STRANGFORD LOUGH ECOLOGICAL CHANGE INVESTIGATION (SLECI)

Work Package 1.
Nature and extent of community change within Strangford Lough

1.2
SUBTIDAL SURVEY

1.2.1
Broadscale Mapping of Strangford Lough's Subtidal Habitats: The Application of an Evolving Technology

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Contents

1 Introduction

Knowledge of benthic habitats and associated marine life (biotopes) is fundamental to marine resource management, and an integrated approach to marine stewardship. In 1998, the Oslo and Paris Commission (OSPAR) recognised the need to assess which marine habitats required protection, through the production of an inventory of habitats. Further drivers for such habitat studies have come from the increasing development of mariculture, the implementation of the EC Habitats Directive, the EC Water Framework Directive and the move towards ecosystem- based fisheries management.

Subtidal broadscale habitat mapping represents an amenable method of surveying the spatial extent and area of habitats, and may also contribute towards an assessment of species composition and overall habitat structure. As such, broadscale mapping may contribute towards a monitoring programme. Modern acoustic remote sensing technologies such as RoxAnn™ Acoustic Ground Discrimination System (AGDS) (Marine Microsystems Ltd. / Stenmar Sonavision Ltd.), along with GIS (Geographical Information Systems) allow the production of broadscale habitat maps at a relatively low cost and improved spatial coverage compared with traditional survey techniques involving direct point sampling, such as grabs or diver surveys, used in isolation.

It should be emphasised that broadscale habitat maps represent a first stage in subtidal habitat investigations and their place is in giving an overview of habitat distributions and heterogeneity over large areas to facilitate further detailed surveys that can allow mapping of precise boundaries and investigate habitat condition. AGDS-based mapping can be conducted at a relatively low cost in comparison to other methods and can be completed in difficult environments to give continuous coverage maps over extensive areas. When AGDS data is combined with other survey methods the combination may be effective and powerful.

This project aimed to produce a broadscale map for Strangford Lough (excluding the Narrows, which have been previously mapped with some difficulties due to high water movement and turbulence). There have been a number of previous mapping efforts, ranging from diver-based surveys (Roberts, 1975; Erwin, 1977; Erwin *et al*., 1986; Brown, 1989), remotely operated vehicle (ROV) video surveys (Service, 1990) and AGDS surveys (Magorrian *et al.,* 1995; Mitchell and Service, 2004). The present study attempts to map habitats in areas that have previously been unsurveyed and present a consistent overview of the subtidal environment of the lough. Comparison will be made between the habitat distribution trends revealed by the current work and previous maps.

1.1 Mapping scale

The scale at which habitat mapping is undertaken is an important consideration. Generally, subtidal mapping encompasses the meso and macro habitat scales (1m to 1km; see figure 1 below), which includes at the lower end of the scale for structures such as horse mussel (*Modiolus modiolus*) clumps and at the upper end of the scale for entire rocky reefs. The scale chosen for habitat mapping represents a compromise between the need for detailed maps and the available survey resources. In the case of this project, broadscale mapping is being undertaken, with a map pixel size of $20m^2$, which reflects the average resolution of the survey techniques employed. Within each pixel all habitats are averaged. In the case of RoxAnn acoustic ground discrimination surveys, the echosounder transducer beam width, angle, shape, water depth and survey track spacing all have implications on survey resolution. Discrete habitats that occur on a scale that is less than the area of the echosounder footprint will be averaged with other habitats within the footprint.

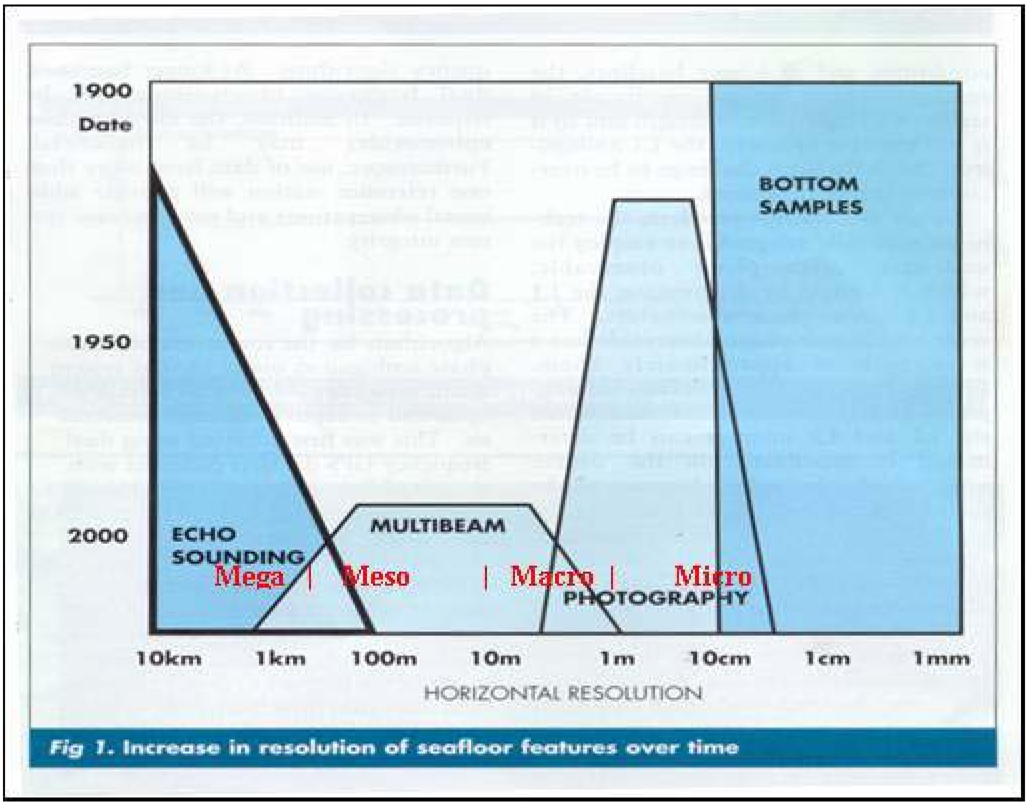

Figure 1. Habitat scale in relation to habitat survey approaches 1900 to present.

1.2 Habitat classification approach

Habitats may be defined as 'spatially recognisable areas where the physical, chemical and biological environment is distinctly different from surrounding environments' (Valentine *et al*., 2003). The way in which habitats are defined practically depends largely upon available data and spatial scale, but also on the purpose for which they are defined. This flexibility of delimitation has influenced the development of habitat classification schemes.

Within the UK, a major approach to describing seabed habitats within an area is through the assignment of biotopes, which may be defined as "distinguishable communities based on a series of biological and physical parameters" (Connor *et al*., 1997). Such a methodology has been developed by the Joint Nature Conservation Committee's Marine Nature Conservation Review (MNCR) and BioMar (University of Newcastle). The areas of subtidal biotopes may range over several scales, and although the main basis for classification is biological (community structure as identified from species present and their abundances), it is assumed that the physical environment plays a major role in their distribution. In the case of the hierarchical MNCR classification 'exposure' or energy regime and major substrate type (mud, muddy sand, gravel sands and rock) are the physical parameters used to structure the biological classifications. Of the many physical parameters known to influence benthic species distribution, sediment structure has been shown to exert a major community-structuring influence within a restricted geographical area. Therefore, sediment properties may be used as a basis for habitat classification. Boat-based acoustic systems indirectly measure sediment properties, such as substrate roughness and hardness, which can then be used to map seafloor habitat distributions.

2 Methodology

The field survey comprised two distinct, but interrelated, stages. The first involved the use of boat-based acoustic systems to discriminate between different seabed types, while the second involved the use of ground-truthing techniques such that different habitats could be identified and related to seabed acoustic properties.

The successful use of the RoxAnn™ acoustic ground discrimination system for broadscale habitat mapping is widely documented in literature (Greenstreet *et al*, 1997; Magorrian *et al*, 1995; Foster-Smith *et al*, 2000). By connecting RoxAnn™ (a hydro-acoustic processor) to the transducer of a conventional echosounder, two parameters of the seabed can be derived and recorded: E1 and E2. E1 is an integration of the tail of the first seabed echo and is taken to indicate seabed roughness. E2 is an integration of the whole of the second return echo and provides an index of seabed hardness (for further details see Chivers *et al,* 1990). The E1:E2 values are plotted on an (x/y) grid, which is partitioned into different user-defined coloured regions (boxes), with each colour representing a different 'ground-type'. This method is explained in additional detail in Magorrian *et al.* (1995). RoxAnn gives point data along survey tracks, with the spacing between points controlled by the speed at which the vessel is travelling (usually 5–8 knots) and the data save rate (routinely set to 1s intervals). As such, a degree of interpolation between points is necessary in order to give continuous coverage of the seabed.

A RoxAnn™ acoustic ground discrimination survey was completed over four days starting 10th June 2003 aboard the FPV *Ken Vickers* (Skipper: Davy Eccles; Surveyor: Annika Mitchell). The RoxAnn system used consisted of a

200kHz transducer with a Stenmar Groundmaster™ signal-processing unit and a dGPS (differential Geographical Positioning System) interfaced with a laptop logging data using RoxMap™ software. Data was saved at 1s intervals, such that 85,000 datapoints were recorded over the survey. Tracks were completed at an average spacing of 200m, with depths as shallow as 4m covered (areas that have not previously been RoxAnn surveyed).

Protocols for the analysis of RoxAnn data detailed in Foster-Smith *et al* (2000) were followed. A brief summary is given below. The RoxAnn dataset was exported from RoxMap and split into five spreadsheets due to the large size of the dataset so that it could be edited and examined within Microsoft Excel. The data was cleaned with respect to depth spikes and 'sticking' of E1, E2 and depth values that occurred occasionally when the boat was turning. No positional jumps were present in the data. For each survey days' dataset, E1 and E2 values were standardised by dividing the raw data by the 95th percentile. An along-track variability index was calculated for E1 and E2 values and the entire dataset amalgamated in Surfer (Golden Software, Inc.). The relationships between E1 and E2 and these variables with depth were examined graphically. There was no significant relationship between either variable and depth which deems the data acceptable for further analysis. Depths were tidally-corrected to the nearest port, using ten-minute tidal intervals, to chart datum (using TotalTide tidal prediction software). Note should be made that depth data gathered should not be used for navigational purposes, due to limitations in the tidal-corrections of such data. Positions were converted into Irish National Grid using Geocalc software.

Variograms from each day's survey dataset were produced in Surfer using E1 and E2 values. The variance within these variables appears to level off at a distance of 200-400m between points, which indicates the maximum interpolation distance possible if interpolation is to give more information than simply the local mean. The variables depth, E1, E2, and variability index were interpolated throughout the survey area using Inverse Distance Interpolator to a power of 2 within Surfer, with a specified search radius of 300m and pixel size of 20m. Interpolation girds were 'blanked' using a blanking file that represented areas of islands, coastline and shallow water areas (submerged 'pladdies') to prevent interpolation over such features. The final interpolated grids were then imported into Idrisi (Clark Labs) where raster images of each grid were created, with values stretched between 0-255. Composite images of two combinations of the variables were then produced (A: E1, E2, depth; B: E1, E2, variability index). A collection of all four variables was created and this was used in the unsupervised classification of the data. The ISOCLUST routine in Idrisi was used to produce unsupervised cluster maps for the survey area. 10 clusters were chosen as a nominal starting point (relating to 9 ground-types and 1 for the unsurveyed area), as indicated from the histogram of composite pixel values, using the composite image A as the seeding image. This cluster image was then converted into a vector polygon file and exported as a Shapefile. This was then imported into ArcMap 8.3 Geographical Information System (ESRI) and presented along with the original track data and positions of the video tows and dive sites that form the ground-truthing. Upon the basis of this cluster map and previous knowledge of the marine habitats of Strangford Lough, suggestions were made to the SLECI dive team regarding site choice for the sublittoral diving survey, in order that the team surveyed a representative number of ground-types.

The information gathered from the SLECI diving survey was used as ground-truthing data to allow a supervised classification of the RoxAnn data. A total of 85 dive site videos were analysed to provide a good spatial coverage of ground-truthing data. The first five minutes of clear video footage was used from each dive, which could be related to a buffered area around the dive entry position, which was accurately recorded by dGPS. The 100m transect dives were treated in the same manner as the spot dives due to video coverage limitations. Video was analysed with respect to a sediment description (based upon the Folks triangle), note was made of any additional bedforms (e.g. ripples, megaripples, heavy bioturbation), topography, faunal and floral groups and, where adequate detail permitted, faunal and floral species. This was then classified initially into Erwin's (1977) communities, and then further classified on the basis of habitats that are easily distinguished from the video footage and that are likely to have a distinct acoustic signature (i.e. Can be detected by RoxAnn AGDS by influencing the return echo). RoxAnn cannot distinguish habitats that occur at scales smaller than the echosounder footprint, and therefore each five-minute segment of diver video was classed into only one main / dominant habitat. The video sections could often be subdivided into patches of various habitats but RoxAnn would not have detected such heterogeneity. Notes on substratum, characterising flora, and characterising faunal species (divided into faunal groups) were stored in database (MS Access) and habitat designations added after all the information had been collated. The habitats identified were then assigned corresponding biotope complexes and/or biotopes, based upon the Marine Nature Conservation Review biotope classification scheme (Connor *et al.,* 1997).

Supervised classification is a three-stage procedure and the following steps were followed:

a) 'Training sites' are determined for use in acoustic signature development (see stage b). This is based on ground-truthing data, which is classified accordingly. Training sites are digitised in a GIS around areas of each dive entry position where each habitat was recorded. Allowance is made for positional uncertainty and a small buffer zone was included to ensure sufficient data was included within each habitat class.

b) The training sites are used to develop acoustic signatures for the RoxAnn data set within *Idrisi*, which calculates the mean and range for each of E1, E2, acoustic variability and depth for each habitat. This is undertaken within the software by positionally overlaying the training sites with the appropriate raster images and recording the mean and range of pixel values beneath each training site and storing this data as signature files.

c) A pixel classification method is then applied to the collection of raster images. Maximum likelihood classification was chosen as the classification method as it is universally acclaimed as the most satisfactory method (Bailey and Gatrell 1995, Wilkie and Finn 1996, Eastman 1997). The Maximum Likelihood classification is based on the probability density function associated with a particular training site signature (Eastman, 1997). The acoustic signatures are used to calculate the likelihood of pixel membership to each seabed category. Each pixel is then classified to the habitat it is most likely to belong to. The resulting final raster map is converted into a vector polygon file and exported from Idrisi as an ESRI shapefile. The map was presented in ArcMap 8.3 GIS (ESRI).

Within the GIS the map was examined by overlaying the original acoustic survey track data and the positions and details of the ground-truthing surveys, in addition to adding a coastline. A digital admiralty chart was also used to help verify the maps. The GIS was used throughout the development of the map, especially in aiding the habitat classification process where the ground-truthing data was overlaid upon the unsupervised cluster maps. The final map is best viewed with such associated data, as this gives a clear spatial indication of the raw data that the map is generated from and highlights where areas of uncertainty may lie.

In order to assess the accuracy of the supervised classification approach an error matrix was created within Idrisi which compares the ground-truthing / training-site pixels with the corresponding final map pixels and calculates how many agree in terms of habitat class. Using this error matrix it is possible to ascertain which habitat classes are most readily confused with one another in the classification process. The error matrix for the 2003 Strangford Lough map is provided in the results section below.

The 2003 map was compared with the existing 1993 and 2000 broadscale maps of the Lough central area (each based on RoxAnn AGDS surveys; reported in EHS report January 2004) within the GIS. Comparison is also made with previous mapping efforts (from ROV and diver surveys). Due to differing methodologies, precise habitat areas cannot be compared, but general habitat distribution trends are addressed and the accuracy of the broadscale maps (1993, 2000 and 2003) is also discussed.

3 Results and Discussion

3.1 Habitat classification

The 2003 dive video data was classified into 10 habitat categories (see table 1). This classification is compatible with classifications used in the 1993 and 2000 broadscale habitat maps, with the exception of one category, the 'mud with shell' habitat, which could not be distinguished from the towed video ground-truthing used in the production of the 1993 and 2000 maps. This was due to high densities of dead shell appearing similar to scattered clumps of living *Modiolus modiolus*, and only diver inspection could distinguish between the two (especially as dead shells were frequently intact and filled with sediment, and the dead shell also harboured a high diversity of epifauna). This introduction of an additional habitat category obviously impairs direct comparison between the 1993, 2000 and 2003 maps: this issue is addressed below.

Table 1. Habitat categories identified from video data for broadscale habitat maps (1993, 2000 and 2003) known as 'acoustic habitats' and their relationship to Erwin's 1977 communities and the JNCC / MNCR biotopes and biotope complexes.

Erwin 1977 Community	**Acoustic Habitat**	**JNCC Habitat Classification**
Boulder community	Rubble (cobbles and boulders) **RU**	CR.LCR.BrAs.AmenCio.Ant; CR.LCR.BrAs.LgAsSp; CR.LCR.BrAs.AntAsH
Cobbles community	Rubble (cobbles and boulders) **RU**	SS.IGS.ScupHyd
Coarse sand community	Coarse sediments (sand and gravel) **CS**	SS.CGS; CR.MCR.EcCr.FaAlCr.Bri (pebbles, no cobbles)
Muddy sand community	Muddy sand **MS**	SS.CMS.AfilEcor
Clean sand community	Coarse sediments (sand and gravel) **CS**	SS.CGS.Ven.Neo
Fine mud/sand community	Mud (not burrowed) **MU**	SS.CMS.VirOph; SS.IMX.FaMx.An; SS.IMU.AreSyn; SS.IMU.PhiVir (no *Philine aperta*)
Fine mud community	Mud with burrows **MU_Burrows**	SS.CMS.SpMeg
Mud and shell community	Modiolus community 1 (dense clumps) **MM_1**	CR.SCR.ModCVar; CR.SCR.ModHAs
	Modiolus community 2 (sparse, scattered clumps) **MM_2**	SS.CMX.ModHo, damaged CR.SCR.ModCVar & CR.SCR.ModHAs
2003 only -	Mud with shell (>70% shell) **MU_Sh**	scattered SS.CMX.ModHo; SS.IMX.An

Habitat descriptions are provided below:

- Rubble (cobble and boulder substrates): Such substrates were found near pladdies or in the lower lough, and were often mixed with softer sediments. This represents lag left behind when the drumlins were eroded during the post-glacial ice transgression. This habitat is acoustically distinct because the interstices are not filled with sand and shell. This gives a high return in terms of both roughness and hardness. Epifauna includes tall hydrozoan and bryozoan turf, *Alcyonium digitatum* and *Metridium senile.* In the infralittoral zone *Laminaria* species were common with diverse foliose red algae.

- Coarse sediments with mud: Generally muddy sand with large amounts of shell debris (whole or comminuted) and pebbles or cobbles on the sediment surface. This represents lag partially infilled by sand, muds and shell. Acoustically this habitat produces a moderate roughness return and a moderate-low hardness return. Towards the south of the surveyed area coarse sediments included a larger proportion of gravel and sand (possibly due to the increased strength of tidal currents that winnow away the finer sediments). Common epifauna include *Ascidiella aspersa, Cerianthus lloydii, Liocarcinus depurator, Asterias rubens, Echinus esculentus, Pagurus bernhardus* and more occasionally *Buccinum undatum, Ophiura albida* and *Aequipecten opercularis*. Brittlestar beds are also common on this substrate, with *Ophiothix fragilis* and *Ophiocomina nigra* frequently occurring at densities of greater than 50 individuals per square meter.

- <u>Muddy sand:</u> Sand mixed with finer sediments and comminuted shell debris, generally showing lower species diversity than the coarse sediments with mud. Acoustically the signal is typified by low roughness and moderate to low hardness. This habitat occurs in areas of weak near-bed currents. *Pagurus bernhardus, Buccinum undatum, Liocarcinus depurator* and *Ascidiella aspersa* common.

- <u>Mud (not burrowed):</u> Fine sediments showing little evidence of bioturbation and having a low abundance of macrofauna. Such habitat represents areas of sedimentary deposition, and occurs typically in stable areas with low near-bed shear stress. Acoustically this habitat returns very low roughness and hardness signals.

- <u>Mud with burrows:</u> Mud and muddy-sand sediments, with occasional shell debris, showing extensive evidence of bioturbation by megafauna largely in the form of *Nephrops norvegicus* and *Calocaris macandreae* burrows. In acoustic terms, the uneven surface created by the burrows gives a higher roughness return than the preceding mud habitat, and also returns a slightly higher hardness signal possibly due to the cementing of burrow walls. Other common epifauna include *Turitella communis* and the burrowing crab *Goneplax rhomboids.*

- <u>*Modiolus* community 1 (dense clumps):</u> The clumps subhabitat represents the climax *Modiolus* community, where the mussels form a complex three-dimensional structure on generally featureless mud or muddy-sand sediments. The mussels may be semi-infaunal (partially buried in the sediment) and form aggregates linked by byssus threads. Within the clumps large accumulations of faecal mud and shell debris (whole and comminuted) build up surrounding the living animals, which is bound by the byssus threads. The clumps provide anchorage, shelter and a food source for a wide diversity of epifauna, including *Antedon bifida, Alcyonium digitatum, Ascidiella aspersa, Chlamys varia, Aequipecten opercularis, Ophiocomina nigra, Ophiothrix fragilis, Munida rugosa, Inachus* spp., *Carcinus maenas* and *Liocarcinus depurator*. Such clumps may be considered as biogenic reefs, as they may accumulate up to approximately 50cm above the surrounding sediment. Detailed discussion of the Strangford Lough *Modiolus* communities are provided in Roberts (1975). In general, 'dense clumps' could be recognised from ground-truthing by the height of the clumps (exceeding 20cm above the surrounding sediment) and the density of the clumps (at least one aggregation per 1 m^2). Acoustically this results in a moderate to high level of roughness and moderate to low hardness (dense epifauna softens the return signal despite the hardness of the shell).

- <u>*Modiolus* community 2:</u> A *Modiolus* subhabitat characterised by scattered living and dead *Modiolus* with few aggregations of animals (less than one clump per $1m^2$), low elevation of any clumped mussels above the surrounding sediment, and is frequently characterised by large amounts of dead shell (mainly *Modiolus*; both whole shells and comminuted) on mud or muddy-sand sediments. Such areas may be the result of physical disturbance to *Modiolus* clumps, such as trawling activity. Acoustically, this subhabitat returns a lower level of roughness by comparison to *Modiolus* community 1, but similar or slightly higher hardness. The *Modiolus* predator *Asterias rubens* may be common in such areas.

- <u>Mud with dead shell:</u> Accumulations of whole and comminuted shells (largely *Modiolus*) overlying muddy substratum. This habitat gives a varied acoustic return, as it is heterogeneous habitat, but in general shows moderate levels of both roughness and hardness. No living *Modiolus modiolus. Asterias rubens, Antedon bifida, Liocarcinus depurator, Suberites carnosus, Hydrallmania falcata* and *Buccinum undatum* frequent.

3.2 Raw data: Comparisons between 1993, 2000 and 2003

The raw data upon which a map is based must be presented in order to facilitate a good understanding of the final 'interpreted' habitat map. As comparisons are to be made between the 1993, 2000 and 2003 broadscale habitat maps, the RoxAnn survey track data, ground-truthing positions and habitat designations are provided for each survey in figures 2a, 2b and 2c respectively below.

RoxAnn survey track spacing and 'squaring off' of track turns has implications for the final habitat map due to the effects it has on interpolation of data in between the tracks. In the 1993 survey (figure 2a) the tracks were not all squared off and the track spacing varied throughout the survey area from 100m spacing up to 900m. In areas where track spacing is wider (mainly in the southern lough) there is less real (raw) data for interpolation to be based upon, resulting in greater uncertainty in the habitat designations of such areas. It is also more likely that discrete habitats in between the tracks may occur that were not detected. In 1993, however, there was excellent coverage of ground-truthing (much of which was completed in parallel with the RoxAnn survey allowing 'real-time' ground-truthing). In the 2000 survey (figure 2b), there was greater coverage of RoxAnn tracks, with spacing consistently between 200 and 300m throughout most of the lough except in some areas in the south of the lough where spacing was wider. The survey tracks were squared off throughout the lough, however ground-truthing was less spatially extensive in 2000, and additional video tows from December 2000 and 2002 had to be used to ground-truth the lower lough. In particular, there was a lack of ground-truthing in known areas of *Modiolus modiolus* (identified from previous diving surveys, e.g. Erwin *et al.,* 1986), which may influence the acoustic signature development for the *Modiolus* habitats and have implications for the final habitat map. In 2003 (figure 2c), there was a consistent track spacing of 200-250m throughout the lough, extending into previously unsurveyed areas of the lough. Ground-truthing was quite extensive, although there is a lack of ground-truthing just south of Mahee Island and in the southern central basin (again, December 2000 and 2002 videos had to be used to provide additional ground-truthing in this area). Ground-truthing of *Modiolus*-related areas in 2003 was extensive (as determined from previous maps and records).

Figure 3 below shows a summary of the RoxAnn data collected over the same survey area (clipped to a common area) for the three survey years. The variation between each year is notable but not surprising as each survey did not cover the same tracks and the RoxAnn systems are known to drift in terms of voltage outputs. In addition, the 1993 survey was completed using a 50kHz transducer while both the 2000 and 2003 surveys were completed using a 200kHz transducer. What is most notable is the number of raw datapoints available for interpolation over the same area. The number of datapoints is much greater in 2003 than in previous years, and is lowest in 2000. This would suggest immediately that as there is more data available in 2003 to build acoustic signatures from that this resulting map would be more reliable. Figures 2-3 also demonstrate the substantial differences between the three surveys (which were designed for separate purposes), which confounds any direct and meaningful comparison between resulting habitat maps except for an overall examination of habitat trends.

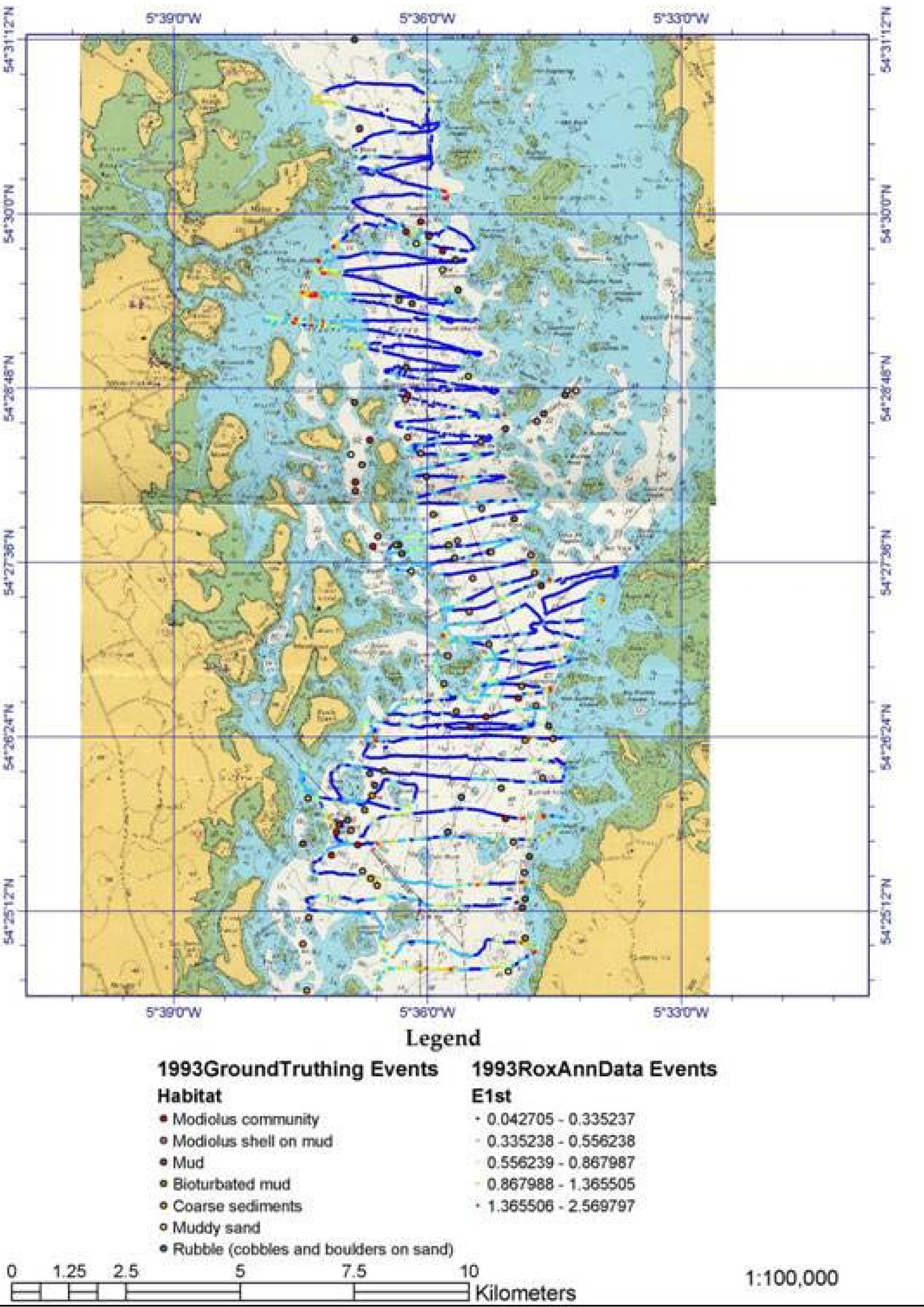

Figure 2a. 1993 RoxAnn survey tracks (coloured according to roughness, or E1) and ground-truthing positions from towed video (classed into habitats; see below).

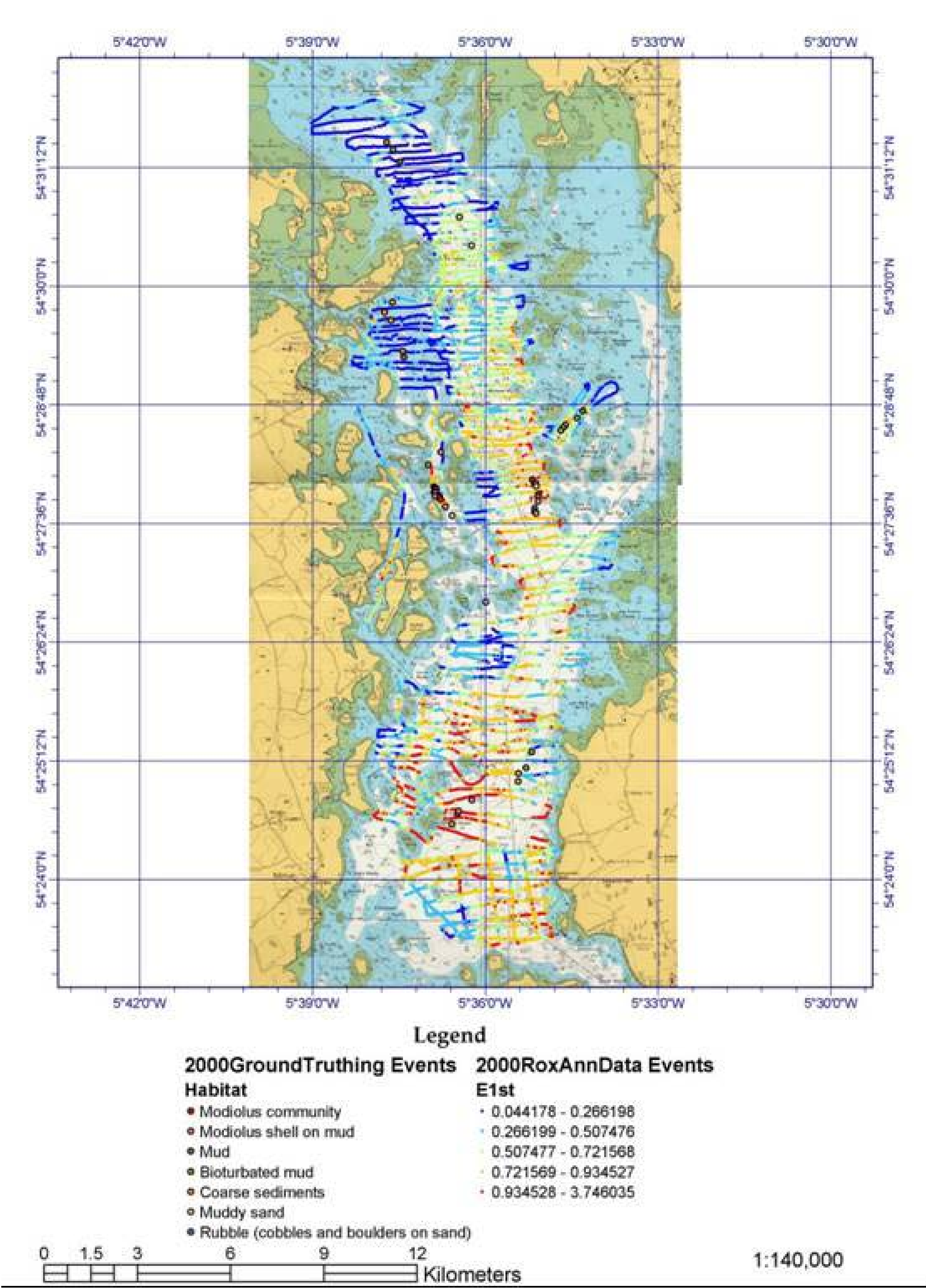

Figure 2b. 2000 RoxAnn survey tracks (coloured according to roughness, or E1) and ground-truthing positions from towed video (classed into habitats; see below).

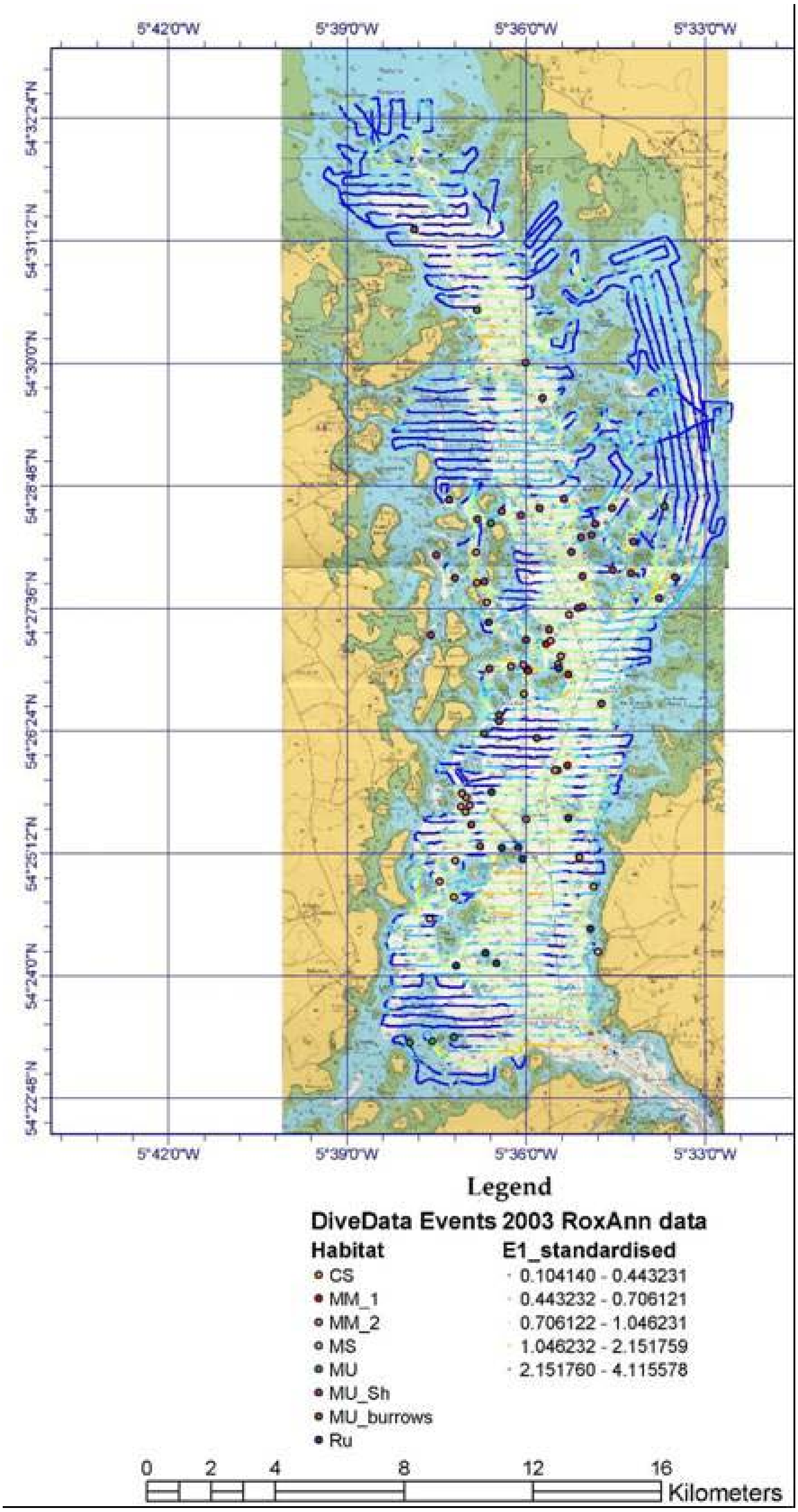

Figure 2c. 2003 RoxAnn survey tracks (coloured according to roughness, or E1) and ground-truthing positions from towed video (classed into habitats; see below).

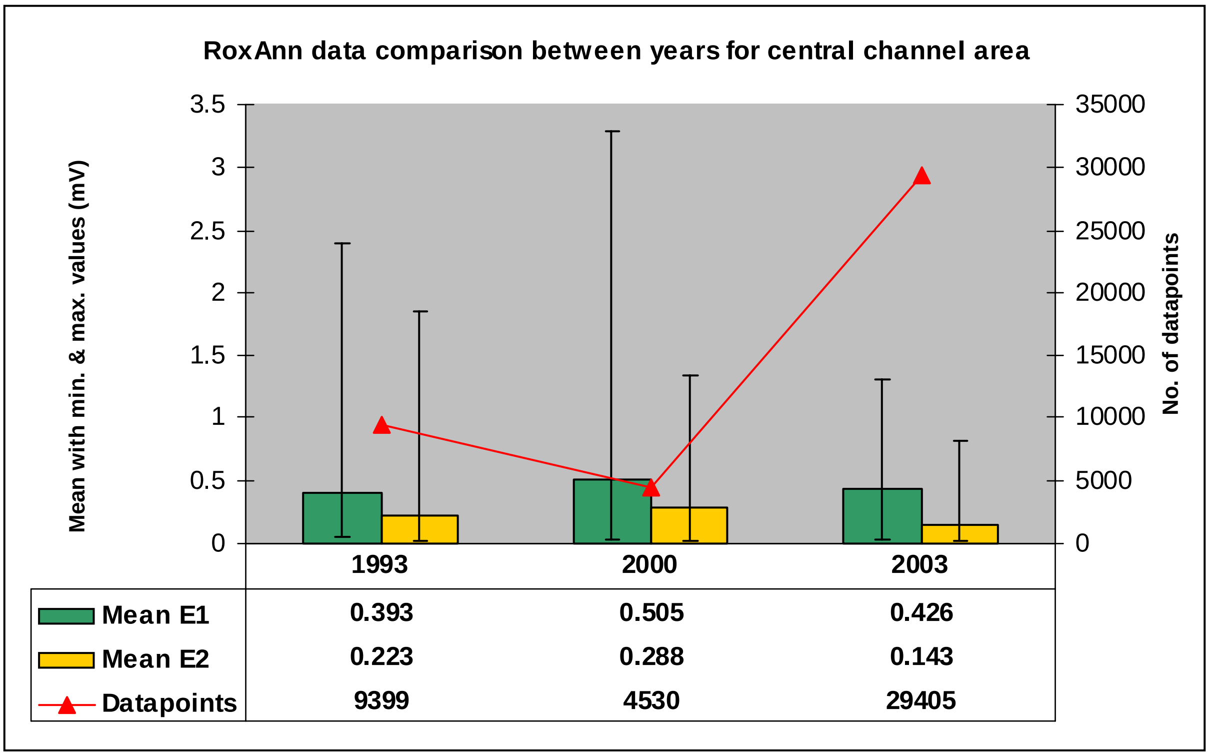

Figure 3. Chart depicting raw RoxAnn E1 and E2 values and datapoint density for the 1993, 2000 and 2003 RoxAnn surveys for the same clipped area (central channel).

3.3 2003 Broadscale Habitat Map: Predicted habitat distributions

Figure 4 below shows a general bathymetry for Strangford Lough based upon the RoxAnn data collected for this project, and also shows place names referred to in the text. Detailed island and pladdy polygons are not available and hence the bathymetric data is erroneous in such areas; the user is encouraged to use the relevant Admiralty chart to identify these complex topographies.

The 2003 final habitat map (figure 5) shows a number of general trends in habitat distribution that are in line with existing local knowledge and previous survey reports (e.g. Service, 1990 fished species distributions, Erwin, 1977 communities map). In the northern part of the lough (north of Mahee Island), mud and bioturbated muds dominate. Large areas of bioturbated mud are also found just south of Mahee Island, southwest of Long Sheelah and throughout the eastern branch of the survey area beside Kircubbin. Within each of these areas there are patches of muddy sand and coarser sediments (sands and gravels). Bioturbated mud and muds are found near the entrance to the Quoile river to the southwest of the lough.

The central channel of the lough is dominated by 'mud with dead shell', from just north of Mahee Island down to Brown Rock in the south. There is a large area of muddy sand west of Round Island adjacent to the bioturbated mud south of Long Sheelah, which extends southwards in deeper water (east of

Ringburr Point and off Marlfield Bay). Muddy sand is also found adjacent to the muds in the southwest of the lough (near the entrance to the Quoile river).

Rubble (cobbles and boulders) is found in patches to the east of the central channel, close to the pladdies (e.g. East of Sand Rock and around S. Buckey Rock). There is a +substantial area of rubble habitat in the southern basin of the lough (east of Taggart Island). Rubble habitat is also found near shore close to the Narrows, especially south of and adjacent to Marlfield Bay in the east and north of Chapel Island in the south. Extensive areas of coarse sediments (sands and gravels) extend throughout the southern basin of the lough; adjacent to the rubble and muddy sand areas south of Ringburr Point.

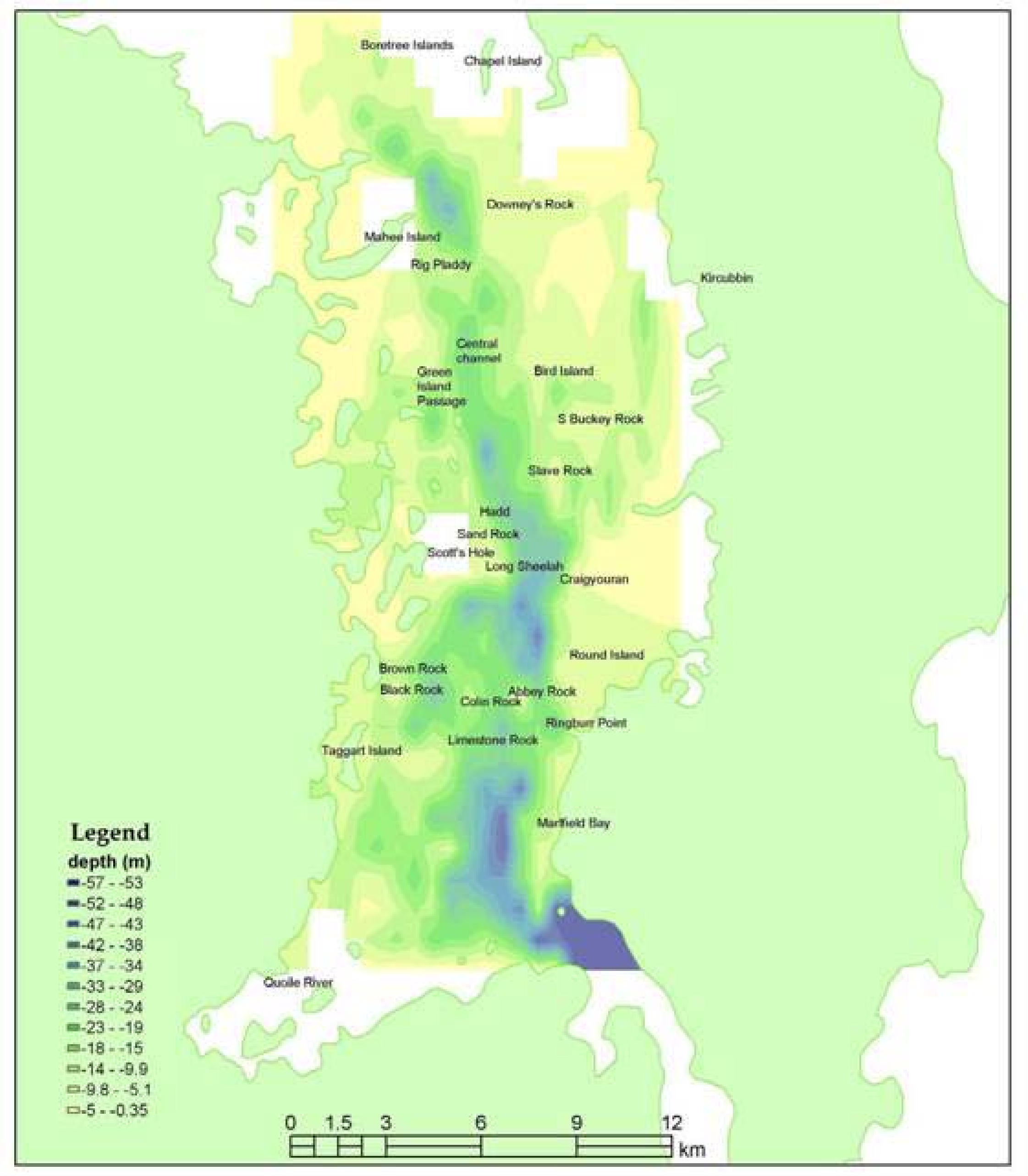

Figure 4. General bathymetry for Strangford Lough main body, based upon interpolated RoxAnn single beam echosounder data (note: should not be used for navigational purposes), with place names referred to in text.

The *Modiolus* habitats (MM_1 and MM_2) are found in patches throughout the central channel and between the pladdies either side of the lough. In the central channel, clumped *Modiolus* beds (MM_1) are found NE of Long Sheelah at the edge of the channel, SW of Bird Island, E of Mahee Island (and around Rig Pladdy), W of Downey's Rock and W of Slave Rock in patches mid-channel. Larger continuous clumped *Modiolus* beds are found west of Round Island, near Colin Rock, in the middle of this basin. Small *Modiolus* beds are found east of Brown and Black Rocks in the south, in

Green Island passage, Scotts Hole, E, SE and N of Sand Rock and in patches S of Boretree Islands (in the north of the lough). Scattered *Modiolus* (MM_2) surround each of the clumped *Modiolus* beds, and also found substantial / notable areas W of Boretree Islands, N of Long Sheelah, E of the Hadd to NW of Craigyouran in the south and west of Round Island in the southern central channel.

Table 2 below indicates the predicted area of each habitat, along with the actual habitat area ground-truthed and the depth ranges of each habitat from the predictive map. It appears that bioturbated mud forms the greatest predicted habitat area within the survey region, followed by mud with dead shell and rubble habitats. Clumped *Modiolus* beds represent the smallest area of habitat predicted (2.41 km^2). In general the depth ranges appear plausible, with the exception of MM_2 (scattered *Modiolus*), which would not be expected to be found in shallow waters.

A very small proportion of the overall survey area was actually ground-truthed, although 85 different sites were visited for ground-truthing purposes. The acoustic signature development and resulting predictive map is therefore based on spatially-limited ground-truthing (as only the dive entry positions were used and buffered: see above). The implications for the accuracy of the final predictive habitat map are discussed below.

Table 2. 2003 Map (whole area) habitat composition (habitat codes as given in Table 1).

Habitat Code	Map Pixels	Area (km^2)	Proportion	Training- site Pixels	Area (km^2)	Proportion	Depth range (m)
MU_sh	20839	8.34	0.14	222	0.089	0.33	-5.8 - -45.9
MU	13502	5.40	0.09	36	0.014	0.05	-2.9 - -22.2
CS	15702	6.28	0.11	106	0.042	0.16	0.3 - -60.7
MM_2	13765	5.51	0.09	88	0.035	0.13	0.8 - -43.5
MM_1	6015	2.41	0.04	26	0.010	0.04	-7.3 - -24.0
Ru	18972	7.59	0.13	48	0.019	0.07	-0.1 - -23.8
MU_burrows	42513	17.01	0.29	72	0.029	0.11	-0.5 - -38.8
MS	13752	5.50	0.09	76	0.030	0.11	-1.0 - -61.6
Totals:	145060	58.02	1	674	0.270	1	

Proportion of map area ground-truthed: **0.0047**

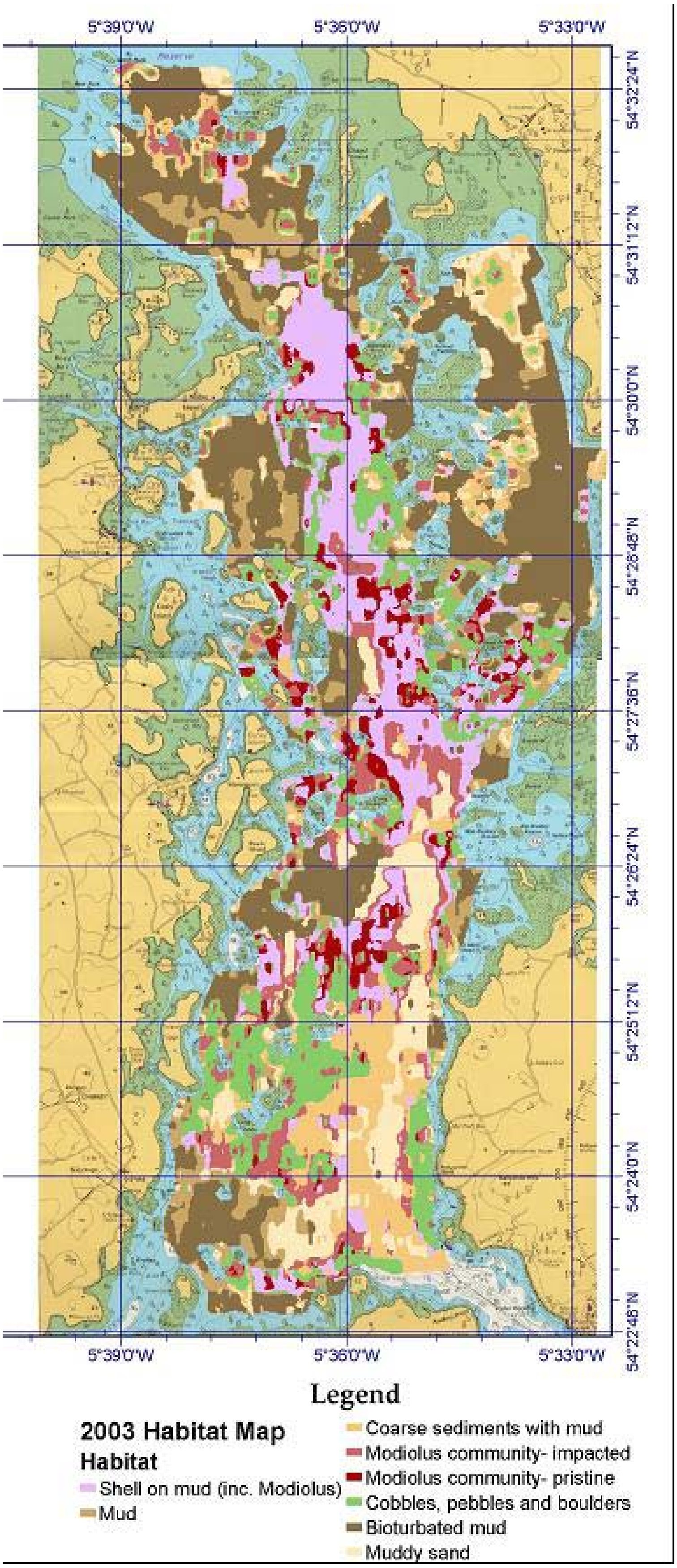

Figure 5. 2003 Habitat Map

3.4 Comparisons of 1993, 2000 and 2003 final predictive habitat maps

For ease of comparison the final habitat maps for 1993, 2000 and 2003 are presented together in figure 6 below. As noted in section 3.2, direct habitat area comparison and pixel-by-pixel agreement are not deemed appropriate due to the differing survey methodologies resulting in substantial differences in raw data, combined with the addition of another habitat category in 2003 (mud with dead shell) therefore only overall habitat distribution patterns are compared in this discussion.

It is readily evident that there are substantial differences between the maps for each of the survey years, however overall the mud areas (both bioturbated and 'featureless' mud) were found in the same areas, and shell habitats (*Modiolus* habitats, muddy sand with comminuted shell and mud with dead shell) were consistently predicted in the central channel (although in 1993 more bioturbated mud was predicted at the edges of the central channel). The coarse sediments were generally predicted in the southern basin and in between some of the eastern pladdies. In order to facilitate comparison between the maps, which are of different survey areas, common areas that appear to differ in their predicted habitat cover have been chosen for further discussion (see figure 6 for areas).

<u>South of Mahee Island.</u>

In 1993, the area was predicted to consist of mud ('featureless') interspersed by small patches of clumped *Modiolus* (MM_1). In 2000, although the largest area still consisted of mud, extensive coarse sediment (sand) patches were also predicted along with small areas of scattered *Modiolus* (MM_2). In 2003, the mud was reclassified as bioturbated mud with smaller areas of mud and muddy sand. Some coarse sediment habitat was predicted at the edge (close to the shore) of the area, but no *Modiolus* was predicted in this region.

<u>NW of Long Sheelah.</u>

In 1993 extensive areas of scattered *Modiolus* were predicted, along with some small patches of clumped *Modiolus.* Coarse sediments were predicted to the west of this area, mud at the extreme west and bioturbated mud to the north. Small patches of rubble (cobbles) were also predicted close to the pladdies. In 2000, this area was largely classified as muddy sand (with comminuted shell) with some patches of clumped and scattered *Modiolus*. Mud was again predicted at the extreme west. No coarse sediments or rubble were predicted. In 2003, the area was largely classified as mud with shell. Some areas of scattered *Modiolus* were predicted (which overlap with the same areas in the 1993 and 2000 maps), and mud was predicted in the extreme west (as in the 1993 and 2000 maps). Coarse sediments were predicted to the NW of the area.

<u>Between Ringburr Point (in the west) and Brownrock Pladdy (in the east).</u>

This is a very heterogeneous area, however RoxAnn track spacing in 1993 and 2000 was wide and therefore these maps are thought to be particularly inaccurate in this region. In 1993 coarse sediments were predicted to the west and the south of the area, with mud to the north and patches of scattered *Modiolus* and extensive rubble areas in the central region and to the west. Very small patches of clumped *Modiolus* were predicted. In 2000, the area was dominated by extensive beds of scattered and clumped *Modiolus* with few small patches of rubble, coarse sediments and muddy sand. The existence of the large *Modiolus* beds throughout this area is likely to be erroneous due to the lack of raw data in the area and the limited ground-truthing. In 2003, large rubble patches and muddy sand areas were predicted. Extensive areas of shell and mud were also predicted, along with two beds of clumped *Modiolus* in the centre of the area.

<u>North of Mahee Island (2000 and 2003 only).</u>

In 2000 this area consisted mainly of 'featureless' mud, with some patches of bioturbated mud, some coarse sediments in shallow areas at the edges and some small areas of scattered *Modiolus* to the south of the region. In 2003 much of the mud was reclassified as bioturbated mud, and coarse sediments were only found in the north of the region, mixed with some scattered *Modiolus*. Some relatively extensive patches of mud with shell were found in the south of the region, and rubbles (cobbles) found in shallow areas.

The reclassification of much of the 'featureless' mud areas to bioturbated mud in the 2003 map is notable, and may be due to more extensive ground-truthing in such habitats. The general trend shown in 2003 is deemed correct with reference to the distribution of fishing for species such as *Nephrops norvegicus*, which are a characterising species of such a habitat.

3.4.1 **Modiolus** *habitat distributions: comparisons between 1993, 2000 and 2003 predictive maps over a common area*

The *Modiolus* habitat distribution and total area coverage is quite different between each survey year, which is likely to be an artefact of the raw data collected for each survey and in particular the distribution of ground-truthing. To facilitate *Modiolus* habitat comparisons, figure 7 below shows 'stripped down' maps for these habitats, clipped to a common area for all three surveys. As above, comparative areas have been selected to aid interpretation of the differences between each survey year.

<u>East of the central channel</u>

In 1993 there appeared to be sparse patches of both scattered and clumped *Modiolus* in this area. However, historically from diving records (Erwin *et al.,* 1986; Brown, 1989) there are reports of extensive *Modiolus* beds in this area. In 1993 there was limited ground-truthing in this exact area, which may account for potential lack of prediction here (due to acoustic signature issues).

In 2000, extensive clumped *Modiolus* beds were found within the scattered *Modiolus* area that covered most of this region. This is thought to be a possible overestimate, due to acoustic signature problems of distinguishing between scattered *Modiolus,* clumped *Modiolus* and thick dead shell. It was very difficult from the towed video footage used to ground-truth both the 1993 and 2000 surveys to distinguish between dead and living *Modiolus* as many shells were covered by thick epifauna and silt. In 2003, mud with dead shell extended throughout the area, interspersed by some small beds of clumped *Modiolus*. This is regarded to be the most likely distribution based upon local knowledge and previous dives, although there are issues here with acoustically distinguishing between the *Modiolus*-related habitats (see below).

<u>Central channel adjacent to Mahee Island</u>

The 1993 predicted distribution indicates that clumped *Modiolus* was found in the shallower water areas west of and including Rig Pladdy in this region. This is regarded to be unlikely due to the depth constraints of *Modiolus* beds found in Strangford Lough (*Modiolus* is generally not found shallower than 10m). In 2000, there was very little clumped *Modiolus* in this area, although there was some scattered *Modiolus* in small patches in deeper waters. In 2003, the deeper waters consisted predominantly of mud with shell, and some areas of living *Modiolus* (mainly scattered).

<u>North of Long Sheelah</u>

There were few clumped *Modiolus* beds predicted in this area in 1993, which existed as small patches. Scattered *Modiolus* was predicted in a band to the east of the area, which forms part of the central channel. In 2000, clumped *Modiolus* was quite extensive in a band bordering the central channel and surrounded by scattered *Modiolus*. No *Modiolus* was predicted in the west of the area. The 2003 map predicted clumped, and some scattered, *Modiolus* in an extensive band adjacent to the central channel and bordered by mud with shell to the east. This bed has been well characterised by the SLECI dive survey and such a prediction of bed extent is regarded as likely.

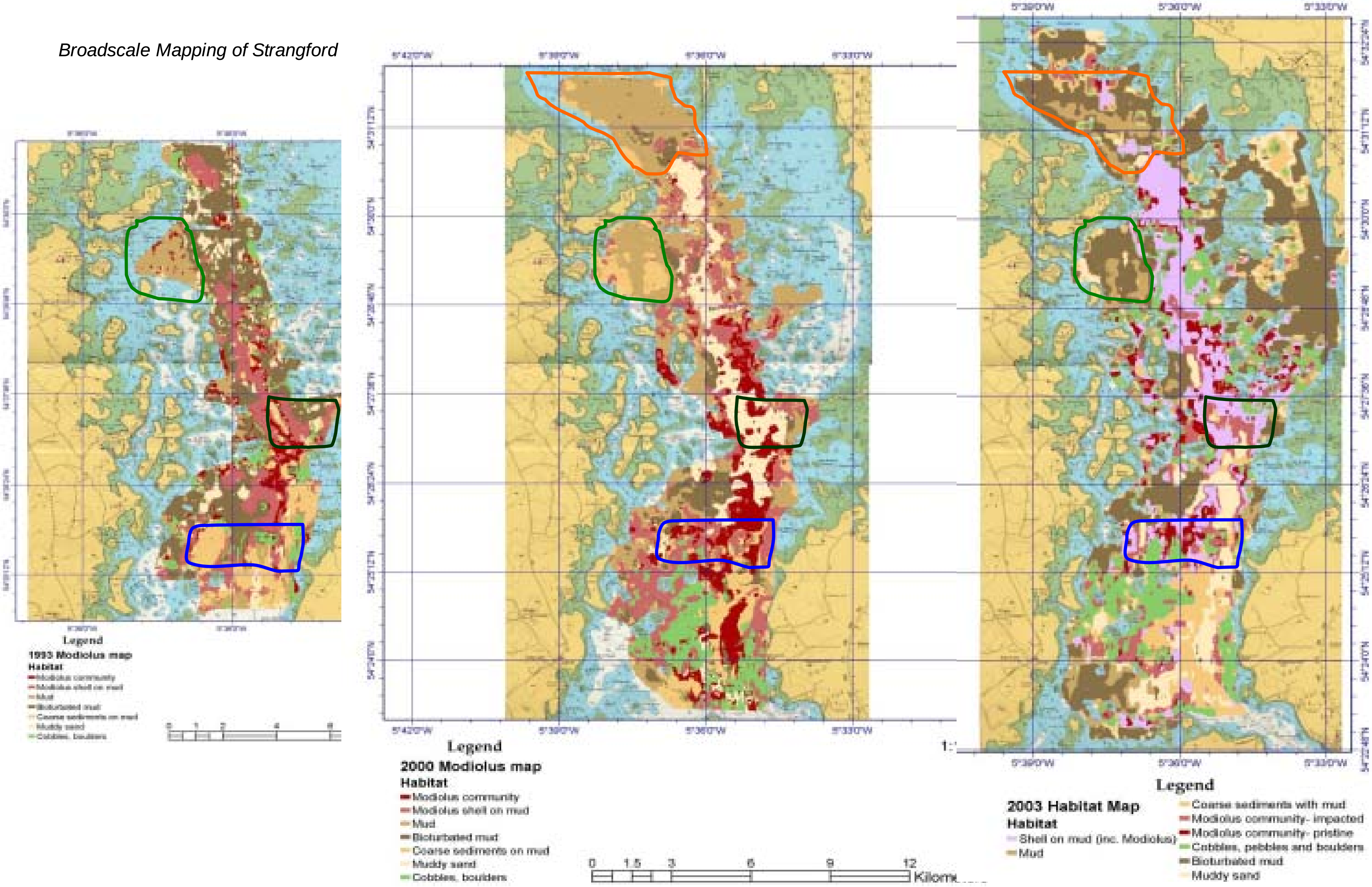

Figure 6. Scaled broadscale habitat maps from 1993, 2000 and 2003 (left to right) with comparative areas highlighted.

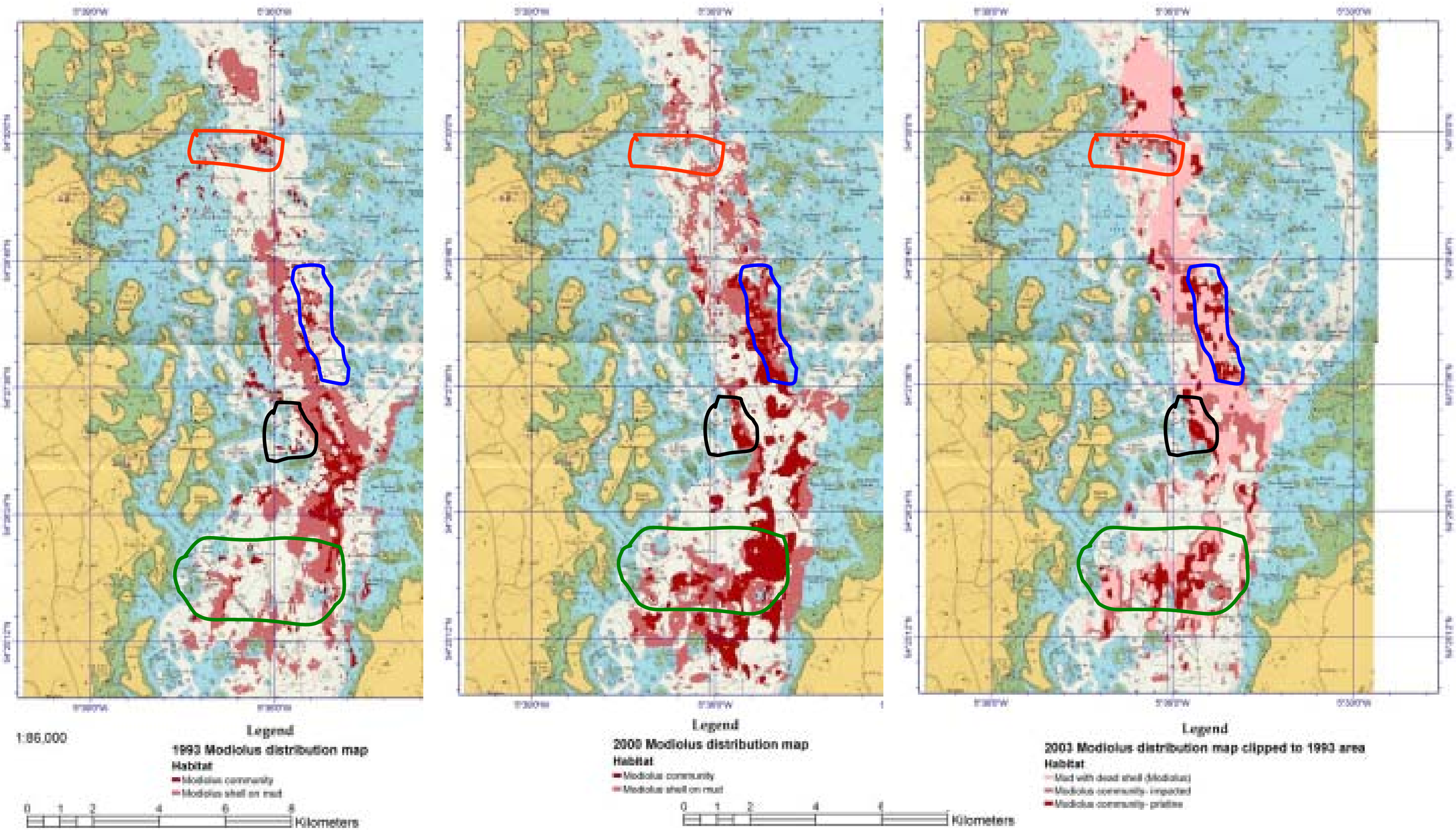

Figure 7. Scaled *Modiolus modiolus* habitat maps from 1993, 2000 and 2003 (left to right) with comparative areas highlighted.

South Basin

Very little *Modiolus* was predicted from the 1993 survey work in this area, due at least in part to the limited raw data in this region (see above). The situation in 2000 was the opposite, with a large area of clumped and scattered *Modiolus* north of Abbey Rock and in the central channel. This is regarded as an overestimate from local knowledge, and highlights the difficulty of reliably comparing these habitats based on the available RoxAnn data. In 2003 there were patches of mud with shell and *Modiolus* east of Brown Rocks, around Limestone Rock extending NW to a bathymetric rise / 'peak' N of Abbey Rock. The *Modiolus* bed for this 'peak' in the central channel has been well documented from the SLECI dives and the predicted extent is deemed probable.

Overall it is clear that the predictive maps based upon three distinct RoxAnn surveys cannot be reliably compared and do show different patterns of habitat distribution. This is due to the differences in the raw data collected for each survey, in particular the locations and extent of ground-truthing and the spacing of RoxAnn survey tracks, combined with habitat discrimination issues from towed video data compared with dive video (2003) ground-truthing data.

3.5 General discussion and accuracy assessment of 2003 predictive habitat map

It appears that in general the 1993 and 2003 maps are broadly similar in terms of actual area coverage of *Modiolus* beds (see figure 8 below), and the fragmented nature of such beds, however beds such as those in the south basin have not been consistently predicted. The 2000 map detected some beds accurately in terms of existing local knowledge, but also overestimated bed extent in many areas. Figure 7 shows how the introduction of an additional habitat category in the 2003 survey changed the proportion of habitats in comparison to 1993 and 2000. In particular this category appears to have 'replaced' much of what was previously classified as scattered *Modiolus* (MM_2), muddy sand and mud (especially with respect to the 2000 map). The proportion of area designated as rubble has also increased in comparison to other years, with a lower proportion of coarse sediments.

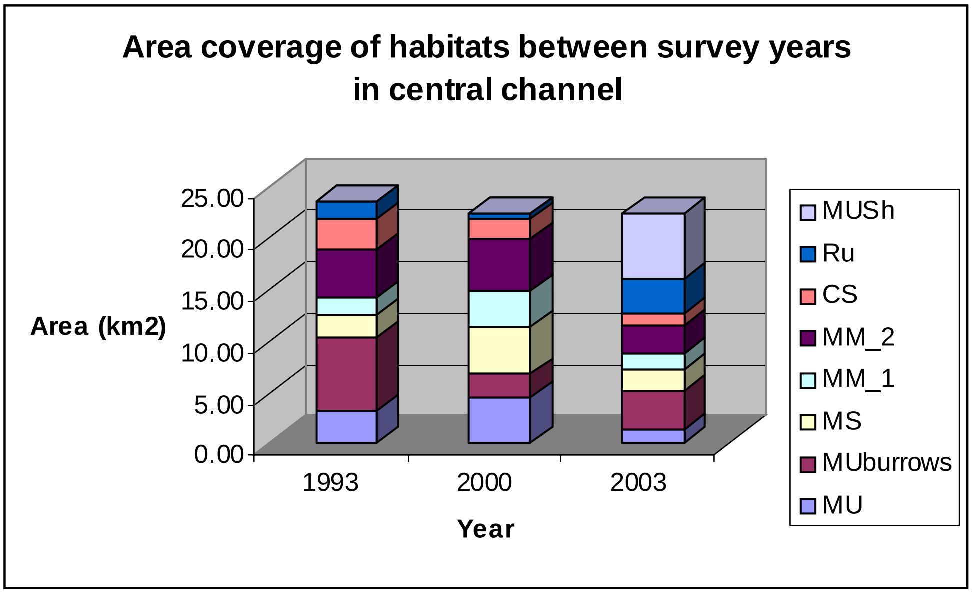

Figure 8. Chart of habitat area coverage for a common area (central channel) between the 1993, 2000 and 2003 survey maps (codes as given in Table 1).

Local knowledge and previous survey efforts appear to support the habitat distributions shown by the 2003 habitat map more than those of the 1993 and 2000 maps. However, as has been mentioned above, the issue of accuracy assessment is important especially for highlighting habitats where prediction is likely to be poor due to acoustic signature overlap. The 2003 map error matrix is provided in table 3 below in order to establish which habitats were readily confused and highlight accuracy issues.

Table 3. Error matrix (pixel-by-pixel comparison) for the 2003 predictive habitat map.

		Ground-truth data									
		MU_sh	MU	CS	MM_2	MM_1	Ru	Mu_burrows	MS	Total	% Error
Mapped units	MU_sh	107	0	21	25	0	13	1	0	167	35.93
	MU	7	18	26	0	0	2	6	5	64	71.88
	CS	4	0	18	1	0	2	0	0	25	28.00
	MM_2	28	0	10	20	3	7	0	0	68	70.59
	MM_1	37	0	13	17	23	2	0	0	92	75.00
	Ru	34	3	15	25	0	22	1	5	105	79.05
	Mu_burrows	5	15	0	0	0	0	62	0	82	24.39
	MS	0	0	3	0	0	0	2	66	71	7.04
	Total	222	36	106	88	26	48	72	76	674	
	% Error	51.80	50.00	83.02	77.27	11.54	54.17	13.89	13.16		**50.15%**

The error matrix in table 3 shows that overall the classification process was 50% accurate, although the results vary greatly between the habitat classes. There are a number of habitats that were readily confused (errors of commission – column '% Error'). Of particular note are the following habitats:

- **Ru**, in which 46% of pixels identified as rubble from the ground-truthing samples were mapped correctly, but only 21% of the pixels mapped as rubble were actually that class. 32% of the remaining pixels mapped to rubble were actually mud with dense shell, and a further 24% of pixels mapped to rubble were actually scattered *Modiolus*. Both of these two habitats may contain thick piles of shell which could give a similar acoustic signature to cobbles.
- **MM_1**, in which 88% of pixels identified as clumped *Modiolus* from the ground-truthing samples were mapped correctly, but only 25% of the MM_1 mapped pixels were actually that class. Most of the remaining pixels mapped to MM_1 were actually mud with dense shell (40%) or scattered *Modiolus* (18%).
- **MU**, in which 50% of pixels identified as mud from the ground-truthing samples were mapped correctly, but only 28% of the pixels mapped as mud were actually that class. Most of the remaining pixels mapped to mud were actually coarse sediments (40%), which were known to have a significant proportion of fine sediment in the central area of the lough.
- **MM_2**, in which only 23% of pixels identified as scattered *Modiolus* from the ground-truthing were mapped correctly, and only 29% of the pixels mapped as MM_2 were actually that class. 41% of the remaining pixels mapped to MM_2 were actually mud with dense shell.

The signature comparison chart below (figure 9) highlights the acoustic signature overlap between the three most readily confused habitats in the map (MU_Sh, MM_2 and MM_1). The chart shows the RoxAnn data values that form the signature for each habitat (with range and mean of signature shown). The raw RoxAnn data values have been standardised and stretched to between 0 and 255 for image processing (see Methodology). Of particular note, both *Modiolus* communities fall within the range of E1 and E2 (roughness and hardness) for mud with shell (MU_Sh), which inevitably causes difficulty with pixel classification. Clumped *Modiolus* (MM_1) has a higher mean roughness and a slightly higher mean hardness than scattered *Modiolus* (MM_2), which in turn has a very slightly higher mean roughness and a notably higher mean hardness than mud with dense shell. This is in line with what would be expected in terms of habitat hardness and roughness. Clumped *Modiolus* shows a smaller range in all four variables (E1, E2, depth and acoustic variability), however this is mostly due to this habitat having the smallest training site area (0.01 km^2) and therefore unlikely to incorporate as much variation. Summary statistics of E1, E2, depth and acoustic variability for each habitat training site were extracted from the relevant Raster files using the Idrisi routine EXTRACT (see table 4 below), and emphasise the degree of overlap in the RoxAnn data values used in each acoustic signature.

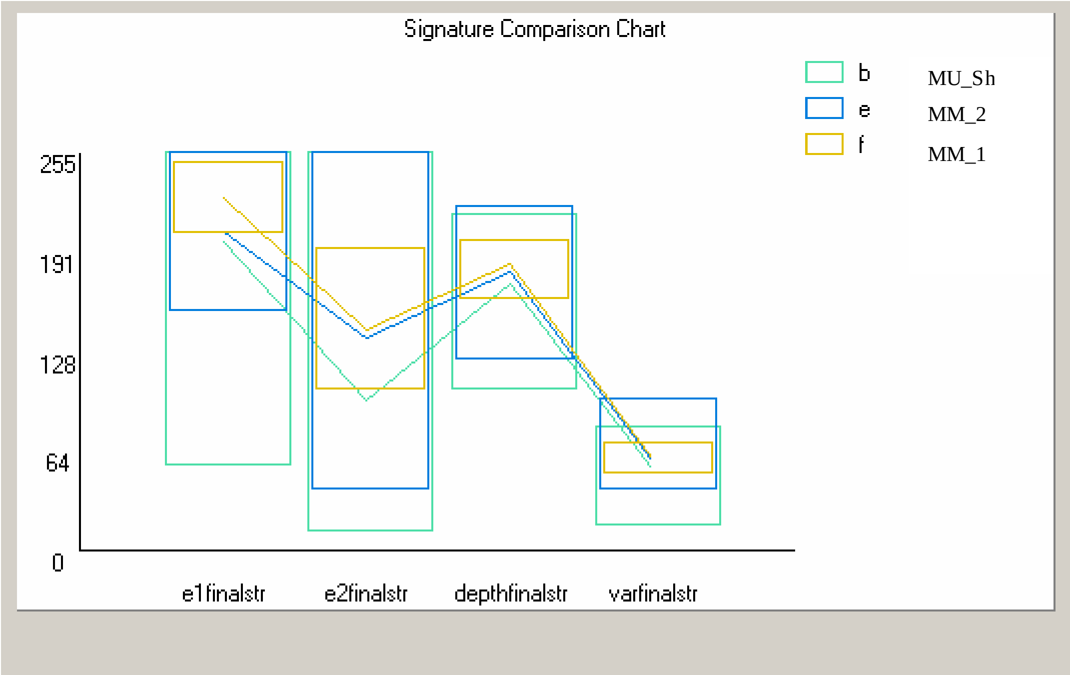

Figure 9. Signature comparison chart for three habitats with overlapping acoustic signatures.

Table 4. Summary statistics for three habitats with overlapping acoustic signatures.

	Summary Statistics (standardised E1 and E2)					
Habitat:	**E1min**	**E1max**	**E1mean**	**E2min**	**E2max**	**E2mean**
MU_Sh	0.212	1.079	0.774	0.051	1.43	0.384
MM_2	0.6	1.1	0.805	0.155	1.064	0.535
MM_1	0.793	0.97	0.885	0.402	0.754	0.551

The acoustic signature overlap between the *Modiolus* habitats and the mud with shell emphasises the difficulty in establishing exact areas for each of these habitats using broadscale acoustic mapping methods. It would be possible to 'tighten-up' the acoustic signatures for each of these habitat categories through further targeted ground-truthing and nested surveys over such areas by RoxAnn AGDS, in order to provide more raw data on which to develop such signatures. Such a work program was planned for the 2003 survey, however due to vessel provision constraints the nested part of the survey design could not be completed in time for this report.

It must be emphasised that the scale at which RoxAnn operates is fundamentally different to that of many ground-truthing methods and therefore error can result from trying to combine the different information types from these different survey tools. This is particularly true in terms of habitat mapping, where for instance underwater video can detect subtle changes in habitat and heterogeneity over short distances, however RoxAnn will merge such heterogeneity due to the size of the echosounder footprint. This has a profound influence over the habitat classification method used to interpret the video data, which must incorporate what is known to be detectable by AGDS. It is possible to introduce habitat categories that are not distinguishable with any confidence by RoxAnn AGDS with consequential loss of accuracy in the final maps. Discrete habitats may also fall in-between RoxAnn survey tracks and are therefore missed by the acoustic data and inaccurately mapped.

Despite these limitations, RoxAnn AGDS is definitely capable of detecting a wide range of substrates and many biological communities have a notable influence of the return echo and therefore can be mapped using RoxAnn. However there are also biological communities that do not have a distinct acoustic signature. It is therefore imperative that RoxAnn-based maps are treated with a degree of caution and further work should be conducted to determine which communities can be distinguished with confidence, based on AGDS data and ground-truthing. Survey design is critical to the accuracy of RoxAnn-based habitat maps and nested survey designs are recommended in future investigations in order to allow for changes in the degree of heterogeneity in ground-type distribution.

Comparison has been made between the *Modiolus* bed distribution shown by the 1993-2003 maps and the reported distribution in Brown (1989). This indicates a loss of *Modiolus* cover in the central channel, particularly in the north of the lough and in between the pladdies to the east and west of the central channel. This is likely to be a real loss rather than an artefact of data processing even when the difficulties of dive-site data extrapolation upon which the Brown (1989) map is based and the broadscale mapping acoustic signature development issues are accounted for, and such a loss has been supported by the SLECI dive survey. Loss and/or damage to the *Modiolus* beds in the central channel (also known as the trawl zone) was first documented in 1990 through an ROV survey (Service, 1990) and has been supported by the subsequent broadscale surveys.

3.6 Future monitoring recommendations

In such a highly heterogeneous area as Strangford Lough, the broadscale habitat maps represent a first stage in a full survey effort for the lough, providing background information that should be used principally to stratify more focussed survey work.

It is difficult to assess what level of change in terms of habitat coverage may be detected using the RoxAnn AGDS, and what level of change may be significant for specific habitats. As analytical methods evolve it is likely that change will be detected more readily as the accuracy of the habitat maps will improve. It is recommended that further resources are made available to fine-tune AGDS-based mapping for the detection of habitat change, in conjunction with other survey strategies such as diver surveying. It is suggested that a broadscale acoustic survey is completed throughout the Lough every 2 years, along with appropriate video and stills camera ground-truthing. The precise survey method (area covered, acoustic method, track spacing, transducer frequency and survey vessel) and data analysis techniques should be replicated as closely as possible between years to enable comparison of the resulting maps and habitat areas. For Strangford Lough, a nested survey design should be adopted so that heterogeneous areas may be mapped with more accuracy, and the ground-truthing should incorporate diver surveys such that more precise acoustic signatures may be developed for the differing biological communities. This may enable detection of temporal and spatial change and allow managers to choose areas for further investigation. In addition, it could be worth investigating the dead shell areas further, with respect to dating the shells in order to assess whether there has be a significant increase in the proportion of dead shell accumulated from recent years. Nunny (1993) described how currents act to distribute dead shell into their ultimate from of shell 'streaks', while more randomly piled shells are generally indicative of recent mortality (Magorrian, pers. comm.). These two 'types' of dead shell may possibly be distinguished over large areas acoustically when combined with adequate ground-truthing.

The change in *Modiolus* habitat distribution between 1993 and 2003, despite the uncertainties of the maps, should be used to alert managers to investigate further. In particular, the expansion and contraction of individual beds should be used to alert managers of a problem. Specific surveys are required to map the precise extent, condition and boundaries of the existing *Modiolus modiolus* beds, through the use of tracked diver surveys. Monitoring of the state of the *Modiolus* beds, mud with shell habitats and bordering areas are required through targeted survey effort. Particle size data is required from a range of these areas, which may form a baseline to assess future change in the sedimentary regime. In order to assess trawling activity in the central lough, which has impacted the distribution of *Modiolus* beds since the diver surveys of the 1970s and1980s, and the persistence of such disturbance on the seafloor, regular sidescan sonar surveys are recommended.

The topography of Strangford Lough is exceptionally diverse and unique in Northern Ireland, and, combined with the resulting three-dimensional hydrodynamic regime, exerts a major influence on the distribution of the biological communities found within the lough. As such, it is recommended that a full-scale multibeam sonar survey coupled with 3D hydrodynamic model development is undertaken in the lough. This will facilitate understanding of community distribution and form an excellent complement to the existing broadscale habitat maps to allow stratification of regular monitoring work, in addition to enabling improved impact assessment.

There has been much recent discussion regarding the use of RoxAnn AGDS for habitat mapping purposes (see Brown *et al*., 2003), and the limitations of the system for such a use are widely documented. This project has been conducted using standard recommended practise for RoxAnn-based surveying (Natura 2000 Marine Monitoring Handbook), and the resulting maps are essentially both predictive and broadscale. Ground-truthing is an essential element in the production of RoxAnn-based habitat maps, and where there have been limitations in the amount of available ground-truthing the resulting maps have a lower accuracy and certainty, and therefore further ground-truthing, by diver, towed underwater video, grab-sampling etc. will further improve the maps and the interpretation of the acoustic data. In the case of the 2003 Strangford Lough map, further ground-truthing would also enable validation of the habitat distribution predictions.

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