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The Scottish Coastal Observatory 1997-2013

Part 1 – Executive Summary

Scottish Marine and Freshwater Science Vol 7 No 26

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

Contents

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1. Background

Scotland's seas are an intrinsic part of its cultural history, identity and economic success. Scottish fishing, aquaculture, tourism, renewable energies, and oil and gas industries are all supported by the oceans around Scotland. Part of the vision of Marine Scotland is to protect Scotland's marine ecosystem while maintaining its economic prosperity.

The state of the oceans is recognised as an important concern at an international scale. The OSPAR Commission and EU have implemented assessment criteria and directives such as the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD) to ensure waters are not negatively impacted by anthropogenic pressures.

The coastal marine environment is subject to frequent short term changes stemming from tides, weather, offshore inflows, inputs from land and freshwater origin, meaning that environmental variability in these systems is very high. It is also subject to natural and anthropogenic pressures such as climate change, ocean acidification and anthropogenic nutrient enrichment. These all have the potential to negatively impact the marine ecosystem and the goods and services it produces. In order to understand the processes involved and identify broader scale changes from short term variability, long term time series spanning more than three decades are required.

2. The Scottish Coastal Observatory

Long term monitoring sites are scarce. There is a concerted plea by both the policy and scientific communities to maintain those in existence and establish additional sites in vulnerable areas. The dynamic nature of the coastal environment means that these areas need to sampled at a high frequency. Marine Scotland Science (MSS) began to address this data gap in 1997 when monitoring for temperature began at Fair Isle and Findon. The first site measuring multiple parameters was also established in 1997, 5 km offshore from Stonehaven on the east coast of Scotland. Additional sites were introduced from 1999, monitoring different combinations of temperature, salinity, nutrients, carbonate chemistry, pigments, algal toxins and plankton. The location of these monitoring sites and information about the parameters collected can be seen in Figure 1 and Table 1.

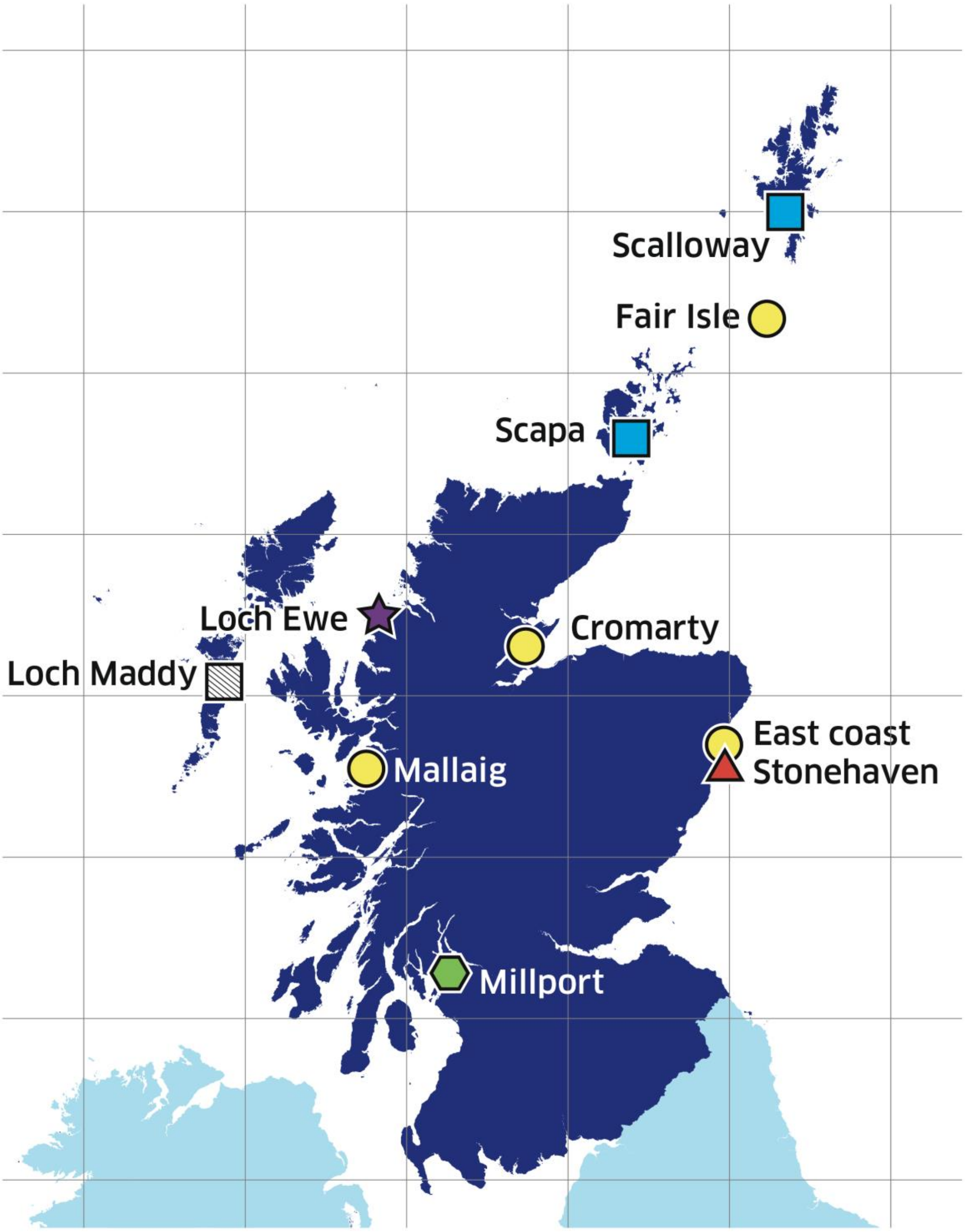

Figure 1: Map of monitoring stations in the Scottish Coastal Observatory. The different symbols represent the different combination of parameters measured; ○ temperature only, ⬢ temperature and phytoplankton, ▨ temperature, salinity, phytoplankton, ■ temperature, salinity, nutrients, algal toxins, phytoplankton, ★ temperature, salinity, secchi depth, nutrients, pigments, algal toxins, phytoplankton, zooplankton, ▲ temperature, salinity, secchi depth, nutrients, carbonate chemistry, pigments, phytoplankton, zooplankton.

Site	Physics			Chemistry						Biology				
	Temp	Sal	Sec	DIP	DSi	TOxN	Amm	TA	DIC	$Phyto_{tox}$	Phyto	Al_{tox}	Chl	Zoo
1 Millport	1997									2005-2013	2005-2013			
2 Mallaig	1999													
3 Loch Maddy	2003	2003-2011		2003-2011	2003-2011	2003-2011	2003-2011			2003-2011	2003-2011			
4 Loch Ewe	1999	2003	2008	2003	2003	2003	2003			1999	2001	2005-2016	2002	2002
5 Scapa	1999	1999		1999	1999	1999				1997	2000	2011-2016		
6 Fair Isle	1997 2000-2003 missing													
7 Scalloway	2000	2000		2000	2000	2000	2000			2000	2001	2011-2016		
8 Cromarty	2004													
9 East coast	1997													
10 Stonehaven	1997	1997	2002	1997	1997	1997	1997	2008	2008	1997	1997		1997	1999

Table 1: Details of parameters measured at the ten coastal monitoring sites. First data indicate start date of monitoring. Finish date entered where appropriate. Parameters are: Temp - temperature; Sal - salinity; Sec - secchi depth; DIP - dissolved inorganic phosphorus; DSi - dissolved inorganic silicate; TOxN - total oxidised nitrogen; Amm - ammonia; TA - total alkalinity; DIC - dissolved inorganic carbon; Phyto - total diatoms and dinoflagellates; $Phyto_{tox}$ - toxic phytoplankton; Al_{tox} - dissolved algal toxins; Chl - chlorophyll '*a*'; Zoo - Zooplankton.

As the importance of time series is increasing at an international level this Scottish programme is receiving more attention. Requests to MSS to contribute data to assessments, provide material for diversity investigations and to validate modelling studies are becoming more frequent. For some parameters such as coastal zooplankton there is very little data available in UK coastal waters. These data collected by MSS are important on a national and European level as they operate two of three coastal monitoring stations in UK and Irish coastal waters where zooplankton is routinely examined. This dataset is becoming a national resource for policy makers and academics in Scotland, the UK and worldwide.

Given the increasing importance of this area of work, MSS have completed a rigorous quality check of all historic data collected as part of this programme. In order to recognise the programme's coherence and set it into the context of the global development of coastal observatories, it has been renamed the Scottish Coastal Observatory (SCObs). One of the first tasks of SCObs was to produce a basic description of the seasonality and variability of the main parameters collected; temperature, salinity, nutrients, carbonate chemistry, phytoplankton, chlorophyll '*a*', algal toxins and zooplankton. This description comprises a three part report (Part 1-Executive Summary, Part 2 –Description of Scotland's Coastal Waters, Part 3-Appendices), and an accompanying dataset which contains all the monthly mean values for the 135 environmental parameters and 68 supporting parameters described in Part 2. This dataset has been given a doi number 10.7489/1761-1 and can be accessed remotely using the Marine Scotland website or by emailing Scobs@gov.scot. More detailed analyses of the data will be produced within the peer reviewed scientific literature.

3. Impact to date

Since 2000 data from these time series have addressed a number of policy driven and scientific issues:

(i) Supported a challenge to the WFD phytoplankton assessment tools and ensured that thresholds were appropriate for Scottish waters.

(ii) Provided the data for the assessment of *Good Ecological Status* for the WFD and *Good Environmental Status* for the pelagic water column for the MSFD. Under the WFD, data from Loch Ewe are used to assess the status of 28 west coast sea lochs and bays, and data from Stonehaven are used in the assessment of 12 coastal water bodies (from the Ugie Estuary to Inverbervie).

(iii) Formed part of the Scottish Ocean Climate Status Report.

(iv) Contributed towards the UK assessment of state in Charting Progress 2, Scotland’s Marine Atlas and UK Marine Climate Change Impacts Partnership (MCCIP) report cards.

(v) Contributed towards the International Council for the Exploration of the Sea (ICES) plankton status reports and the International Group for Marine Time Series (IGMETS) analysis and synthesis of global marine biological changes as seen through biogeochemical and plankton time series.

(vi) Contributed to 37 peer reviewed publications, 15 internal and 13 contract reports, 57 oral and 72 poster presentations at a variety of scientific forums, supported 19 third level and 8 secondary school studentships and been included in 10 outputs from external authors.

4. What do data from this monitoring programme tell us?

The coastal waters around Scotland observe a seasonality typical of northern latitudes:

- Temperature is lowest in spring and highest in autumn. Salinities in the coastal waters monitored are generally < 35 PSU and can be subject to short term freshwater inputs.
- Nutrients accumulate in the water column during the winter months when phytoplankton growth is low.
- When the water column stabilises and light intensity begins to increase during spring, phytoplankton begin to grow and nutrient concentrations are reduced.
- The start of the phytoplankton growing season is characterised by a period of rapid phytoplankton growth and is termed the spring bloom. The highest concentration of the phytoplankton pigment, chlorophyll ’*a*’, is usually recorded each year during this time.
- This burst of phytoplankton production fuels egg production in zooplankton present during the spring bloom.
- Phytoplankton genera with the potential to produce algal toxins are routinely detected in samples from Scottish coastal waters.
- During summer months, nutrient concentrations are often at the limit of detection suggesting that nutrient recycling plays an important role in maintaining phytoplankton production.

- It is during the summer months that most lipophilic algal toxins reach their peak concentration in the water column.
- An autumn phytoplankton bloom can be observed at some sites mainly on the west coast.
- Zooplankton biomass is generally higher at the west coast monitoring site than the east. The annual peak in zooplankton biomass occurs during the autumn on both coasts.

5. Regional differences in Scottish coastal waters

Data from this monitoring programme detail the regional differences in coastal waters around Scotland.

- Temperature data have recorded warmer water temperatures on the west coast compared with sites on the east coast and in Orkney and Shetland.
- Salinity also differs between sites. In some instances this can be a result of the physical location of the site, but the higher salinity values recorded at Scapa and Scalloway suggest that these Orkney and Shetland monitoring sites are more subject to Atlantic influence than sites on the west and east coasts.
- Regional differences in the timing and diversity of phytoplankton blooms have also been observed with the spring bloom observed earlier at sites situated on the west coast, in part influenced by warmer spring time water temperatures.
- Some regional differences in the composition of the phytoplankton community were observed at monitoring sites in the Clyde and Shetland compared with the sites located at the east and west coasts, and Orkney. For example, low cell densities of the diatom genus *Pseudo-nitzschia* were observed during the spring bloom at the monitoring station at Millport and the dinoflagellate genus *Tripos* was infrequently observed at Scalloway.
- The zooplankton community composition observed was similar on the east and west coasts of Scotland. Copepods were the most important component of the mesozooplankton, and the dominant copepods at Loch Ewe and Stonehaven were *Calanus helgolandicus*, *C. finmarchicus*, *Centropages hamatus*, *C. typicus*, *Acartia clausi*, *Paracalanus parvus*, *Pseudocalanus* spp., *Temora longicornis* and the Oithonidae. Some regional differences were observed, for example *Centropages typicus* was more abundant at Loch Ewe while *C. hamatus* was more abundant at Stonehaven. *C. typicus* is considered to be an indicator of temperate Atlantic water.
- Regional differences in the timing of peak biomass of the zooplankton community was also observed between monitoring sites on the east and west

coasts. The spring increase in biomass occurred about a month earlier at Loch Ewe compared to Stonehaven for many taxa, e.g. total copepods, *Pseudocalanus* spp., decapod larvae, barnacle larvae and cnidarians. The autumn biomass peak in the ecologically important copepod *Calanus helgolandicus* at Stonehaven is almost double that seen at Loch Ewe.

6. Are the coastal waters around Scotland warming?

Temperature values observed over the 17 year period of this monitoring programme are important as they are likely to be significant drivers of the observed ecosystem variability but this time series is too short to identify climate change. Data from the long-term monitoring site at Millport in the Clyde, which began in 1971, suggest that the period 1997-2013 is likely to be the warmest 17 year period for coastal sea temperatures since this monitoring began.

From the SCObs data, no overall warming trend can be observed between 1997 and 2013. The warmest years during this monitoring period were observed around 2003. The latter part of the measurement period was characterised by more variable and often cooler conditions, including the very cold winters of 2010 and 2011. The warm period around 2003 was observed at both inshore and offshore sites. Air temperatures across Scotland were higher than normal and data from offshore monitoring sites indicate that 2003 was a record year of warm and salty conditions in the North Atlantic.

The lowest annual mean surface temperatures were observed during 2000 across all sea areas. The very cold winter of 2010 did not have as strong an impact on sea surface temperatures as it did on air temperatures, although North Sea and Clyde temperatures were relatively low in December 2010. In contrast to 2003, these conditions were not reflected particularly strongly in offshore areas suggesting that the main driver of this cold year was atmospheric conditions rather than broader patterns in oceanic circulation.

7. Is the nutrient status of Scottish coastal monitoring sites changing?

Nutrient enrichment has been assessed using OSPAR Ecological Quality Objectives (EcoQOs) at the relevant monitoring sites. Dissolved inorganic nitrogen (DIN) and total oxidised nitrogen (TOxN) (normalised) concentrations were below the prescribed current UK and Scottish elevated concentrations. This is consistent with the relatively low population densities and industrial activities in Scotland. The majority of samples were also below the prescribed UK background concentrations.

Spatial differences were observed in winter nutrient concentrations around the Scottish coast with the highest monthly average TOxN and DIP concentrations recorded at Scalloway. This may reflect the greater proportion of Atlantic water in this area, as evidenced by the highest average annual salinity.

All sites in this monitoring programme were within non-problem areas as defined by the Water Framework Directive (WFD). High interannual variability was observed between sites in the timing of nutrient uptake by the phytoplankton community.

In summary, no obvious temporal trend for any of the nutrients at any station in the Scottish Coastal Observatory could be observed.

8. Are Scottish coastal waters being impacted by ocean acidification?

Increased uptake of atmospheric CO_2 by the ocean is altering its carbonate chemistry resulting in a reduction of the pH of seawater. Carbonate chemistry parameters; total alkalinity (TA) and dissolved inorganic carbon (DIC) were measured at Stonehaven between 2009 and 2013. Calcite saturation (Ω_{ca}) and pH were derived. These data represent the only high frequency time series of these parameters in Scottish coastal waters and provide a unique insight into weekly, seasonal and interannual variability.

The data reveal considerable variability on a weekly time scale at the Stonehaven monitoring site. On a seasonal scale, a relationship with the phytoplankton growing season could be observed as DIC is lowest and pH and TA highest when phytoplankton biomass is elevated.

Both the derived pH and calcite saturation decreased at the Stonehaven site during 2012 and 2013. At Stonehaven, this event coincided with unusually high salinity water in the autumn of 2012, followed by very low temperatures in the spring of 2013, both of which can impact carbonate chemistry in the sea. This event is consistent with other observations around UK waters over the same period.

Ocean acidification is a fairly slow process, evolving over decadal time-scales and it is not possible to determine if Scottish coastal waters have been impacted during the short timescale of this work. The OSPAR/ICES Study Group on Ocean Acidification (SGOA) and the Global Ocean Acidification Observing Network (GOA-ON) have both identified the need for a commitment to long-term monitoring at sites in coastal and inshore waters to distinguish long-term anthropogenic signals from short-term spatial and temporal variability. To understand the changes that occurred during

2012 it is clear there is a need for integrated monitoring, which includes measurement of physical, chemical and biological parameters such as temperature, nutrients and phytoplankton.

9. Is the plankton community in Scottish coastal waters changing?

The duration of the SCObs time series is too short to confirm established changes in the plankton community given the degree of interannual variability in coastal systems. A number of fluctuations have been observed since monitoring began. During the early part of the time series, the timing and diversity of the phytoplankton community was relatively stable. Between 2005 and 2013, the phytoplankton community became much more variable with diatoms present throughout most of the growing season.

Data from the Stonehaven monitoring site capture a period from 2000-2004 where a signal could be seen in a number of different parameters. The intensity of the spring phytoplankton bloom was considerably reduced. This is reflected in the low diatom cell counts and chlorophyll '*a*' concentrations recorded. During this period, the highest annual concentrations of chlorophyll '*a*' were often recorded in autumn which was in contrast to previous/subsequent years when it was observed in late spring/early summer. This suggests that events at the start of the phytoplankton growing season can potentially influence the phytoplankton community later in the year. This autumn phytoplankton community was dominated by the potential toxin producing diatom *Pseudo-nitzschia*, its growth fuelled by unused dissolved silicate in the system. Since 2005, the main chlorophyll '*a*' peak is again observed during the spring/summer months most years and the diatom genus *Skeletonema* has become more abundant.

Some phytoplankton species are too small to monitor routinely. Solid Phase Adsorption Toxin Tracking (SPATT) passive sampling technique has been used to investigate the presence of the dinoflagellates genus *Azadinium* by monitoring the presence of the algal toxins azaspiracid-1 (AZA-1) and azaspiracid-2 (AZA-2) in the water column. *Azadinium spinosum* is a confirmed producer of these toxins in Scottish waters. Closures of shellfish harvesting areas as a result of high concentrations of AZAs have caused a lot of problems to the Irish shellfish industry. SPATT data from the Loch Ewe SCObs monitoring site repeatedly recorded higher concentrations of AZA-1 in the water column during the winter when the cell density of phytoplankton is minimal.

Most animals in the zooplankton have short lifecycles (less than one year) that are largely controlled by temperature, so monitoring of zooplankton provides an ideal indicator of the impacts of climate change in the marine ecosystem. Most marine organisms have larval stages that spend time in the plankton. The larvae that form part of the zooplankton community at Stonehaven and Loch Ewe include the larvae of most of animals that can be seen living on the sea floor in Scottish waters, e.g. barnacles, worms, crabs, starfish and larvae of commercially important species of crabs, lobster (decapods) and shellfish (bivalves). There is also increasing interest in the possible effects of ocean acidification on marine animals that rely on calcification as part of their physiology. Animals at Loch Ewe and Stonehaven in this category are gastropod larvae, pteropods, bivalve larvae and starfish larvae.

A high degree of interannual variability was observed in the zooplankton community. SCObs data show a temporal change in biomass of a number of zooplankton taxa on both east and west coasts around 2008. These include an increase in the biomass of total copepods including *Calanus finmarchicus* and *C. helgolandicus* at both Loch Ewe and Stonehaven until 2008. Contrary to observations published in the scientific literature which report *C. helgolandicus* being a smaller size than *C. finmarchicus,* both of these copepods were observed to be a similar size at both SCObs monitoring sites. A decrease in the biomass of bivalve larvae and barnacle larvae was recorded at both sites until 2008. There was an observed decrease in the biomass of calcifying plankton until 2008 at Loch Ewe and decapod larvae biomass increased at Stonehaven during this period. The cause of these changes are under investigation.

A consistent decrease in the biomass the larval stage of decapods (e.g. crabs) was observed in Loch Ewe since monitoring began. Other groups showed no temporal trend in biomass. For example, the Cnidaria (jellyfish), which are widely considered to be increasing as a response to climate change, showed no temporal trend in biomass.

10. Recommendations

Six recommendations for the future of SCObs are suggested:

(i) Continuation: The SCObs time series should be maintained to ensure that environmental changes in coastal waters can be identified and interpreted on a regional scale. Inherent in this recommendation is the maintenance of the skills and equipment necessary to perform this monitoring and that the technologies used remain current. Some of these skills, e.g. plankton analysis, take years to develop and MSS is one of a few laboratories in the UK where this analysis can be performed at an advanced level.

(ii) Enhance access: SCObs is a national resource. Access to data and sample material should remain available to the scientific community and the public. MSS are happy to collaborate with parties interested in working with SCObs data and sample material.

(iii) National/international integration: SCObs data should be integrated in national and international networks such as evidence groups for the WFD and MSFD, International Council for the Exploration of the Sea (ICES), OSPAR Commission and International Oceanographic Commission (IOC) so that it is readily available for relevant national and international assessments.

(iv) Analysis and its dissemination: Analysis of the SCObs data should continue in order to allow the dynamics of the coastal environment in Scotland to be understood on a regional scale, as well as to identify how it is influenced by local and wider scale environmental drivers e.g. pollution, climate change. Analysis of the SCObs data by the wider scientific community data should be encouraged through strategic collaborations. The results of these analyses should continue to be submitted to the peer reviewed scientific literature. SCObs scientific outputs should also be presented in public friendly formats and avail of Scottish Government initiatives such as NMPi, topic sheets, the Scottish Government website to maximise access to this information.

(v) Context setting: SCObs is currently comprised of fixed point monitoring sites. A priority for future work should be to establish the extent of coastal area these monitoring sites represent.

(vi) Enhancing the network: If funding becomes available, the following steps should be considered to enhance the SCObs network:

- Millport: Biological monitoring at the SCObs site at Millport ceased operation in 2013 due to a reduction in available resource. Restarting this monitoring site and expanding the variables measured should be investigated.
- Adding Parameters: Expanding monitoring to include parameters such as carbonate chemistry, zooplankton and dissolved toxins at additional existing SCObs sites should be considered.

- Adding Sites: Lastly, once the options above have been implemented, adding additional sites could be considered.

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Staff of Loch Duart Salmon

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