Acoustic seabed classification: identifying fish and macro-epifaunal habitats

Steven Freeman[1], Melanie Bergmann[2], Hilmar Hinz[2], Micheal Kaiser[2] and Jim Bennell[2]

[1] *ABP Marine Environmental Research Ltd. Pathfinder House, Maritime Way, Southampton, Hampshire SO14 3AE*
[2] *School of Ocean Sciences, University of Wales-Bangor, Menai Bridge, Anglesey, LL59 5EY, UK*

[1] (e-mail: sfreeman@abpmer.co.uk)

Abstract: Increasing use of seabed resources and the effects of fishing on the seabed requires an urgent need to assess the extent and diversity of those habitats affected. Traditional techniques of site-specific sampling do not adequately map the extent of seabed habitats and prone to overlooking uncommon habitats. Assessing the utility of remote sampling techniques such as swath bathymetry and acoustic ground-discrimination systems is important because they provide a predictive basis for better-targeted benthic sampling. Acoustic surveys were conducted in conjunction with traditional biological sampling methods at eight study sites selected for differences in demersal fish abundance, in the Irish Sea. Using a 2-m and 3-m beam trawl, distinct fish and macro-epifaunal assemblages were identified. These were strongly associated with acoustically distinct habitats identified using QTC VIEW™. Sidescan images provided detailed information on surface texture and gross substrata types, whilst sediment samples were used effectively to ground-truth acoustically distinct habitats. An index of habitat complexity was correlated with acoustic data, which provided an effective assessment method for mapping the spatial extent of fish and macro-epibenthic habitats.

Introduction

There is an increasing awareness of the wider ecological effects of fishing on the marine ecosystem. Consequently, new approaches to fisheries management are sought that consider both the implications of exploitation for the harvested species, and the ramifications of the fishing activity that may arise from by-catches, alteration of trophic interactions and habitat alteration (Jennings and Kaiser 1998; Gislason and Rice 2000). The consideration (and amelioration) of the effects of fishing on marine habitat that is critical for certain life-stages of commercially important fish species

has become a legal requirement in the United States with the revision of the Magnuson-Stevens Fisheries Conservation and Management Act (1996). These habitats have been termed 'essential fish habitat' and would include habitats that are spawning grounds, nursery areas, provide specific feeding resources, provide shelter from predators and act as migration routes (Benaka 1999).

For many fish species, the location of spawning and nursery areas is well known. Often these occur close to the coastline and some are already protected from anthropogenic disturbance (e.g. Pastoors et al. 2000). However, the spawning activities and the juvenile stages of fish constitute a relatively small proportion of their life-history. Throughout the life-span of most fishes, the majority of their time will be allocated to feeding and the avoidance of being eaten by predators. For many commercially important fish species, adult stages are found in the deeper water further offshore where it is logistically more complicated to study the characteristics of their habitat in detail. Currently, there is a pressing need to identify the characteristics of habitats that have an important or 'essential' functional role for particular species or types of fish (e.g. piscivores/herbivores/omnivores or flatfish/roundfish). Once such habitat characteristics have been identified, the next step of the process will be to quantify the extent of fish habitat resources. The successful management of these habitats requires an understanding of the interactions among species and the environment in which they live (e.g. Bax et al. 1999). However, as yet no general methodology has been developed to define which elements might constitute an essential fish habitat. While a number of authors have described the links between seabed habitats and benthic faunal demography (e.g. Langton and Robinson 1990; Kostylev et al. 2001) few have related the biological and physical components of seabed habitat to the demography of fishes (see Kaiser et al. 1999).

Numerous studies have shown the demography of benthic invertebrate assemblages to be correlated with one or more environmental components. For example, the composition of the substrata, bathymetry and near-bed hydrodynamics have been shown to influence the distribution of many benthic invertebrate and fish assemblages (Tyler and Banner 1977; Warwick and Uncles 1980; Rosenberg 1995; Ventura and Fernandes 1995; Freeman et al. 1999; Kaiser et al. 1999; Freeman and Rogers 2002). Few previous studies have examined the habitat features of the seabed that might be linked to the distribution of demersal fish and epibenthic communities (Basford et al. 1990; Kaiser et al. 1999; Rees et al. 1999; Ellis et al. 2000). Furthermore, the spatial extent of these communities is still described by site-specific data. This means that samples are collected at well-spaced intervals and extrapolation of these data to previously unsampled areas is entirely subjective without more detailed sampling. The use of spatial statistics (e.g. interpolation techniques such as kridging) to make inferences about their distribution may be statistically unreliable because biological sample stations are often either well spaced or lack extensive geographical coverage. If, however, sufficiently good links could be made between benthic species and their habitat i.e. sediment type, then extrapolation of data into unsampled areas could be based on the presence or absence of these physical components. A further extension of this work is the establishment of the link between the substrata and associated benthos and the fish that utilise this habitat. Such an approach would

enable managers to identify more rapidly areas of potential importance for fish species associated with particular habitat types.

One approach to determine the spatial patterns of bottom dwelling organisms is to use remote sensing technology such as side-scan sonar, multibeam swath bathymetry and acoustic ground-discrimination systems (AGDS). Recent advances in the power and reliability of these acoustic mapping technologies have provided an effective tool to delineate and characterise the habitat feature of the seabed that are important to demersal fish and benthic faunas (Magorrian et al. 1995; Greenstreet et al. 1997; Collins et al. 1998; Bornhold et al. 1999; Freeman and Rogers 2002; Kostylev et al. 2001). We consider that the substratum is the single most important physical component of the benthic environment because it partly determines stability and it is the primary level of habitat complexity to which emergent and infaunal biota add another level of complexity. Advances in the reliability of the single-beam acoustic ground-discrimination systems (e.g. QTC VIEW and RoxAnn™) have provided accurate maps of different seabed substrata. (Magorrian et al. 1995; Greenstreet et al. 1997; Collins and McConnaughey 1998). These studies validated the differentiated habitat-types with ground-truth samples of sediments and in some cases benthic biota. As yet, none of the studies undertaken to date has attempted to link differentiated habitat types with their associated fish assemblages.

The purpose of the present study was to examine whether QTC VIEW could be used to determine seabed habitat heterogeneity and provide a remote and predictive method of delineating habitat related to benthic and demersal fish assemblages. If strong links between QTC data and bottom dwelling organisms could be made, then it would provide an efficient tool for delineating the spatial extent of their habitats. This would provide important information on the geographical extent of habitat resources available for those fish species closely associated with particular seabed habitats.

Materials and methods

Survey area and protocol

All the sampling reported in the present paper was undertaken on-board the RV Prince Madog (l.o.a. 34.9m) in August 2001. Seven distinct sites in the northern Irish Sea (Fig. 1) were chosen for investigation on the basis that they contained either high (4 sites) or medium (3 sites) abundances of commercially important fish species (cod *Gadus morhua* L., whiting *Merlangius merlangus* [L], and haddock *Melanogrammus aeglefinus* [L]). Fish abundance data was extracted for the last 10 years from databases of groundfish stock assessments held by the Centre for Environment, Fisheries and Aquaculture Science annual beam trawl surveys, and the Department of Agriculture and Rural Development of Northern Island annual otter trawl surveys. A medium abundance station was allocated to each high abundance station of comparable depth in as close vicinity as possible for comparison of biological/environmental features. The details of the temporal distribution of fish throughout the Irish Sea is not key to the present paper and will be covered in more detail elsewhere.

At each site, a 2000 x 600m area that ran in the direction of the prevailing current was surveyed entirely with a side-scan sonar system. Side-scan sonar was

connected to a sonar processor fitted with the real-time side-scan mosaicing to allow information about the surface features of the seabed to be viewed during survey tows [see below for methodology]. The acoustic ground-discrimination system QTC VIEW (Quester Tangent Corporation) was used simultaneously to collect detailed data on seabed substrata [see below for methodology]. The output from both the side-scan sonar and QTC VIEW were then consulted to determine whether there were any major differences in habitat type within the survey area. If major differences were found then the subsequent biological sampling was duplicated in each area to determine whether the apparent habitat differences were reflected in benthic and fish assemblage composition. As QTC initially indicated the presence of two acoustically distinct habitats at station D35 (Belfast Lough), two habitats were sampled at this site and treated as different station groups D35A and D35B in all subsequent analysis.

Side-scan sonar survey

A CM800 side-scan sonar system (Cmax Ltd) was operated using the high frequency option (325kHz) with a sonar range of 100m on both the port and starboard channels giving a total seabed swathe width of almost 200m. This configuration was the optimum compromise between providing adequate coverage in an acceptable time with a suitable resolution. To map each site 3 parallel tracks, 2000m long, were surveyed at line intervals of 200m in order to provide a nominal 100% sonar coverage of the seabed in the selected area.

The analogue signal output from the CM800 system was fed into a GeoPro 2 Sonar Processor (Geoacoustics Ltd) so that images of the seabed texture could be displayed in real time as the survey progressed. This had the major advantage that the extent of the sonar coverage could be monitored and the ship's heading adjusted to maintain optimum track to avoid missing areas of the seabed between adjacent swathe and perhaps more importantly to avoid too much overlap between adjacent sonar scans. The other advantage that the real time mosaicing system has over the CM800 is that the overall sonar mosaic could be reviewed on completion of the site survey so that decisions on the subsequent sampling protocol could be made immediately.

NMEA navigation data (WGS 84) from the ship's DGPS system were input into both sonar systems via RS232 serial interfaces. The CM800 sonar data were saved onto magnetic optical discs for post processing and subsequent generation of hardcopy images. The data displayed by GeoPro were saved to the hard disc and the complete sonar mosaic shown on the computer screen was also saved as a bitmap image.

Post-processing of the CM800 data initially required that the files be converted from the propriety Cmax Ltd. Format into Q'mips format to be compatible with the Octopus 461 Sidescan Processing Toolkit used for mosaic production. This toolkit was then used to generate a series of mosaic 'tiles' (250m square) for each site. These sonar 'tiles' can then be assembled using CAD or GIS (MapInfo) packages to produce a sonar mosaic/map of the seabed for the sites surveyed. These images were then used to describe the surface features and identify the gross seabed sediment changes

in habitat type at each of the survey sites. This information was used to ground-truth QTC data.

QTC VIEW

The acoustic ground-discrimination system (AGDS) QTC VIEW (series 4) was used to determine the characteristics of the seabed substratum at 7 sites in the Irish Sea. The advantage of this hull mounted AGDS is that it can be operated whilst the beam trawl is being towed behind the ship without interference. It also provides a means to determine the type of seabed substrate at stations not previously sampled using conventional ground-truthing methods such as sediment grabs and underwater cameras. QTC VIEW characterises the seabed through the shape of the returning echo generated from the ships echo sounder, which uses a single beam to insonify the seabed. These data are then analysed using a series of algorithms that describe the waveform shape by 166 feature variables; these reflect the physical properties of the seabed (Collins et al. 1996, Collins and McConnaghey 1998). The acoustic acquisition software QTC VIEW was used in an unsupervised mode and connected to a SIMRAD EK-60 echo sounder, that was operated at 120kHz. The reference depth was set to 25m to encompass the full range of operational depths (~15-75m) encountered during our beam trawl surveys. Echoes are collected, stored and merged with navigation data using a global positioning system (GPS) by QTC VIEW before being clustered in the software QTC IMPACT™ (version 1.2). IMPACT reduces these data into 3 Q-values using a principal component analysis (PCA) algorithm. A k-means iterative clustering algorithm is then used to divide Q-space into logical clusters, which are based on a number of statistical options built into the software (Quester Tangent Corporation Manual, 1999). During the post-processing phase, all acoustic survey data were merged together to form a single file. Merging data in this way provides the only statistically robust method to compare surveys and, therefore, a more reliable method to infer substrata type at those stations not previously ground-truthed. Since each acoustic survey contained a large number of records only those classifications that accounted for >70% of each survey was taken to represent the overall seabed substrata composition of a particular station. In addition, the QTC IMPACT software provides a confidence value (%) for each data point used in its classification process. This provides a relative level of certainty to each particular class. All classes with confidence values <95% were removed.

Sediment type

To interpret differences in the acoustic properties of the seabed substrata, QTC data was ground-truthed by examining sediment samples collected with a Day grab (0.1m²). A visual description of the sediment at each site was recorded, photographed and a small subsample removed for particle size analysis. The samples were stored at -20°C on board ship to await further analysis back in the laboratory. After thawing, the sediment was dried at 60°C to dry weight and 100g removed. Samples were soaked overnight in 1l of sodium hexametaphosphate (6.2g in 1l of fresh water) to desegregate the sediment particles (Buchanan 1984). After pouring off the supernatant, the soil was redried and then separated into its component size fractions by dry-sieving with a reciprocating shaker. The different fractions were then weighed. The organic content of the sediment was determined from sub-

samples of the dried sediment, weighed before and after combustion in a muffle furnace for 5h, and hence provided an estimate of the ash-free dry weight of the samples (Holme and McIntyre 1984).

Biological sampling

At each sampling site 4 samples were collected with a 2-m beam trawl towed for 5 minutes timed from the moment the trawl winch stopped paying out warp. The 2-m beam trawl was fitted with a 1 mm meshed cod-end liner and a chain-matrix and towed at a speed of 2 knots (Jennings et al. 1999). Samples were sieved over a 5 mm mesh. Epibiota were counted, wet-weighed on a motion-compensated balance (±1g) and identified on-board ship or preserved for later examination back in the laboratory. Similarly, 4 samples were collected using a 3-m beam trawl fitted with a chain-matrix and an 84mm diamond mesh cod-end. The cod-end was fitted with a 40mm square meshed liner and each tow was 20 minutes in duration at a speed of 4 knots (timed as before). All fish were removed from the samples, counted, weighed and identified. A consistent-sized subsample of epibenthic invertebrates was taken from each catch, sorted as before. It was not possible to count individuals for sessile colony forming biota such as hydroids, anthozoans and bryozoans; hence, only biomass was determined for these organisms. As these organisms form an important component of the habitat composition, we used only the biomass data in our subsequent analyses. Stones, broken shell and structures such as polychaete worm tubes were also separated from the catch and weighed.

Data analysis

All multivariate community statistics were undertaken using the PRIMER analytical package (Clarke and Warwick 1994). Our sites were assumed *a priori* to have distinct assemblages. The community biomass data were clustered using the Bray-Curtis index of similarity and the group-average method of linkage. Ordination graphs were plotted after subjecting the data to multi-dimensional scaling (MDS). As QTC initially indicated the presence of 2 acoustically distinct habitats at station D35 (Belfast Lough) an ANOSIM test was done to determine significant differences between the faunas of these sub-stations. The subset of species that contributed most to the Bray-Curtis similarity was determined using the programme SIMPER. These species represent the vast majority of the similarity between samples at each site. The programme BIOENV was used to determine to what extent environmental variables (percentage total organic carbon, depth, median grain-size, weight of stones, weight of shell, weight of worm tubes, percentage silt) at each site were associated with the inter-site biological relationships as represented in the biomass MDS plot.

Sampling was undertaken at a range of scales. Tows with the 2-m and 3-m beam trawl swept approximately 600m² and 7200m² of the seabed respectively. Hence, samples collected with the 2-m beam trawl may reveal a different level of habitat heterogeneity that will tend to be smoothed out when samples are collected with the 3-m beam trawl.

Principal component analysis (PCA) was used to examine the association between beam trawl stations, based on seawater depth, habitat complexity derived from QTC data, side-scan sonar and biological data [see method below], and tidal near-bed velocity, which was estimated for each survey station by squaring water

velocity values produced from the POLPRED offshore tidal prediction system (Proudman Oceanographic Laboratory, 1997). For a detailed explanation of near-bed velocity, readers are referred to Dyer (1986). Since the POLPRED modelled data-points were based on a 7-mile grid, the geographical information system (GIS) MapInfo ™ was used to identify the closest value to each of our stations. PCA is an appropriate method for identifying patterns using non-independent data (Kendal 1980). The analysis produces a bivariate plot of stations using the 2 main principle components (pc1 and pc2), where the distances between stations represent a genuine difference in their physical characteristics. Stations that are close together, for example, share a greater similarity in their habitat than those wider apart. It was assumed that by using PCA differences between demersal fish and epifauna habitats could be identified and thus characterised by the physical components of their environment.

Habitat complexity

The structural features of the seabed surface are an important component of any benthic habitat. Since, QTC VIEW data has previously been reported to reflect more than seabed sediment texture, e.g. micro-topography and emergent epifauna (Collins et al. 1996, Bornhold et al. 1999), an index of habitat complexity was developed using information from side-scan sonar, Day grabs and beam trawls (Table 1). Values for the index were used to reflect the relative magnitude of difference between each seabed feature. Using side-scan descriptions, for example, a smooth seabed was scored as 1, whereas a rough seabed scored a maximum of 8 because such structural complexity is more likely to attract fish for shelter. Rough seabed features included boulders, rocks and a mix of coarse substrata, whilst a description of bedforms included sand ripples and shallow ridges. Sediment descriptions were taken from observations of the Day grab samples collected at each station; only the surface features and sediment types were recorded. The total score for all categories were used to reflect the final habitat index value for each station.

Results

As might be anticipated, the species composition of replicate 3-m and 2-m beam trawl tows from each station group clustered closely together while replicate tows from different station groups were clearly separated (Fig 2*a-c*). Tows from high and medium fish abundance station pairs were always distinct from other pairs of stations e.g. C49 and D245 were distinct from D35A and D35B, although station pairing of D79 and C213 were noticeably more distinct than all other pairings. The initial distinction of two acoustically distinct habitats at station D35 (A and B) were found to be acoustically similar following subsequent post-processing analysis using QTC IMPACT. In addition, these A and B stations showed no significant difference in terms of their biota (ANOSIM R=0.052, p=0.314), although we remained to be treated them as two stations.

Ground fish (3-m beam trawl)

Generally, at all station groups, except for the coarse sediment stations D245 and C49, dab and plaice tended to be the dominant fish species (Table 2). The

percentage contribution of each species' biomass to station similarity was calculated and tabulated along a gradient of increasing grain size at each station (see Table 3). This sequence was used to elucidate the transition in dominant species' identity across stations. Witch dominated the fish assemblage at fine sediment stations C213 (58%) and D79 (25%). At 35A and B, plaice and dragonet were found to be dominant. At these two stations juvenile cod also contributed to the overall similarity of the biomass. In addition to dab and plaice, which were the most abundant species at the sandy stations C27 and C30, sole, solenette and scaldfish also contributed to the overall similarity. At the coarse sediment station D245, the lesser spotted dog fish was the dominant species (59%) followed by red gurnard (18%) and dragonet (11%). At the complimentary station C49 (also coarse sediment) red gurnard (40%), dab (19%) and dragonet (13%) contributed most to the similarity. Thus, high and medium abundance stations for cod, whiting and haddock were associated with a variety of different fish assemblages.

Macro-epifauna (3-m beam trawl)

The cluster analysis and MDS ordination of macro-epifauna biomass showed similar patterns to that recorded for the ground fish where high and medium station pairs were always found in close proximity to each other (Fig. 2*b*). As for the percentage contribution of fish species' biomass to station similarity differences in grain size were used to elucidate the transition in dominant species' identity for macro-epifauna. Although present at all stations, the starfish *Asterias rubens* seemed to have a higher contribution at stations C213 (79%) and D79 (25%), that were characterised by fine sediments (Table 4). The sea mouse is generally a characteristic species of muddy sediments and thus not surprisingly contributed to 16% of the similarity associated with D79. D35A and B were distinguished by sessile epifauna such as *Flustra* spp., emergent Bryozoa/Hydrozoa, plumose anemones (*Metridium senile*) and dead men's fingers (*Alcyonium digitatum)*, species that are generally associated with hard substrata (pebbles/boulders). *A. rubens* and the brittlestar *Ophiura albida* contributed most to the similarity at C27 and C30. Other important species included the sand star, the hermit crab *Pagurus bernhardus* and the ophistobranch *Philine aperta*. At D245 and C49 queen scallops, a species that is associated with coarse sand and gravel, contributed the highest percentage (14%, 26%) to similarity. Here, *A. rubens* and the whelk *Buccinum undatum* were also important. In addition, C49 was characterised by the brittlestars *Ophiothrix fragilis* (10%) and *O. albida* (8%), the bryozoan *Alcyonium diaphanum* (5%) and the hermit crab *Pagurus prideaux* (5%).

Macro-epifauna (2-m beam trawl)

Replicate samples from 2-m beam trawls clustered less clearly together *cf.* replicate samples from 3-m beam trawls (fish and macro-epifauna) (Fig. 2*c*). The third tow at C30, for example, had less than 5% similarity with any other sample (the catch consisted of three brittlestars, *Ophiura ophiura,* only). Two replicate tows at D35 also showed a dissimilar biomass composition compared to the other replicates of that station. Results from ANOSIM indicate that the species compositions of habitat A and B at D35 were not significantly different ($R=0.146$, $p=0.200$). The species

composition of complimentary high and medium abundance station pairs was generally more similar than the similarity between other stations.

The Norway lobster was the most dominant species at the fine sediment stations C213 (89%) and D79 (74%) (Table 5). The swimming crab *Liocarcinus depurator* had the highest percentage contribution to the similarity of D35A (48%), followed by *O. albida* (15%). D35B was dominated by *A. rubens* (31%) and emergent Bryozoa/Hydrozoa (27%). Both stations were also characterised by the weed-like bryozoan species *Flustra foliacea* and *Securiflustra securifrons*. The sandy stations C27 and C30 were dominated by *A. rubens* (90% and 50%, respectively). At C30, *O. albida* (25%) and *P. bernhardus* (11%) also contributed to the overall similarity. The coarse sediment station D245 was dominated by the sea urchin *Psammechinus miliaris* (35%), queen scallops (15%) and emergent Bryozoa/Hydrozoa (12%). The biomass of C49 was characterised (81%) by dead men's fingers and queen scallops.

Habitat characteristics and QTC VIEW

The physical characteristics of each survey station are summarised in Table 3. Classification of QTC VIEW data identified 5 statistically distinct classes. Visual inspection of each QTC class plotted in the mapping software MapInfo showed that most of the survey tracks had little class variability reflecting the homogenous nature of the seabed. When decimated Q1 and Q2 values for each of these distinct classes were compared with changes in water depth they were not strongly correlated (Fig. 3). QTC class 5, for example, that characterised soft muddy sediments, was found at 2 different depths, 33m (D79) and 40m (C213). In addition, QTC class 2 (D35A and B) and 4 (C245) were found at similar water depths (36-42m). The QTC VIEW system is designed, however, to correct for depth changes during data acquisition (Collins [Quester Tangent Corporation], personal communication) by transformation of the full waveform (or echo) to a predetermined reference depth, set to 25m for the present study. Principal component analysis (PCA) showed that pc1 and pc2 accounted for 72% of the variability in the data, and that the distribution of surveys stations, which were based on all the habitat characteristics (Table 3), showed a distinct directional pattern (Fig. 4). Stations had the same general order as that presented in Table 3 where, for example, C213 and C79 were characterised by fine substrata and high total organic carbon, whilst C49 and D245 were distinguished by coarse substrata with relatively high proportions of shell, stones and *Lanice* tubes.

A strong association was found between the habitat characteristics of stations mapped by pc1 and pc2 and the superimposed QTC VIEW acoustic classes 1-5. Class 5 (C213 and D79) was strongly associated with the physical variables fine sediment grains (%<62μm), a high median phi and total organic carbon (%). By contrast, class 1 (D245) and 3 (C49) were associated with much coarser sediments characterised by a high total shell, rock and polychaete tube weight. There was some variability between intermediate classes such as class 4 (D35A and 35B), where 2 of the 8 stations were characterised by much coarser substrata with a high proportion of shell. Class 2 (C27 and C30) was another intermediate classification occurring between class 3 and 4.

MDS plots of all 3-m and 2-m beam trawl stations for demersal fish and epifauna identified biologically distinct communities that corresponded with

superimposed QTC VIEW data (classes 1-5) (Fig. 5*a-c*). One advantage of using MDS is that the distance between each station represents a relative measure of the similarly of species. Station groupings with a Bray-Curtis similarity coefficient of <47% (demersal fish), <38% (3-m beam trawl epifauna) and <35% (2-m beam trawl epifauna) were identified by a dashed line and superimposed on each MDS plot. Acoustically these groups showed very distinct seabed habitats, although the degree of correspondence between stations became increasingly less distinct when compared with the 2-m beam trawl epifauna groupings (Fig. 5*c*). Demersal fish station groups showed the highest level of correspondence with QTC VIEW data. The only exception were the complimentary stations C213/D79, that were identified as having different fish assemblages despite being classified as having acoustically similar seabed types (class 5). At both of these stations, witch was the dominant fish species, but D79 differed slightly by containing more fish species such as dragonet, long rough dab (*Hippoglossoides platessoides*), grey gurnard (*Eutrigla gurnardus*) and whiting. Other differences were reflected in the type of species collected from D79, which tended to be comprised of more scavenger species than C213 such as the sea mouse (*Aphrodita aculeata*), swimming crab (*L. depurator*), hermit crab (*P. bernhardus*) and sand star. By contrast, when the 2-m beam trawl data are used to identify benthic assemblages, C213/D79 were both biologically similar. Although the Norway lobster was the predominant species at both stations, D79 was slightly different because it was also characterised by the shrimp *Crangon allmanni* and the common starfish *A. rubens* (Table 4).

PCA based on depth, habitat complexity (Table 1) and tidal near-bed velocity showed that some station parings were clearly defined by different habitat characteristics (Fig. 6). The main habitat differences between stations C213 and D79, for example, was that the latter station was characterised by shallower water depths, a slightly higher nearbed water velocity and slightly higher structural complexity, despite sharing a similar QTC VIEW classification. The fact that some stations shared the same seabed substrata indicates the inherent complexity of the benthic environment, and that sediment alone is not always a suitable proxy for habitat type. Other notable differences in habitat characteristics were between the station pairings D245/C49 and C30/C27, but these stations were all acoustically distinct.

Discussion

The current movement towards ecosystem approaches to fisheries management will necessitate a better understanding of the relationship between the demography of demersal fish in relation to their habitat requirements. Effective management will therefore require the acquisition of the extent and location of key habitat resources. The present study has shown that by combining information from both the acoustic ground-discrimination systems QTC VIEW and side-scan sonar, distinct seabed substrata and their biogenic features can be used effectively to characterise the habitats used by demersal fish assemblages. Insonification of the seabed using QTC demonstrated that acoustic properties reliably reflect distinct and recurrent patterns in the demography of bottom dwelling fish and invertebrates.

Although the use of acoustic seabed classification to characterise substrata is not a new concept, few previous studies have used this technique to identify features of the seabed that may be considered 'essential' features of fish habitats, (Collins and McConnaughey 1998; Bax et al. 1999; Williams and Bax 2001). The development of a robust and cost-effective approach to mapping the spatial extent of fish habitats must be based on an understanding of the linkage between the seafloor, as that characterised by acoustic classification and the biology. Seabed substrata and surface bedforms are important habitat features for demersal fish because they support the growth of many sessile organisms that create structurally complex environments. For fish, these environments provide micro-habitats, feeding grounds and refugia from predators (Auster 1998; Kaiser et al. 1999) and reflect, in some way, the morphological, physiological and behavioural adaptations of these more mobile organisms (Jones 1950; Warwick and Uncles 1980; Frid et al. 2001). Developing reliable methods that can identify such features and enable their spatial extent to be mapped will underpin the requirements needed by fisheries managers to identify and protect the 'essential' characteristics of habitats. Approaching habitat mapping from this perspective will also support the mandatory requirements of the Magnuson-Stevens Fisheries Conservation and Management Act (1996), in that the 'essential' features of a habitat are identified through links with the environment and thus made predictable. Our results show that acoustically distinct seabed habitats are strongly associated with different fish and epifaunal assemblages. These acoustic and biological associations indicate that patterns in their distributions may be predictable. Stations C49 and D245, for example, were composed of different seabed substrata and habitat complexity, that when mapped using QTC VIEW were acoustically distinct from each other. At D245 the lesser-spotted dogfish was the main characteristic species, whereas at C49 dab and dragonet were characteristic. Not all species characterised a particular habitat as, for example, red gurnards also contributed to similarity at both of these stations. Species such as the red gurnard may be considered as habitat generalists because they appear to be able to occupy a wider range of different habitat types compared to other species. Williams and Bax (2001) showed that different fish communities on the south-eastern Australian continental shelf were also characterised by the same species, despite differences in the physical nature, e.g. depth and seabed substrata. In the present study, substrata and habitat structure were strongly associated with differences in the biological aspects of the community.

The adult stages of many commercially important fish species are found in offshore waters where it is more difficult to study habitat characteristics. Traditional techniques that use site-specific sampling gears such as beam trawls and Day grabs (Basford et al. 1990; Kaiser et al. 1999; Rees et al. 1999; Freeman et al. 1998; Ellis et al. 2000) could be considered as inadequate for mapping the true extent of seabed habitats and may be prone to overlooking less common habitat types. Samples that are well-spaced usually require extrapolation to previously unsampled areas in order to infer their distribution. Using spatial statistics to make these inferences is statistically unreliable when samples are usually well-spaced and lack extensive geographical coverage. Remotely operated tools that describe and identify links between the physical factors of the benthic environment to individual species could

provide a mechanism for predicting their distribution and abundance. Although this will depend on the strength of the link a species has with its environment. Several studies have examined the application of single-beam echo sounder technology such as QTC VIEW and RoxAnn to discriminate between different seabed substrata (Magorrian et al. 1995; Greenstreet et al. 1997; Collins and McConnaughey 1998). Because all single-beam echo-sounder technologies insonify the seabed with only a single footprint, which is intermittently spaced, they do not provide total coverage of the seabed as in side-scan and multi-beam systems. Moreover, the distance between footprints varies depending on boat speed and the ping rate of the echo sounder, whilst the spread of the footprint itself is proportional to changes in depth. Such intermittent collection of QTC data may have accounted for some of the variability observed in our ground-truth data. Our study showed that QTC VIEW provided an effective method to predict substrata at survey stations and to determine whether our beam trawls had been towed over a number of distinct habitat types. It is likely that this heterogeneity is, in itself, an important habitat trait that may be an 'essential' characteristic of fish habitat. An indication of this habitat heterogeneity over which the trawl was towed may provide additional information to account for situations in which the composition of the total catch contains a broader range of species than expected. The results suggest that QTC VIEW is an effective proxy for the physical characteristics of seabed habitat, thus providing a potentially reliable and remote means to quantify habitat complexity.

Generally, the spread of Q1 and Q2 values for all classes, with the exception of class 4, were tightly packed. This suggests that these seabed types were acoustically homogeneous in their composition and not influenced by external acoustic noise. This finding was corroborated by the side-scan sonar mosaics produced for each study site that also indicated that the seabed was homogenous. Acoustic noise is often generated by changes in vessel speed, particularly when turning. However, during post-processing of QTC data, turning circles were removed from the dataset to minimise these potential effects. Class 2 (stations C27 and C30) had a much wider scattering of Q-values than any of the other classifications. From our previous experience using QTC VIEW, this tends to occur at relatively shallow water depths where there is a tendency for an increase in the reflectance and strength of the returning echo to the transducer, particularly if it has a narrow beam setting. Although C27 and C30 have a chart datum of between 19 and 20m, at the time of the acoustic survey depths were close to 14 m, which in our experience is close to the minimum conformable depth for QTC VIEW. The acoustic profile of Q1 values showed that the proximity of soft -sediment stations D79 and C213 were closely related (in acoustic terms) to the coarser sediment stations C49 and D245 (Fig. 4). This may be explained by the highly reflective properties of some soft sediments that are composed of tightly packed grains, which can emanate the acoustic properties of hard substratum by sending back a relatively strong echo to the transducer (Jackson and Briggs, 1992). Q1 components explain most of the variability in the PCA, although how much of this is described by this single component is unknown. It has been suggested that all the 3 components or Q-values describe >90% of the variability (B. Collins, QTC, Marine Technology Centre, 99-9865 West Saanich Road, Sidney, B.C. V8L 5Y8, Canada, personal communication).

Snelgrove and Butman (1994) noted that substrata alone were not universally accepted as the only factor to influence the distribution of bottom-dwelling organisms because of the inherent complexity of the benthic environment. Other environmental factors such as depth and tidal near-bed velocity have been shown to influence the distribution of many fish and epifauna species (Glemarec 1973; Tyler and Banner 1977; Warwick and Uncles 1980; Gibson and Robb 1992; Rogers 1992; Rosenberg 1995; Freeman and Rogers 2002). In the present study, PCA was used to show that station pairings that had similar acoustics characteristics, but were biologically distinct, differed in depth, near-bed water velocity and habitat complexity. The complimentary stations C213 and D79, for example, differed in near-bed water velocity and depth, whereas C30/D27 showed differences in habitat complexity and depth. Methods that either describe or predict patterns in benthic faunal demography using single factors such as sediment, however, are generally inadequate over broad spatial scale (Freeman and Rogers 2002). In the present study, when seabed substrata (derived from QTC data) were combined with information on habitat complexity, depth and near-bed water velocity, the characterisation of fish assemblages was more effective. Consequently, when detailed information on the spatial extent of seabed substrata is made available using an acoustic seabed discrimination system, e.g. QTC VIEW, it provides an important basis for subsequent environmental information to be overlaid. Habitat characteristics for fish and benthic fauna have been widely used to assess their habitat requirements and shown to be central to the understanding of their distribution and abundance (Spivak et al. 1994; Speich and Wahl 1995; Mezquita et al. 2000). To build on this information and provide a more effective management tool there is a need to quantify the spatial extent of benthic habitat and their resources, and an understanding of species interactions and with their environment. Our findings demonstrate that QTC VIEW can discriminate between different seabed substrata across a range of depths. Thus, QTC VIEW would appear to be a useful tool for large-scale mapping of broad-scale fish habitat characteristics. Such a map could provide a predictive basis for a stratified survey to ground-truth these acoustic properties. However, it is clear that QTC needs to be used in conjunction with a suite of additional sampling techniques (e.g. trawls, grabs and underwater video cameras) to elucidate finer-scale features (e.g. patches of gravel, emergent fauna) that may be critical in terms of their importance to fish. Ultimately, understanding the broad-scale distribution of benthic habitats is fundamental to the management of marine ecosystems as it provides a framework for evaluating changes in the environment resulting from the effects of human disturbance (Sotheran et al. 1997).

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Fig 1. The location of the eight distinct sites surveyed in the northern Irish Sea during August 2001
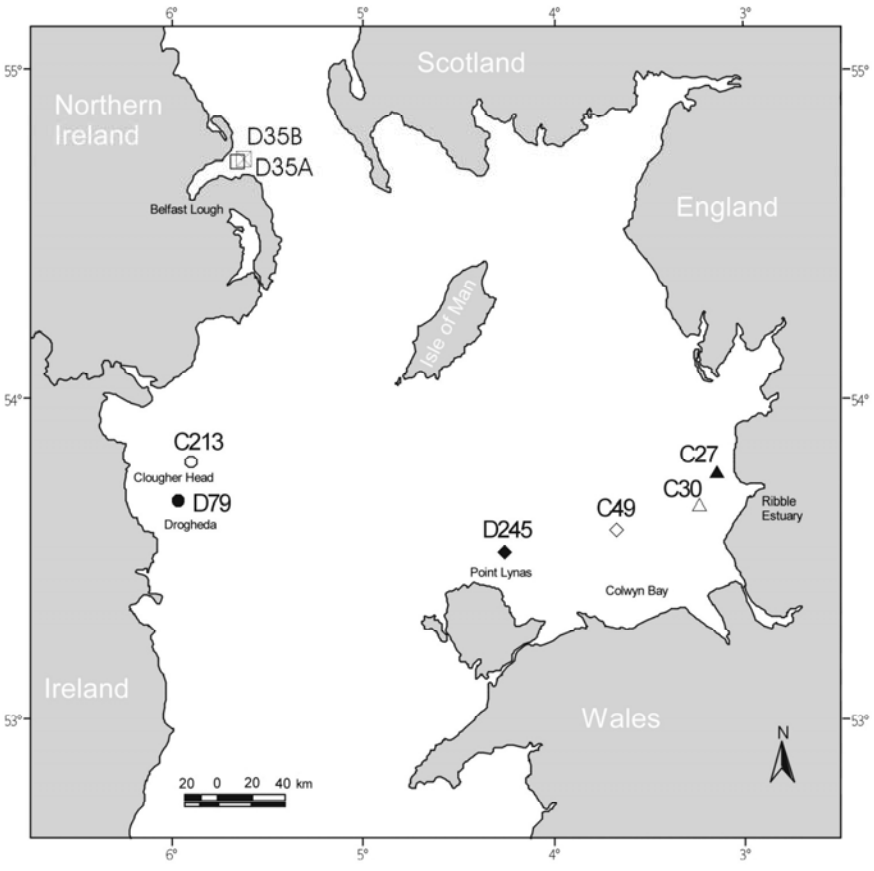
38

Fig 2. CLUSTER analysis and MDS plots of 2m and 3m beam trawl station groups for all sites surveyed in the northern Irish Sea. A) 3-m beam trawl fish abundance, B) 3-m beam trawl macro-epifauna abundance, and C) 2-m beam trawl macro-epifauna.
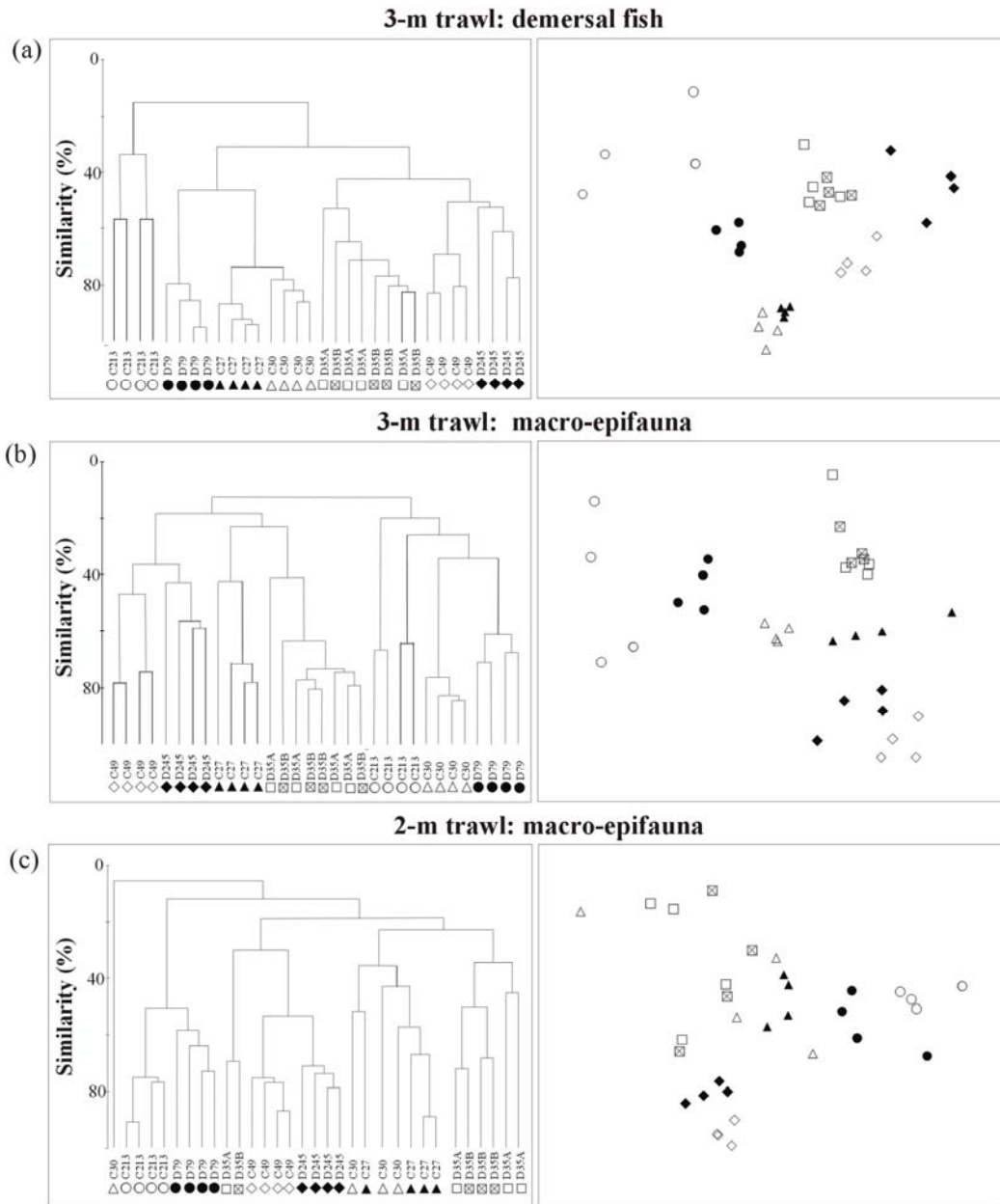

3-m trawl: demersal fish

(a)

3-m trawl: macro-epifauna

(b)

2-m trawl: macro-epifauna

(c)

Fig 3. The relationship between water depth, Q1 and Q2 values within Q-space as classified (classes 1-5) by the clustering software QTC IMPACT. Clouds of data show the spatial extent of each survey sites based on their acoustic similarity to each other.

40
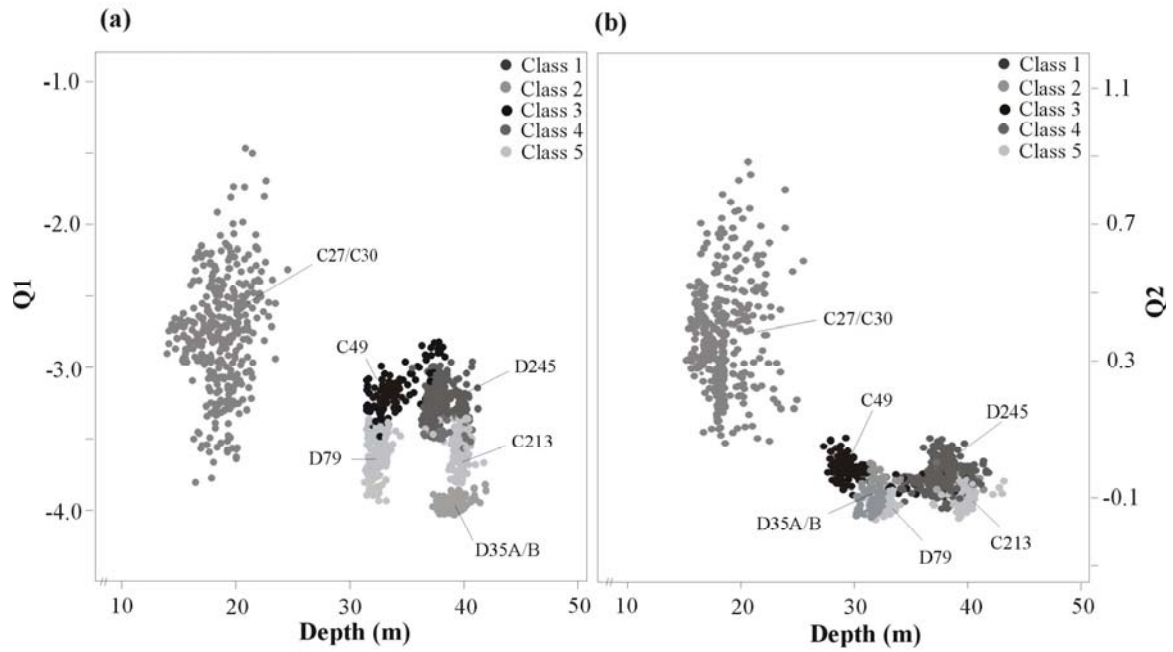
Fig 4. The distribution patterns of all survey stations based on principal component analysis of six physical characteristics of the seabed substrata; total shell weight (g), total stone weight (g), weight of *Lanice* tubes (g⁻¹), mean grain size, %<62μm grain size, and total % organic weight of Day grab samples. QTC classifications 1-5 for each station have been superimposed on the data. Arrows indicate the loading of each physical factor on the pc axes.
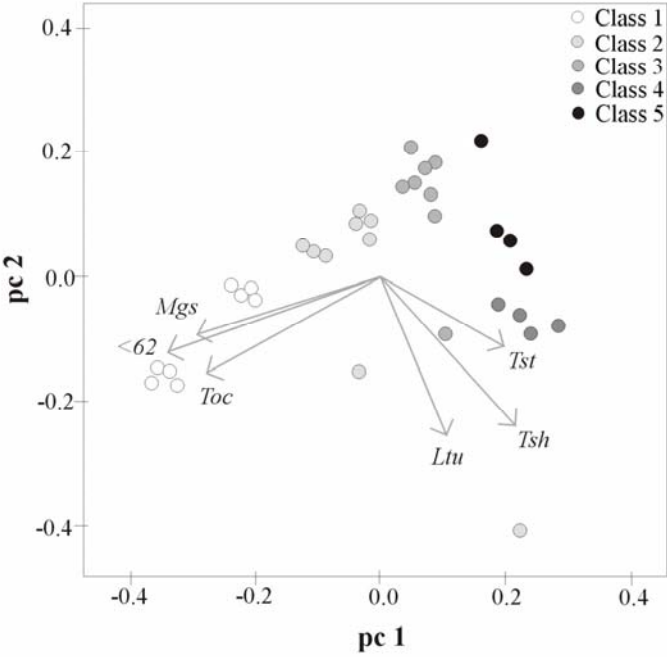
Fig 5. MDS plots of all 3-m and 2-m beam trawl station groupings for all station surveyed in the northern Irish Sea. QTC VIEW classifications (1-5) have been superimposed to denote their spatial extent in relation to each grouping. A) 3-m beam trawl fish abundance, B) 3-m beam trawl macro-epifauna abundance, and C) 2-m beam trawl macro-epifauna.

3-m trawl: demersal fish

3-m trawl: macro-epifauna

2-m trawl: macro-epifauna
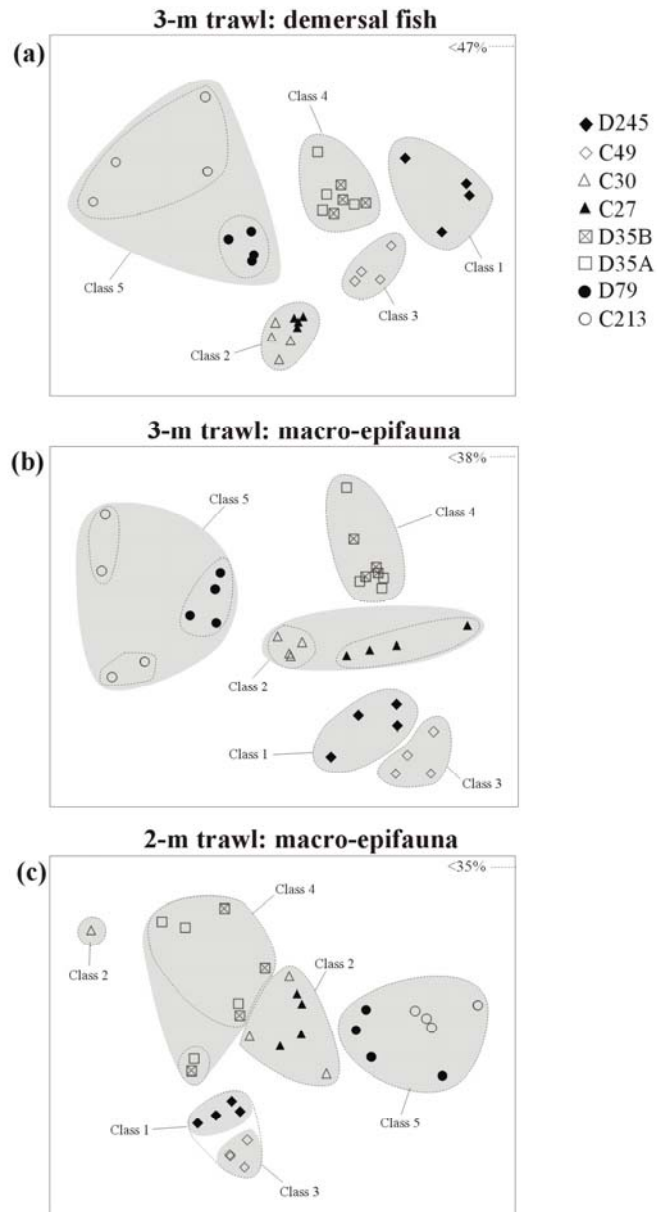
Fig 6. The distribution patterns of all survey stations based on principal component analysis of water depth, habitat complexity and tidal near-bed velocity. Arrows indicate the loading of each physical factor on the pc axes.
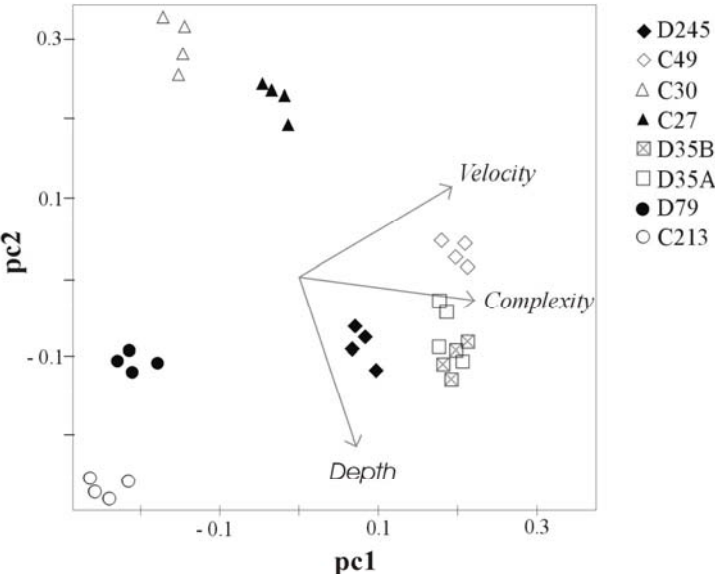
Table 1. Habitat complexity index values for each seabed feature identified using sidescan sonar, sediment characteristics of Day grab samples, and the weight (kg.h^{-1}) of stones and shells collected within a 2-m and 3-m beam trawl.

Gear:	Feature		Score
Sidescan	Smooth seabed		1
	Rough patches		2
	Bedforms		4
	Rough seabed		8
Day grab			
Sediment description	Mud		1
	Muddy sand		2
	Sand & shell		4
	Gravel, sand & stones		8
	Gravel, sand, stones & large shell		12
PSA	%<62μm	>20	1
		10-20	2
		0-10	3
	Tubes (g^{-1})	0	0
		1-3	1
		4-6	3
Beam trawl	Stone (kg.h^{-1})	0	0
		1-1000	3
		>1000	9
	Shell (kg.h^{-1})	0	0
		1-1000	1
		1000-2000	3
		>2000	7

Table 2. The contribution (%) of all fish species caught by a 3-m beam trawl to the Bray-Curtis similarity using the SIMPER analysis.

Species	Common name	Stations							
		fine sediment					*coarse sediment* ►		
		C213	D79	D35B	D35A	C27	C30	D245	C49
Glyptocephalus cynoglossus	witch	58	25	-	-	-	-	-	-
Lesueurigobius friesii	fries goby	5	-	-	-	-	-	-	-
Hippoglossoides platessoides	long rough dab	-	8	-	-	-	-	-	-
Eutrigla gurnardus	grey gurnard	-	8	-	-	-	-	-	-
Merlangius merlangus	whiting	-	5	8	-	-	-	-	-
Gadus morhua	cod	-	-	16	3	-	-	-	-
Trisopterus minutus	poor cod	-	-	3	-	-	-	5	-
Agonus cataphractus	hooknose or pogge	-	-	-	3	-	-	-	-
Aspitrigla cuculus	red gurnard	-	-	-	4	-	-	18	40
Callionymus lyra	dragonet	-	10	21	39	-	-	11	13
Limanda limanda	dab	16	14	11	9	30	38	-	5
Pleuronectes platessa	plaice	14	24	31	32	20	23	-	19
Buglossidium luteum	solenette	-	-	-	-	10	7	-	-
Trigla lucerna	tub gurnard	-	-	-	-	6	-	-	-
Scyliorhinus canicula	lesser spotted dogfish	-	-	-	-	1	-	59	-
Solea solea	common sole	-	-	-	-	15	19	-	8
Arnoglossus laterna	scaldfish	-	-	-	-	6	6	-	6
Total no. of species		4	7	6	6	7	5	4	6

Table 3. Physical habitat characteristics of all sites surveyed in the northern Irish Sea.

Habitat characteristics	○ C213	● D79	□ D35A	⊠ D35B	▲ C27	△ C30	◆ D245	◇ C49
Depth (m)	40	33	37	39	19	20	39	32
Water velocity (m.s^{-1})	0.3	0.4	0.7	0.7	0.7	0.6	0.7	0.7
Stones (g)	0	0	902	935	0	0	7238	0.0
Shells (g)	0	195	1360	3925	39	17	4897	4632
M.grain.size	2.5	2.4	2.1	2.2	1.4	1.2	0.2	-0.1
% <62μm	27	19	11	5	0	1	1	1
% Organic Carbon	7	4	3.4	2	1	1	2	2
Lanice.tubes.(g^{-1})	0	0	1	6	5	1	0	0
QTC classes	5	5	4	4	2	2	1	3
Sediment descriptions	Mud	Mud	Muddy sand, shell, stones	Muddy sand, shell, stones	Sand, shell	Sand, shell	Gravelly sand, large shell	Gravelly sand, shell, stones
Sidescan features	Smooth, uniform	Smooth, uniform	Uniform, some rough patches	Uniform, some rough patches	Bed forms, shallow relief	Bed forms, shallow relief	Rough seabed, bed forms	Smooth seabed
Habitat complexity	3	5	12	18	12	13	39	19

46

Table 4. The contribution (%) of all macro-epifauna species caught by a 3-m beam trawl to the Bray-Curtis similarity using the SIMPER analysis.

| Species | Common name | Stations | | | | | | | |
| | | fine sediment | | | | | coarse sediment | | |
		C213	D79	D35B	D35A	C27	C30	D245	C49
Cancer pagurus	edible, brown crab	21	-	4	-	-	-	-	-
Aphrodita aculeata	sea mouse	-	16	-	-	-	-	-	-
Neptunea antiqua	red whelk	-	3	-	-	-	-	-	-
Alcyonium parasiticum	bryozoan	-	-	8	-	-	-	-	-
Suberites spp.	sponge	-	-	4	-	-	-	-	-
Metridium senile	plumose anemone	-	-	10	13	-	-	-	-
Liocarcinus depurator	swimming crab	-	14	8	24	6	-	-	-
Astropecten irregularis	sand star	-	16	-	-	9	14	-	-
Flustra spp.	hornwrack	-	-	21	19	-	-	-	-
Emergent Bryozoa/Hydrozoa		-	-	14	6	-	-	10	-
Alcyonium digitatum	dead men's finger	-	-	6	9	-	-	-	3
Asterias rubens	common starfish	79	25	17	10	37	21	13	14
Pagurus bernhardus	hermit crab	-	18	-	10	9	16	7	-
Echinocardium cordatum	sea potato	-	-	-	-	6	-	-	-
Philine aperta	ophistobranch	-	-	-	-	6	8	-	-
Ophiura albida	brittlestar	-	-	-	-	18	21	-	8
Buccinum undatum	common whelk	-	-	-	-	-	9	11	12
Psammechinus miliaris	sea urchin	-	-	-	-	-	5	7	6
Crossaster papposus	sun star	-	-	-	-	-	-	13	-
Aequipecten opercularis	queen scallop	-	-	-	-	-	-	14	26
Henricia oculata	bloody henry	-	-	-	-	-	-	-	2
Modiolus modiolus	horse mussel	-	-	-	-	-	-	-	2
unidentified Ascidians	sea squirt	-	-	-	-	-	-	-	3
Hyas spp.	spider crab	-	-	-	-	-	-	-	4
Ascidiella aspersa	sea squirt	-	-	-	-	-	-	-	3
Ophiothrix fragilis	brittlestar	-	-	-	-	-	-	-	10
Alcyonidium diaphanum	sea chervil	-	-	-	-	-	-	-	5
Pagurus prideaux	hermit crab	-	-	-	-	-	-	-	5
Total no. of species		2	6	9	7	7	7	7	14

47

Table 5. The contribution (%) of all macro-epifauna species caught by a 2-m beam trawl to the Bray-Curtis similarity using the SIMPER analysis.

Species	Common name	Stations fine sediment C213	D79	D35B	D35A	C27	C30	coarse sediment D245	C49
Nephrops norvegicus	Norway lobster	98	74	-	-	-	-	-	-
Crangon allmanni	shrimp	-	5	-	-	-	-	-	-
Flustra foliacea	hornwrack	-	-	15	12	-	-	-	-
Securiflustra securifrons	bryozoan	-	-	20	12	-	-	-	-
Liocarcinus depurator	swimming crab	-	-	-	48	-	-	-	-
Metridium senile	plumose anemone	-	-	-	7	-	-	-	-
Ophiura albida	brittlestar	-	-	-	15	-	25	-	-
Pagurus bernhardus	common hermit crab	-	-	-	-	-	11	-	-
Asterias rubens	common starfish	-	14	31	-	90	50	8	3
Emergent Bryozoa/Hydrozoa		-	-	27	-	-	-	12	-
Astropecten irregularis	sand star	-	-	-	-	-	7	-	-
Aequipecten opercularis	queen scallop	-	-	-	-	-	-	15	30
Psammechinus miliaris	sea urchin	-	-	-	-	-	-	35	8
Alcyonium digitatum	dead men's finger	-	-	-	-	-	-	-	51
Pagurus prideaux	hermit crab	-	-	-	-	-	-	4	-
Buccinum undatum	common or edible whelk	-	-	-	-	-	-	4	-
Crossaster papposus	sun star	-	-	-	-	-	-	9	-
Echinus esculentus	common sea urchin	-	-	-	-	-	-	5	-
Total no. of species		1	3	4	5	1	4	8	4

48