Marine GIS for Management of Scottish Marine Special Areas of Conservation

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In May 1992, the European Community published the Habitats Directive aiming to conserve internationally important species and habitats across their European range. The first part of the directive required member states to identify, designate, and protect the most important sites to ensure that the extent and range of specific habitats and populations of constituent species are maintained over time within these Special Areas of Conservation (SAC). The Habitats Directive also enabled member states to establish management plans for the long-term maintenance of the SACs where considered necessary. The sites included both terrestrial and marine habitats and species. The human activities taking place within the sites were also considered where management measures were enacted, and focus on the conservation interest was maintained. Consideration of the sustainable development of human activities within marine SACs marked this directive as different from many historical conservation actions and demonstrated that the conservation of species diversity is not seen as incompatible with sustaining human activities within protected areas. The use of GIS became a key component in the mapping and management of marine SACs along with the use of remote survey and evaluation techniques similar to those provided by geophysical sonar that is now widespread in the marine community.

In 1996, the UK marine conservation organizations established the UK Marine SACs Project to help implement the Habitats Directive in the UK. The key tasks of this project included the development of methods to enable an assessment of the condition of habitats within twelve marine SACs around the coast of Britain and the management of these sites. A key message to emerge from the Marine SACs Project was the need to have a process for managing and integrating the large and diverse databases of information that exist for each site. It was also essential that this information be disseminated to a wide audience of stakeholders (English Nature et al. 2001). The Habitats Directive also requires member states to undertake surveillance on the condition of the sites with the subsequent reporting of this work every six years (Articles 11 and 17). The use of GIS is core to meeting these obligations, in particular those of initial marine SAC surveillance, mapping the distribution of individual habitat components, and establishing baselines for determining future change. In Scotland, thirty-four marine sites were proposed for SAC designation and the acquisition of the necessary data for management purposes for each of these is ongoing under the overall direction of Scottish National Heritage.

Scottish Marine SACs

The coastline of Scotland, at nearly 16,500 kilometers in length, contains a vast range of habitats from flooded fjords to enclosed bays and large forths or estuaries. The west coast is highly exposed to the North Atlantic, but has a climate that is modified by the North Atlantic Drift. The character of the shoreline is dependant on a number of physical factors including wave and wind exposure, salinity, geology, tidal range, and the strength of currents. Over 85 percent of Scotland's population live within ten kilometers of the coast and a significant proportion of Scotland's revenue is derived from activities conducted in the coastal zone. As a consequence, it is vital to the long-term sustainable development of the coastal zone that the natural habitats are preserved and managed in conjunction with economic development.

Each marine SAC around Scotland's coast is unique with different biological, physical, and human elements. In order to manage each of the sites, it is necessary to not only evaluate the key elements such as the species, setting, and human activity, but also to understand why these components are important. It is only through this process that one can then evaluate the level of change on a site that might have a detrimental impact upon the important habitats of species and cause site degradation. Questions about the future use of these sites must be addressed by local user groups, conservation organizations, and government to ensure that their management is to the long-term benefit of society. For each of the SACs, a thorough evaluation of the scale of natural "inherent" variability within the system is undertaken so that impacts of an anthropogenic nature can be determined. Changes within marine SACs could include physical modifications such as an increase in siltation (e.g., from increased dredging activity), increases in abrasion from more frequent storm activity, and chemical changes arising from synthetic and nonsynthetic compounds or radionuclides.

Survey program

A variety of remote and direct sampling methods are necessary for the collation and evaluation of historic information and the acquisition of new data for each marine SAC. (Foster-Smith et al. 2000). Broad-scale remote sampling methods include satellite observations, aerial photography, and acoustic surveys. Satellite and aerial photography techniques have limited water penetration capabilities within the marine environments on the east coast of Scotland, but are more applicable in the clearer waters on the west coast where light can penetrate 5 to 15 meters. These methods provide rapid, large-area coverage for some of the diverse shallow inlets, bays, and marsh habitats that would be prohibitively expensive to survey using other techniques. For rapid

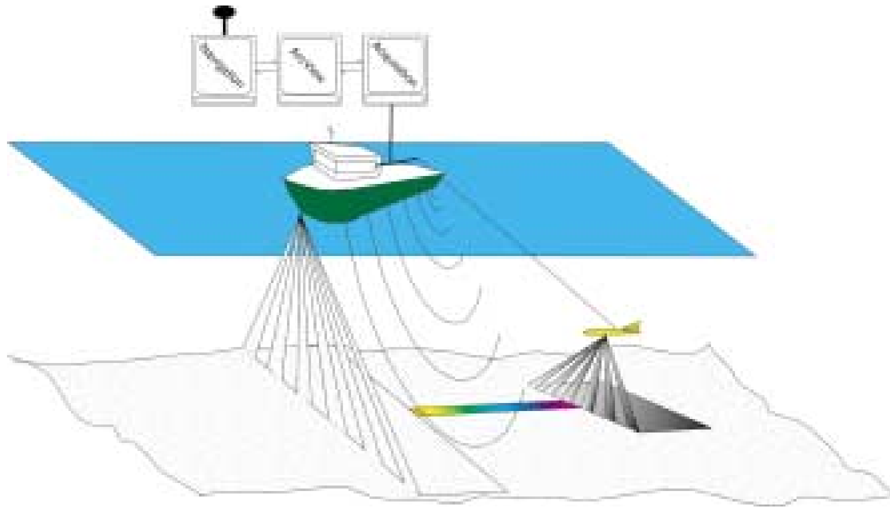

Figure 1: Schematic of acquisition and on-board processing system.

broad-scale remote mapping of areas not accessible to aerial remote sensing techniques, acoustic methods based on echo sounders, sidescan sonar, and multibeam sonar are used. Both the aerial and acoustic remote survey techniques require "ground truth" validation using data collected by a range of standard sampling methodologies.

Over the last two years, procedures have been developed by the University of St. Andrews and Heriot Watt University that enable a rapid turnaround in the processing of broad-scale acoustic survey information. All geophysical survey data was acquired and processed on-site during the survey to provide digital bathymetric models with draped sidescan and classed sonar reflections from the seafloor. During data collection, a separate computer running ArcView is present onboard the survey vessel so data can be transferred via a network in near real-time. This computer is also in communication with the navigation computer providing navigation information from a differential global positioning system (GPS) (figure 1). Preliminary biological evaluation and sediment classification is accomplished in the field based on information derived from a range of sampling techniques including diver-based observations with video and still cameras, remote video drops, ROV (remote operated vehicle) video, and sampling from grabs and cores. The seafloor habitat type was initially classed by combining this ground validation data with a knowledge of species biology, bathymetric position (aspect and slope), sidescan textural signature, and acoustic ground discrimination values. The habitats are grouped together in areas or polygons that exhibit the same ranges of conditions. At present, this process is a manual comparison of conditions with limited discrimination scripts written in Avenue; however, current research is focusing on the development of a set of logic-based automated habitat assignment routines for use within the GIS.

Historical data

An evaluation of historical data for input to the GIS is vital if the database is to be used as a management tool. In many SAC areas, the first novel survey data collected might be regarded as the baseline data; however, there is often extremely important information in the recent geological record that should also be considered. For example, an evaluation of changes in the Scottish landscape is not complete without consideration of the changes in agricultural

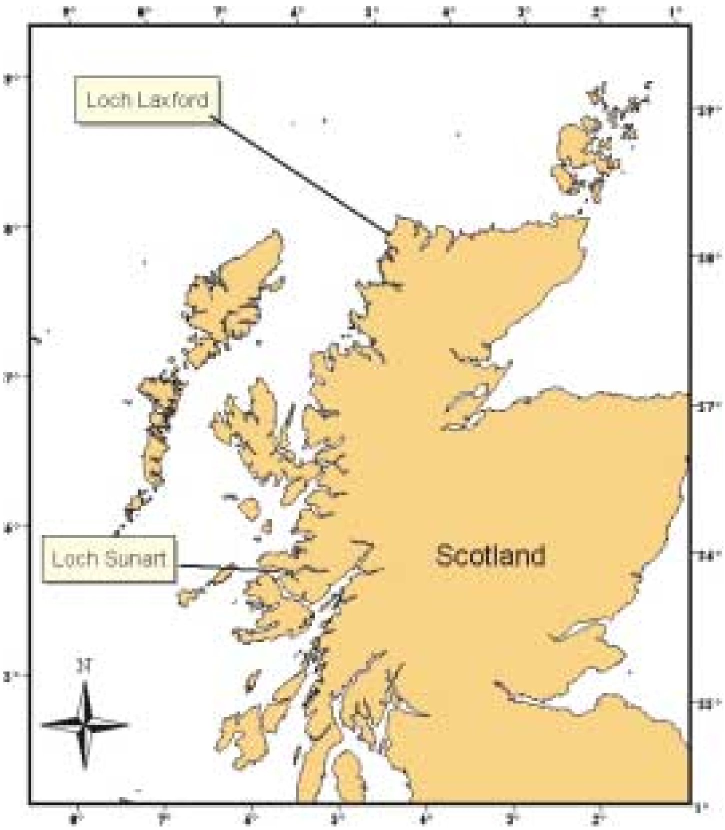

Figure 2: Location map of Loch Laxford and Loch Sunart marine Special Areas of Conservation.

practice during the highland clearances of the 1700s to 1800s. During this time, when large-scale sheep farming practices were introduced and local deforestation began, there was a significant change in physical and chemical inputs from streams to coastal areas. These changes are recorded in the sediment accumulations within lochs as is the story of climatic change during the last glaciations. Coring programs for sampling and dating sub-bottom material from the sea lochs is an important part of the baseline data gathering from these areas of conservation.

New survey data

A detailed bathymetric chart is a key element to understanding and delineating the range of habitats within marine SACs. Historically, these have been provided by access to UK Admiralty Charts or by taking echosounding measurements in the field. In these formats, the spatial resolution is not sufficient to record the small-scale changes that can influence the biological communities encountered. Therefore, it is necessary to obtain new bathymetric information for the construction of digital models using sidescan systems such as the Submetrix System 2000 and multibeam sonar such as the Reson Seabat 8125. Information from these detailed charts includes not only the depth but also the slope and slope angle or exposure angle of the seafloor. This is of particular importance when determining the spatial distribution of marine benthic communities.

The benefit of this high resolution for the undertaking of a geological appraisal is demonstrated in Loch Sunart, a 28-kilometer long and 130-meter deep sea loch on the west coast of Scotland (figure 2). The bathymetric profile of the loch is complex as it is subdivided into three major basins or sub-loch units separated by narrow and shallow sills. Each of the sub-basins contains remnant features from the last major glacial events in northern Europe during the Devensian period (before approximately ten thousand years ago) and sedimentological features resulting from deposition during glacial retreat. At the eastern end of the inner loch, these include a number of approximately north-south trending, sharp-crested ridges identified on the bathymetric chart (figure 3a). The amplitude swaths (sidescan like images) over these features suggest that they are sediment ridges rather than exposed bedrock at the surface (figure 3b). An analysis of the slope magnitude (figure 3c) and aspect of the ridges (figure 3d) using GIS show that the west facing slopes were steeper than east facing slopes. A comparison of the shape of these features with other glacial moraines reveal that they could represent De Geer type glacial moraines similar to those reported on Baffin Island by Boulton (1986) for debris deposited by grounded ice in front of glaciers. These features are not evident in the deeper parts of the loch below forty meters. This suggests a rapid ice retreat across the over-deepened section leading to grounding and stalling of the retreating ice sheet on the shallower seafloor to the east. In order to determine the exact nature of these features, a follow-up research program is proposed using sub-bottom profiling systems to determine the stratigraphy of the cores.

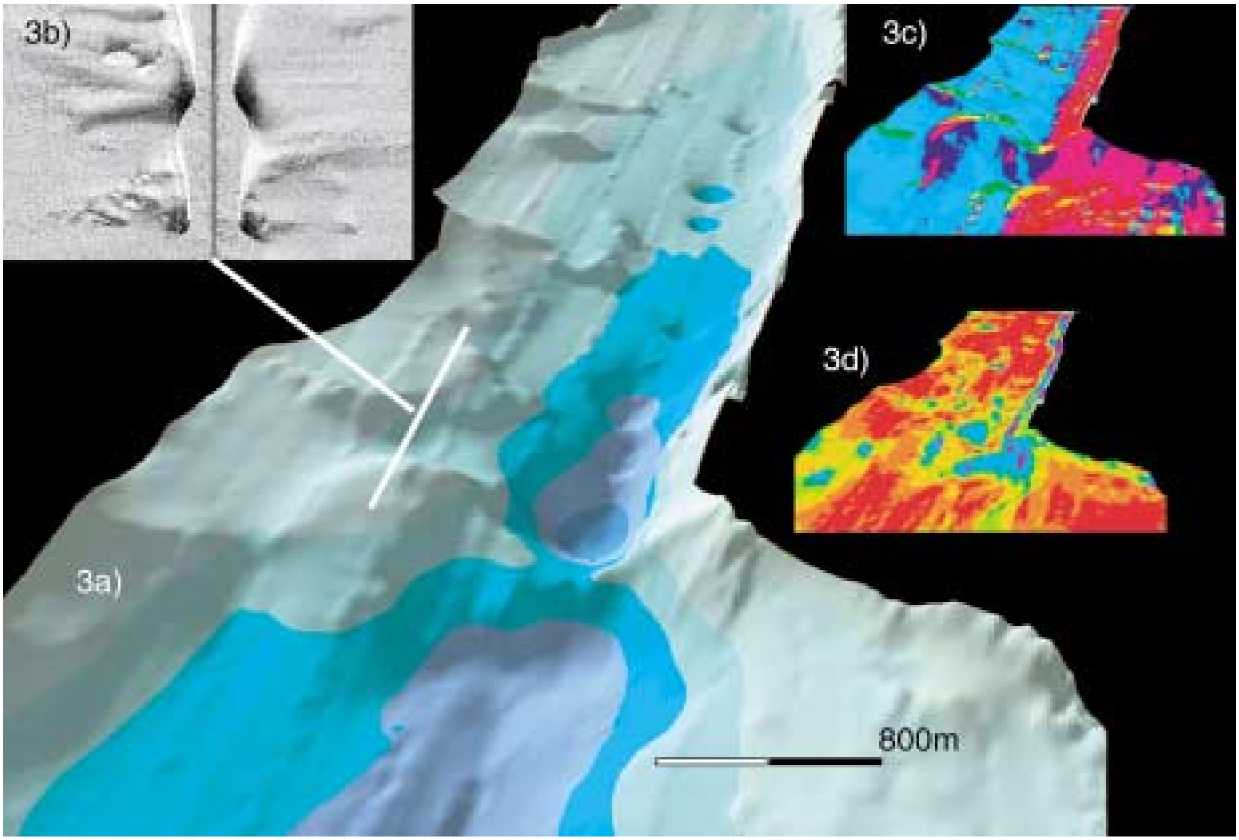

Figure 3: a) Digital bathymetric model of inner Loch Sunart; b) amplitude (sidescan) image over N–S trending ridges; c) slope aspect across ridges; d) slope magnitude across ridges.

Surface information

Detailed scientific information on the nature of the seafloor is available through a number of acoustic remote sensing methods including sidescan sonar, bathymetric sidescan, multibeam sonar, and acoustic ground discrimination sonar. The resulting images are then draped onto the bathymetry (Blondel and Murton 1997). While this provides a good representation of bottom conditions, the method often suffers from difficulty in georeferencing the images. With the new generation of multibeam sidescan, bathymetric sidescans, and multibeam sonar, georeferencing is achieved during the acquisition of the data. The resulting amplitude maps have very high spatial resolution (Bates and Byham 2000). A view of an amplitude map draped on a bathymetric chart for Loch Laxford (c.f. figure 2) on the west coast of Scotland is shown in figure 4a. The spatially referenced view clearly shows the rocky outcrops as the dark areas of high bathymetric relief and the uniform sediment in the bottom of the loch as lighter shades. This interpretation is further corroborated with information on the strength of acoustic echo-signal reflection from the seafloor recorded using Acoustic Ground Discrimination Sonar (AGDS). AGDS reflection strength in terms of the roughness and hardness of the seafloor are compared to biological and sedimentological type through ground truth observations (Chivers et al. 1990; Sotheran et al. 1997). The method has the advantage of being easily implemented on a wide range of survey vessels and records data along line tracks from beneath the survey vessel. These have been color-coded as an overlay to the sidescan over the rock areas shown in detail in figure 4b.

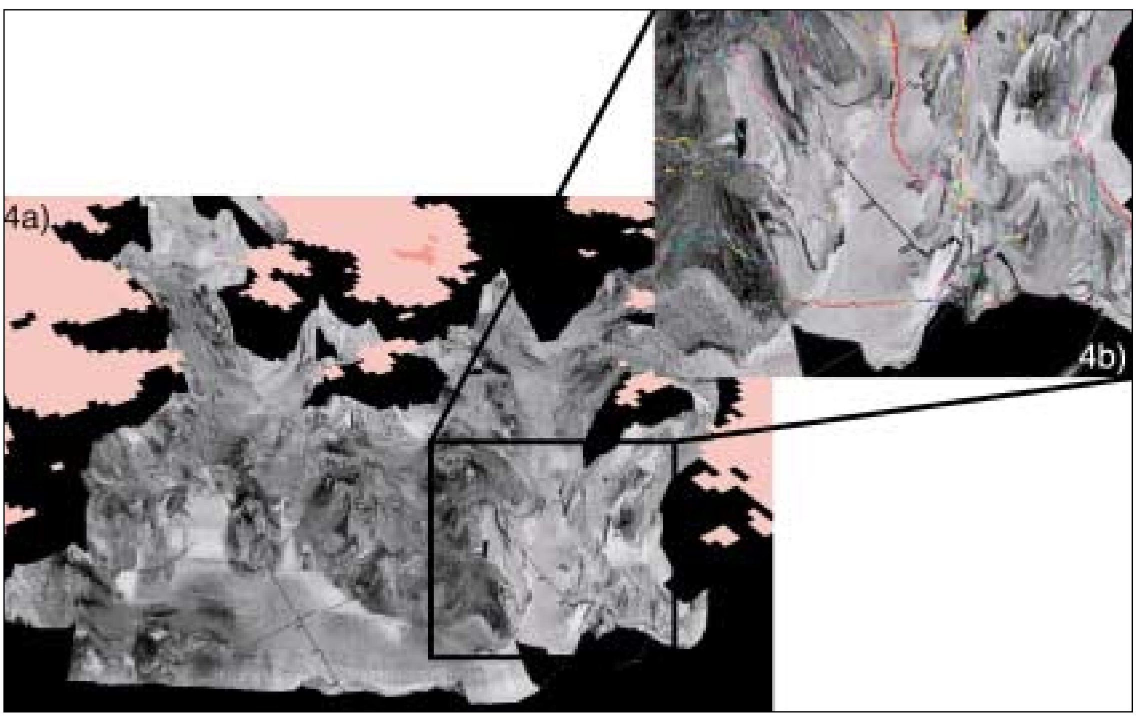

Figure 4: a) View looking east into the outer part of Loch Laxford; b) expanded view of loch floor overlaid with acoustic ground discrimination line track data.

Future developments

While the information described above provides a detailed broad-scale description of benthic conditions within a marine SAC, so far to date information is not regularly recorded for properties in the water column at the sites. Data about the volume of water and the water quality within a marine SAC also provides critical information about the health of the sites. Evaluating the water column is more problematic than evaluating signatures on the seafloor, as changes tend to occur within a more rapid timeframe and thus require the GIS to include time-based data. Key information from the water column includes temperature, salinity, conductivity, currents, and chemical signatures. This information is used for creating many of the circulation models and, in conjunction with the data from subbottom sediments, for re-creating circulation models for past climatic conditions. At present, this type of analysis is at the research stage in the School of Geography and Geosciences for the Scottish marine SACs program and many challenges are foreseen with respect to addressing true volumetric measurements of the water column. In assessing transient populations within the marine SACs (pelagic fish and marine mammals), similar difficulties are expected. Direct sampling and acoustic measurements are marginally successful to this study in evaluating these aspects of an SAC. However, it is anticipated that the latest technologies such as the multibeam sonar may provide a way forward and represent the next generation of survey technologies.

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