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Annual Cycles of Physical Chemical and Biological Parameters in Scottish Waters (2013 Update)

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Abstract

Tables describing the annual cycles of physical (temperature, salinity, density and water column stability), chemical (nitrate, orthophosphate, silicate, ammonia and oxygen saturation) and biological (particulate organic carbon, particulate organic nitrogen, chlorophyll-*a* and phaeophytin) parameters are presented for twenty six sub-areas of Scottish coastal and oceanic waters. These tables have been derived from observations made by the Marine Laboratory, Aberdeen, during the period 1960-2010.

Introduction

For over 100 years Marine Scotland, under various names, has conducted marine research in the waters around Scotland. From the earliest times this included the measurement of physical and chemical parameters at standard sections worked routinely over a number of years, and at *ad hoc* stations whose timing and location were determined by individual projects. This paper presents summary tables of a selection of these parameters in twenty six sub-areas of Scottish waters selected because of their distinct hydrographic characteristics.

Only data from 1960 have been used for a number of reasons. Prior to that time salinity, a vital parameter used when determining the origins and history of particular water masses, was determined chemically. Initially salinity samples were analysed by the Laboratory of the Government Chemist, with varying degrees of accuracy and quality control. In later years the analysis was taken on by staff of Marine Scotland, Marine Laboratory, Aberdeen, where it has stayed through to the present day. Many of the chemical techniques presently used for the determination of nutrient concentrations were standardised in the early 1960s. Therefore, data prior to this are of limited value and must be used with caution. Since the early 1960s, analysis techniques, and to a large extent the analysts themselves, have been fairly consistent within the Marine Laboratory. The effect of this has been a high quality, internally consistent data set.

Any collection of environmental data, such as that which exists within the Marine Laboratory, is of most value if it can be readily accessible and in a form useful to potential "customers". Today, this means a computer archived database which may be used in a flexible, user-friendly and problem-oriented manner. Such a database has been constructed from oceanographic data collected by the Marine Laboratory since 1960.

Objectives

This paper presents summary tables derived from the database described in the previous section. These should prove useful for a variety of purposes, such as examining general conditions in particular sea areas, detailing annual cycles of chemical and biological parameters for comparison with the results of physical and ecological models, and targeting specific enquiries that may be answered using the main database itself. An example of the use of the tables presented here was the characterisation of the various water types in Scottish waters, and their nutrient content, for the 1992 Quality Status Report for submission to the North Sea Task Force. The annual cycles of temperature, salinity and nutrients are also presently being used, together with annual cycles of transports into and around the North Sea, to compute heat, salt and nutrient budgets.

Methods

1. Source Data

The source data from which the database has been constructed consist of computer files in two standard formats; .HYD format containing depth, temperature and salinity data and .CEM format containing standard chemical and biological parameters. A .HYD file exists for every research vessel cruise carried out since 1960 and a .CEM file if there were chemical measurements performed during the cruise. In addition, each station within the file contains header information such as latitude and longitude of the station, time and date, sounding and the number of depths sampled at the station. The data in the .HYD file can either have been collected by reversing water bottle or by profiling CTD instrumentation. Where CTD instruments have been used the .HYD file contains a condensed form of the data collected. This means that no more than twenty one depths are extracted from a CTD instrument profile for inclusion into a .HYD file.

2. Database

In order to facilitate rapid data searching and retrieval, the standard format files have been processed using an intermediate program which results in a large disc-based file amalgamating the data from many individual cruises.

For two previous reports (1992 and 1999) the database files were stored as Record Management Services (RMS) files. This type of database structure became redundant due to the decommissioning of our VAX mainframe system.

For the last report (2005) the above database was converted to a flat ASCII file. This file now contains over 318500 lines of depth data up to the end of 2010 on which this report is based. Each line of data contains the following information: position (latitude and longitude), station number, cruise number, date (day, month, year), time (GMT), International Council for the Exploration of the Sea (ICES) ship code, sounding and pressure and one or more of the following parameters: temperature, salinity, density, oxygen, saturated oxygen, phosphate, nitrate, silicate, carbon, nitrogen, chlorophyll and phaeophytn.

The table below provides a summary of the data held in the database file:

Five year period	Total number of stations	Total number of individual depths
1960-64	4,281	18,448
1965-69	2,391	10,198
1970-74	3,705	16,844
1975-79	1,948	10,905
1980-84	1,759	9,828
1985-89	2,853	21,535
1990-94	3,384	35,059
1995-99	3,808	40,535
2000-04	5,775	74,118
2005-09	5,709	73,613
2010	501	7,499
Total	36,114	318,582

The database file occupies approximately 56.6 megabytes of disk space. At each depth, as many as eleven individual parameters may be measured. The increased use of CTD profiling instruments can be detected from the table above. A dramatic increase in the number of individual depths used in this report can be seen from the late 1980s to the present date. This can largely be put down to the increased use of CTD's. Only standard depths are extracted from the CTD data files for inclusion in the data base. The number of standard depths extracted from the CTD data files never exceeds twenty one and the standard depths are determined by the sounding listed on the station.

In this paper twenty six sub-areas have been defined geographically and represent distinct hydrographic regimes. Monthly means and standard deviations have been extracted for all of the standard parameters regularly reported in the .HYD and .CEM files. From these means and standard deviations annual cycles have been computed (see below). A suite of programs has been written to search the database file to extract the data and to produce these tables of means and standard deviations for the twenty six sub-areas listed below.

3. Measurement Techniques

The tables present the monthly mean values, where data is available, of the eleven observed parameters and of two derived parameters (density and stability). The various methods used to determine these values are briefly described:

Temperature (T): This has traditionally been measured using reversing thermometers mounted on Knudsen bottles. Thermometers are held at set depths for six minutes to allow equalisation to the ambient temperature before the bottles are triggered. Increasingly since the late 1970s temperatures have been obtained using temperature sensors mounted on CTDs. These and the reversing thermometer readings are cross-checked against each other to identify erroneous measurements or instrument faults. After the mid nineties approximately 95% of all temperature readings were taken using CTDs, the reliability of these readings determined by manufacturer's biannual recalibration. Accuracy = +/-0.02°C.

Salinity (S): The traditional method employed over the period 1960-1990 has been to collect water samples at standard depths using Knudsen reversing water bottles. Salinity is then determined using a bench-top inductive salinometer, calibrated using IAPSO standards. Since about 1980, salinities have been increasingly determined *in situ* using conductivity sensors mounted on CTDs. These are calibrated against samples collected by reversing bottles at calibration stations performed periodically throughout a cruise. Accuracy = +/-0.005. As salinity is now defined as a ratio no units are used (UNESCO, 1978).

Density (SIG-T): The density anomaly has been computed using the formulae presented in UNESCO (1983) with the required input parameters of temperature and salinity. Accuracy = +/-0.01 kg m^{-3}.

Oxidised nitrogen (NO_3): Samples for the determination of inorganic nitrogen are stored in a deep freeze. Concentrations are determined as nitrite following reduction with copper-coated cadmium (Stearns and Strickland, 1967). Accuracy = +/-10%. Units = µg-at/l.

Orthophosphate (PO_4): If samples are not to be analysed immediately, the samples are fixed with chloroform and stored in a cool place. Concentrations are determined by a manual phospho-molybdate complex colorimetric method (Murphy and Riley 1962). Accuracy = +/-10%. Units = µg-at/l.

Silicate (Si): Samples are stored in plastic bottles in a cool place. Concentrations are determined by a silicomolybdate manual colorimetric method (Mullin and Riley 1955), later modified following Strickland and Parsons (1968). Accuracy = +/-10%. Units = µg-at/l.

Ammonia (NH_3): Samples to be used for ammonia determination are stored frozen. A manual colorometric method is used, using phenol hypochlorite with potassium ferrocyanide to form indophenol blue complex. Accuracy = +/-10%. Units = µg-at/l.

Particulate Organic Carbon (POC): Samples are filtered onto glass fibre filters (Whatman GFF) and the filters deep frozen. Analysis used to be done by a wet oxidation method, followed by titration with a thiosulphate solution (Strickland and Parsons, 1968). Since the early 1970s all analysis has done by a combustion method with measurement on a Perkin-Elmer CHN analyser.

Thawed samples are exposed to hydrochloric acid fumes prior to combustion in order to remove inorganic carbonate. Accuracy = +/-10%. Units = µg/l.

Particulate Organic Nitrogen (PON): These values are obtained from the Perkin-Elmer analyser using the same sample as used to determine particulate organic carbon. Accuracy = +/-10%. Units = µg/l.

Chlorophyll-*a* (CHL): Samples are filtered onto glass-fibre filter papers and stored in deep freeze. The chlorophyll-*a* is extracted by grinding the filter papers in a solution of 90% acetone and determining the concentration on a flourometer. Accuracy = +/-10%. Units = µg/l.

Phaeophytin (PHAE): After the chlorophyll-*a* concentration has been determined the samples are dosed with dilute hydrochloric acid and the phaeophytin concentration again determined flourometrically (Strickland and Parsons, 1968). Accuracy= +/-10%. Units = µg/l.

Oxygen (O_2): At the time of collecting the samples, the oxygen is fixed with manganese chloride and alkali-iodide solutions. Dissolved oxygen concentrations are determined using the standard Winkler method. These are converted into percentage saturations using the recorded *in situ* temperature and salinity. Accuracy = +/-10%. Units = % saturation.

Stability (STAB): The stability of the water column is expressed as the log of the mean of the potential energy anomalies (Simpson *et al.*, 1978) calculated for each individual station in a sea area. The potential energy anomaly is defined as:

$$V = \frac{g}{h} \int \rho . \ \overline{\rho} \, z \, dz$$

4. Data Processing

Search methods

As described above the main database has been searched using boxes whose boundaries are defined as latitudes and longitudes or as polygons whose vertices are also defined as latitudes and longitudes. The boundaries of each box and the vertices of each polygon are presented as header information in each summary data table, and are summarised in Figures 1-5.

In previous Annual Cycles Reports (1992, 1999) the data from the areas (Figures 4-5) defined along the standard hydrographic sections (JONSIS, Fair Isle/Munken and Nolso/Flugga) were extracted as groups of individual stations. For example, the Fair Isle Current (FIC) area contained only data from the JONSIS stations 1, 1a and 2. In Annual Cycles Report (2005) the boxes were defined to extract the data for the areas FIC and ONNS and polygons are defined to extract the data for areas AW_MUNKEN, AW_NOLSO, FCCS_MUNKEN, FCCS_NOLSO, FCCN_MUNKEN and FCCN_NOLSO. This extraction method is also used for this report. The change in the extraction procedures for these areas results in the inclusion of station data that were sampled at other times other than when the standard sections were being sampled.

In addition, the areas defined along the standard hydrographic sections (The JONSIS, Fair Isle/Munken, and Nolso/Flugga sections - Figures. 4 and 5) are representative of different water types. The indices so derived have been used previously by Turrell (1992a, 1992b).

Calculations

Monthly means and standard deviations within each of these areas, and between set depths are also presented. If no data is available in any month, a value is derived by linear interpolation using adjacent monthly mean values. If a gap of more than three months exists, then no interpolation is performed and no annual cycle is derived. The number of data points used to compute each monthly mean is also archived.

Annual cycles of each parameter, A, have been calculated using a least -squares fitting procedure, of the form:

$$A = A_{avg} + A_{amp} \sin\left(2\frac{\pi}{Y}\ (t \quad \phi)\right)$$

where A_{avg} = annual average value, A_{amp} = amplitude of annual cycle, t = time in months (1st January = 0), Φ = phase shift (months) and Y = 12 (Maddock and Pingree, 1982).

It should be noted that while a sinusoidal annual cycle may describe the variability of parameters such as temperature and salinity accurately, such functions are not always suitable for chemical or biological parameters. Although the program which generates the tabular output automatically fits sine functions, and these may be useful in a variety of applications, the mean values must be closely inspected to determine if such a function is valid

The depth limits for the derivation of surface and bottom values have been determined from previous work in each sub area and from a preliminary examination of the data.

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Area Descriptions

Coastal Waters - East Coast (Figure 1)

1. Outer Moray Firth (OMF)
2. Inner Moray Firth (IMF)
3. North East Coast (NEC)
4. Outer Firth of Forth (OFF)
5. South East Coast (SEC)

Coastal Waters – Shetland Islands (Figure 2)

1. Sullom Voe (SULVOE)

Coastal Waters - West Coast (Figure 3)

1. Clyde Sea (CLYDE)

Shelf Waters - West Coast (Figure 3)

1. Malin Shelf - Inner (MALININ)
2. Malin Shelf - Outer (MALINOUT)
3. West of Hebrides (WHEB)
4. North Minch (MINCHN)

Shelf Waters - North Coast (Figure 4)

1. North Coast - North (NC_N)
2. North Coast - South (NC_S)

Shelf Waters - North Sea (Figure 4)

1. Central Northern North Sea (CNNS)
2. Offshore Northern North Sea (ONNS)
3. Fair Isle Current (FIC)
4. Cooled Atlantic Water (CAW)
5. East Shetland - Inshore (ES_I)
6. East Shetland - Offshore (ES_O)

Oceanic Waters (Figure 5)

1. Rockall Bank (ROCKALL)
2. Atlantic Water - Nolso (AW_NOLSO)
3. Atlantic Water - Munken (AW_MUNKEN)
4. Faroe-Shetland Channel - Central (FSCC_NOLSO)
5. Faroe-Shetland Channel - Central (FSCC_MUNKEN)
6. Faroe-Shetland Channel - North (FSCN_NOLSO)
7. Faroe-Shetland Channel - North (FSCN_MUNKEN)

Table Explanation

For each sea area two tables are presented:

1. Mean values
2. Standard deviations

On each table the following information is given:

1. Area name (code letters).
2. Northern latitude of sea area.
3. Southern latitude of sea area.
4. Western longitude of sea area.
5. Eastern longitude of sea area.
6. Total number of stations in sea area from which mean and standard deviation computed.
7. Minimum sounding observed in sea area.
8. Maximum sounding observed in sea area.
9. Number of data points.
10. Minimum sampled depth.
11. Maximum sampled depth.

Data is then split into near-surface values and near-bottom values. The depth range of each layer is indicated. The following notes apply to the data presented within the data tables:

Mean Values

1. < - this symbol implies the mean value for that month has been determined by interpolation from adjacent months.

2. Blank - no data is available for these months, and none from adjacent months +/-2 months).

Standard Deviations

Value of 0 - this implies that only one value of this parameter was available.

The tables described for the sea areas are listed at the back of this document. Other tables can easily be generated for other defined areas and can be produced as necessary. However, in the majority of any other defined areas outside of the areas listed in this document are likely to contain very little data to construct a table with any meaningful data.

Figure Legends

Figure 1 Summary of boxes and sub-portions of standard sections used to derive monthly means from which annual cycles of oceanographic parameters have been derived – coastal waters east of Scotland.

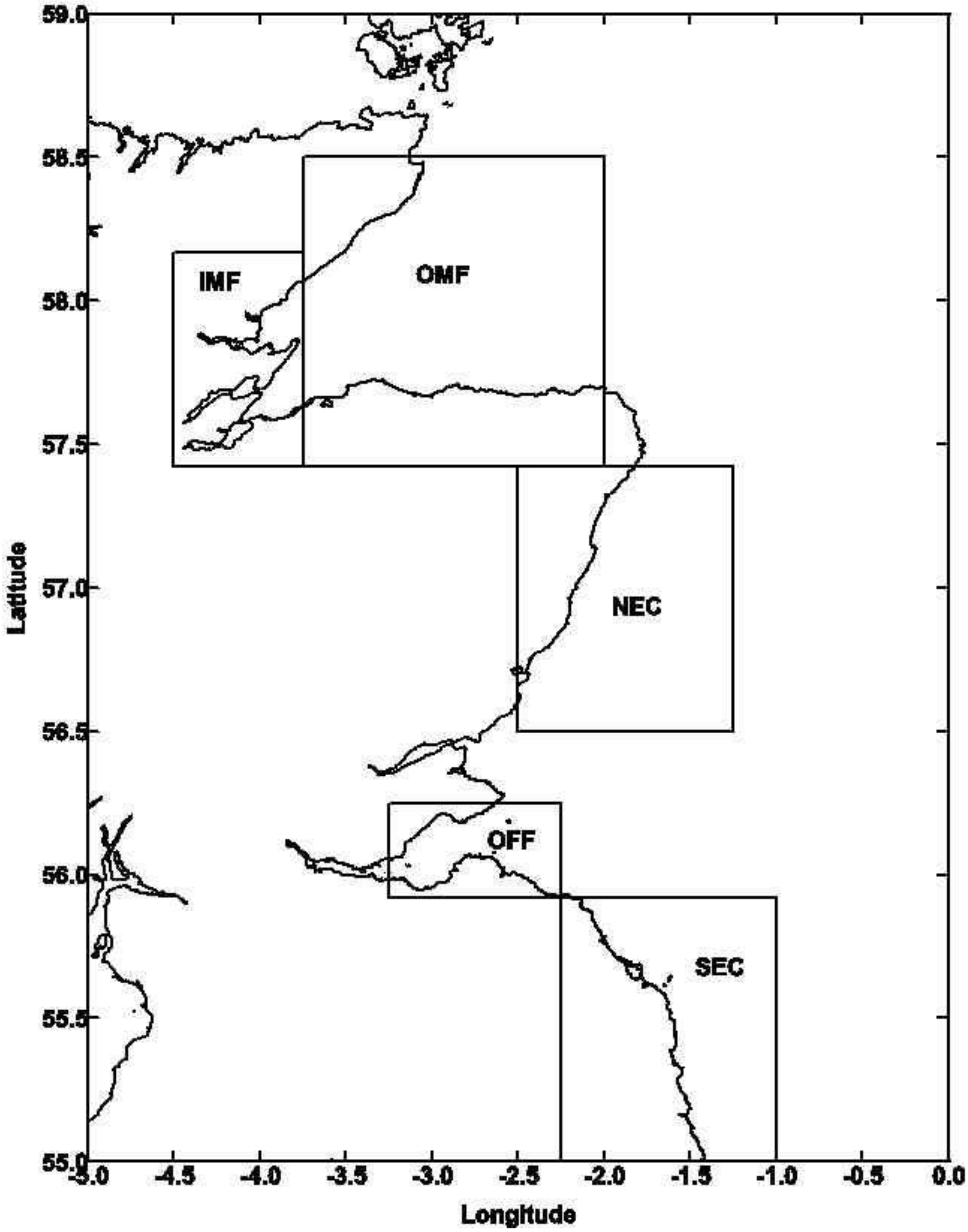
Figure 2 Summary of boxes and sub-portions of standard sections used to derive monthly means from which annual cycles of oceanographic have been derived – Sullom Voe.

Figure 3 Summary of boxes and sub-portions of standard sections used to derive monthly means from which annual cycles of oceanographic parameters have been derived – coastal and shelf waters of west Scotland.

Figure 4 Summary of boxes and sub-portions of standard sections used to derive monthly means from which annual cycles of oceanographic parameters have been derived – shelf waters north and east of Scotland.

Figure 5 Summary of boxes and sub-portions of standard sections used to derive monthly means from which annual cycles of oceanographic parameters have been derived – oceanic waters north and west of Scotland.

Figure 1



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58.0
57.5
57.0
56.5
56.0
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55.0
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-4.0
-3.5
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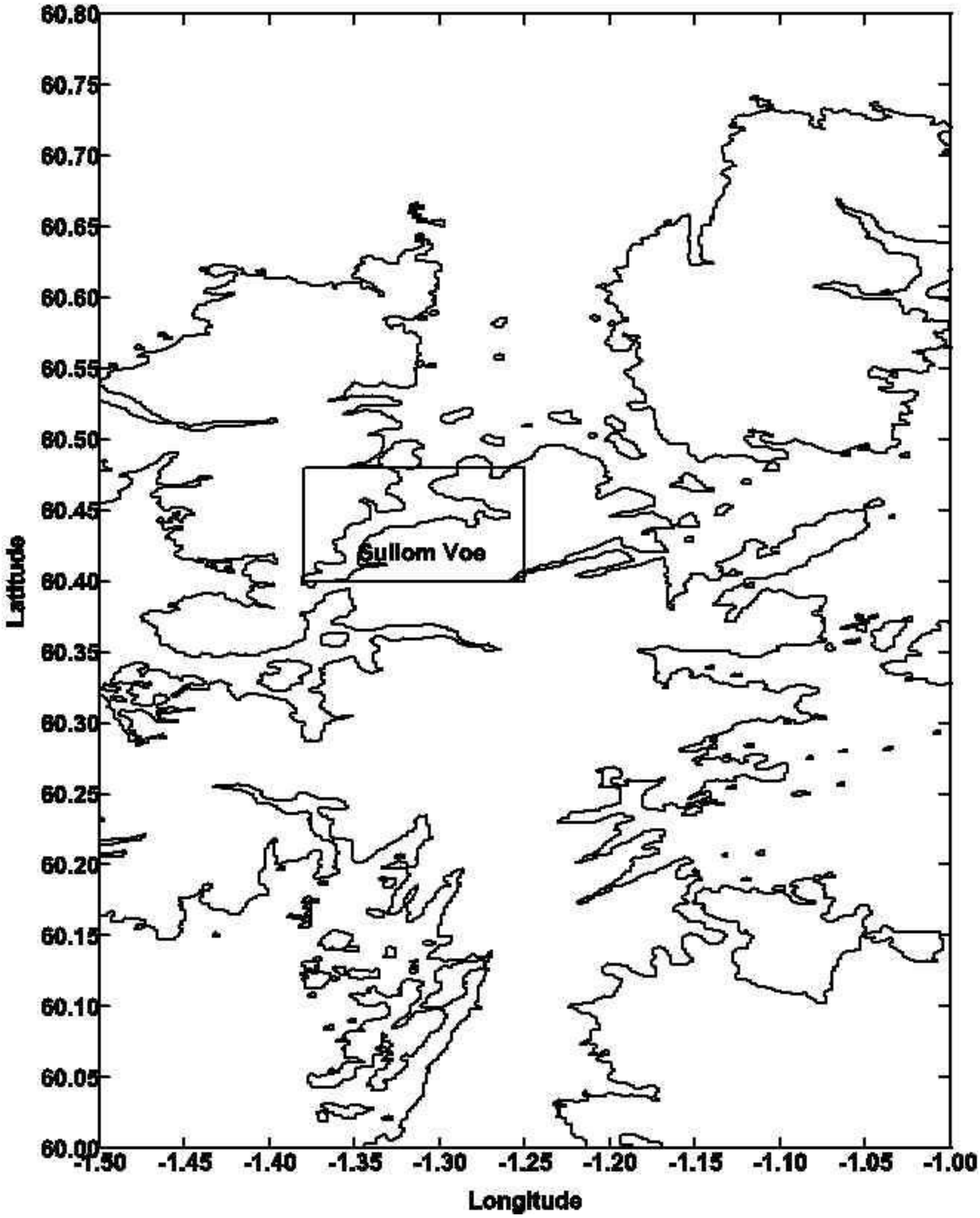
Longitude
IMF
OMF
NEC
OFF
SEC

Figure 2



Sullom Voe
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60.30
60.25
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60.15
60.10
60.05
60.00
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-1.45
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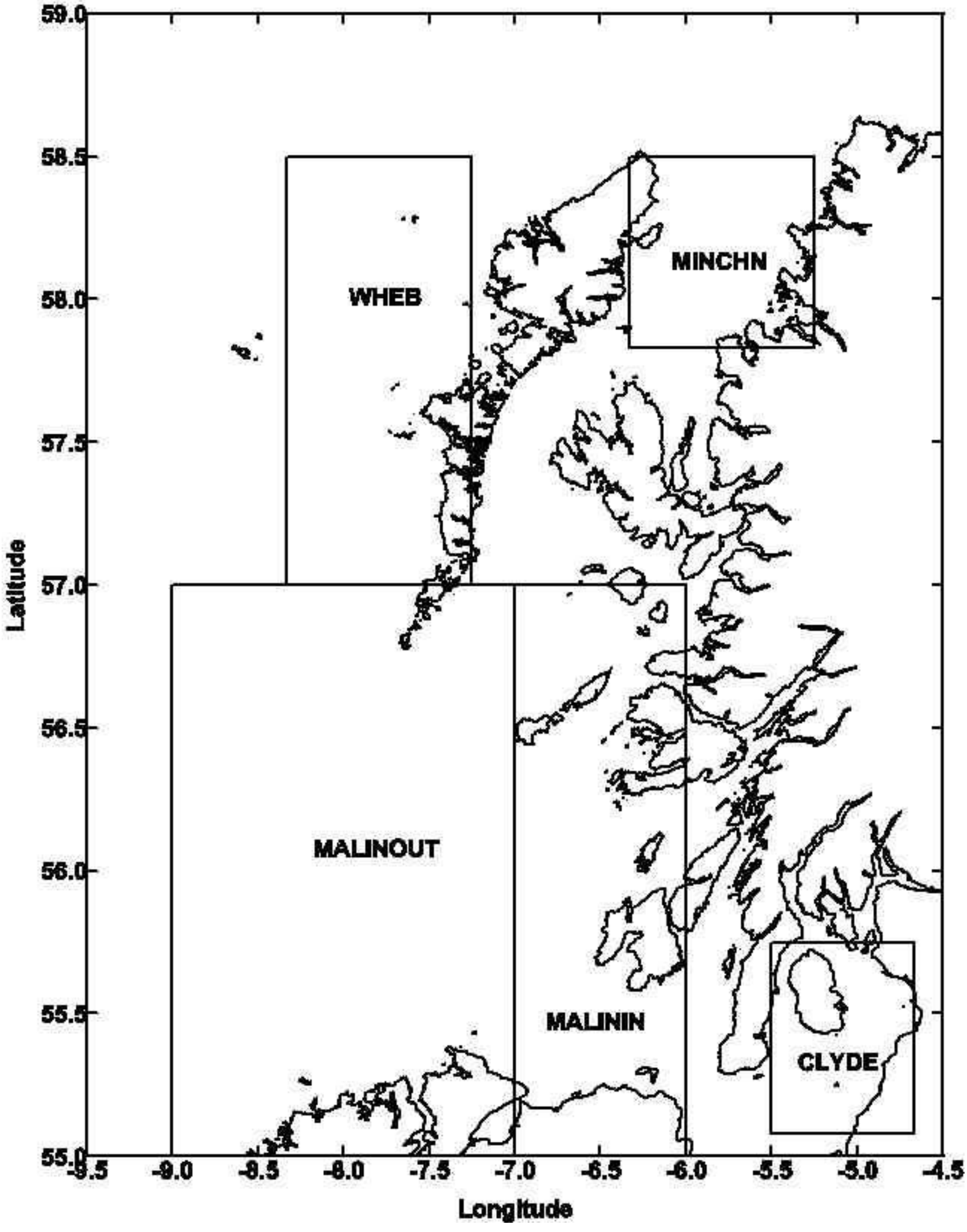
-1.00
Longitude

Figure 3



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-8.0
-7.5
-7.0
-6.5
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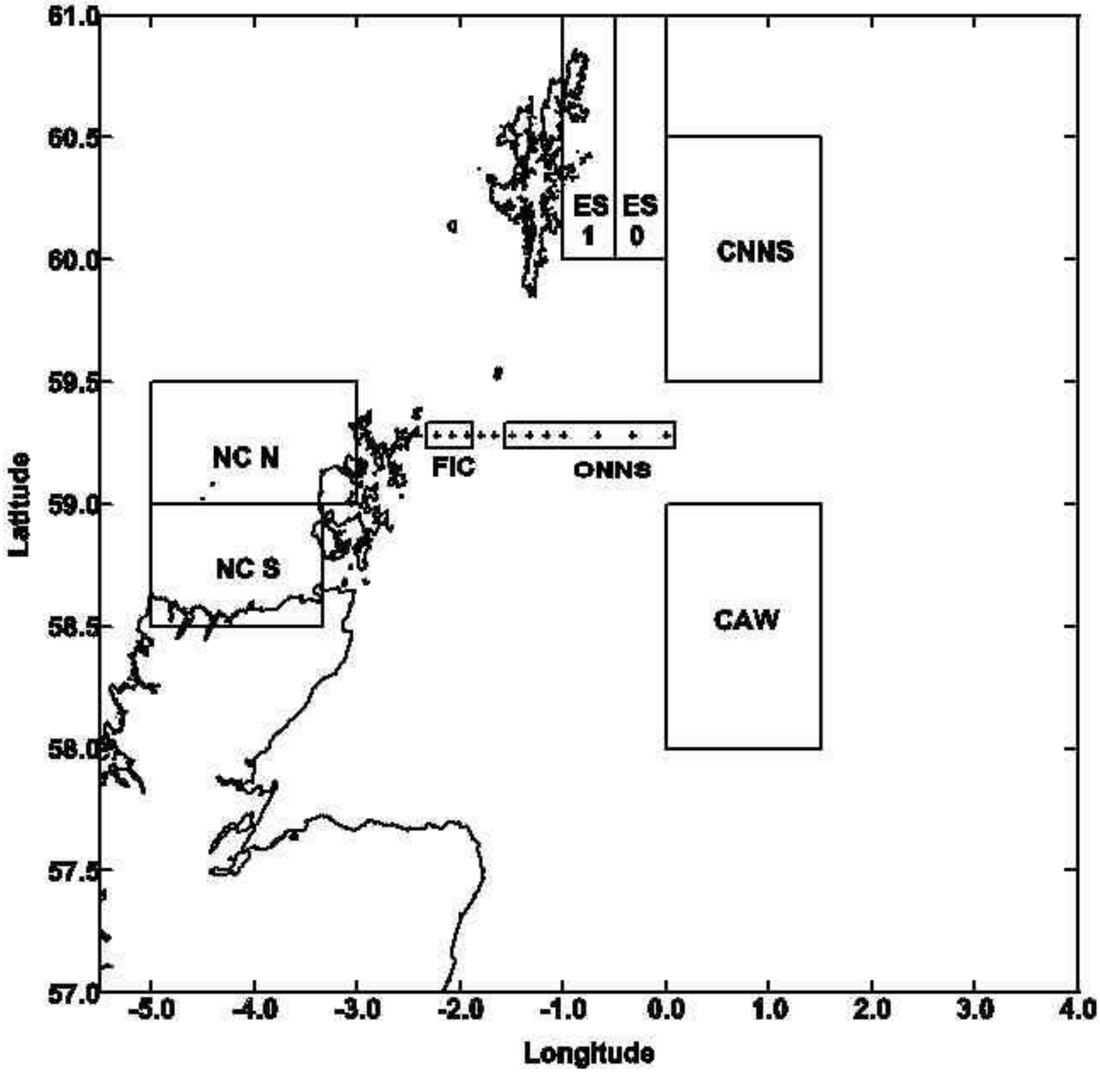
Longitude
WHEB
MINCHN
MALINOUT
MALININ
CLYDE

Figure 4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Latitude
Longitude
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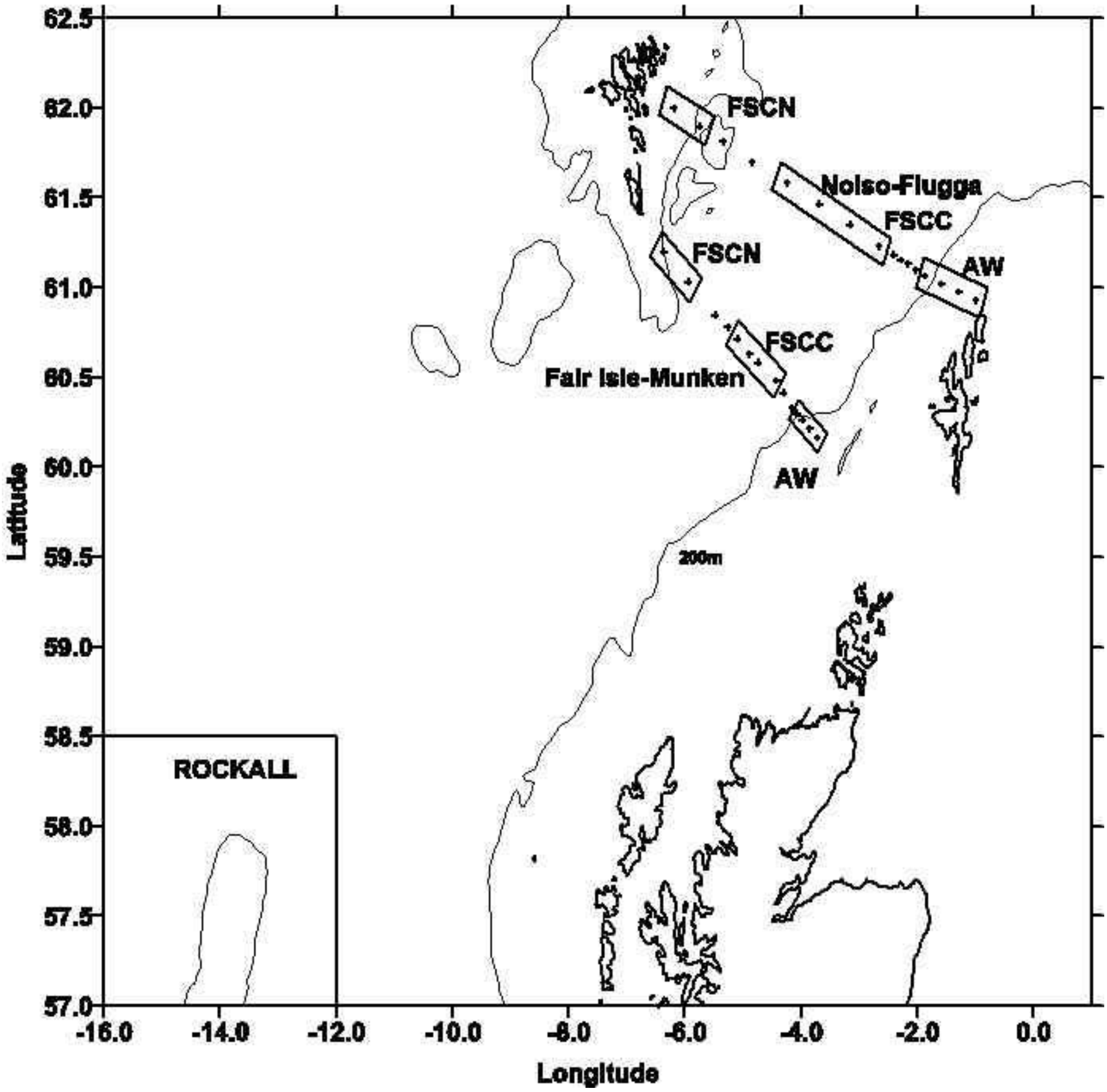
ES 0
CNNS
NC N
NC S
FIC
ONNS
CAW

Figure 5



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Latitude
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-14.0
-12.0
-10.0
-8.0
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-4.0
-2.0
0.0
Longitude
FSCN
Nolso-Flugga
FSCC
AW
FSCN
FSCC
Fair Isle-Munken
AW
200m
ROCKALL

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