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Fisheries and Aquatic Ecosystems Branch
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EFF Project: Ecosystem Based Management of Irish Fisheries and other resources (CA/033766/11)

Work Package 2:

Field surveys of the Malin Shelf ecosystem in winter and summer 2012 and winter 2013

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Contents

Summary
Three research surveys were undertaken to the Malin Shelf to acquire up-to-date scientific information on the physical, chemical and biological parameters of this important, but much under-studied, region of the UK shelf.

Results of the key ecosystem variables show that the water column of the Malin Shelf is vertically mixed during winter causing elevated near surface concentrations of nitrate (approx. 10.4 μM) and horizontal gradients in both temperature and salinity. A marked salinity front north of Malin Head is evident across the region separating cool, low salinity inner shelf water from oceanic water.

During summer, the ecohydrodynamics of the shelf are much more complex with seasonal stratification and a tidal mixing front between Islay and Malin Head (Pingree 1978; Simpson et al. 1979; Gowen et al. 1998). The Islay front is somewhat different from other fronts in that the salinity component of it was an extension of the Irish Salinity Front (ISF), a prominent feature to the west of Ireland that separates coastal and oceanic water (McMahon et al. 1995).

The slope current (Booth and Ellett, 1983) is another prominent feature of the western Oreland shelf region with a poleward flow of warm saline water parallel to the shelf break (Burrows and Thorpe, 1999) persistent throughout the year and on the Hebridean shelf (north of the Malin Shelf). It potentially transports warm temperate species of phytoplankton that have been recorded off the south west of Ireland (Raine et al., 1993) to the Malin Shelf break region (Gowen et al., 1998).

In recent years, extensive blooms of *Karenia mikimotoi* have been reported on the west coast of Ireland as well as the western waters of Scotland Davidson et al. (2009) causing mortalities of a wide range of marine organisms including farmed fish.

Several blooms of *Karenia mikimotoi* occurred in Irish coastal waters between the Mayo and Donegal during late June and July 2012 and were responsible for large scale mortalities of benthic organisms and wild fish (J Silke pers. Comm.). The survey to the Malin shelf in July 2012 recorded a *K. mikimotoi* bloom (4×10^6 cells L^{-1}) on the oceanic side of the shelf break decreasing towards Malin Head while no reports on *K. mikimotoi* blooms were logged in Scottish waters in 2012. This indicates that while some ocean water penetrates onto the Malin Shelf, this does not extend east of Malin Head. The separation of oceanic, outer shelf and inner shelf water on the Malin Shelf during summer is also supported by the distinct patterns in the distribution of oceanic, shelf and coastal species of plankton reported by Gowen et al (1998).

In conclusion, the results of the presented surveys indicate that the waters of the Malin Shelf isolate the Irish Sea so drastically that any influence that long-term climate change may have on ecosystem structure and functioning in the Irish Sea, is

more likely to be the result of a direct influence on the Irish Sea itself (e.g. an alteration in the seasonal development of stratification), rather than an indirect effect brought about by changes in the exchange processes between the Irish Sea and the outer shelf regions.

Introduction

In 2011 the Department of Agriculture and Rural Development (DARD) awarded a European Fisheries Fund (EFF) grant to AFBI to provide advice on the implementation of an ecosystem approach to the management of Irish Sea fisheries and other resources. The study was divided into four work packages: (1) to document the science and best practice relating to the implementation of an ecosystem approach to managing marine fisheries and other ecosystem services (2) three ecosystem surveys of the Malin Shelf sea area (3) investigate fisheries yield/ primary production relationships;(4) to determine the status of the western Irish Sea micro-plankton community.

This is a report to DARD on work package 2. The rationale for this was to collect data that could be used to aid the distinction between the influence of climate change and human pressure on marine ecosystems as it is a requirement of the MSFD. It is important because remedial action will not be required if failure to achieve good environmental status (GES) is due to climate. The ecosystem surveys of the Malin Shelf will contribute to the Western Shelf Observatory and add to our understanding of whether the western Irish Sea ecosystem is being influenced by local human pressure or climate change. The key aim was to undertake three research surveys to acquire up to date scientific information on the state of the western Irish Sea ecosystem by May 2013. The AFBI research vessel '*Corystes*' was used to make routine measurements of key ecosystem variables in the western Irish Sea and adjacent sea areas and further develop and enhance the AFBI time-series on physical oceanographic and biological data. The surveys to the Malin shelf region took place in January and July 2012 and in January 2013. These surveys were expected to compliment ongoing DARD funded ecosystem health surveys of the Irish and Celtic Sea. The measure of success was the compilation of the physical and biological data into a database that is specifically linked to a suite of data analysis tools operated by Cefas.

The Malin Shelf

The Malin Shelf is the name given to the large area of shelf sea immediately north of Ireland and to the south west of Scotland. To the east, the shelf is confined by the land mass of Northern Ireland, the Scottish mainland (Mull of Kintyre) and the Island of Islay. Water depth is typically ~80 m and the bottom topography is rocky and irregular. As the shelf becomes more open to the east, water depth increases to an average of 150m (Sherwin, 1988) and the topography of the outer shelf region becomes relatively sandy and smooth. The edge of the continental shelf (shelf edge or shelf break) around the United Kingdom is typically taken to be at a depth of ~200m (Pingree et al., 1999). On the Malin Shelf, the shelf break is located at approximately 9.5° W and is well defined with a smooth and steep cliff down to ~ 2200m at the bottom of the Rockall Trough (Sherwin, 1988).

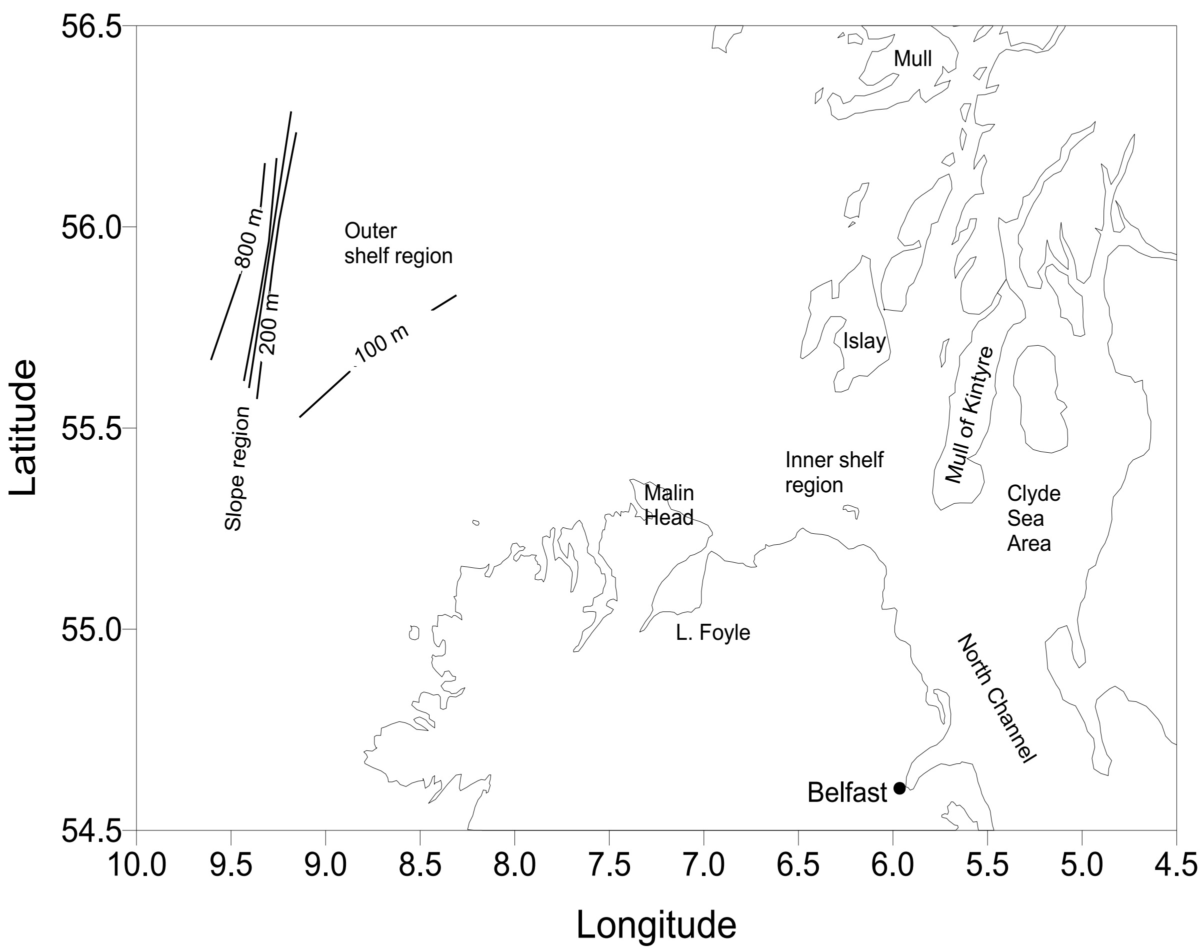

Figure 1: A map of the Malin Shelf region and the names of places mentioned in the text.

Methods

The methods section is divided into two parts. The first part includes details on the collection and analysis of the survey data while the second part consists of a brief description of the European Marine Ecosystem Observatory (EMECO) data tool.

Survey data

A grid of stations was surveyed in the North Channel and on the Malin Shelf between 15th and 20th January 2012, 20th and 23rd July 2012, and 12th and 14th January 2013 onboard the RV *"Corystes"*.

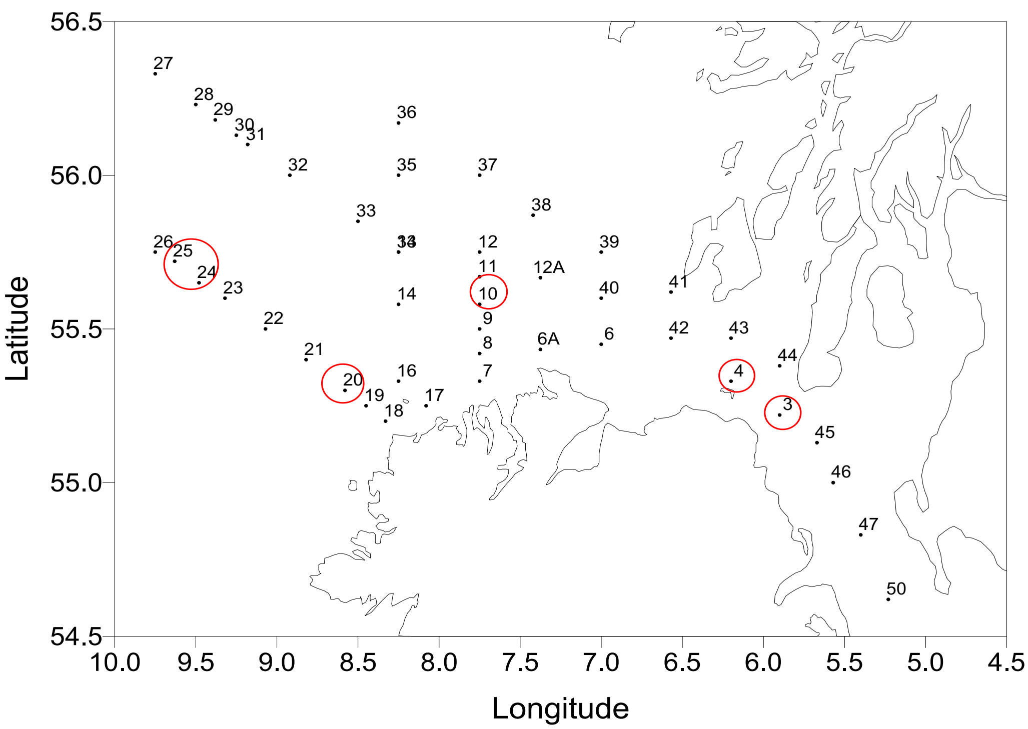

Figure 2: A map showing the Malin Shelf region and the stations worked during surveys in January and July 2012 and January 2013. The red circles indicate where the microplankton data were completed. In the text all Malin Shelf stations are prefixed with the letter M. They have been left out of the figure for clarity.

Due to weather conditions not all of the stations were worked during each survey. Details of the stations worked during each survey can be found in Annex 1 (see Table A 1). At each station, vertical profiles of conductivity, temperature, and depth were recorded using a Sea-Bird SBE 32 (Sea-Bird Electronics, Inc. Washington USA with an SBE 9plus CTD). Salinity was estimated from the temperature and conductivity measurements generated internally by the CTD instrument. Water samples for nutrients, chlorophyll, and phytoplankton analysis were collected using a rosette water sampler with twelve 5L bottles assembled by Sea-Bird Electronics, Inc., Washington USA with the SBE 9plus CTD instrument underneath.

For the determination of dissolved inorganic nitrogen, silicate and phosphate, water samples were stored and frozen for later analysis using a Bran Luebbe segmented continuous-flow analyser (TRAACS) employing automated colorimetric methods. The chlorophyll samples were immediately processed and analysed onboard following the method described by Tett (1987b). A Turner Designs model 10A-U-005-CE was used to measure chlorophyll fluorescence. Water samples (250ml) for microplankton analysis were fixed with 2mL of neutral Lugol's iodine solution and stored in amber glass bottles in the dark until further analysis.

Table 1: An overview of parameters sampled.

Parameter	**Methods**
Physical data	
Temperature, salinity	CTD profile (every 0.5m)
Chemical data	
Nitrate, Phosphate, Silicate	Water samples at discrete depths
Biological data	
Chlorophyll	Water samples at discrete depths
Microplankton data	Water samples at discrete depths

The graphs and plots presented in the results section were created in Windows Excel (profile plots, cell abundance, and biomass percentage). Contour plots to display surface characteristics and shelf to shelf features of temperature, salinity, nutrients and chlorophyll were created using Surfer 7.

EMECO data tool

The European Marine Ecosystem Observatory (EMECO) is a consortium of agencies and institutes with responsibility for both the monitoring and assessment of marine ecosystem threats and status (health), and also for improving understanding through research in European shelf-seas. The consortium brings together existing monitoring, modelling and research capabilities to create a European infrastructure. EMECO was formed to improve the evidence base for formal environmental assessments, provide integrated assessments (from physics to fish) and to meet legal requirements imposed by the Marine Strategy Framework Directive (MSFD).

In this way, EMECO is an "End-to-End" system from data to integrated, policy relevant information products. A flow diagram on the functionality of EMECO can be found in the Annex (Figure A1).

Results

The results section shows results for the data collected and analysed from the three Malin Shelf surveys. The EMECO data tool output is presented and discussed in the discussion section.

Survey data

Physical and chemical data

In the following section the data are displayed in two different ways. First, the near surface distribution of temperature, salinity, nitrate, and chlorophyll (exclusively July 2012) is shown for the Malin Shelf region. Second, the vertical distribution of these variables is illustrated using data collected from three stations selected to represent the different hydrodynamic regions of the Malin Shelf: North Channel (station M47); inner shelf region (station M40); on the slope beyond the shelf break (station M30).

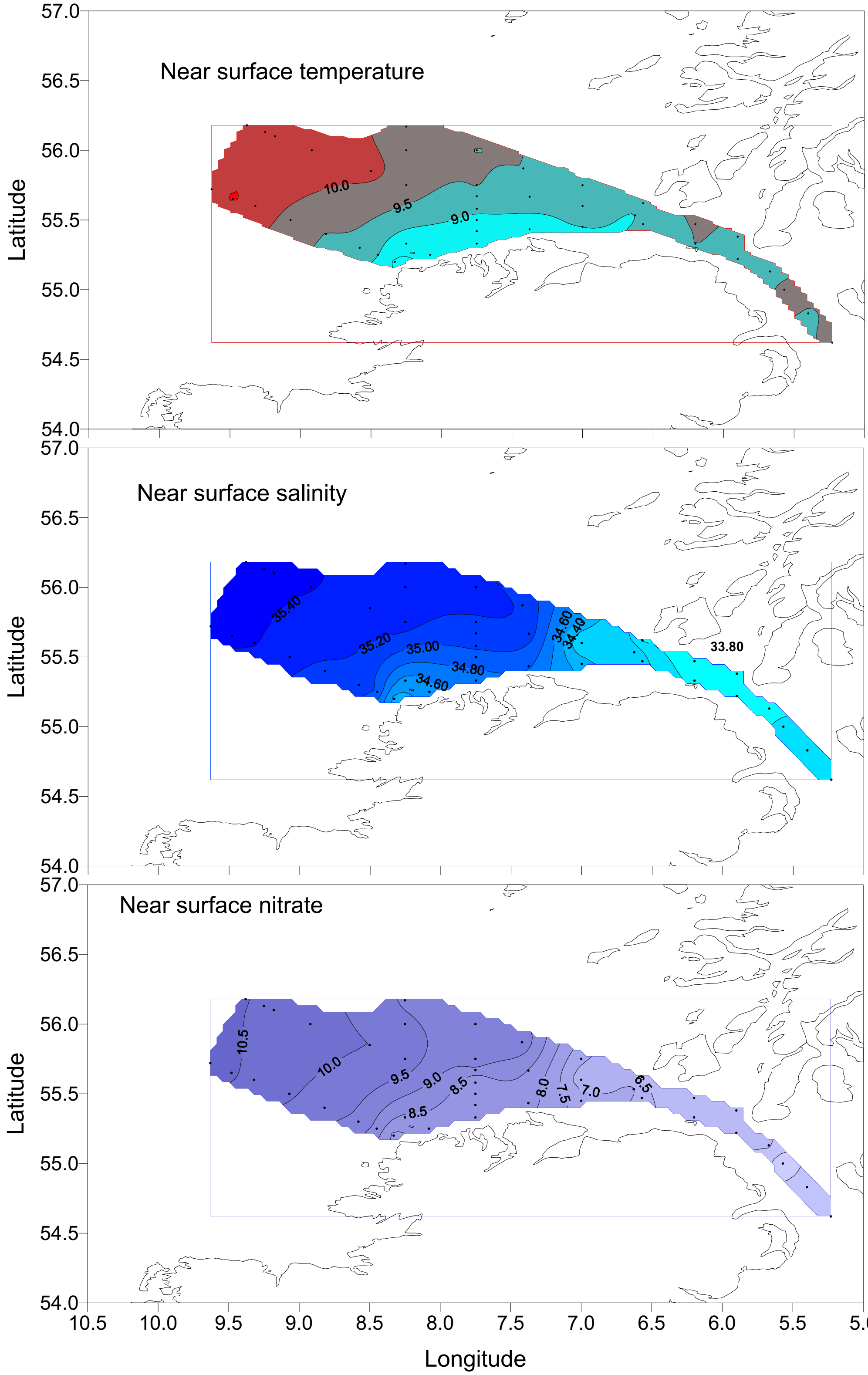

Figure 3: The distribution of near surface temperature (° C), salinity and nitrate (μM) in the North Channel and on the Malin Shelf during January 2013. The contour intervals are 0.5° C for temperature, 0.2 salinity units and 0.5 μM for nitrate.

The winter surface data presented in Fig. 3 are for January 2013 because this survey was complete (all stations sampled) while in January 2012, a few stations could not be sampled due to bad weather conditions. However, the data collected in January 2012 are presented in the discussion to support particular points.

Cold (9° C) near surface water was observed in the North Channel (stations M50 to M45) and warmer (10.5° C) water was found at the shelf break (stations M33 to M29 and M23 to M25) (Figure 4). The cold North Channel water had a low salinity (33.94, at M50) compared to 35.43 at station M30 on the slope. The highest concentration of dissolved inorganic nitrogen (nitrate, NO_3) was 10.62 μM measured at station M24 in the outer shelf region.

The temperature, salinity, and nitrate profiles for the three selected stations (North Channel: M47, Inner Shelf: M40 and on the slope: M30) indicate that the water column in January 2013 was vertically mixed (isothermal and isohaline) in all three areas (Figure 4). At this time of year the surface data therefore provide a good indication of the characteristics of the deeper water.

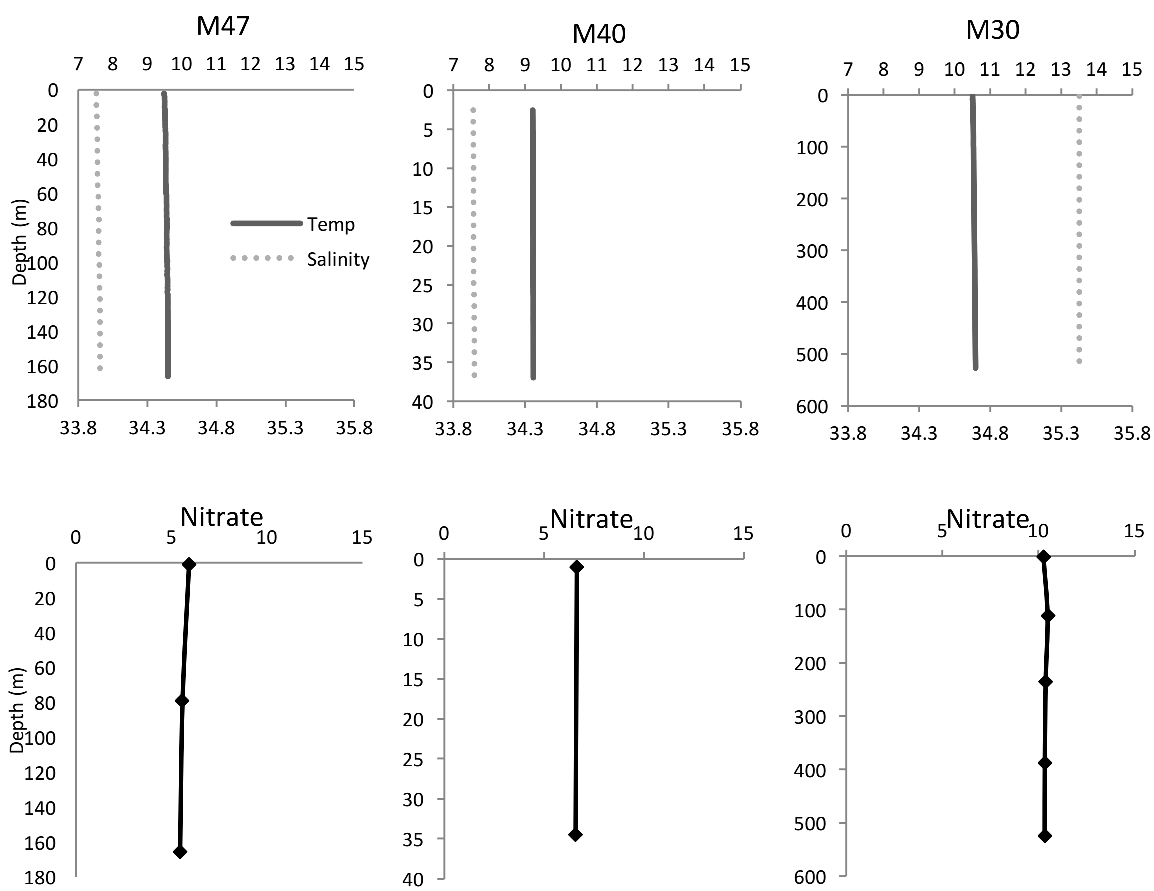

Figure 4: Vertical profiles of temperature in ° C (solid line in top graphs), salinity (dotted line

in top graphs), and nitrate in μM (bottom graphs) at Malin Shelf stations (M47, M40 and M30) in January 2013.

The summer surface plots show a different pattern to the winter plots (Figures 5 and 6). The warmest near surface water (14.4° C) was located in the outer shelf region and was associated with higher salinity (35.32). There was a marked surface gradient in temperature (1.0 °C) north of the Malin Head. The maximum near surface nitrate concentrations (3.14-3.48 μM) were measured in waters between stations M3 and M41. Nitrate concentrations in near surface waters on the shelf were ≤ 0.5 μM, although at the northern end of the shelf edge transect (M29) the near surface concentration was 2.8 μM. During the July 2012 survey there were two areas of elevated near surface phytoplankton biomass (as measured by chlorophyll). One at station M6 (3.8 mg m^{-3}) offshore from Lough Foyle and the second (18.5 mg m^{-3}) at station M25 located on the slope.

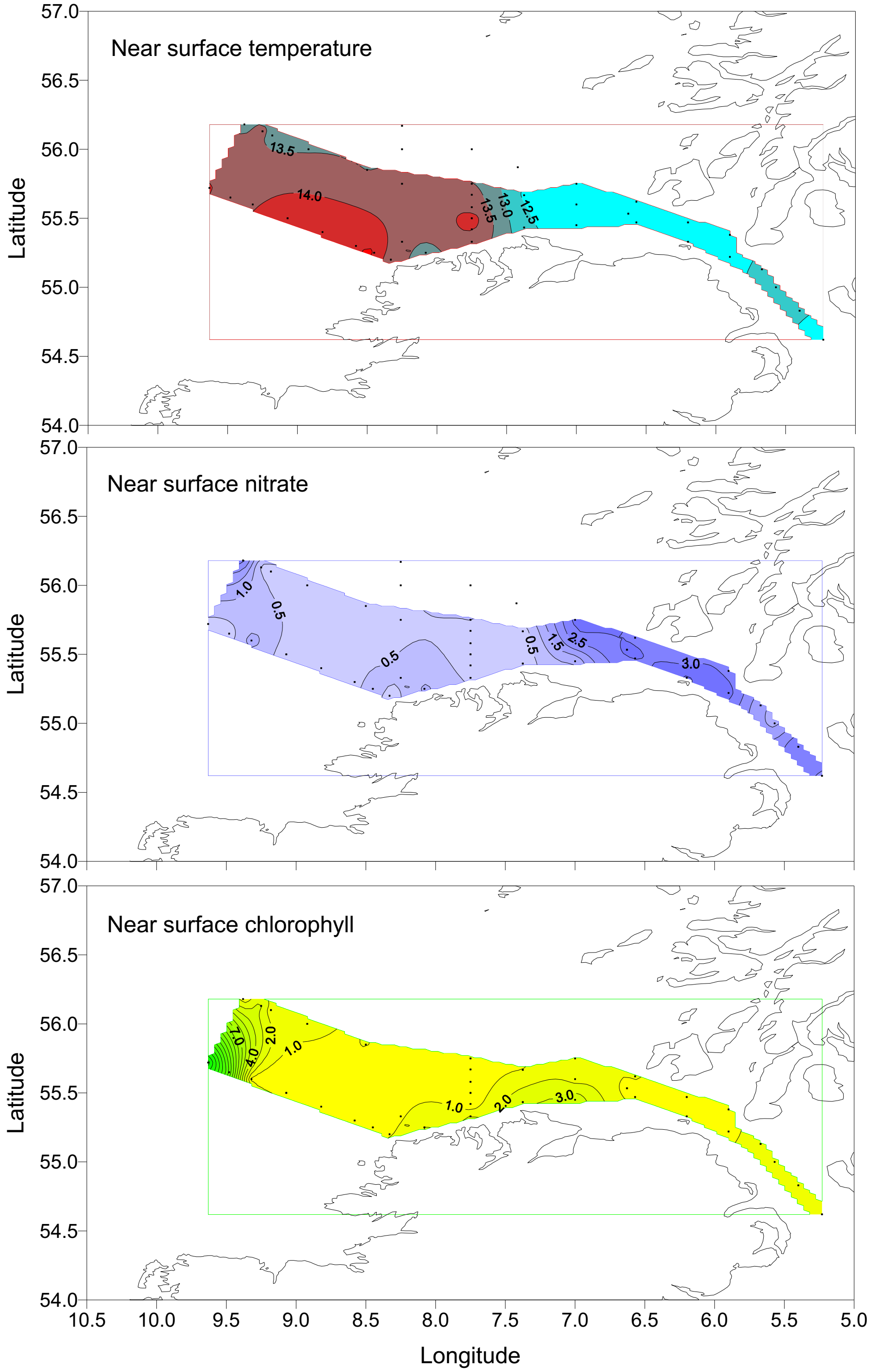

Figure 5: The near surface distribution of temperature (° C), nitrate (μM), and chlorophyll (mg m^{-3}) in the North Channel and Malin Shelf region in July 2012. The contour intervals are 0.5° C for temperature, 0.5 μM for nitrate and 1 mg m^{-3} for chlorophyll.

The summer profile plots (Figure 6) generally show a different pattern to the winter plots (Figure4. The warmest near surface water (13.6° C) was located on the slope (represented by station M30) and was associated with high salinity (35.41). Near surface temperature in the inner shelf region (represented by station M40) was 12.2° C and the vertical profiles shows an isothermal and isohaline water column with a salinity of 33.87. The profile shown for M47 representing the North Channel area indicates a slight thermal and saline stratification over the top 20m (surface temp: 12.6° C; bottom temp: 11.8° C; surface salinity: 33.97; bottom salinity: 34.02). The vertical distribution of summer nitrate shows high variation at all three sites (Figure 6). There was a vertical gradient in nitrate at station M47, with a sub-surface minimum of 2.54 μM at a depth of 17.3m and a maximum concentration of 3.62 μM in the bottom water. At the inner shelf station M40, nitrate was almost uniformly distributed throughout the water column (top and bottom concentrations of 2.76 μM and 2.66 μM, respectively). The biggest difference in surface to bottom nitrate concentration was found at the slope station M30. Here, the surface concentration was 0.29 μM and bottom water concentration 12.23 μM NO_3. The chlorophyll concentrations for all three stations show a reverse pattern to the nitrate concentrations for July 2012 (Figure 7). The North Channel and the inner shelf regions had low chlorophyll values (maximum 1.1 mg m^{-3} and 1.6 mg m^{-3}, respectively) compared to the outer shelf region on the slope with a maximum of 3.5 mg m^{-3} in surface waters.

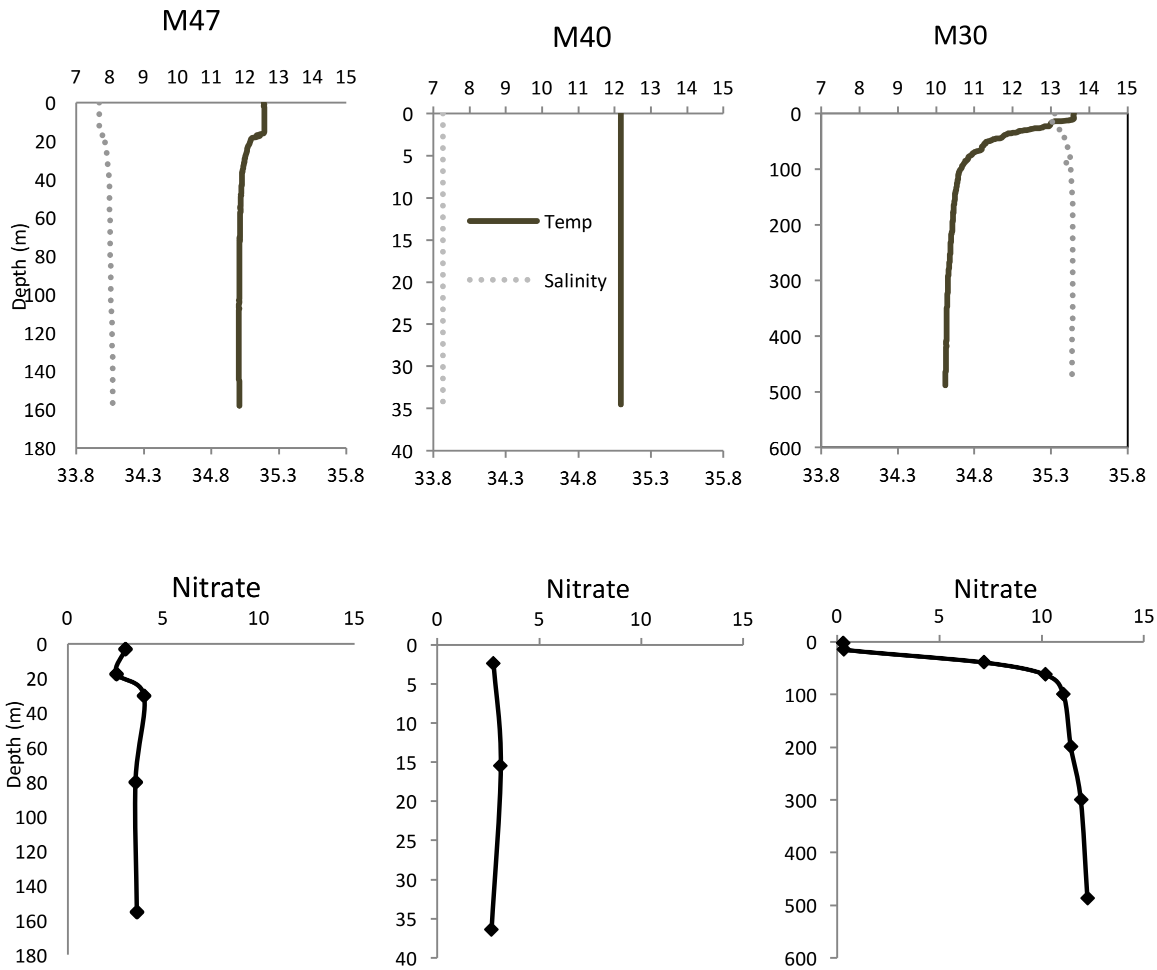

Figure 6: Vertical profiles of summer temperature, salinity, nitrate and chlorophyll distribution for the water column for the Malin Shelf stations (M47, M40 and M30). Temperature is given in ° C; nitrate and chlorophyll concentrations are displayed in μM and mg m^{-3}, respectively.

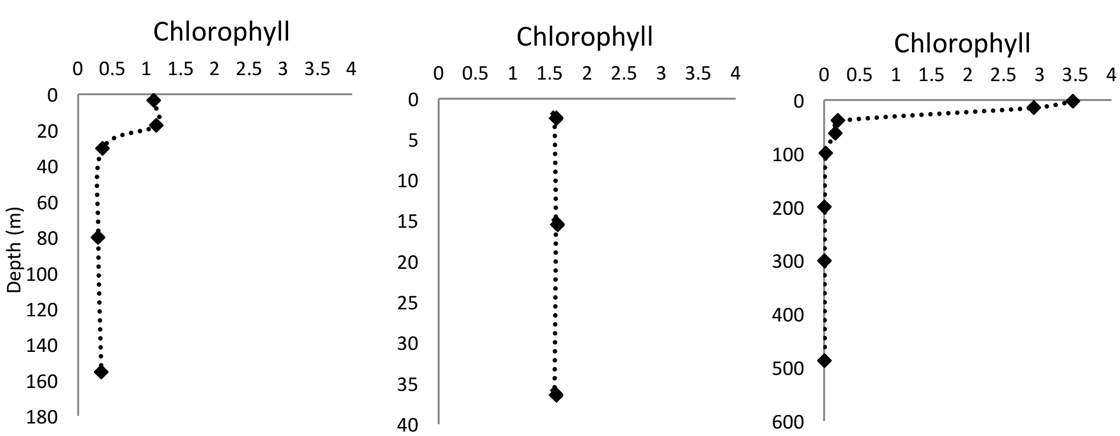

Figure 7: Vertical profile of summer chlorophyll concentration (mg m^{-3}) at the three Malin Shelf stations (M47, M40 and M30).

Cell abundance and biomass

In this section cell abundance (cells L^{-1}) and carbon biomass (mg C m^{-3}) of microplankton analysed in samples from selected stations are presented for July 2012.

The graph in Figure 8 shows total microplankton cell abundance (cells L^{-1}) on a $\log_{10}$ scale for the stations identified in Figure 2 (p.4).

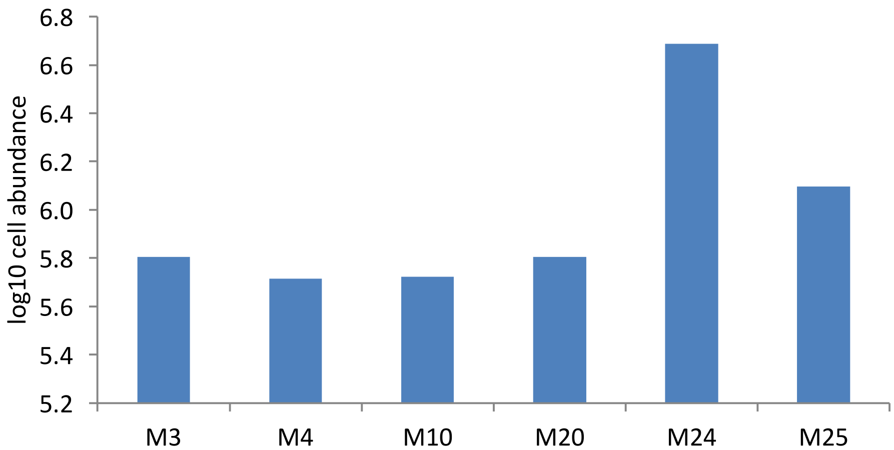

Figure 8: Total microplankton abundance (cells L^{-1}) displayed on a $\log_{10}$ scale in near surface waters at selected stations in July 2012.

The microplankters found in the summer survey in July 2012 were micro-flagellates, diatoms, ciliates and dinoflagellates. The graph in Figure 8 shows that at station M24 the total cell abundance was highest (4.8 x 10^6 cells L^{-1}) while M4 showed the lowest total cell abundance (5.2 x 10^3 cells L^{-1}). The figures presented here are total cell abundance and micro-flagellates generally dominated these numbers. However, micro-flagellates although in high abundance have a relatively small biovolume and therefore their carbon biomass contribution can be low.

When cell abundance was converted to carbon biomass, differences in microplankton composition were observed across the Malin Shelf. In the North Channel micro-flagellates and diatoms dominated the composition while the outer Shelf stations were dominated by medium to large sized dinoflagellates (Figure 9). At stations M20, M24 and M25 a bloom of the toxic dinoflagellate *Karenia mikimotoi* was observed with a maximum cell abundance of 4,734,000 cells L^{-1} and carbon biomass of 12.56 mg m^{-3} at station M24.

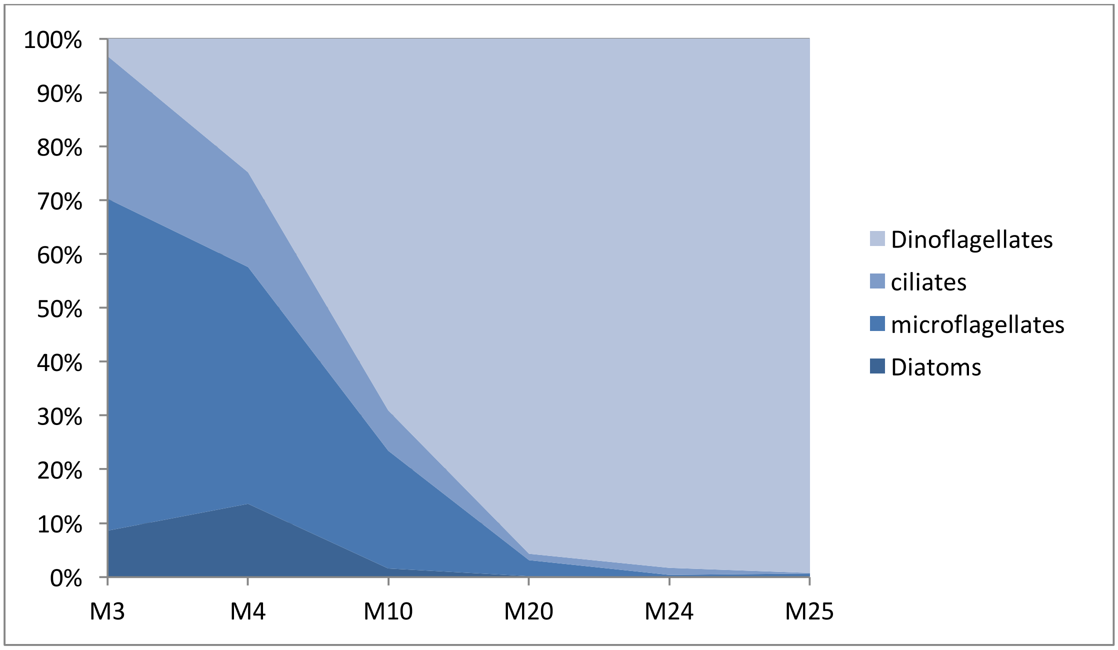

Figure 9: The relative contribution (as a percentage) of diatom, micro-flagellate, ciliate and dinoflagellate carbon biomass (mg C m^{-3}) to total microplankton carbon biomass at selected Malin Shelf stations in July 2012.

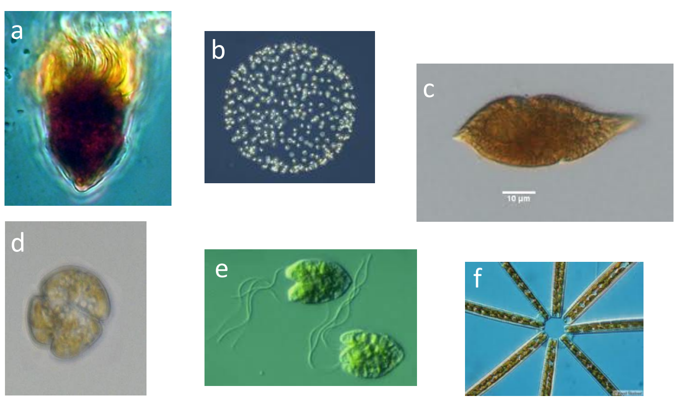

Figure 10: Images of the most common taxa observed in near surface water samples collected from the Malin shelf in July 2012 a) ciliate (unknown species) b) *Phaeocystis* sp. c) *Gyrodinium* sp. d) *Karenia mikimotoi* e) micro-flagellates f) *Thalassionema nitzschioides.*

Discussion

Survey data

The aim of this work package, to undertake three research surveys to acquire up to date scientific information on the state of the western Irish Sea ecosystem by May 2013, has been met. Results of key ecosystem variables in the western Irish Sea and adjacent sea areas were presented and are compared to peer review publications in the following section.

The three surveys of the Malin Shelf provide up to date data on the physical environment, distribution of inorganic nutrients and summer microplankton. Collectively, these data provide a useful addition to our understanding of this important (but much under studied) region of the UK shelf and by combining these results with those from earlier studies it is possible to establish the general conditions that prevail on the shelf during winter and summer.

As expected, the water column on the Malin Shelf was vertically mixed during the winter (Figure 4). This mixing extended down to at least 500 m on the slope (see M30 in Figure 4) in 2013, and is the reason for the elevated near surface concentrations of nitrate (10.66 and 10.24 µM at station M30 in January 2012 and 2013, respectively) over the slope compared to the inner shelf region (6.65 µM at M40). Hydes et al. (2004) observed a similar situation during February 2000 and reported a near surface concentration beyond the shelf (in ocean waters at 12° W) of 11.00 µM and 10.30 µM immediately adjacent to the shelf break.

Horizontal gradients in both temperature and salinity were evident across the shelf in January 2012 and 2013 (Figure 3) and a marked salinity front north of Malin Head separated cool, low salinity inner shelf water from oceanic water. It is evident from the data that oceanic water (salinity 35.00 – 35.40) extends onto the shelf (Figure 3 and 4) during winter. This is consistent with earlier observations made by Ellett (1979) who noted that at this location, Atlantic water flows onto the shelf to the north of Ireland the west of Islay. It therefore appears that this represents typical conditions on the shelf in winter. According to Ellett (1979) and others (Ellett & Edwards (1983); and Hill et al. (1997) this flow merges with northward flowing Irish Sea/ Clyde water and forms a coastal current (Figure 11). This Scottish coastal current is diverted around the Outer Hebrides with some flow between the Outer Hebrides and the Scottish mainland.

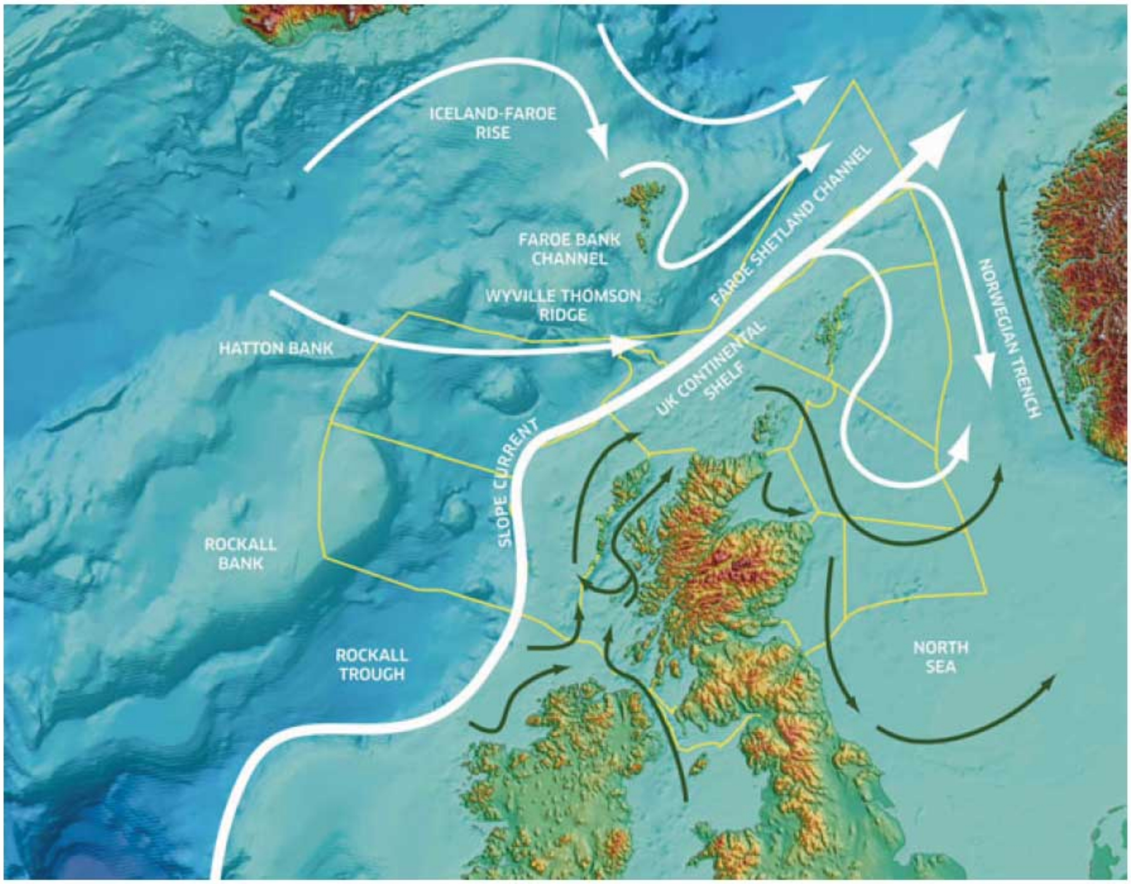

Figure 11: A diagram of the generalised flow of water through the northern Irish Sea, across the Malin Shelf and around the west of Scotland. Source: Baxter et al. (2011)

The situation in summer (July 2012) is very different and the picture is much more complex. There were vertical and horizontal gradients in both temperature and salinity. Regions of deeper more open coastal waters, in which tidal flows are weak, undergo seasonal thermal or thermo-haline stratification. The Celtic Sea (Fasham et al. 1983), North Sea (Tett et al. 1993; Mills et al. 1994; Lee et al. 2002), western Irish Sea (Gowen et al. 1995; Horsburgh et al. 2000) and Sound of Jura (Jones et al. 1984) provide examples. A key physical feature of such regions are the tidal mixing fronts (e.g. Simpson & Hunter 1974; Pingree et al. 1975) that develop at the interface between vertically mixed seasonally stratifying waters.

On the Malin Shelf, there is a tidal mixing front (the Islay front) between Islay and Malin Head (Pingree 1978; Simpson et al. 1979; Gowen et al. 1998). The surface manifestation of the front can be seen as the marked vertical gradient in temperature north of Malin Head (Figure 11) and by the abrupt change in near surface temperature recorded by the ship's flow through CTD (Figure 12). However, Figure 12 also shows that at the same location there were marked changes in near surface salinity, which represents the salinity component of the Islay front. The Islay front differs from other fronts (e.g. the western Irish Sea front) because of the proximity of these salinity gradients.

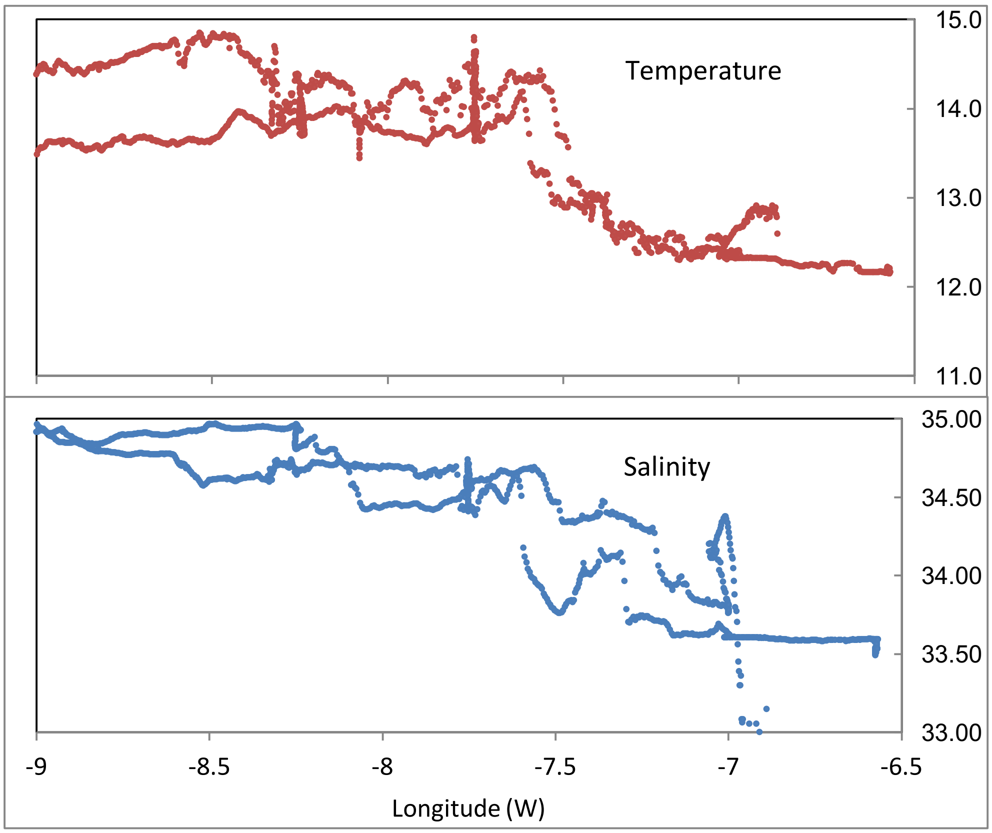

Figure 12: Near surface temperature (top graph) and salinity (bottom graph) along the ships course during the EFF project survey in July 2012.

The July 2012 data show that, as in winter, oceanic water penetrates onto the outer Malin shelf (Figure 12x) during summer. Gowen et al. 1998 made a similar observation in August 1996 and the two data sets indicate that this is a characteristic feature of the oceanographic conditions on the shelf during summer. Furthermore, Gowen et al. (1998) suggested that the salinity component of the Islay front was an extension of the Irish Salinity Front (ISF), a prominent feature to the west of Ireland that separates coastal and oceanic water (McMahon et al. 1995). McMahon et al. (1995) stated that the position of the ISF is defined by the 35.30 isohaline and in Figure x this isohaline has been coloured blue, to illustrate the location of the Irish salinity front on the Malin Shelf.

A second prominent feature of the western shelf region of Ireland and the United Kingdom is the slope current (Booth and Ellett, 1983). This is a poleward flow of warm saline water parallel to the shelf break (Figure 13) and the following summary has been drawn from Burrows and Thorpe (1999). The slope current is a persistent feature throughout the year and on the Hebridean shelf (north of the Malin Shelf) the maximum mean slope current is located between 0 and 15km west of the 500 m depth contour and is 25 km wide on the Hebrides slope. The current flow is ≈ 20 cm s^{-1} and transports approximately 1 Sv (Sverdrup = 10^6 m^3 s^{-1}) of warm saline water northwards. In winter the flow is uniform from the surface to 350 m but in summer has a maximum speed at a depth of 200 m. During a survey of the region in February 2000, Hydes et al. (2004) recorded elevated near surface temperature and salinity (9.8° C and 35.40, respectively) at the shelf break (≈9° W) that they considered to be indicative of the shelf edge current. Gowen et al. (1998) observed a component of the current in August 1996, as a core of warm saline water between depths of 200 and 400 m on the slope.

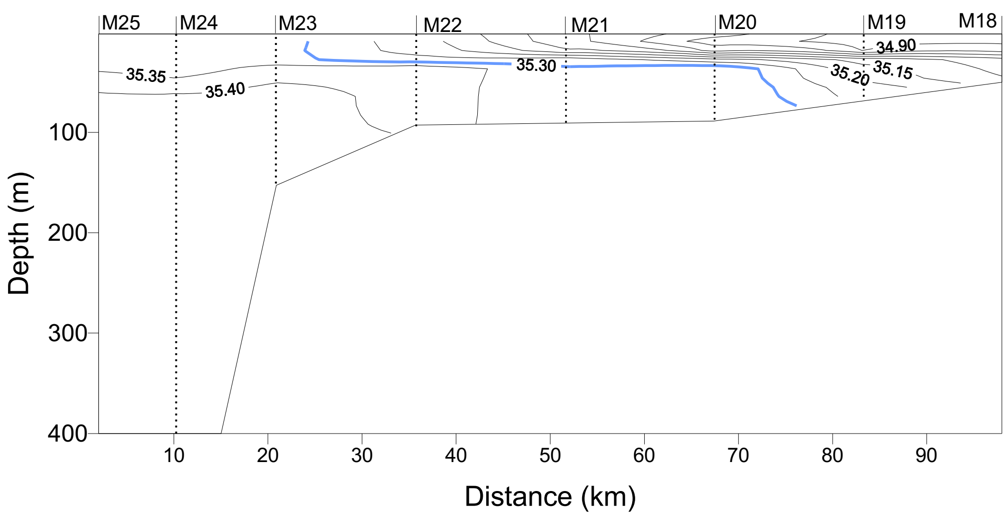

Figure 13: A vertical section of salinity along a transect from station M25 on the slope to station M19 in coastal waters of the north west of Ireland in July 2012. The 35.30 isohaline marking the location of the Irish salinity front is coloured blue.

Pingree et al. (1999) concluded that while the continental slope acted as a barrier to the exchange between the ocean and the shelf, the slope acts as a 'conductor or chute channelling alongslope flow from south of Ireland to the Northern North Sea'. This connectivity along the western seaboard of Ireland and the British Isles raises questions about the transport of plankton. Raine and McMahon (1998) suggested that dinoflagellate populations could be transported along the southern coast of Ireland from the Celtic Sea at ≈ 10 – 15 km d^{-1}. The slope current may also transport warm temperate species of phytoplankton that have been recorded off the south west of Ireland (Raine et al., 1993) to the Malin Shelf break region (Gowen et al., 1998). Whether the Irish coastal current is continuous with the Scottish coastal current is unclear but such a coastal current could aid the distribution of harmful algal bloom (HAB) species along the western seaboard of Ireland and Scotland.

In recent years extensive blooms of *Karenia mikimotoi* have caused mortalities of a wide range of marine organisms including farmed fish in coastal waters of Ireland and the west of Scotland. According to Davidson et al. (2009), large *K. mikimotoi* blooms occurred in Scottish waters in 1999, 2003 and 2006. The 2003 bloom (18.0×10^6 cells L^{-1}) around the Orkney and Shetland Islands was responsible for the deaths of 53,000 farmed fish. The 2006 bloom was the most extensive and extended from the island of Mull on the west coast to the Shetland Isles and the north east coast (Stonehaven). No major fish kills were reported but there were reports of mortalities of benthic organisms including lugworms, blue mussels (*Mytilus edulis*), common starfish (*Asterias rubens*) and king scallops (*Pecten maximus).*

Extensive blooms of *K. mikimotoi* occurred in Irish coastal waters in 2005 (Silke et al. 2005). The first bloom (3.0×10^6 cells L^{-1}) appeared off the northwest coast in May and the second (3.7×10^6 cells L^{-1}) occurred in waters off the south west in July. Both blooms were associated with widespread mortalities of farmed shellfish along the coasts of County Mayo and County Galway. Fish and crustacean mortalities were reported from the counties of Kerry, Donegal, Galway and west Cork and in July, mortalities of polychaete worms and cockles (*Cerastoderma)* were reported from County Donegal.

Several blooms of *Karenia mikimotoi* also occurred in Irish coastal waters between the Mayo and Donegal coastal area during late June and July 2012 and were responsible for large scale mortalities of benthic organisms and wild fish (J Silke pers. Comm.). The July 2012 EFF project survey of the Malin Shelf took place in mid July and a *K. mikimotoi* bloom (4×10^6 cells L^{-1}) was observed at stations M 24 and M25 on the oceanic side of the shelf break. Interestingly, there were no reports of *K. mikimotoi* blooms in Scottish waters in 2012.

The origin of these blooms and whether there is any connectivity between the Irish and Scottish blooms remains unclear. On the basis of a review of the occurrence of harmful species of phytoplankton in coastal waters of Ireland and the British Isles, Gowen et al. (2012) suggested that the geographical distribution of *K. mikimotoi* results from suitable ecohydrodynamic conditions (seasonally stratifying waters) and the adaptation of this phytoplankter to these conditions. Large populations of dinoflagellates (especially *K. mikimotoi*) often develop at tidal mixing fronts. Pingree et al. (1978) observed up to 50,000 cells L^{-1} *K. mikimotoi* at the front in July 1977 and Gowen et al. (1998) recorded 300,000 cells L^{-1} at the front in August 1996. Populations growing at the Islay front could be transported north in the Scottish current but the northerly flow of Atlantic water onto the shelf to the north west of Ireland, argues against these populations being the origin of blooms in coastal waters of the west coast of Ireland. There is a consensus that blooms originate in open shelf waters. For example, Raine et al. (1993) concluded that a *K. mikimotoi* bloom in Bantry Bay during the summer of 1991, had been advected towards the coast from the shelf and Davidson et al. (2009) were of the opinion that the widespread 2006 bloom in Scottish coastal waters originated in shelf waters.

It is striking that *K. mikimotoi* blooms have not been reported from the Malin shelf or northern Irish Sea. At the time of the large *K. mikimotoi* on the west coast of Ireland in July 2005, *K. mikimotoi* was observed in Loughs Foyle (31,100 cells L^{-1}), Larne (17,260 cells L^{-1}), and Belfast (400 cells L^{-1}) (FSANI unpublished data) and in waters to the north of the North Channel (4,551 cells L^{-1}) but not in the Irish Sea (AFBI unpublished data). Similarly, at the time of the *K. mikimotoi* bloom on the west coast of Ireland during July 2012, the abundance in coastal waters on the north coast only reached between 6,000 and 61,220 cells L^{-1} in Lough Foyle and was absent from Larne Lough (FSANI data). This pattern is consistent with the oceanographic data which show that while some ocean water penetrates onto the Malin Shelf, this does not extend east of Malin Head. The separation of oceanic, outer shelf and inner shelf water on the Malin Shelf during summer is also supported by the distinct patterns in the distribution of oceanic, shelf and coastal species of plankton reported by Gowen et al (1998).

By combining the Malin Shelf survey data with AFBI survey data from the Irish Sea and Celtic Sea (Figure 14) it is possible to obtain a quasi-synoptic picture of the region as a whole, in particular the contrast between the two outer shelf regions and the contrast between the outer shelf and inner shelf regions. The winter section (Figure

15) illustrates the difference in the depth of winter mixing that occurs at the ocean shelf boundary. Mixing extended to a greater depth on the Malin Shelf slope (~500 m) compared to the Celtic Sea shelf break slope (~200 m) and this is why the near surface winter nitrate concentration was higher (~10.5 μM) adjacent to the Malin shelf break compared to ~7.0 μM at the Celtic Sea shelf break.

Figure 14: A map of Ireland and the western fringe of the United Kingdom showing the continental shelf (Malin Shelf in the north, Celtic Shelf in the south) and shelf break. The yellow line represents the approximate transect line of sampling stations surveyed in January and July 2012, and January 2013.

Winter characteristics for January 2012

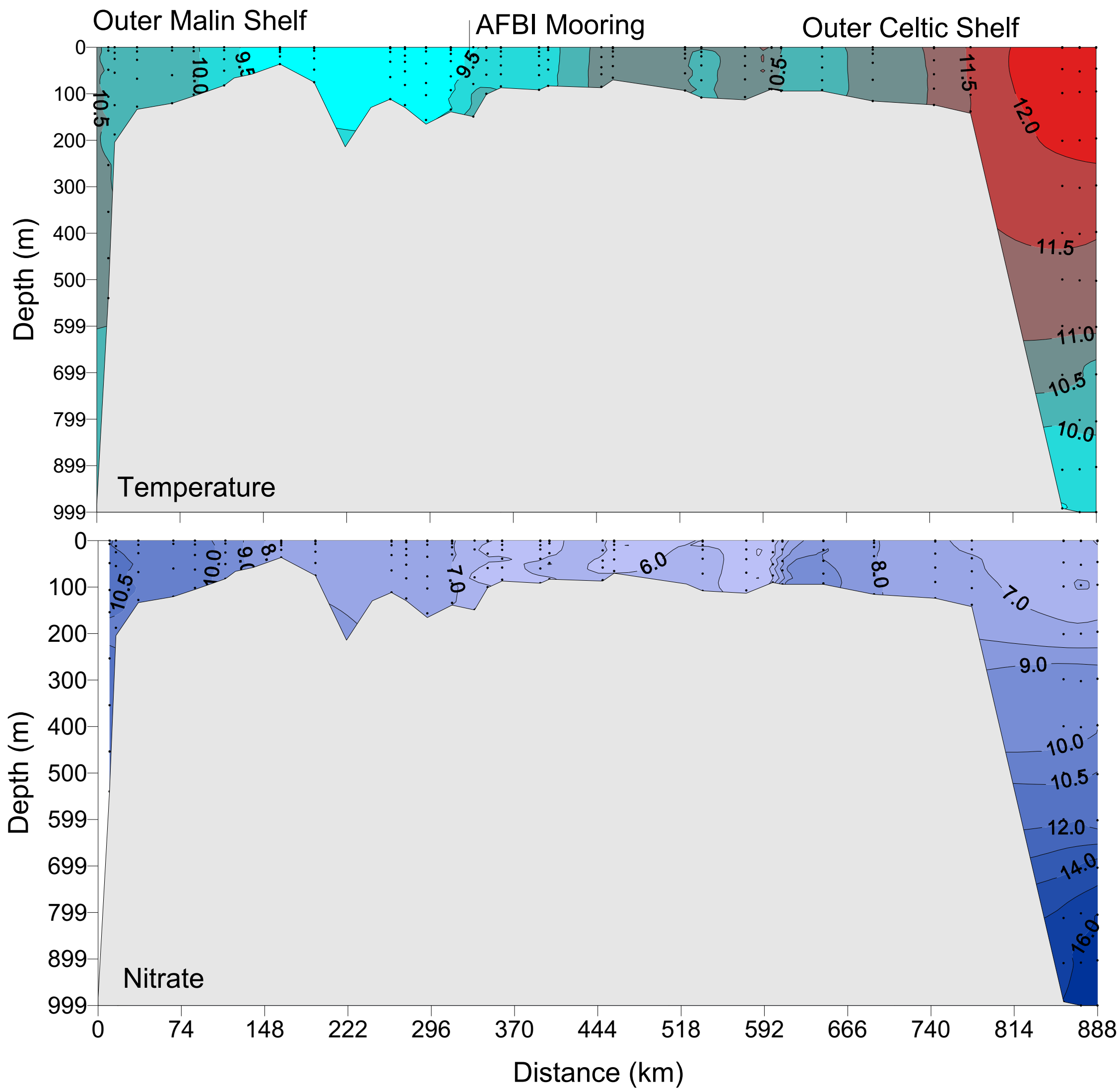

Figure 15: The vertical and horizontal distribution of temperature and nitrate in January 2012 along the shelf edge to shelf edge transect (Figure 14) in January 2012. Top graph: temperature (° C); bottom graph: nitrate (μM).

The summer data (Figure 16) show the complex physical oceanography of the region as a whole and again the contrast between the Malin Shelf and Celtic Sea. Surface warming had isolated cool deeper water on the shelf and in the Irish Sea and the elevated biomass of phytoplankton associated with the frontal boundaries on the Malin shelf in the Irish Sea and in the Celtic Sea is clearly seen as rather small isolated pockets of enhanced production.

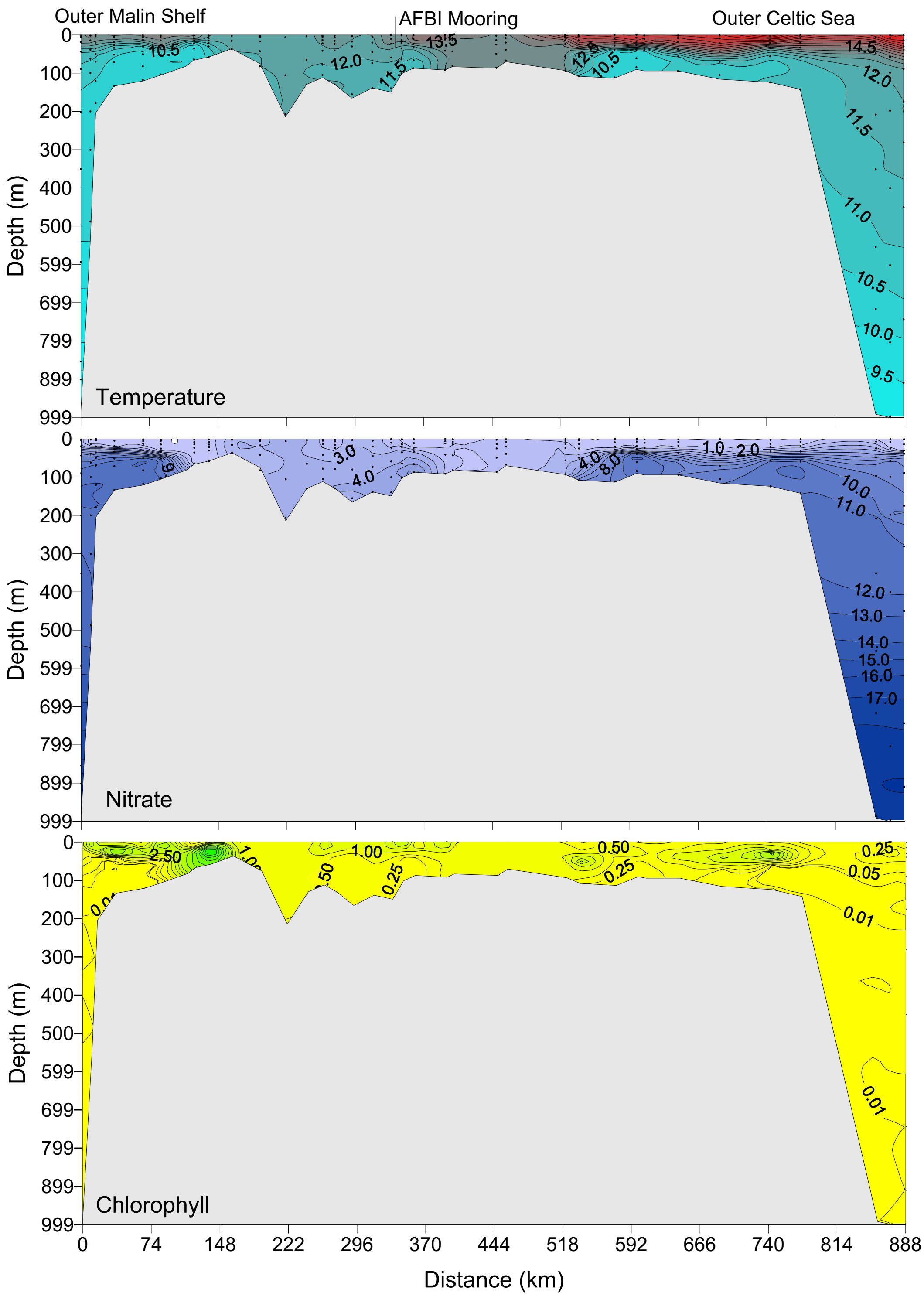

Figure 16: The vertical and horizontal distribution of temperature nitrate and chlorophyll along the shelf edge to shelf edge transect (Figure 14) in July 2012. Top graph: temperature (° C); middle graph: nitrate (µM); bottom graph: chlorophyll (mg m^{-3}).

The contour section from the Malin Shelf break to the Celtic Sea shelf break shows how far the Irish Sea is from the outer shelf/ ocean boundary region. In addition to this geographical isolation, the physical oceanography of the region brings about a physical isolation of the Irish Sea from the outer shelf regions. The near ocean provides the source water for the inner shelf and there is a net northerly flow through the Irish Sea from the Celtic Sea. However, as has been shown, oceanic water does not penetrate very far onto the Malin Shelf and the same is generally true for the Celtic Sea shelf region. For example, Hydes et al. (2004) estimated that the transit time for water from the Celtic Sea shelf break to the Irish Sea was in the order of 6 years.

Given this apparent isolation, any influence that long-term climate change may have on ecosystem structure and functioning in the Irish Sea, is more likely to be the result of a direct influence on the Irish Sea itself (e.g. an alteration in the seasonal development of stratification), rather than an indirect effect brought about by changes in the exchange processes between the Irish Sea and the outer shelf regions. Modelling studies provide one way of addressing this question and AFBI has established a collaborative study with the UK Meteorological Office for this purpose. The data collected during the three EFF project surveys (and the additional summer survey agreed by DARD) will make a valuable contribution to this study.

EMECO data tool

The measure of success was the compilation of the physical and biological data into a database that is specifically linked to a suite of data analysis tools operated by Cefas.

Before data can be output and visualised in the form of maps or graphs, they have to be uploaded to the EMECO data platform. It is worth mentioning that EMECO is not a database as it does not store data. Every user keeps their own data base and uploads data to EMECO whenever required. In Figure 17 an example of an EMECO data output in the form of a map is given for the chlorophyll data (mg m^{-3}) obtained during the July 2012 survey to the Malin Shelf, Irish Sea and Celtic Sea. High chlorophyll concentrations were observed just beyond the shelf break of the Malin Shelf and in the coastal waters of the western and eastern Irish Sea (chl >1.94 mg m^{-3}). Low chlorophyll concentrations were observed in the North Channel, across the Irish Sea and the Celtic Shelf edge (chl <1.94 mg m^{-3}).

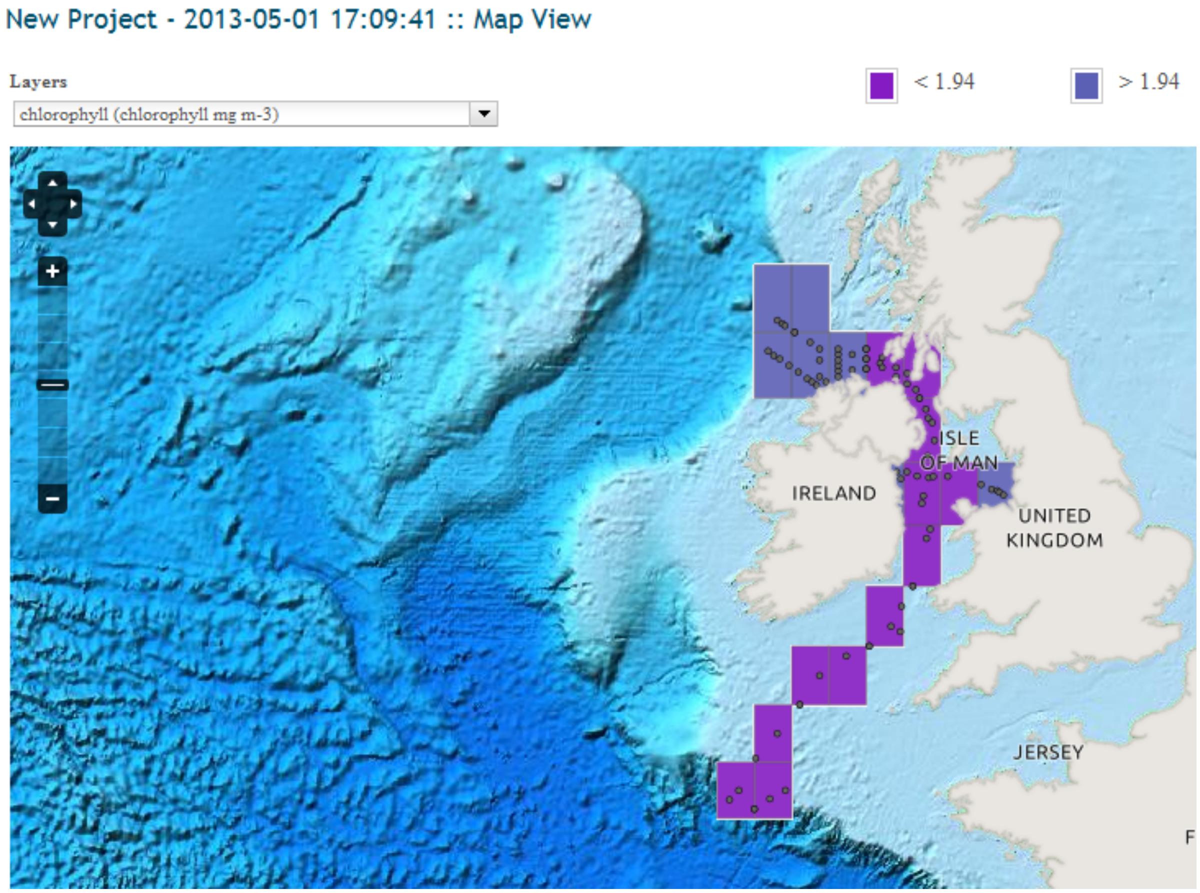

Figure 17: A map showing the near surface distribution of chlorophyll concentrations (mg m^{-3}) for the July 2012 survey of the Malin Shelf, Irish Sea and Celtic Sea. The purple colour represents chlorophyll concentrations > 1.94 mg m^{-3} and the light blue indicates chlorophyll concentrations < 1.94 mg m^{-3} while the dots represent the sampling stations.

Outreach/further studies

Continuation of this work would be useful and necessary to gain more knowledge and understanding of the structure and functioning of the western Irish Sea ecosystem and whether it is influenced by local human pressure or climate change. The modelling work will form an essential part to investigate the influence of climate change in the Irish Sea and how it could affect fisheries. It could possibly also shine some light on whether or not climate change will result in more severe problems with *Karenia mikimotoi* blooms.

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Annex 1

EMECO data tool

The development of the European Marine Ecosystem Observatory (EMECO) was funded by the Department of Environment Food and Rural Affairs (Defra) and is operated by the Centre of Environment Fisheries and Aquaculture Science (Cefas). It forms a consortium of agencies and institutes with responsibility for both monitoring and assessment of marine ecosystem threats and its status that is ecosystem health (structure and functioning), and also for improving understanding through research in European shelf-seas. The consortium brings together existing monitoring, modelling, research capabilities to create a European infrastructure. EMECO was formed to improve the evidence base for formal environmental assessments, provide integrated assessments (from physics to fish) and to meet legal requirements imposed by the Marine Strategy Framework Directive (MSFD).

In this way, EMECO is an "End-to-End" system from data to integrated, policy relevant information products (see Figure A1).

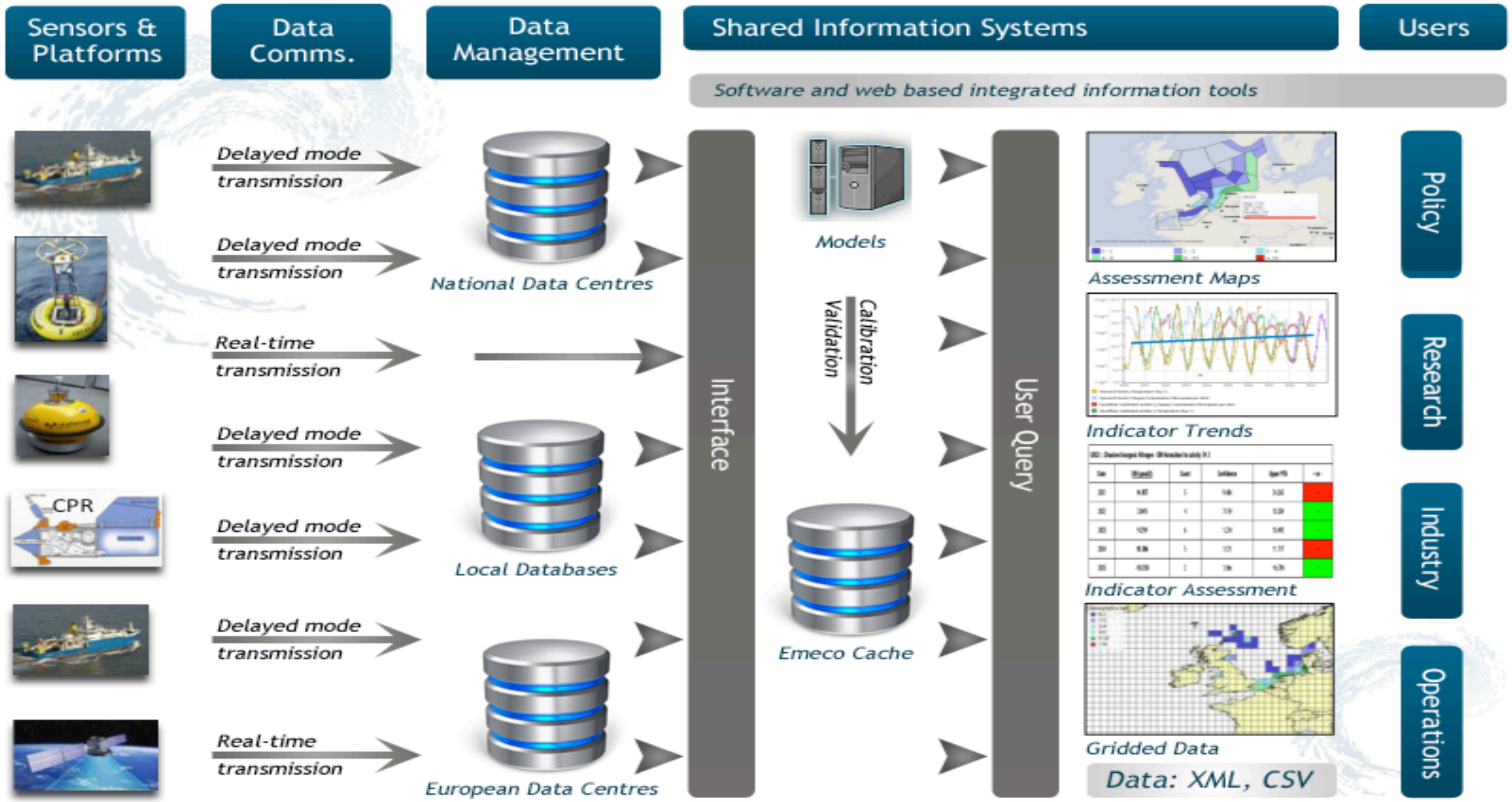

Figure A1: Flow diagram of the EMECO system. Data are generated throughout Europe. The In situ, remote sensing and modelled data are then transferred to the operator's databases and/or other European and national databases. Data may be available in real-time, near real-time and/or delayed mode and may be quality assured (QA'd) or non-quality assured (non-QA'd). The EMECO XML Schema interfaces with these databases to import data into the EMECO

Database. Users can then query the EMECO database using the online query tool to generate integrated information products (text cited from http://www.emecodata.net/content.php?page_id=38 visited on 15th April).

Table A 1: Overview table of worked stations and parameters sampled during each survey

Station	Nutrient Jan 2012	Temp/Sal Jan 2012	Microplankton Jan 2012	Nutrient July 2012	Temp/Sal July 2012	Microplankton July 2012	Nutrient Jan 2013	Temp/Sal Jan 2013	Microplankton Jan 2013
M3	√	√	√	√	√	√			
M4	√	√	√	√	√	√	√	√	√
M6				√	√		√	√	√
M6a					√		√	√	
M7	√	√		√	√		√	√	√
M8				√	√		√	√	√
M9				√	√		√	√	√
M10				√	√	√	√	√	√
M11				√	√	√	√	√	
M12	√	√		√	√	√	√	√	√
M12a				√	√	√	√	√	√
M13		√		√	√				
M14				√	√	√	√	√	√
M16				√	√	√	√	√	√
M17	√	√		√	√	√	√	√	√
M18	√	√	√	√	√	√	√	√	√
M19	√	√		√	√	√	√	√	√
M20	√	√		√	√	√	√	√	√
M21	√	√		√	√	√	√	√	
M22	√	√	√	√	√	√	√	√	√
M23	√			√	√	√	√	√	√
M24	√		√	√	√	√	√	√	√
M25				√	√	√	√	√	√
M29				√	√	√	√	√	
M30	√	√	√	√	√	√	√	√	
M31	√	√		√	√	√	√	√	
M32	√	√		√	√		√	√	√
M33	√	√		√	√	√	√	√	
M34	√		√			√	√	√	√
M35							√	√	√
M36							√	√	√
M37							√	√	√
M38							√	√	
M39				√	√	√	√	√	√
M40	√	√	√	√	√	√	√	√	√
M41				√	√	√	√	√	√
M42	√	√		√	√	√	√	√	
M42a				√	√	√	√	√	√
M43				√	√	√	√	√	
M44				√	√	√	√	√	√
M45	√	√		√	√	√	√	√	√
M46	√	√		√	√	√	√	√	
M47	√	√		√	√	√	√	√	√
M50				√	√	√	√	√	√

√ denotes analysed samples

Table A2: The top five species identified in July 2012 displayed in total cell abundance (cells L^{-1})

Station	Taxa	Cell abundance cells/per litre	Station	Taxa	Cell abundance cells/per litre
M25	*Karenia mikimotoi*	862,400	M20	*Karenia mikimotoi*	253,120
	Microflagellates (<10µm)	121,500		Microflagellates (<10µm)	159,990
	Heterocapsa triquetra	96,750		Unidentified flagellates	60,750
	Phaeocystis sp.	76,500		Unidentified Prasinophytes	47,250
	Gyrodinium large (>45um)	32120		*Heterocapsa triquetra*	17,160
M24	*Karenia mikimotoi*	4,734,000	M3	Microflagellates (<10µm)	562,500
	Microflagellates (<10µm)	51,300		Cryptophytes	37,840
	Unidentified flagellates	36,900		*Thalassionema nitzschioides*	15,400
	Heterocapsa triquetra	22,500		Unidentified flagellates	7,480
	Cryptophytes	18,900		Ciliates	3,080
M10	Microflagellates (<10µm)	346,500	M4	Microflagellates (<10µm)	436,500
	Unidentified flagellates	81,000		Cryptophytes	38,280
	Pseudo-nitzschia delicatissima	12,760		*Skeletonema* sp.	7,040
	Protoperidinium bipes	12,320		Monad flagellates	5,280
	Halosphera minor	12,320		*Cylindrotheca closterium*	3,080

Table A3: Species list of identified and counted species found in the Malin Shelf during surveys in 2012 and 2013

Cerataulina pelagica	*Meuniera membranacea*	*Oxytoxum* spp.
Chaetoceros danicus	*Navicula* small (50µm)	*Prorocentrum micans*
Chaetoceros debilis	*Navicula* medium (51-150µm)	*Protoperidinium bipes*
Chaetoceros decipiens	*Navicula* large (151-300µm)	*Protoperidinium brevipes*
Chaetoceros small (<21µm)	*Nitzschia* spp.	*Protoperidinium* spp.
Chaetoceros medium (21-40µm)	*Odontella sinensis*	*Scrippsiella* spp.
Chaetoceros didymus	*Pleurosigma* sp.	small armoured dinos (10-25µm)
Corethron criophelum	*Pseudo-nitschia seriata* (group)	small naked dinos (10-25µm)
Coscinodiscus spp.	*Pseudo-nitzschia delicatissima* (group)	*Karenia mikimotoi*
Dithylum brightwellii	*Thalassionema nitzschioides*	*Torodinium* spp.
Guinardia delicatula	*Alexandrium* spp.	*Dictyocha fibula*
Guinardia striata	*Ceratium furca*	*Dictyocha speculum*
Lauderia annulata	*Ceratium fusus*	*Prasinophytes*
Leptocylindrus danicus	*Ceratium horridum*	*Cryptophytes*
Leptocylindrus minimus	*Ceratium lineatum*	micro-flagellates (<10µm)
Melosira nummuloides	*Ceratium minutum*	*Phaeocystis* spp.
Paralia sulcata	*Ceratium tripos*	*Rhodomonas* spp.
Rhyzosolenia styliformis/imbricata	*Dinophysis accuminata*	*Euglenophytes*
Rhizosolenia setigera	*Dinophysis rotundata*	*Dididium* sp.
Rhizosolenia pungens	*Gonyaulax* spp.	*Leegardia* sp.
small centric diatoms (10-25µm)	*Gymnodinium* small (<25µm)	*Lohmaniella strobilidium*
Stephanopyxis turris	*Gymnodinium* medium (25-45µm)	*Mesodinium spp.*
Thalassiosira angulata	*Gymnodinium* large (>45µm)	*Strombidium* spp.
Thalassiosira rotula	*Gyrodinium* small (<25µm)	*Tintinnids*
Thalassiosira sp.	Gyrodinium medium (25-45µm)	*Laboea*
Asterionella sp.	*Gyrodinium* large (>45µm)	Ciliates
Asterionella glacialis	*Heterocapsa triquetra*	Copepods
Cylindrotheca closterium	*Katodinium* sp.	Unidentified flagellates

Diploneis	*Lingulodinium*	*Pronoctiluca pelagica*
Licmophora sp.		*Halosphera minor*