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Seasonal shelf-sea front mapping using satellite ocean colour and temperature to support development of a marine protected area network

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ABSTRACT

Front detection and aggregation techniques were applied to 300-m resolution MERIS satellite ocean colour data for the first time, to describe frequently occurring shelf-sea fronts near to the Scottish coast. Medium resolution (1-km) thermal and colour data have previously been used to analyse the distribution of surface fronts, though these cannot capture smaller frontal zones or those in close proximity to the coast, particularly where the coastline is convoluted. Seasonal frequent front maps, derived from both chlorophyll and SST data, revealed a number of key frontal zones, a subset of which were based on new insights into the sediment and plankton dynamics provided exclusively by the higher-resolution chlorophyll fronts. The methodology is described for applying colour and thermal front data to the task of identifying zones of ecological importance that could assist the process of defining marine protected areas. Each key frontal zone is analysed to describe its spatial and temporal extent and variability, and possible mechanisms. It is hoped that these tools can provide guidance on the dynamic habitats of marine fauna towards aspects of marine spatial planning and conservation.

1. Introduction

The Marine (Scotland) Act 2010 and the UK Marine and Coastal Access Act (2009) include new powers and duties to designate Nature Conservation Marine Protected Areas (MPAs) to protect important biodiversity and geodiversity in Scotland's seas. The principles for the identification of a MPA network in Scotland's seas are set out in the MPA Selection Guidelines, which establish that fronts are one of five large-scale features included on the list of MPA search features to guide the design of the network. The other large-scale features on the list are shelf banks and mounds, shelf deeps, seamounts and continental slope. Large-scale features were included in order to help build ecosystem function into the development of the MPA network, for example through helping to identify areas of wider functional significance. Persistent hydrographic features, such as fronts, are widely recognised as supporting enhanced biological activity. Mixing at the boundary between two water bodies can lead to elevated primary and secondary production (Franks, 1992; Samuelsen et al., 2012) and as a result serve to aggregate species at higher trophic levels. There are many published studies associating marine animals with fronts (reviewed by Scales et al., in revision-b), for example fish (e.g. Bakun, 2006; Munk et al., 2009), seabirds (e.g. Bost et al., 2009) and basking sharks (Sims and Quayle, 1998). Seabirds and basking sharks are among the priority species targeted for conservation through MPAs, and frontal features were included in the 2013 MPA consultation in Scotland; there is ongoing work in relation to fronts and assessment of MPA search locations.

This paper utilises 300 m resolution ocean colour imagery in order to create mapping and interpretive products that were used to provide advice on MPAs in Scotland's seas. Frequent front maps for UK seas were previously produced, based on ocean thermal imagery at 1–3 km resolution and indicate on a continuous scale the percentage of time over each season that strong fronts are observed at each location (Miller and Christodoulou, 2014). These maps provide an indication of surface thermal fronts in Scotland's seas, however only fronts with surface thermal signatures were detected. Furthermore the mapping was not of sufficient resolution to capture smaller frontal zones or those in close proximity to the coast. Scotland has a particularly convoluted coastline which means that a significant proportion of frontal zones were beyond reach of these existing thermal front maps (Miller et al., 2014).

Higher-resolution (300-m) ocean colour data are now available through Medium Resolution Imaging Spectrometer (MERIS). The aim of this project was to apply front detection to the 300 m ocean colour data, allowing observations of fronts much closer to the

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coast and within estuaries. Ocean colour products such as chlorophyll-*a* offer a number of benefits for observing fronts. The algae or suspended sediment acts as a tracer for physical processes, and hence may indicate fronts that only have a density gradient rather than a thermal gradient. In addition visible light is reflected back from several metres into the water column, depending on turbidity, so it is possible to observe fronts that would be obscured in sea surface temperature data by wind mixing, stratification or surface heating. Mapping fronts based on the chlorophyll signal, rather than temperature alone, may also provide a more direct indication of the enhanced primary production that can be associated with frontal areas.

2. Methodology

2.1. Geographical area

Fig. 1 depicts the bathymetry surrounding Scotland, dominated by a steep continental shelf break though with many significant topographic features on the shelf within the range of 100–150 m depth, and islands including the Inner and Outer Hebrides, Orkney and Shetland. The study region was selected to cover a majority of the Scottish exclusive economic zone (EEZ) considered by the MPA process, extending to beyond the shelf break. The EEZ was intersected with a bounding box from 54.1 to 64.1°N, −13.8 to 3.8°E.

2.2. Satellite data

2.2.1. MERIS full-resolution 300-m ocean colour

The primary dataset for this study was the Medium Resolution Imaging Spectrometer (MERIS) sensor on board the European Space Agency (ESA) Envisat satellite, operational between March 2002 and April 2012. MERIS acquired 15 spectral bands in the 390–1040 nm range of visible to near-infrared reflectance. A global archive of 300-m MERIS full-resolution (FR) data were acquired from the ESA near-real time rolling archive, as Level 2 (ESA N1 format) files containing calibrated reflectances, geophysical parameters and georeferencing data.

Queries were implemented using ESA's Earth Observation Link (EOLi) system to identify all the MERIS data granules that overlapped the study region. The matching data were located in the Plymouth Marine Laboratory (PML) data archive and processed and mapped using PML's Generic Earth Observation Processing System (GEOPS). The data were mapped to Mercator projection, giving image dimensions of 3316×3743 pixels for a minimum horizontal resolution of 300 m within the area.

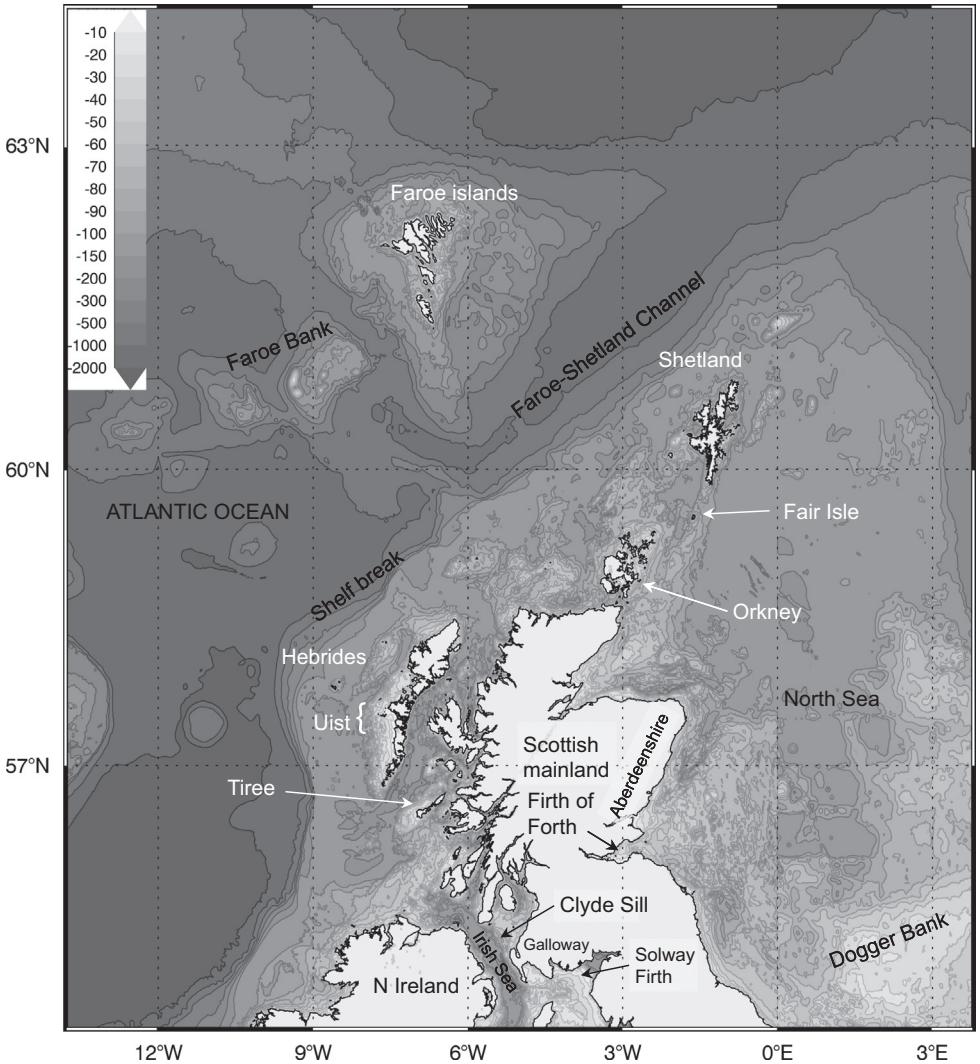

Fig. 1. Bathymetry map of Scottish waters, with shaded depth contours in metres, and selected features of interest labelled. This was generated using the GEBCO_08 global 30 arcsecond grid, based on quality-controlled ship depth soundings and satellite-derived gravity data.