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# Predicting the distribution of sublittoral benthic biotopes using acoustic remote sensing

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**Abstract.** To implement the European Directive on conservation of natural habitats (92/43/EEC), government conservation agencies, in this case Scottish Natural Heritage (SNH), must identify areas as possible Special Areas of Conservation (pSACs). To inform the future management and monitoring of these sites, SNH need to know the distribution of habitats and species in Scottish marine SACs. Distribution of marine benthic biotopes (habitats and their associated species) was predicted for two physiographically different pSACs in Scotland: Papa Stour in Shetland, and Lochs Duich, Alsh and Long, NW Scotland. The methodology involved acoustic remote sensing, ground validated by remote video and grab sampling, with analysis and display of results using a PC based GIS. Field surveys were carried out in 1996. Acoustic track point data obtained were interpolated to obtain a continuous polygon coverage of the acoustic properties of the seabed within each pSAC area. An acoustic signature for each biotope type, or biotope complex was determined by buffering the ground validation sites, intersecting buffers with acoustic track data, and deriving descriptive statistics for each acoustic variable. Spatial analysis of acoustic and ground validation data within the GIS was then used to produce a continuous coverage polygon map of predicted biotope types for each pSAC.

**Keywords:** Acoustic remote sensing; Biotope; GIS; Lough Alsh; Lough Duich; Louich Long; Papa Stour; SAC; Scotland; Underwater video.

**Abbreviations:** AGDS = Acoustic ground discrimination system; bcd = Below chart datum; cSAC = candidate Special Area of Conservation; pSAC = possible Special Area of Conservation; SAC = Special Area of Conservation; SNH = Scottish Natural Heritage.

## Introduction

The UK government is committed to the implementation of the European Council Directive (92/43/EEC) on conservation of natural habitats and of wild fauna and flora, commonly known as the EC Habitats Directive. This Directive was a major contribution from the European Community to the Biodiversity Convention at the Rio Earth summit of 1992. The requirements of the Habitats Directive were adopted into UK law under the Conservation (Natural Habitats) Regulations 1994 (1995 in Northern Ireland) – referred to here as the Regulations.

The Directive requires that member states select and present to the EC a list of sites for consideration as Special Areas of Conservation. These sites are selected to represent certain habitats and species that are listed in Annex I and II of the Directive. Seven of the 198 habitat types and nine of the 623 species listed in the annexes of the Directive are found in the marine environment of the UK.

In compliance with the Directive, the UK government has charged its conservation agencies – Scottish Natural Heritage (SNH) in Scotland – with the task of identifying and selecting a UK-wide suite of marine *possible* Special Areas of Conservation (pSACs). These were identified in 1995 and extensive public consultations were undertaken on their initial selection. In October 1996, on completion of the consultation process, 14 Scottish marine SACs were presented to the EC as *candidate* Special Areas of Conservation (cSACs).

To inform the future development of management schemes for marine SACs and to assist in the formulation of conservation objectives (required under the Regulations), it is necessary to obtain broad scale survey information of the extent, distribution and quality of the habitats and associated communities (biotopes) within the selected sites. This process will allow the identification of areas of particular sensitivity and also allow a more targeted approach to site management. There is a requirement within the Directive to monitor and report upon the condition of the sites once every six years. To facilitate this monitoring, baseline information had to be obtained. This baseline includes information from detailed Phase II surveys (Hiscock 1996) of sample sites within the intertidal and subtidal areas, and more broad scale mapping of the intertidal and subtidal areas to obtain an overview of the extent and distribution of the habitats and associated biota.

## Description of possible Special Areas of Conservation surveyed

Distribution of subtidal marine benthic biotopes (habitats and their associated species) was predicted for two physiographically different SACs: Papa Stour in Shetland (a candidate SAC); and Lochs Duich, Alsh and Long, on mainland western Scotland near Skye (a possible SAC), using acoustic remote sensing, ground validated by video of the seabed and grab sampling of sediments.

Papa Stour is a small, remote island in western Shetland, separated from mainland Shetland by Papa Sound, through which strong tidal currents flow. The cSAC area (see Fig. 1) encompasses the island and part of the adjacent mainland coast. Both the island and mainland coasts are very exposed to winds and sea swell from the west and south, and subject to strong tidal currents. The island itself is also very exposed to northerly winds and sea swell. Deep water occurs close inshore, with maximum depth within the cSAC area to the north and west ca. 60 m below chart datum (bcd). The shores are rugged and predominantly rocky, with high cliffs to the west, lower cliffs to the east, numerous stacks, arches and caves, and several islands and offshore skerries. In the shallow sublittoral (down to ca. 20 m bcd) the substratum is largely rugged bedrock with coarse mobile sand. Offshore the substratum is predominantly coarse sands and gravels with low outcrops of bedrock. The main island of Papa Stour also has four shallow voes or inlets, which provide shelter from prevailing wind and waves.

Lochs Duich, Long and Alsh pSAC (see Fig. 1), in contrast, are very sheltered from wind and sea swells by the island of Skye, and the hills and mountains which surround the lochs. The shallow sublittoral areas of all three of the lochs are predominantly steep and rocky, and all have deep sediment basins separated by shallower sills. Lochs Duich, Long and Alsh are amongst the deepest of the Scottish sealochs, with maximum depths of over 100 m bcd in outer Loch Alsh and the centre of Loch Duich. Lochs Duich and Long in particular have very steep, vertical or overhanging rock shores extending into the sublittoral, with submarine cliffs of around 80 m depth in upper Loch Duich. There are relatively shallow sills in the middle narrows and at the entrance of Loch Long; between Lochs Duich and Alsh; in mid Loch Alsh between the mainland and Glas Eilean; and between Skye and the mainland at the two entrances to Loch Alsh (Kyle Akin to the northwest and Kyle Rhea to the southwest). In these narrows very strong tidal currents occur, with currents at spring tides up to 7 knots (kn) in Kyle Rhea, and 3 kn in Kyle Akin (Admiralty Chart 2540). Freshwater inputs to the system can be high, and due to the sheltered nature of the lochs, incoming freshwater is often not mixed within the water column. This may result in up to around 6 m depth of fresh water lying on top of salt water within Loch Long and upper Loch Duich at times of high freshwater inputs.

The biological interest of the two SACs relates to their differing environmental conditions. Papa Stour cSAC was selected for its reefs and caves, with biological communities characteristic of northern wave exposed conditions. Lochs Duich, Long and Alsh pSAC was selected also for its reefs, but particularly those characteristic of very sheltered conditions and subject to considerable freshwater influence, and for tide swept reefs in a range of salinity conditions.

### *Survey techniques*

Due to the large areas of seabed needing to be surveyed, Scottish Natural Heritage (SNH) required a broad scale survey strategy to be adopted, and preferably one which could incorporate previous data. Remote sensing was therefore required, however such methods using visual or other spectra are not suitable to map seabed types in deep and turbid waters (Davies et al. 1997). Acoustic remote sensing with analysis of data within a Geographic Information System (GIS) appeared to be the best available option. The methodology selected was developed by the *BioMar* team at the University of Newcastle-upon-Tyne, England (now *BMap* team), and involved acoustic remote sensing, ground validated by remote video, grab sampling and diver recording, with analysis of data and display of results within a GIS (Davies et al. 1997). This combination of methods was also capable of incorporating previous survey data where accurate site positions were available. Such biological data were available from previous surveys by various methods for seven sites in Papa Stour, and 68 sites in Lochs Duich, Alsh and Long.

The acoustic and ground validation surveys were carried out by Entec personnel and subcontractors from 10th to 19th August 1996 for Papa Stour cSAC,

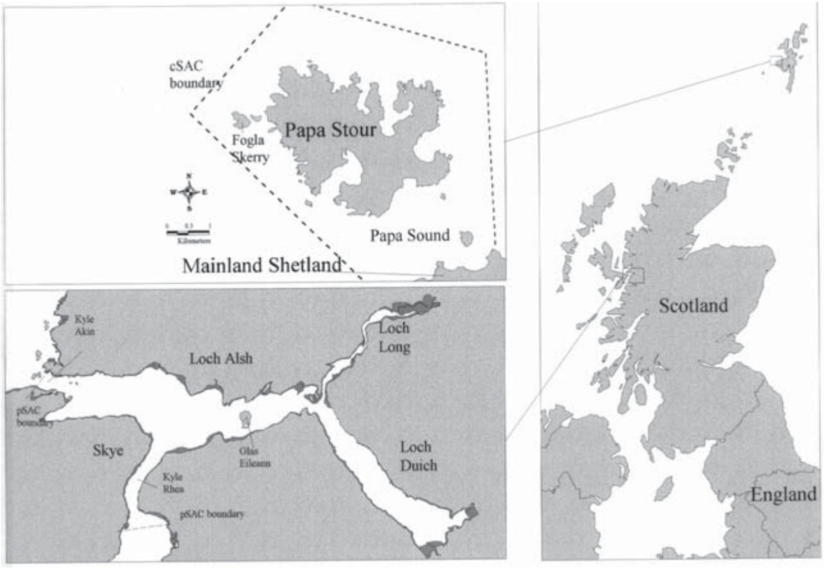


**Fig. 1.** Locations of Papa Stour cSAC and Lochs Duich, Alsh and Long pSAC.

and from 15th to 22nd September 1996 for Lochs Duich, Long and Alsh pSAC.

An acoustic ground discrimination system (AGDS), combined with a Global Positioning System (GPS) for position fixing, linked to a personal computer with navigation and data collection software recorded data on acoustic properties of the seabed at 5-sec intervals. Whilst the boat travelled along a set path at a speed (over ground) of ca. 4 kn, continuous sets of measurements (or tracks) of the physical nature of the seabed were recorded and displayed on the computer using navigation software.

For Papa Stour, the seabed over most of the survey area was at less than 30 m bcd, with a maximum depth at the boundary of the cSAC of ca. 60 m bcd. A *RoxAnn Groundmaster*™ AGDS was used, which analyses the primary and multiple return echoes from a high frequency (200 kHz) echo sounder to quantify the depth, roughness (echo 1 or E1) and hardness (echo 2 or E2) of the seabed (Chivers et al. 1990). The maximum operating depth is limited by the power output of the echo sounder used. The power output of high frequency echo sounders is generally, and was in this case, too low to give sufficiently good second echo (E2) returns in water deeper than approximately 45 m, depending on the nature of the seabed. The *RoxAnn*™ system requires both the first and second echo returns to function properly, and this system was therefore operating at the limit of its capability in the deep areas at the boundary of the Papa Stour cSAC.

For Lochs Duich, Alsh and Long, acoustic data were required from shallow waters down to over 100 m depth. A *RoxAnn*™ system with high frequency sounder would not give ground discrimination in such deep waters. A *RoxAnn*™ with low frequency sounder could discriminate in deeper waters, but would not provide sufficient ground discrimination in shallow water. The system employed was a *QTC*™ acoustic ground discrimination system, also with a 200 kHz echo sounder, which analyses the shape of only the primary echo return (Collins et al. 1996), and can therefore operate successfully in both shallow waters and down to over 100 m depth. The *QTC*™ system outputs depth and three parameters Q1, Q2 and Q3, to describe the shape of the echo.

AGDS are designed to map in real time the physical characteristics of the seabed, and do not take account of depth in their classifications of different seabed types. This poses problems in the use of such systems for mapping of biological communities, as the same biological communities may occur on very different seabed types, and water depth is a fundamental factor in determining the type of biological community present. It is therefore necessary to post-process the acoustic data and calibrate them with ground validation data, for successful mapping of biological communities.

### *Ground validation*

The acoustic data were ground-validated by high quality drop-down video for epifaunal information and/or grab sampling areas of seabed for infaunal information. Sites were located where preliminary examination of the acoustic data indicated areas with acoustically different properties; and in areas with apparently the same acoustic properties, but with a wide depth range. In the latter case, validation sites were located in both deep and shallow water within these areas. In sedimentary areas, grab samples for infaunal and particle size analysis were taken in addition to the video sample.

Video recordings obtained were analysed to describe the physical and biological characteristics of the seabed to compile an inventory of biotopes present within the survey. Sites were assigned to biotope types according to the Marine Nature Conservation Review (MNCR) biotope manual, Version 96.7 where possible (Connor et al. 1996), or provisional new biotopes were described if a record did not fit into any of the existing biotope types. In kelp forests and parks where the substratum type was not visible, and where the variety and detail of understorey flora and fauna was not clearly distinguishable from the video, some difficulty was encountered in allocating sites to biotope types. This was because the biotope classification (Version 96.7) did not have enough suitable broad categories in which to fit observations where Phase II level information (Hiscock 1996) on a site was not available. Difficulties were also encountered in relating infaunal data from grab samples to epifaunal data from videos to fit biotope descriptions in the biotope manual.

*Interpolation of acoustic data*

The acoustic track data points obtained as described above (Figs. 2 and 4) were converted to a continuous polygon coverage of the acoustic properties of the seabed by interpolating between adjacent data points to calculate values for intermediate areas within *Surfer for Windows™*. Standard geo-statistical procedures were employed for the interpolations; a review of geo-statistics by Rossi et al. (1992) suggested that the procedure *kriging* was most suited to random data points (Davies et al. 1997). *Surfer for Windows™* provides a kriging algorithm to reduce the track data to a rectangular grid of data points for the survey area. Display of the interpolated results as a grid, rather than smoothing the data to provide hard boundaries, which in these areas do not usually exist, subliminally reflects the resolution of the predicted data. The grid size, in this case of 50 m × 50 m, should be selected as appropriate for the acoustic track spacing achieved during the survey (which was between 100 m and 500 m in these cases). A larger grid should be selected where track spacing is greater, to indicate the lesser resolution of the track data. The resulting map is interpreted as the topographic and physical habitat map.

*Matching of acoustic and ground validation data*

The map of acoustic properties of the seabed was analysed with biotope data from ground validation sampling within *MapInfo™* GIS, to produce a predictive map of biotope distribution. Part of this analysis was to derive an acoustic signature for each recorded biotope or group of biotopes. The *MapInfo™* buffer capability was used to create a 50-m buffer around each ground validation site or line; 50 m was selected as an appropriate size buffer, to reflect the accuracy of position fixing during the ground truthing. Each buffer was then coded according to the biotope recorded at that ground validation site. Within *MapInfo™*, acoustic data points falling within each buffer were then captured, and assimilated into a table. In the few cases where more than one biotope was distinguished from one video tow, the buffer around the video tow line was split logically into sections representing each biotope. Minimum, maximum, mean and variance values of the acoustic variables E1, E2 and depth (for *RoxAnn™* data) or Q1, Q2, Q3 and depth (for *QTC™* data) were generated within *MapInfo™* from the captured acoustic data for each buffer, to form an acoustic signature for each biotope or group of biotopes.

Using the acoustic signatures for each biotope group to construct Boolean queries, areas which matched each signature were selected in turn and shaded according to the corresponding biotope. An example of a query would be: "Select all areas where E1 is between 0 and 0.5, and E2 is between 0.15 and 0.75, and depth is less than 5 m, code these areas with biotope type 1". These codes were used to prepare the maps (Figs. 3, 5 and 6) showing the distribution of the biotopes or biotope groups, by assigning a shade or fill to each individual code.

The boat used for the survey of Loch Long was different to that used for the rest of the survey due to a low bridge at the entrance of the Loch preventing access by the main survey vessel. It is generally accepted that acoustic data obtained from different boats under different environmental conditions may not be comparable, therefore acoustic signatures were derived separately for Loch Long using only biotopes found in that Loch, and acoustic signatures for Lochs Duich and Alsh using only acoustic and ground validation data obtained in those lochs.

The range of data points within different signatures may overlap with each other. When data are mapped, this may result in some areas with narrow data ranges being obliterated by others with a very wide spread of data points within a signature. Therefore manipulation of the signatures for each biotope was required, in particular for those biotopes with only a relatively small number of associated data points, but a very wide data range. This was an iterative process, of reviewing the data range for each biotope, checking the ground validation data to see how well particular records fitted with the relevant biotope description, possible re-allocation of ground validation sites to another biotope, then re-calculating the statistics for the particular signature,

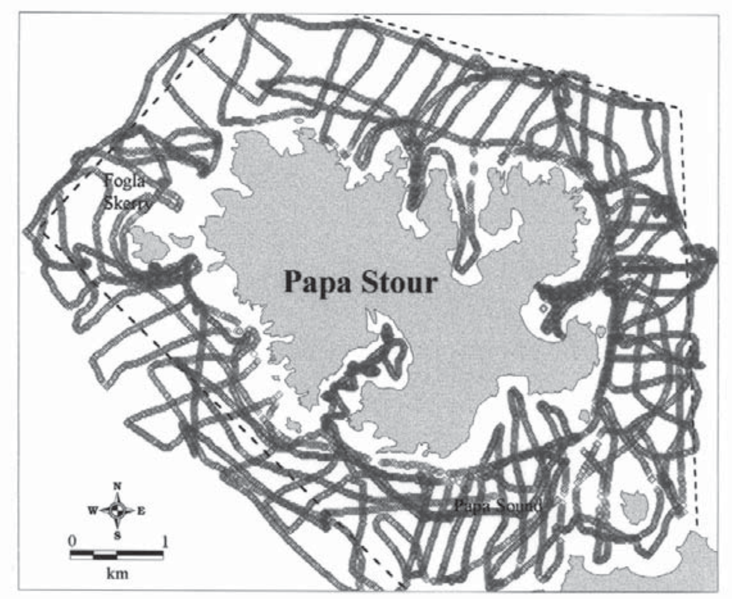


**Fig. 2.** Acoustic track data for Papa Stour.

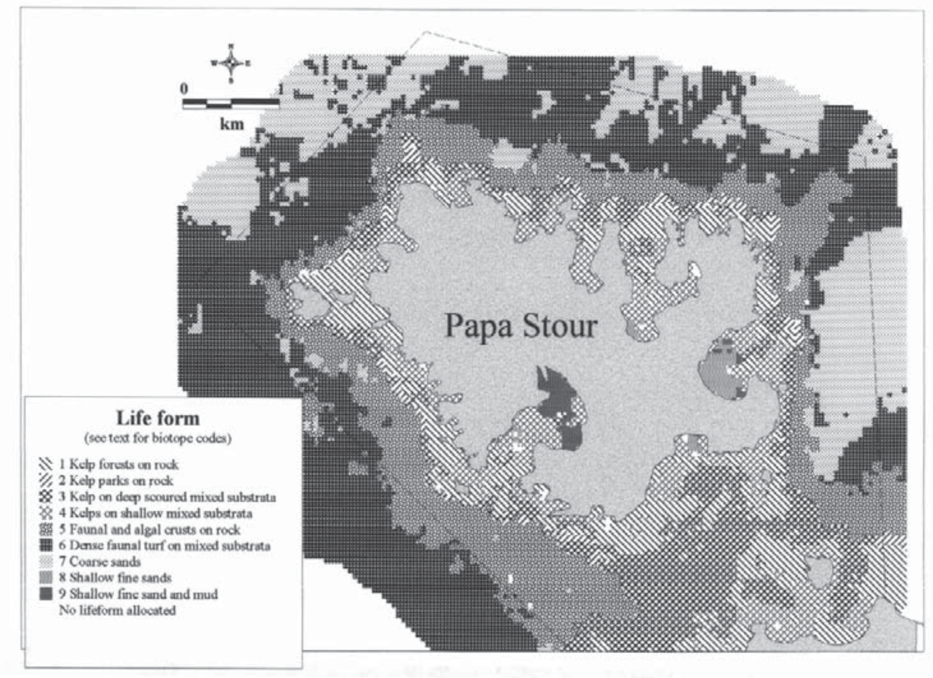


**Fig. 3.** Predicted distribution of life forms within Papa Stour cSAC.

**Table 1.** Life form description for Papa Stour (see Fig. 3).

| Life-form description | Constituent biotope codes (Connor et al. 1996) |
|---|---|
| Kelp forests on rock | MIR.LhypGz.Ft, MIR.Lhyp.Ft |
| Kelp parks on rock | MIR.Lhyp.TPk, MIR.LhypGz.Pk |
| Kelp on deep scoured mixed substrata | MIR.LsacScrR |
| Kelps on shallow mixed substrata | MIR.XK, SIR.Lsac.X |
| Faunal and algal crusts on rock | ECR.AlcC |
| Dense faunal turf on mixed substrata | ECR.AlcTub, MCR.FaAlc, MCR.Oph |
| Coarse sands | PS.CGS, PS.IGS |
| Shallow fine sands | PS.IMS |
| Shallow fine sand and mud | PS.IMS.Are |

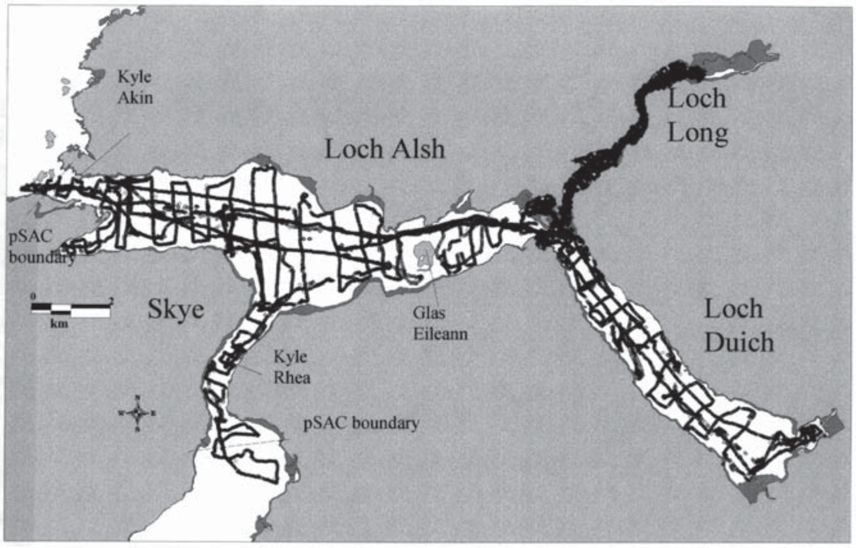


**Fig. 4.** Acoustic track data for Lochs Duich, Alsh and Long.

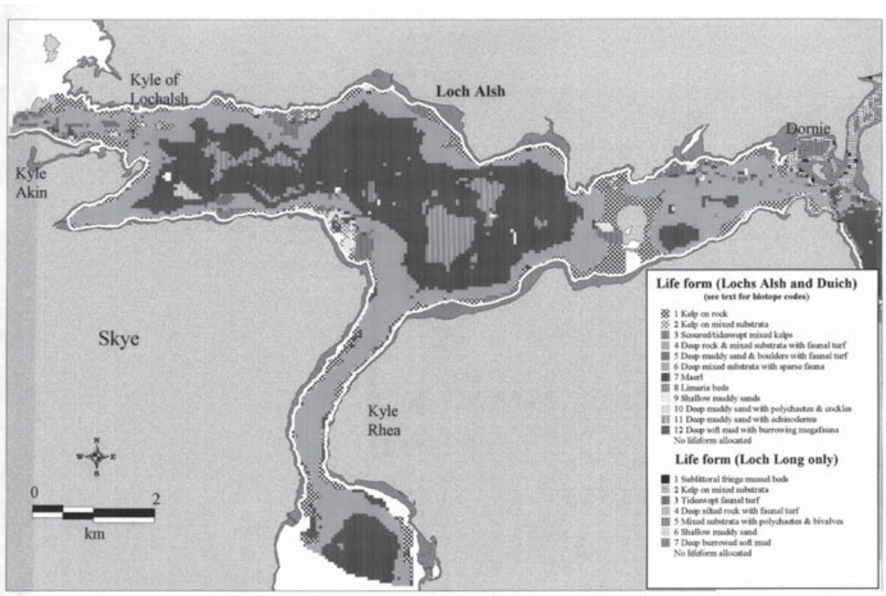


**Fig. 5.** Predicted distribution of life forms within Loch Alsh, Kyle Akin and Kyle Rhea.

and reviewing again.

Some difficulty was encountered in this process, as we found that at this level of survey, the acoustic data ranges for some biotopes were not distinguishable separately. This was found where different biotopes have similar life forms (Bunker & Foster-Smith 1996), and occur on the same substratum types. An example of this occurred on steep bedrock and boulders in the Lochs Duich, Long and Alsh pSAC. Ground validation recorded at least two biotopes on steep rock below the kelp zones: dead men's fingers (*Alcyonium digitatum*) where the rock or boulders were wave exposed or tideswept, and brachiopods (*Neocrania anomala*) and solitary sea squirts (ascidians) where steep bedrock or boulders occurred in sheltered, still water conditions. These two biotopes are very distinct, yet both consist of animals with similar form and size, and occur on the same substratum type, albeit in differing environmental conditions. Unfortunately, the range of acoustic data associated with the buffers for ground validation sites allocated to these two biotope types was wide, and overlapping, and we could not distinguish acoustically between the two on the basis of the acoustic data. This problem was overcome by allocating one acoustic signature (with a consequently wide data range) to several biotopes with similar life form, in this case termed 'deep rock and

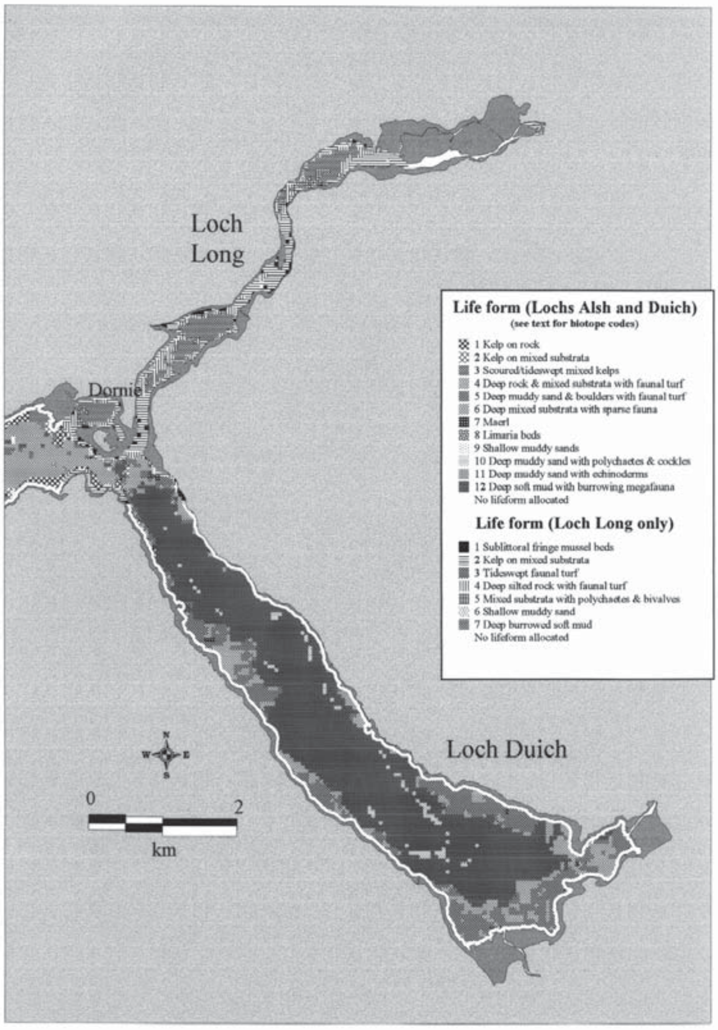


**Fig. 6.** Predicted distribution of life forms within Loch Duich and Loch Long.

**Table 2.** Life-form descriptions for **a.** Loughs Duich and Alsh; **b.** Lough Long (see Figs. 5 and 6).

| Life-form description | Constituent biotope codes (Connor et al. 1996) |
|---|---|
| **a. Loughs Duich and Alsh** | |
| Kelp on rock | MIR.Lhyp.Pk, Lhyp.TPk |
| Kelp on mixed substrata | MIR.Lhyp.Ft, SIR.Lsac.Ft, SIR.Lsac.X |
| Scoured/tideswept mixed kelps | MIR.XK |
| Deep rock and mixed substrata with faunal turf | ECR.AlcTub, MCR.Oph, SCR.NeoPro, DAL.SCR.ModOph |
| Deep muddy sand and boulders with faunal turf | SCR.ModHo, DAL.CMS.ModEch |
| Deep mixed substrata with sparse fauna | DAL.CMX.Fa |
| Maerl | IGS.Phy |
| Limaria beds | IMX.Lim |
| Shallow muddy sands | DAL.IMS.PAB |
| Deep muddy sand with polychaetes and cockles | DAL.CMS.Pcer |
| Deep muddy sand with echinoderms | DAL.CMS.PE |
| Deep soft mud with burrowing megafauna | CMU.SpNep, CMU.Beg, DAL.CMS.Bur, DAL.CMS.BvPol |
| **b. Loch Long** | |
| Sublittoral fringe mussel beds | SLR.Myt.X |
| Kelp on mixed substrata | MIR.Lhyp.Ft, SIR.Lsac.Ft, SIR.Lsac.X |
| Tideswept faunal turf | ECR.AlcTub |
| Deep silted rock with faunal turf | SCR.SoAs |
| Mixed substrata with polychaetes and bivalves | DAL.CMX.PolBv |
| Shallow muddy sand | DAL.IGS.PolVS |
| Deep burrowed soft mud | CMU.SpNep, CMU.Beg, DAL.CMS.Bur, DAL.CMS.BvPol |

mixed substrata with faunal turf'.

Tables 1, 2 and 3 relate to the legend of the maps in Figs. 3, 5 and 6, and show the MNCR biotope codes (Connor et al. 1996) for each life-form category used on the maps. Biotope codes prefixed with DAL or PS are provisional new biotopes identified during the Lochs Duich, Long and Alsh survey, or the Papa Stour survey respectively. Phase II MNCR forms were completed for these biotopes during our surveys, and the forms submitted to MNCR for verification.

Where there were known to be sublittoral cliffs along the eastern edges of Loch Duich, with deep soft sediment on the seabed below, the interpolated acoustic data close to the shoreline were misleading. The acoustic system, because it was directed vertically downwards from the sea surface, could not detect the cliffs, and showed only the soft sediment adjacent to them. This was felt to be misleading when represented on the maps, therefore a blanked-out buffer zone of 50 m width was applied to the maps within the GIS along the whole coastline of Lochs Duich and Alsh. This method was thought valid as acoustic data were not obtained consistently very close to the shoreline during the survey. This was not, however, implemented for the Loch Long data, because acoustic data were obtained close to the shore in this case, and as the loch is so narrow, this procedure would remove all data for some narrow stretches of the Loch.

## Use of the information

The information gathered and presented from the two surveys will have a number of key applications. The surveys were commissioned primarily to gather information that would assist in the implementation of the Regulations (1995) which deliver the requirements of the Habitats Directive.

Under the regulations the relevant and competent authorities (local authorities and other regulating bodies) are expected to undertake their management of the site so that the conservation features of the site are maintained. The conservation agencies are required to provide the relevant authorities with a series of conservation objectives which will ensure the maintenance of the conservation features. The relevant authorities are encouraged to develop a more integrated approach to the management of the site and with advice assistance from the conservation agencies develop a management scheme to deliver the conservation objectives. This whole process is expected to involve detailed and wide consultation and discussion.

One of the most important uses of the data provided by the surveys is to provide a starting point for these discussions. Clearly it is difficult to initiate discussions with other interested bodies and individuals on the future management of a site without a comprehension of the distribution and extent of the habitats and communities found in the site.

SNH are using graphical data in a GIS environment to consider the approach to the development of targeted conservation objectives for both SACs. Both SACs have been proposed for their rocky reef habitats and communities. Having graphically mapped data showing the general distribution and extent of the rocky areas of the site will allow for conservation objectives and the future management scheme to focus on these areas.

The following initial uses of the data have been identified:

- The development of conservation objectives under the Regulations can become more focused and area specific using the information on the extent and distribution of the conservation features, habitats and communities of the sites;
- The development of a management scheme for each site may use the data gathered during these surveys to develop a zoned approach to the practical management of the sites. This will enable appropriate management measures to be targeted to the most sensitive and vulnerable features of the sites;
- The extent and distribution and, when considered with detailed Phase II information, the quality of the biotopes may be monitored;
- Graphically mapped data will be used as part of the baseline data for monitoring the condition of the SACs, which must be reported to the EC every six years;
- Under the regulations, any new proposed development plan or project would be subject to the appropriate assessment of its likely impact on the conservation features of the site; the data gathered during the surveys described here will assist SNH to advise on marine impacts within the two SACs;
- Graphically mapped data assist in the management of intertidal and adjacent Sites of Special Scientific Interest;
- Graphically mapped data inform SNH staff in case work issues that affect the site;
- The graphical mapped data can be incorporated into future interpretive material for the sites.

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