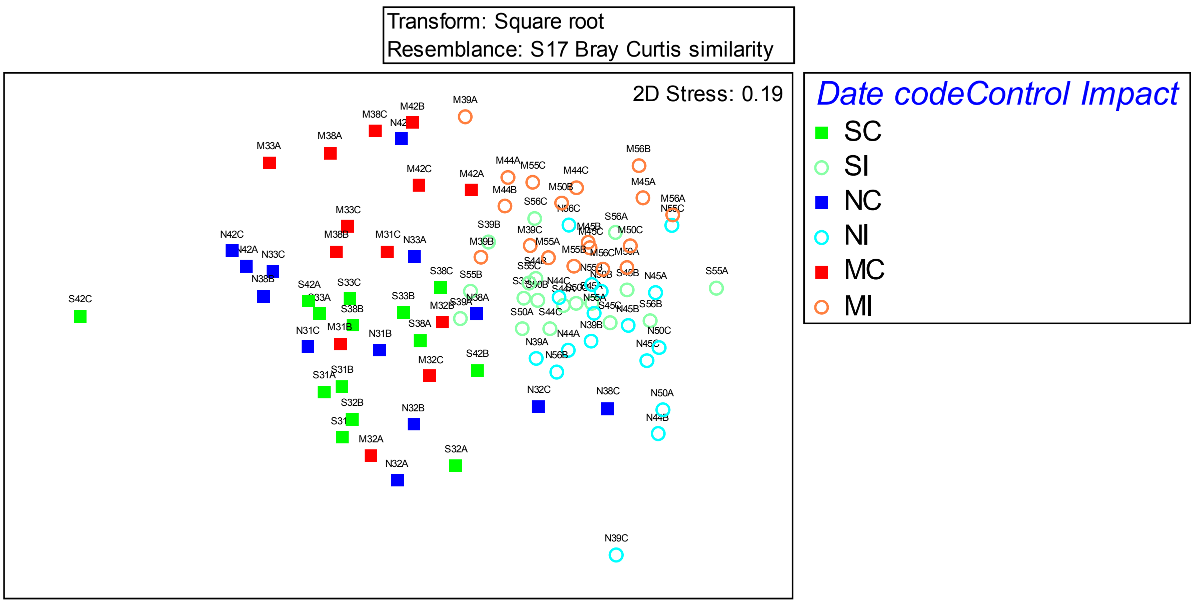

Figure 2. MDS ordination plot of northern Control (C) and Impact (I) sites for all three time periods (S=September 2009, N=November 2009 and M=March 2010)

The 2-d MDS configuration (Figure 11) of the northern core samples shows a clear separation of the community assemblages in control and impact sites but the September impacts (before the fishery) are grouped with November impacts.

Further SIMPER analysis on the core data found that, the polychaete worm, *Pygospio elegans* was the main contributing species (17.74%) to the dissimilarity between northern control and impact communities along with the bivalves, *A. tenuis* and *M. balthica* (Table 21). *Angulus tenuis* was the main contributing species (16.41%) to the community differences between control and impact sites in the southern sampling areas. In both sampling areas, north and south, average abundances of *A. tenuis* were higher in the impact sites than in the control.

Table 21. Results of SIMPER analysis on core data for between group dissimilarities for control and impact sites from both northern and southern sampling areas

Northern Sites	Average dissimilarity = 68.65					
Species	**Av.Abund C**	**Av.Abund I**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Pygospio elegans	2.05	0.57	12.18	1.19	17.74	17.74
Angulus tenuis	0.31	1.32	8.24	1.68	12	29.75
Macoma balthica	1.3	0.38	8.15	1.48	11.88	41.62
Scoloplos armiger	0.76	0.09	5.65	1.07	8.23	49.86
Nephthys hombergii	0.45	0.98	5.34	1.4	7.77	57.63
Owenia fusiformis	0.17	0.75	5.27	1.22	7.67	65.3
Cerastoderma edule	0.67	0.79	5.18	1.17	7.54	72.84
Bathyporeia guilliamsoniana	0.41	0.33	4.55	0.73	6.63	79.47
Hydrobia ulvae	0.52	0	4.3	0.82	6.26	85.73
Gammarus locusta	0.12	0.07	1.47	0.58	2.14	87.88
Crangon crangon	0.1	0.13	1.45	0.59	2.11	89.99
Phyllodoce mucosa	0.13	0.08	1.28	0.59	1.86	91.86
Southern Sites	Average dissimilarity = 46.31					
Species	**Av.Abund C**	**Av.Abund I**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	1.65	2.09	7.6	1.31	16.41	16.41
Macoma balthica	0.93	0.59	6.46	1.3	13.96	30.37
Hydrobia ulvae	0.95	0.06	5.56	0.66	12	42.37
Cerastoderma edule	0.77	0.95	5.22	1.25	11.28	53.64
Nephthys hombergii	1.03	1.23	3.79	1	8.19	61.83
Crangon crangon	0.22	0.38	3.19	1.01	6.88	68.71
Pygospio elegans	0.38	0.09	2.59	0.68	5.59	74.3
Scoloplos armiger	0.29	0.08	2.29	0.76	4.93	79.24
Owenia fusiformis	0.12	0.16	1.84	0.66	3.98	83.22
Mya arenaria	0.27	0	1.5	0.46	3.24	86.46
Donax vittatus	0.16	0	1.33	0.28	2.88	89.34
Bathyporeia guilliamsoniana	0.04	0.06	0.71	0.43	1.53	90.87

Macoma balthica along with *P. elegans* were the top two key contributors to the similarity within the northern control sites. *Angulus tenuis* and *N. hombergii* were the main contributing species in the northern impact sites (Table 22). The top main contributing species were the same for both the control and impact sites in the southern sampling area.

Table 22. Results of SIMPER analysis on the core data for within group similarities of control and impact sites in both the northern and southern sampling areas

Northern Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Control	Average similarity: 42.65				
Macoma balthica	1.3	12.25	1.5	28.73	28.73
Pygospio elegans	2.05	11.92	1.2	27.95	56.68
Cerastoderma edule	0.67	4.39	0.78	10.29	66.97
Scoloplos armiger	0.76	4.37	0.72	10.24	77.22
Hydrobia ulvae	0.52	2.86	0.52	6.69	83.91
Nephthys hombergii	0.45	2.62	0.62	6.14	90.05
Impact	Average similarity: 54.86				
Angulus tenuis	1.32	17.91	2.28	32.65	32.65
Nephthys hombergii	0.98	13.04	1.96	23.78	56.43
Cerastoderma edule	0.79	8.94	1.02	16.29	72.72
Owenia fusiformis	0.75	7.22	1.03	13.17	85.89
Pygospio elegans	0.57	3	0.52	5.47	91.35
Southern Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Control	Average similarity: 44.32				
Angulus tenuis	1.65	17.96	1.16	40.53	40.53
Nephthys hombergii	1.03	11.41	1.26	25.75	66.28
Cerastoderma edule	0.77	6	0.96	13.54	79.82
Macoma balthica	0.93	3.98	0.62	8.98	88.8
Hydrobia ulvae	0.95	1.78	0.35	4.01	92.81
Impact	Average similarity: 68.94				
Angulus tenuis	2.09	29.33	4.17	42.54	42.54
Nephthys hombergii	1.23	18.63	5.06	27.03	69.57
Cerastoderma edule	0.95	11.82	1.41	17.15	86.71
Macoma balthica	0.59	5.66	0.89	8.22	94.93

Declines in average abundances of certain contributing species were recorded over the three time periods. *Pygospio elegans*, and *A. tenuis*, the top two species contributing to the dissimilarity between northern impact sites between September and November 2009, both declined in average abundances (Table 23). Conversely, between November 2009 and March 2010 the average abundances of both species increased. The increasing abundances of the crustacean *Bathyporeia guilliamsoniana*, resulted in it being the third main contributing species (11.79%) to community dissimilarities within the northern impact sites, from September 2009 to March 2010. Between September 2009 and March 2010 average abundances of *P. elegans* and *C. edule* declined, however abundances of *B. guilliamsoniana*, *O. fusiformis* and *M. balthica* increased over the same period. Average abundances of *A. tenuis* were the same having decreased in November 2009.

Table 23. Results of SIMPER analysis on core data for between group dissimilarities for impact sites from both northern and southern sampling areas

Northern Impact Sites						
September & November 2009		Average dissimilarity = 47.10				
Species	**Av.Abund S**	**Av. Abund N**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Pygospio elegans	1.07	0.17	9.01	1.23	19.13	19.13
Angulus tenuis	1.52	0.88	7.33	1.21	15.56	34.69
Owenia fusiformis	0.67	0.75	6.15	1.28	13.05	47.74
Nephthys hombergii	1.2	0.75	5.71	1.27	12.12	59.86
Cerastoderma edule	0.92	1.14	5.42	1.23	11.52	71.37
Macoma balthica	0.35	0.26	3.64	1.01	7.73	79.11
Crangon crangon	0.32	0.07	2.83	0.9	6.01	85.11
Bathyporeia guilliamsoniana	0.1	0.19	2.17	0.71	4.61	89.73
Scoloplos armiger	0.09	0.05	1.29	0.43	2.75	92.47
September 2009 & March 2010		Average dissimilarity = 44.19				
Species	**Av.Abund S**	**Av. Abund M**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Pygospio elegans	1.07	0.45	7.49	1.22	16.96	16.96
Cerastoderma edule	0.92	0.34	5.56	1.36	12.59	29.55
Bathyporeia guilliamsoniana	0.1	0.71	5.21	0.98	11.79	41.33
Owenia fusiformis	0.67	0.82	4.81	1.2	10.87	52.21
Angulus tenuis	1.52	1.52	4.11	1.24	9.31	61.52
Macoma balthica	0.35	0.53	4.09	1.16	9.25	70.76
Nephthys hombergii	1.2	0.98	3.92	1.24	8.87	79.63
Crangon crangon	0.32	0	2.42	0.85	5.47	85.1
Scoloplos armiger	0.09	0.13	1.59	0.47	3.59	88.7
Gammarus locusta	0	0.19	1.59	0.6	3.59	92.29
November 2009 & March 2010		Average dissimilarity = 50.84				
Species	**Av.Abund N**	**Av. Abund M**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Cerastoderma edule	1.14	0.34	8.55	1.45	16.83	16.83
Angulus tenuis	0.88	1.52	7.28	1.29	14.33	31.16
Owenia fusiformis	0.75	0.82	6.53	1.41	12.84	44
Bathyporeia guilliamsoniana	0.19	0.71	5.87	0.98	11.54	55.54
Macoma balthica	0.26	0.53	4.74	1.15	9.32	64.86
Nephthys hombergii	0.75	0.98	4.45	1.1	8.76	73.62
Pygospio elegans	0.17	0.45	4.36	0.93	8.58	82.2
Gammarus locusta	0.03	0.19	2.07	0.64	4.07	86.27
Phyllodoce mucosa	0.07	0.17	1.97	0.68	3.88	90.15
Southern Impact Sites						
September & November 2009		Average dissimilarity = 32.54				
Species	**Av.Abund S**	**Av. Abund N**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	2.52	1.65	7.79	1.63	23.93	23.93
Cerastoderma edule	1.06	0.85	4.46	1.05	13.7	37.63
Macoma balthica	0.54	0.65	4.4	1.26	13.53	51.16
Crangon crangon	0.48	0.28	3.8	1.19	11.66	62.83
Nephthys hombergii	1.14	1.31	2.67	1.26	8.2	71.02
Owenia fusiformis	0.06	0.25	2.29	0.83	7.03	78.05
Pygospio elegans	0.19	0	1.73	0.65	5.31	83.36
Scoloplos armiger	0.1	0.06	1.21	0.47	3.72	87.08
Hydrobia ulvae	0.06	0.06	0.94	0.46	2.89	89.97
Bathyporeia guilliamsoniana	0.12	0	0.9	0.5	2.77	92.74

The chief contributing species to the within group community similarity of the southern impact samples was the same for September and November 2009 (Table 24).

Table 24. Results of SIMPER analysis on the core data for within group similarities of control and impact sites in both northern and southern sampling areas for September 2009. November 2009 and March 2010

Northern Impact Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 62.84				
Angulus tenuis	1.52	19.68	3.38	31.31	31.31
Nephthys hombergii	1.2	15.25	2.28	24.27	55.58
Cerastoderma edule	0.92	10.29	1.7	16.38	71.96
Pygospio elegans	1.07	8.52	1.02	13.56	85.52
Owenia fusiformis	0.67	5.49	0.93	8.74	94.26
November 2009	Average similarity: 54.59				
Cerastoderma edule	1.14	19.86	1.84	36.38	36.38
Angulus tenuis	0.88	12.94	1.52	23.71	60.09
Nephthys hombergii	0.75	11.51	1.7	21.09	81.18
Owenia fusiformis	0.75	7.21	0.86	13.2	94.38
March 2010	Average similarity: 60.39				
Angulus tenuis	1.52	22.7	4.14	37.59	37.59
Nephthys hombergii	0.98	13.16	2.05	21.78	59.38
Owenia fusiformis	0.82	9.05	1.4	14.98	74.36
Bathyporeia guilliamsoniana	0.71	5.6	0.96	9.27	83.63
Macoma balthica	0.53	3.86	0.7	6.38	90.01
Northern Control Sites					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
September 2009	Average similarity: 46.46				
Pygospio elegans	2.49	13.22	1.39	28.46	28.46
Macoma balthica	1.49	11.74	1.25	25.27	53.73
Scoloplos armiger	1.08	6.43	0.99	13.83	67.56
Cerastoderma edule	0.85	5.52	1.07	11.87	79.43
Nepthys hombergii	0.67	3.88	1.05	8.35	87.78
Hydrobia ulvae	0.53	2.84	0.52	6.12	93.9
November 2009	Average similarity: 40.83				
Pygospio elegans	1.77	10.75	0.97	26.32	26.32
Macoma balthica	1	10.02	1.27	24.54	50.86
Hydrobia ulvae	0.77	5.18	0.68	12.69	63.55
Scoloplos armiger	0.67	4.74	0.81	11.61	75.16
Cerastoderma edule	0.68	4.69	0.65	11.49	86.65
Nepthys hombergii	0.35	2.18	0.46	5.34	91.99
March 2010	Average similarity: 44.41				
Macoma balthica	1.42	15.26	2.57	34.37	34.37
Pygospio elegans	1.9	11.25	1.51	25.33	59.7
Bathyporeia guilliamsoniana	1.07	6.2	0.63	13.96	73.66
Cerastoderma edule	0.48	2.84	0.71	6.39	80.05
Scoloplos armiger	0.53	2.01	0.45	4.53	84.59
Nepthys hombergii	0.32	1.64	0.46	3.7	88.29
Owenia fusiformis	0.34	1.59	0.47	3.57	91.86

March 2010 south

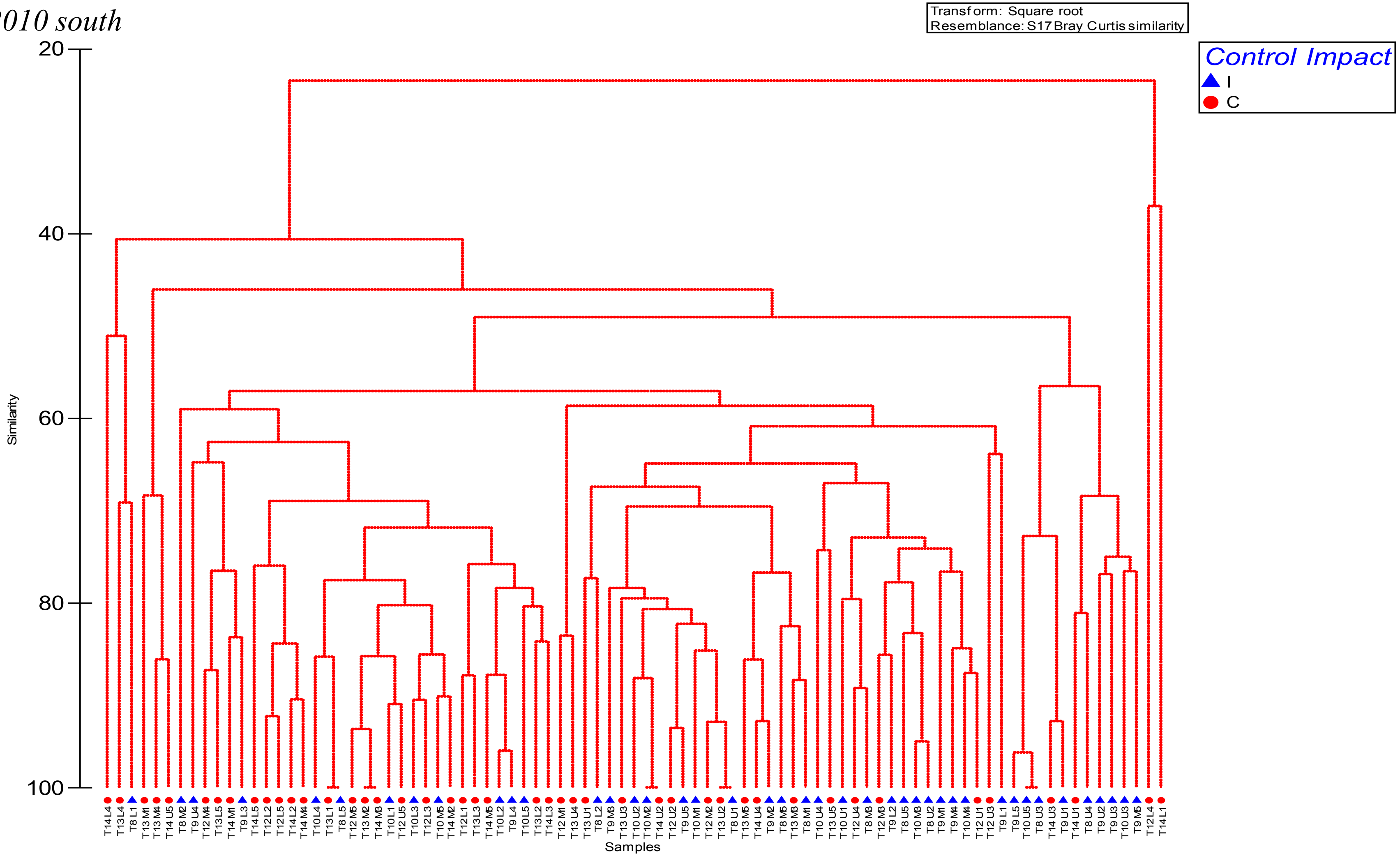

Figure 12. Dendrogram of hierarchial agglomerative clustering output to classify macrobenthic core data from Dundalk Bay, collected from the southern sampling area in March 2010. The clusters have been assessed by a SIMPROF significance test. All samples are joined by red lines and are not significantly different.

No significantly different clusters were determined by SIMPROF carried out in conjunction with the hierarchial agglomerative cluster analysis on data collected from the southern sampling area in March 2010 (Figure 12).

R values from the two-way ANOSIM analysis indicated community divergence between control and impact sites (0.118; p=0.03%) and between shore levels (0.303; p=0.01%). The higher value for location along the shore suggests this factor may have more of an influence on community differences than CI. Pair wise comparison of upper, middle and lower shore shows highest divergence between upper and lower shore (Table 25).

Table 25. Matrix of R-values from pairwise comparisons of shore level communities from March 2010

	Mid	Upper
Lower	0.259 (p=0.01%)	0.481 (p=0.01%)
Mid		0.175 (p=0.01%)

The polychaete *Nephthys hombergii* was the main contributing species (16.08%) to dissimilarities between control and impact sites and between the mid and upper shores. While the polychaete, *Owenia fusiformis,* was the main contributor to the dissimilarity between the lower and mid (21.99%) and lower and upper (28.69%) shores ((Table 26)

Higher numbers of the crustacean *Bathyporeia guilliamsoniana* were recorded from both the control and impact sites in the southern sampling area.

Table 26. Results of SIMPER analysis on core data for between group dissimilarities for impact and control and shore levels from the southern sampling area for March 2010

March South Sites						
Impact & Control		Average dissimilarity = 40.58				
Species	**Av.Abund I**	**Av.Abund C**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Nepthys hombergii	1.03	0.96	6.53	1.08	16.08	16.08
Owenia fusiformis	0.56	1.08	6.42	0.89	15.82	31.9
Angulus tenuis	2.46	2.23	5.92	1.1	14.59	46.48
Macoma balthica	0.61	0.19	5.37	0.86	13.24	59.72
Pygospio elegans	0.12	0.4	3.58	0.69	8.83	68.55
Donax vittatus	0.39	0.15	3.49	0.72	8.61	77.16
Bathyporeia guilliamsoniana	0.18	0.24	2.69	0.63	6.63	83.79
Scoloplos armiger	0.07	0.12	1.51	0.43	3.73	87.52
Eteone longa	0.11	0.07	1.35	0.41	3.33	90.85
Shore Levels						
Lower & Mid Shore		Average dissimilarity = 44.72				
Species	**Av.Abund L**	**Av.Abund M**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Owenia fusiformis	1.69	0.75	9.83	1.36	21.99	21.99
Angulus tenuis	1.9	2.68	8.32	1.11	18.6	40.59
Nepthys hombergii	0.94	1.23	5.85	1.09	13.08	53.67
Donax vittatus	0.53	0.1	4.44	0.87	9.93	63.61
Pygospio elegans	0.41	0.25	3.94	0.79	8.81	72.41
Bathyporeia guilliamsoniana	0.11	0.39	3.41	0.8	7.62	80.03
Macoma balthica	0.11	0.39	3.38	0.66	7.56	87.59
Scoloplos armiger	0.16	0.03	1.48	0.44	3.31	90.91
Lower & Upper Shore		Average dissimilarity = 52.62				
Species	**Av.Abund L**	**Av.Abund U**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Owenia fusiformis	1.69	0.1	15.1	1.74	28.69	28.69
Angulus tenuis	1.9	2.41	7.75	1	14.73	43.42
Nepthys hombergii	0.94	0.82	6.7	1.11	12.72	56.15
Macoma balthica	0.11	0.66	5.55	0.92	10.55	66.69
Donax vittatus	0.53	0.17	4.72	0.83	8.97	75.66
Pygospio elegans	0.41	0.15	4.06	0.78	7.72	83.38
Scoloplos armiger	0.16	0.1	2.1	0.52	4	87.38
Bathyporeia guilliamsoniana	0.11	0.13	1.8	0.48	3.42	90.79
Mid & Upper Shore		Average dissimilarity = 40.81				
Species	**Av.Abund M**	**Av.Abund U**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Nepthys hombergii	1.23	0.82	7.68	1.23	18.83	18.83
Owenia fusiformis	0.75	0.1	6.76	0.94	16.56	35.39
Macoma balthica	0.39	0.66	5.52	0.94	13.52	48.92
Angulus tenuis	2.68	2.41	5.43	1.26	13.31	62.22
Bathyporeia guilliamsoniana	0.39	0.13	3.7	0.76	9.06	71.29
Pygospio elegans	0.25	0.15	2.93	0.56	7.17	78.45
Donax vittatus	0.1	0.17	1.93	0.51	4.74	83.19
Eteone longa	0.14	0.08	1.71	0.47	4.2	87.39
Cerastoderma edule	0.1	0.1	1.61	0.47	3.95	91.34

Discussion

Dundalk Bay contains six habitats with qualifying interests listed in the Habitats Directive and 11 intertidal biotopes were identified by Aquatic Services Unit, UCC, in 2008. Of the 11 intertidal biotopes identified 'Polychaetes and *Angulus tenuis* in littoral fine sand' (LS.LSa.FiSa.Po/PoAten) is the most dominant within Dundalk Bay and the majority of the designated cockle fishing areas overlap this biotope. The faunal community recorded during the current survey work most closely resembles the Eunis biotopes '*Cerastoderma edule* and polychaetes in littoral muddy sand' (LS.LSa.MuSa.CerPo) and 'Polychaetes and *Angulus tenuis* in littoral fine sand'. The former biotope is defined as consisting of extensive clean fine sand or muddy sand shores with abundant cockles (*Cerastoderman edule*) and an accompanying community including species such as *Eteone longa*, *Scoloplos armiger*, *Pygospio elegans*, *Capitella capitata*, *Crangon crangon*, *Bathyporeia* sp., *Hydrobia edule* and *Macoma balthica*. The latter biotope occurs on the mid and lower shore on moderately wave-exposed and sheltered coasts, with predominantly fine sand which remains damp throughout the tidal cycle. The sediment is often rippled, and an anoxic layer may occasionally occur below a depth of 10 cm, though it is often patchy. The infaunal community is dominated by the abundant bivalve *Angulus tenuis* together with a range of polychaetes. The presence of polychaetes may be seen as coloured burrows running down from the surface of the sediment. Burrowing amphipods [Bathyporeia] spp. may occur in some samples of this biotope. The infauna of this biotope may be reduced during winter, as increased storminess and wave action increases sediment mobility and may lead to some species migrating or being washed out of the sediment.

Previous studies have shown that the composition and functioning of biotopes can be changed and impaired by dredging (Collie *et al*., 2000; Dernie *et al*., 2003 and Sewell *et al*, 2007). It is generally expected that there will be a reduction in species diversity and abundance in the areas where the dredge has operated for a period of time. Evidence suggests that potential impact and recovery time is very site specific (Sewell *et* al., 2007). However in sites with moderately mobile sediments it is possible for natural disturbances to have a greater effect than dredging (Sewell *et* al., 2007).

Summary statistics and ANOVA of the data indicated mainly seasonal and spatial but also short lived fishery effects in *A. tenuis* and *C. edule*. The fishery effect was less than 4 months. The two-way ANOSIM analysis carried out on both the quadrat and core data recorded differences between all three factors CI, 'location' (north and south sampling areas) and BA. Although all of the R-values recorded were greater than zero, indicating some divergence in community structure, they were all less than 0.5, suggesting that a high level of species overlap within communities also exists across all sampling areas. Further one-way analysis on both the quadrat and core data showed that there was a significant difference in CI stations in the northern sampling area (Quadrat R=0.346 (p=0.01%) and Core R=0.653 (p=0.01%))

prior to any fishing activities in September 2009. The R-values for the core data remained consistently above 0.5 for all three time periods, therefore, the difference in community structure between northern CI sites can be regarded as a spatial effect rather than a fishery effect. Most of the northern control sites were located in the upper shore, where *M. balthica* is usually prevalent, while the impact sites were located within the mid and lower shores where *A. tenuis* is more commonly found, thus the main bivalve species contributing to the community structures were different for both areas. The quadrat data indicated an increase in community divergence (>R values) over time between the CI sites from September 2009, to November 09, to March 2010. This is a result of increases in abundances of *A. tenuis* and the polychaete, *Owenia fusiformis* within the impact sites, while both these species were recorded in low abundances within the control samples. *M. balthica* remained a key species (>20% contribution) within the control samples, over time, but did not occur in great abundances in the impact samples.

Community structure within the southern control and impact sites was more similar, prior to fishing (September 2009), with no significant difference being detected post fishery in November. Significant differences were identified between the impact communities recorded in September and November 2009, with decreases in abundances of all three main bivalve species. A significant difference was also seen between the control sites over the same time period.

Analysis of the southern core samples collected in March 2010 showed no significant difference between the faunal community recorded in the dredged area and the control area. Although slight differences in community structure at various levels up the shore were determined, they were not significantly different and in general the communities strongly overlapped.

References (incomplete)

Bell, M.C. and Walker, M. (2005). Desk study to assess the impact of cockle suction dredging on The Wash and North Norfolk Coast European marine site. English Nature Research Reports, No 670.

Collie, J.S., Hall, S.J., Kaiser, M.J. and Poiner, I.R. (2000). A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Ecology, **69**, (5), 785-798.

Crowe, O. (2008). Irelands Wetlands and their waterbirds: Status and Distribution. Birdwatch Ireland, Newcastle, Co. Wicklow. 402 pp.

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.

Elliott, M., Nedwell, S., Jones, N.V, Read, S.J., Cutts, N.D. and Hemingway K.L. (1998). Intertidal sand and mudflats and sub-tidal mobile sandbanks (Vol II). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs project). 151 Pages.

Ens, B.J., Smaal, A.C., and De Vlas, J. (2004). The effects of shellfish fishery on the ecosystems of the Dutch Wadden Se and Oosterschelde. Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II). Alterra-rapport 1011, RIVO-rapport C056/04, RIKZ-rapport RKZ/2004.031. Wageningen: Alterra.

Fahy, E., Carroll, J. and Murran, J. (2005). The Dundalk cockle (Cerastoderma edule) fishery in 2003-2004. Irish Fisheries Investigations 14, 16pp. Biomass, size and age structure of Cockles (*Cerastoderma edule*) in Dundalk Bay, May 2010. Marine Institute Unpublished Report, 16pp.

Sewell, J., Harris, R., Hinz, H., Votier, S. and Hiscock, K. (2007). An assessment of the impact of selected fishing activities on European marine sites and a review of mitigation measures. The Marine Biological Association and the University of Plymouth. 217 Pages.

Tylers-Walters, H. (2003). Cerastoderma edule, Common cockle. Marine Life Information Network. Biology and Sensitivity Key Information Sub-programme. Marine Biological Association Plymouth. http://www.marlin.ac.uk/species/cerastodermaedule.htm