Long-term environmental studies in the Irish Sea: a review

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Executive Summary

This review aims to outline long-term research from the Irish Sea. Data held by the Port Erin Marine Laboratory, Isle of Man and School of Ocean Sciences, University of Wales, Bangor are described and details of sampling methods, sites and time series are given. Major findings from these long-term studies are summarised and their limitations outlined. Current research is presented along with future approaches, illustrating how these important and unique data can aid understanding and prediction of marine environmental change.

Between 1892 and the present date, investigations have been carried out into the physical, chemical and biological components of the Irish Sea. Formal time series have been collected by Port Erin Marine Laboratory since 1904, with offshore sampling commencing in the 1950s and further expansion in the 1960s and 1990s. Today three fixed stations and an Irish Sea-wide transect are maintained.

Investigations have been undertaken in the Menai Strait, North Wales since 1948 by the University College of North Wales (now the School of Ocean Sciences, University of Wales, Bangor). These investigations have been mainly in support of individual research projects rather than a formal sampling programme, however, weekly sampling has been maintained since November 2000 with support from NERC. This support will run until May 2004. The more complete time series in the data base are for temperature, salinity, nutrients and chlorophyll.

Together, these data series constitute a unique record of long-term change in the Irish Sea. Key findings from these data are as follows:

1. Significant changes in nutrient levels have been observed throughout the last 40 years in both coastal and offshore locations. Most notable is a large increase in nitrate and phosphate, coincident with a marked rise in primary production. More recently, declines in nutrient levels have also been mirrored in primary production levels.

2. There has also been an increase in sea temperature over the last four decades of around 1° C.

3. Distinct regional differences have been noted in salinity and nutrient relationships, with the eastern Irish Sea notably enriched relative to the west. Large-scale differences in the timing and duration of the spring and autumn phytoplankton blooms at different locations have also been noted.

Additional value is being gained from these studies through the compilation of a database of phytoplankton species identified, with particular emphasis on harmful algal bloom species, providing a baseline for the northern Irish Sea.

Future opportunities are discussed, arising from recent developments in technology. These include supporting the development of coupled physical-ecosystem models and the development of real-time sampling. These opportunities make long-term time series more valuable than ever. However, recent changes in funding support and the short-term nature of funding in general are currently threatening the continuation of these series.

1. Historical Background

Marine science investigations in the Irish Sea have a long history. In 1885, Sir William Herdman FRS formed the Liverpool Marine Biological Committee to study the Irish Sea and to found a marine laboratory. This was established in 1892 on Puffin Island, at the northern end of the Menai Strait in North Wales. However, the Puffin Island laboratory only lasted five years and was abandoned, not least because of its inaccessibility during poor weather. The Committee moved to two small, custom-built laboratories beside Port Erin Bay on the Isle of Man. Herdman considered the waters off the Island the cleanest and richest he had ever seen and the laboratory proved very popular. In 1902, sponsored by the Isle of Man Government, a new much grander building was built on the south side of the bay. In 1919 responsibility for the laboratory was taken over by Liverpool University and later it became the first institute in Great Britain to offer a degree in Marine Biology.

Following the closure of the Puffin Island station, no research station existed in North Wales until 1948, when a marine biological station was formally established as part of the University College of North Wales. This station is now part of the University of Wales, Bangor's School of Ocean Sciences (SOS). Situated on the north side of the Menai Strait which separates Anglesey from mainland Wales (Figure 1), the department is ideally sited for monitoring changes in the Irish Sea. Although a coastal station (sampling is carried out from the end of the St George's Pier), there is negligible freshwater inflow, low population density and the current flow through these narrows and flushing time means that the Strait is representative of the Irish Sea.

This review aims to outline the long-term research that has been conducted in the Irish Sea by these two longstanding laboratories. The work undertaken by each of the laboratories is described and details of survey methods, sites and time series are given. Major findings from long-term studies are summarized and their limitations outlined. Future approaches are discussed, illustrating how these important and unique data can aid understanding and prediction of environmental change.

2. Port Erin Marine Laboratory

The locations of the sampling sites are shown in Figure 2 and Figure 5. Development of the time series are summarised in Table 1. Sampling methods are described in Table 2.

2.1 The early work: Port Erin Breakwater

Time series investigations at the Port Erin Marine Laboratory date back to the beginning of the 20th century, not long after the foundation of the laboratory. The Annual Report of the Liverpool Marine Biological Committee for 1903 states:

"*The temperature and specific gravity observations suspended for a time while we moved into the new building, were resumed ... we adopted a new and rather fuller weekly form for our observations, and began to record air and sea temperatures for the Meterological Office*" (Chadwick, 1903).

Having previously been involved with early investigations of the English Channel (Lankester *et al.*, 1900), Herdman now sought to instigate basic routine hydrographic measurements of sea surface temperature. Commencing in 1904, these were collected daily from the Port Erin breakwater, located close to the Laboratory. Other variables and monitoring stations were subsequently added to the Port Erin work. Herdman published several papers on the phytoplankton of Port Erin Bay back in the early part of the 20th Century (Herdman, 1918). Daily measurements of salinity were not added to the breakwater monitoring programme until 1965.

This data series is still collected and forms one of the longest and most complete hydrographic time series in existence. Samples are taken directly from the shore, which is rocky and drops off rapidly to around 10 m. There are strong tidal currents, the water is well mixed, and the temperature and salinity measurements from this location seem little affected by their proximity to land, being generally similar to offshore surface determinations. There is a large degree of variability in the SST data, although a general increasing trend is clear throughout the series, indicating a rise in SST of around one degree over the last century (Figure 3).

2.2 Offshore measurements: *Cypris* and *Baynargh*

In the 1950s, formal programmes were initiated investigating the hydrography and nutrient chemistry of Irish Sea waters. The proximity of the Breakwater to terrestrial runoff and inputs meant that it was considered unrepresentative of Irish Sea nutrient levels, so the *Cypris* station was established, approximately 5 km west of Port Erin in water of 37 m depth, by Mr D.J. Slinn. This was convenient to Port Erin Harbour where the Laboratory's smaller vessel *Cypris* was based, enabling regular twice-monthly sampling. The establishment of this station also allowed for samples to be taken from a range of depths.

The initial rationale for the monitoring work was twofold: firstly to provide some basic understanding of the local hydrology, and secondly to provide baseline environmental data essential for the interpretation of the many biological investigations conducted at the laboratory. Their importance was recognised straight away, as noted in the Annual Report for 1954:

"*The motor boat* Cypris *has, however, been used for making weekly observations on salinity, temperature and phosphate off Port Erin, and it is hoped to continue these more or less in perpetuity, since their cumulative value increases continuously with time*" (Colman, 1955).

Initially, measurements of salinity, temperature and soluble reactive phosphorus were recorded (1954). Over the years other variables were also added, including silicate (1958), total oxidised nitrogen (1960), chlorophyll (1966) and phytoplankton (1995). This programme continues today and provides one of the longest nutrient chemistry time series in existence (see Figure 4).

As the hydrography of the local waters came to be better understood, it was realised that the proximity of summer stratification and frontal systems (see Pingree & Griffiths, 1978) to the *Cypris* station might make is unrepresentative of all local waters. Consequently, in 1994 the *Baynargh* station was established a similar distance offshore on the eastern side of the Isle of Man, in an area where the waters are permanently mixed. This station was established by Ms. T.M. Shammon and is sampled with the same frequency and protocols as the *Cypris* station. Results from *Bayrnargh* have demonstrated the large differences in properties between the stations, especially pronounced in biological variables (Shammon & Hartnoll, 2003 and references therein).

A 40-year time series of nutrients (nitrate, phosphate and silicate) from the *Cypris* station was analysed by Allen *et al.* (1998) to address concerns regarding raised nutrient levels and possible eutrophication of the Irish Sea. They found nitrate levels to have risen substantially, approximately doubling between 1960 and 1990, before levelling off, though with great subsequent variation. Phosphate levels were also seen to have risen markedly until 1990, but had then declined. On the other hand, silicate levels, though variable, had not changed overall through the period. It was concluded, with little doubt, that the increases had been due to anthropogenic input, despite these data coming from the central Irish Sea, removed from major input sources.

A coincident increase in primary productivity, measured as chlorophyll a concentration during the late spring bloom, was noted by these authors and associated with the increased nutrient levels (Allen *et al.*, 1998). More recently, there have been signs of a decline in primary production (Shammon & Hartnoll, 2003).

Concerns over the quality and consistency of the historical data used by Allen *et al.* (1998) led Gowen *et al.* (2002) to re-evaluate the *Cypris* data set using more recent data as well as areal winter surveys of the Celtic and Irish Seas. They concluded that the trends in the Isle of Man time series were unlikely to have resulted from changes in analytical procedure and personnel, although concerns over data quality could not be resolved, as no independent data exist to validate the time series.

These authors also showed distinct regional differences in salinity and nutrient relationships, with the eastern Irish Sea notably enriched relative to the west. The inclusion of more recent data showed that phosphate levels have declined since the late 1980s, whereas nitrate concentrations have remained stable since the mid-1970s. and there is an absence of a trend for silicate. They concluded that trends in nitrate and phosphate are consistent with changes in riverine concentrations of these two nutrients and the biogeochemical processes controlling their cycling in shelf waters. In offshore areas of the Irish sea, lower concentrations of nitrate than expected could be explained by denitrification (Gowen *et al.*, 2002).

2.3 The bigger picture: the Port Erin Line at 54° N and other additions.

Since the 1950s, the 54° N parallel (often referred to as the Port Erin Line) has been sampled on an intermittent basis, however, in 1992 systematic bi-annual research cruises along this line were initiated. The 54º N parallel sampling line crosses the Irish Sea from Carlingford Lough to Morecambe Bay, passing just south of the Isle of Man. Depth profiles for the range of variables investigated are determined at each of the stations (see Figure 5). The line was sampled in summer and winter and has revealed large variations across the Irish Sea, placing the Manx sampling in a wider perspective. These cruises have shown striking differences between the western and eastern Irish Sea in both the winter nutrient maximum and summer chlorophyll production in both surface and deeper waters (see Shammon & Hartnoll, 2002a, 2002b, 2003, Kennington *et al.* 2003 and references therein).

In recent years (2001, 2002, 2003), thanks to funding from both the Manx Government and the UK's Environment Agency, these cruises have been able to be undertaken on a monthly basis between January and September enabling studies on the seasonality of nutrients and phytoplankton (Figure 6) to be reviewed along the transect (Kennington *et al.*, 2003). Further work with the Environment Agency extended these cruises to cover the north-eastern Irish Sea from the Solway Firth to Liverpool Bay (Kennington *et al.*, 2003).

These cruises have concentrated on the seasonality of nutrients and phytoplankton across the Irish Sea and have shown large-scale differences in the timing and duration of the spring and autumn plankton blooms at different locations. Additionally, these studies have provided a baseline of phytoplankton species composition in the Irish Sea with particular emphasis upon nuisance and potentially toxic species (an overview of this work can be seen at http://www.liv.ac.uk/plankton and http://www.liv.ac.uk/hab). These studies are important from the perspective of several European and national legislative obligations. The data on the winter nutrient distributions around the Irish Sea has subsequently been mapped over a five year period and has enabled the long-term data collected from the *Cypris* station to be placed in a larger Irish Sea context (Kennington *et al.*, 2002, Hartnoll *et al.*, 2002).

2.4 Funding
For most of its history the time series sampling work was funded from the general budget of the laboratory: from 1903-1919 the Liverpool Marine Biological Committee operated and funded the laboratory, and from 1919 this operation was taken over by Liverpool University.

The value of the time series work was clear, but it was nevertheless often seen as a 'service' activity with a lower scientific profile. Thus, when John Slinn, the member of staff responsible for the work, was due to retire without replacement at the start of the 1990s, the programme was at serious risk. At that time other long time series, including many of those in the English Channel, had already been discontinued. Support for the monitoring programme was secured from the Isle of Man Government by Dr. Steve Hawkins (now Prof. Hawkins, Director MBA, UK), and this support is still being provided. From 1995, ongoing collaborative work supported by the Environment Agency extended the scope of sampling to include monitoring of the north-eastern Irish Sea, placing the local time series in a broader context. The work is now recognised as valuable in the context of global warming, eutrophication and compliance with a variety of national and international directives and obligations. In recent years, funding for the long term sampling and monitoring programmes undertaken at the *Cypris*, *Baynargh* and Breakwater stations has been progressively reduced and funding for the extended Port Erin Line (54° N) programme is unlikely to continue after 2003.

3. School of Ocean Sciences, University of Wales, Bangor

3.1 Historical work and data recovery
Since 1948, the Menai Strait has been investigated by staff and students from the Departments of Physical Oceanography and Marine Biology, now joined as the School of Ocean Sciences, generating a considerable amount of physical, chemical and biological data for a large number of M.Sc. and Ph.D. theses and research projects. The scale and diversity of these projects has been such that it is not amenable

to a short summary of the key findings. The database (see below) lists the relevant individual projects.

Prof. Peter Williams at SOS recognised that these historical data represented a wealth of information and understood the value of recovering and compiling them into historical datasets. Furthermore, he realised that few long-term datasets for UK waters exist over multi-decadal time scales and that insights into the environmental changes that have occurred in the Menai Strait, as well as in the wider Irish Sea, could be gained. A programme was therefore set up, in collaboration with Dr. Gay Mitchelson-Jacob, to mine SOS archives, quality audit the data and compile the various datasets into a single database which can be queried for each determinand. The Menai database currently holds around 25,000 observations dating back to 1955 and is composed of commissioned research and postgraduate project measurements plus data from the Environment Agency and the Countryside Council for Wales.

The more complete time series within the Menai Strait database are for nutrients (nitrate, nitrite, ammonia, phosphate and silicate), temperature, salinity and chlorophyll. Figure 7 shows the spread of sampling throughout the timespan of the database. Detailed information about source and analytical methods used can be found linked to each dataset within the database, accessible from http://www.sos.bangor.ac.uk/research/msd/index.htm. Although analytical techniques have been refined since the 1950s, there is no reason to suspect that this would cause systematic change in the measurement of a determinand and so bias time series data. Throughout the work careful attention was given to the use of appropriate standards and there is no evidence of bias in the data over the period of analytical change.

3.2 Current sampling and funding

A programme of sampling to continue the database (funded as part of a NERC grant) has run since November 2000 and will continue until May 2004 when funding ceases. Measurements are taken from St George's Pier, located next to SOS, at weekly intervals throughout the year within an hour of high tide. Surface water samples for salinity, nutrient and chlorophyll analysis are taken with record of temperature and Secchi depth. Sampling for salinity, temperature, water level and turbidity has also been funded by the Countryside Council for Wales, for a period from 2003-2007, as part of an on-going programme led by Dr Des Barton to monitor the Menai Strait. This sampling, which started in 1995, includes comprehensive meteorological sampling for wind speed and direction, air temperature, relative humidity, air pressure and rainfall.

3.3 Summary of long-term changes

Sea surface temperature (SST) data for the Menai Strait dates back to 1961 and continues to be measured on a weekly basis. There has been an increase in temperature (Figure 8) over the last 4 decades and this increase appears to be high (>1° C). However, this jump in temperature is due to the dataset spanning the very cold years of 1962/63 and latterly the exceptionally warm temperatures of the 1990s. Further examination of the SST dataset revealed that the increase in temperature is not consistent across all months of the year.

Nutrient and salinity results are presented in detail in Evans *et al.* (2003). In summary, a broad trend has been observed for nitrate and phosphate time series data with an increase in concentrations from the early 1960s through to the 1980s followed by a decline in the 1990s. This can be seen in Figure 9 which also shows the comparison of these parameters for the *Cypris* Station. Silicate arguably also follows this trend. Salinity data for the Menai Strait goes back to 1955 and most observations fall between values of 31 and 34. Of great interest is the fact that salinity has not remained constant since the mid 1950s but has fluctuated, albeit over a small range. For example, measurements were consistently lowest during 1957 (annual mean 32.3) and highest in 1963 (annual mean 33.7) and 1996 (annual mean 32.7). Significantly, during the period of nutrient measurement from 1963 to the present, there has been a broad shift in salinity opposite to nutrient change: salinity observations having decreased from the 1960s to the 1970s/80s and then increased in the 1990s (Figure 10). This mirrored pattern points to the influence of anthropogenic input of nutrients via freshwater but examination of the available records for river nutrient loading over the past 25 years shows no overall pattern of change paralleling that seen for Menai Strait nutrient concentrations. The conclusion drawn from this was that climatic forcing of the mixing zone between freshwater and seawater could explain the nutrient/salinity shifts observed over the decades at the Menai Strait sampling station. This would mean that in addition to anthropogenic nutrient pollution from land affecting marine nutrient concentrations there is also a background effect of water mass shifts altering measurements at fixed point sampling stations like St George's Pier.

4. Discussion

The importance of long-term records is progressively being recognised as anthropogenically driven climate change and more direct disturbances, such as fishing and pollution, are increasingly identified as major influences on marine ecosystems (Hawkins *et al.*, 2003). This recognition is coupled with an urgent need to understand the mechanisms by which these influences act on the marine environment. This is of primary importance in order to interpret current changes and predict future impacts, thereby enabling effective management and conservation of marine biodiversity and resources. Furthermore, research emphasis will undoubtedly shift in future with different problems becoming apparent; thus records of today could help resolve future problems.

Records from the Irish Sea presented in this review have exceptional significance due to a combination of factors, namely 1) the location of the Isle of Man in the centre of the Irish Sea, straddling a hydrographic boundary between permanently well-mixed and seasonally stratified waters, and the situation of long-term monitoring stations reflecting both these water properties (*Cypris* and *Baynargh*), 2) the juxtaposition of the Menai Strait sample station to those around the Isle of Man giving a north-south comparison of changes, 3) the wide range of environmental and biological parameters that have been systematically recorded at both laboratories and 4) the long temporal scale over which these observations extend, with the longest series (Port Erin Breakwater) uninterrupted by the two World Wars which caused large gaps in other long-term series, such as those from Plymouth.

There are inevitably potential significant limitations to such long-term data series. Firstly, methods used are not necessarily consistent throughout the series. This results from a variety of factors, such as the development of new and increasingly accurate techniques and the use of different equipment. Nonetheless, Gowen *et al.* (2002)

concluded that the observed trends were unlikely to have resulted from changes in analytical procedure. Secondly, the quality of the Isle of Man historical data has proved impossible to determine due to the lack of other records for comparison (Gowen *et al.*, 2002). This demonstrates the importance of ensuring current records are subjected to external quality control, such as through the European-wide QUASIMEME scheme for nutrient and pigment data, now used in Port Erin.

These historical data have been key for developing understanding of the Irish Sea and its ecosystem, particularly the east-west gradients in water properties and associated biota. The *Cypris* station has shown long-term changes in nutrient concentrations which have been related to riverine inputs and biogeochemical processes. These data give an important baseline by which the impact of anthropogenic inputs on offshore regions of the Irish Sea can be judged. Similarly, data from St Georges Pier in the Menai Strait provides a coastal baseline. The more recent *Baynargh* station and 54° N transect cannot yet be classified as long-term series but are already providing useful data, both in providing context for other stations and through generating a record of seasonal and interannual variability in waters not previously sampled. Furthermore, added value has been gained from these series by provided a baseline for phytoplankton species composition in the Irish Sea, with particular emphasis upon nuisance and potentially toxic species. Thus, these studies have provided key information for both scientific research and from the perspective of several European and national legislative obligations (e.g. Water Framework Directive).

Currently several collaborative efforts are underway in the Irish Sea. Scientists from Port Erin and Bangor are comparing their long-term series with data from more recently established stations, such as those maintained by the Department of Agriculture and Rural Development (DARD) in Northern Ireland and both the Environment Agency and Proudman Oceanographic Laboratory (POL) in the UK. Further collaborations are underway with surveys that provide a much broader spatial perspective, such as the continuous plankton recorder survey of SAHFOS and the Irish Sea surveys of CEFAS. The DEFRA Irish Sea Pilot project for ecosystem-based management is reliant on these collaborations to provide environmental information. The establishment of the Marine Environmental Change Network by DEFRA in 2002 has also allowed these observations to be put into a wider British and Irish framework. On the other hand, money to maintain this network of observations in the Irish Sea is increasingly hard to obtain. This is particularly apparent for the stations maintained by Port Erin Marine Laboratory where a reduction in funding has led to time series activities again coming under threat.

Finally, recent advances in technology mean these long-term programmes are more valuable than ever before. Future directions being pursued include collaborations in support of the development of coupled physical-ecosystem models (e.g. POLCOMS-ERSEM[1]) using Irish Sea time-series data to expand relationships between surface and subsurface properties with ecosystem-wide responses, leading to prediction of future changes. Understanding processes regulating marine ecosystems can require sampling over varied temporal scales. Recent technologies such as advanced telemetered instruments, e.g. SMART buoy system developed by CEFAS, can

[1] Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS), European Regional Seas Ecosystem Model (ERSEM)

enhance ongoing research as well as focus sampling strategies by providing real-time data. Importantly, such instruments yield *in situ* profile data from the water column, so, together with satellite-derived information, can greatly extend the spatial and temporal extent of measurements. This is fundamental in order to capture processes that occur at multiple scales and understand how they operate within the marine environment. These technologies have already been employed by POL with the establishment of the Liverpool Bay Coastal Observatory (cobs.pol.ac.uk) and DARD maintain two SMART buoys off the Northern Irish coast. Thus, there is now an opportunity to establish an Irish Sea wide network for continuous, real time monitoring.

In conclusion, these unique Irish Sea time series are increasingly valuable for the detection of ecological responses to environmental change and their future predictions. The legacy of observations collected throughout the last century has clearly demonstrated the importance of this work in contributing to our understanding of the coastal marine environment. In the face of current unprecedented rates of change, it is vital that the lessons of the past are learnt and these programmes are fully supported and maintained for the future.

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Table 1 Start dates for the various monitoring programmes operated by the Port Erin Marine Laboratory. See Figure 1 for position of sampling stations.

Variable	Sampling station			
	Port Erin Breakwater	Cypris	Baynargh	54˚N parallel*
Temperature	1904	1954	1994	1953
Salinity	1965	1966	1994	1965
Dissolved oxygen		1954	1994	1953
Inorganic nitrogen		1960	1994	1961
Inorganic phosphate		1954	1994	1953
Inorganic silica		1958	1994	1961
Total nutrients		1994	1994	1994
Chlorophyll		1966	1994	1966
Toxic phytoplankton		1992	1992	
Phytoplankton profile		1998	1998	1998

*54˚N parallel has been regularly sampled only since 1992

Other significant dates:

1992 – ‘red tide’ reporting scheme established
1995 – collaborative work with EA in NE Irish Sea initiated

Table 2 Current sampling techniques for Port Erin Marine Laboratory Stations

Station	Sample type	Equipment	Methods
Breakwater	Temperature	Certified thermometer (Sea Ice Office).	Daily surface sample.
	Salinity	Glass salinity bottles with plastic inserts.	Daily surface sample. Stored in dark cool conditions. Bench salinometer (PortaSal).
Cypris/ Baynargh	Temperature/ Salinity	IOS-type bottle & reversing thermometer or Nansen-Petteren insulated bottle & thermometer.	Samples twice monthly at 0, 5, 10, 20 m & bottom. Stored in dark cool conditions. Bench salinometer (PortaSal).
	Chlorophyll a	Rosette sampler & NIO bottle.	Samples twice monthly at 0, 5, 10 & 20 m. Extraction method: Overnight at 4° C using 90% acetone as solvent Analysis using spectrophotometric methods (HMSO, 1980).
	Nutrients: Nitrate, Nitrite, Ammonium, Phosphate, Silicate.	Rosette sampler & NIO bottle.	Samples twice monthly at 0, 5, 10 & 20 m. Autoanalyser, Skalar SAN^{++}, 0.45µm membrane filter with GF/C prefilter, Frozen storage at –20°C
	Phytoplankton	Rosette sampler	Samples weekly at surface & 10 m intervals. Preserved in Lugol's Iodine. Settled in Utermohl chambers and counted/identified by inverted light microscopy.
9 stations on Port Erin Line (54° N)	Temperature/ Salinity	CTD profiler (SeaBird electronics SB19) & M.O. Thermometer.	Samples 2 to 5 times per year at surface & 10 m intervals. Bench salinometer (PortaSal).
	Chlorophyll a	Rosette sampler & NIO bottle. Depth profiling Fluorometer (SeaBird electronics SB19).	Sampled 2 to 5 times a year at surface stations only. Used to callobrate fluorometer. Extraction method: Overnight at 4° C using 90% acetone as solvent Analysis using spectrophotometric methods (HMSO, 1980).
	Nutrients: Nitrate, Nitrite, Ammonium, Phosphate, Silicate.	Rosette sampler & NIO bottle.	Sampled 2 to 5 times a year at surface and 10 meter intervals. Autoanalyser, Skalar SAN^{++}, 0.45µm membrane filter with GF/C prefilter, Frozen storage at –20°C
	Phytoplankton	Rosette sampler	Samples at surface & 10 m intervals. Preserved in Lugol's Iodine. Settling in Utermohl chambers and counted/identified using inverted light microscopy.

Table 3 Current sampling techniques for St George's Pier, taken weekly from surface waters.

Sample type	Equipment	Methods
Temperature	Hand held digital thermometer	
Salinity	Glass salinity bottles	Stored in dark conditions Salinometer
Chlorophyll	51 Aspirator	Extraction method: 4 hours at –20° C using 90% acetone as solvent Analysis using fluorometric methods (Knap *et al.* 1996)
Nutrients: Nitrate, Nitrite, Ammonium, Phosphate, Silicate.	51 Aspirator	Autoanalyser, QuickChem 8000, GFF filtration, Frozen storage at –20°C (Hubert & Diamond, 2000)

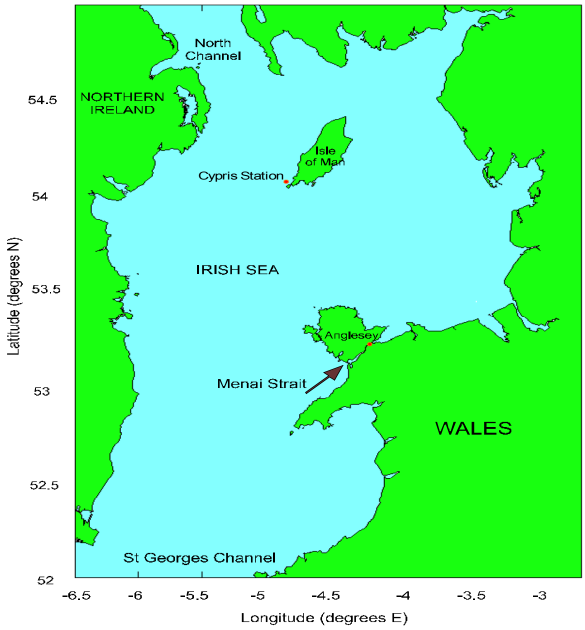


Figure 1 Location of the Menai Strait and *Cypris* sampling stations.

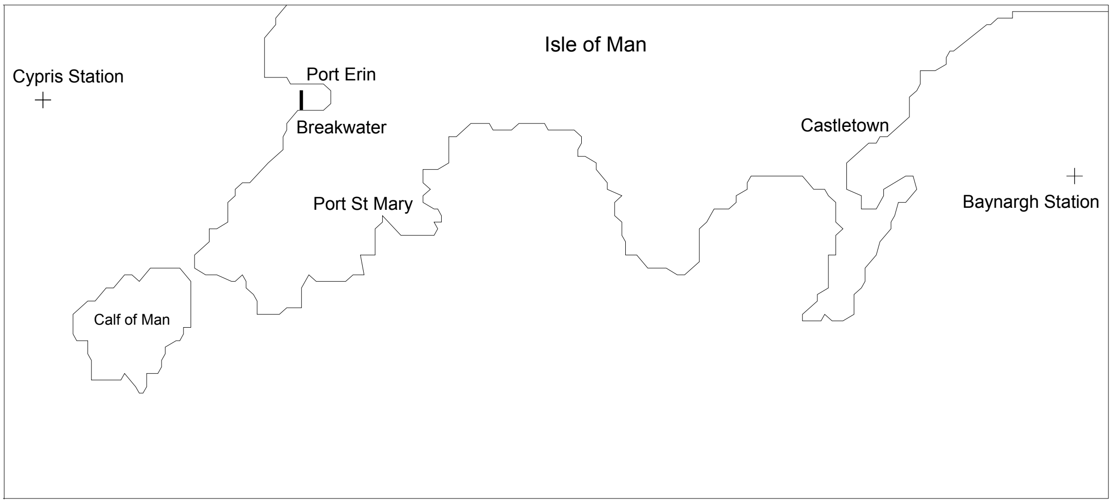


Figure 2 Locations of Port Erin Marine Laboratory's sampling stations (*Cypris* and *Baynargh*) around the Isle of Man.

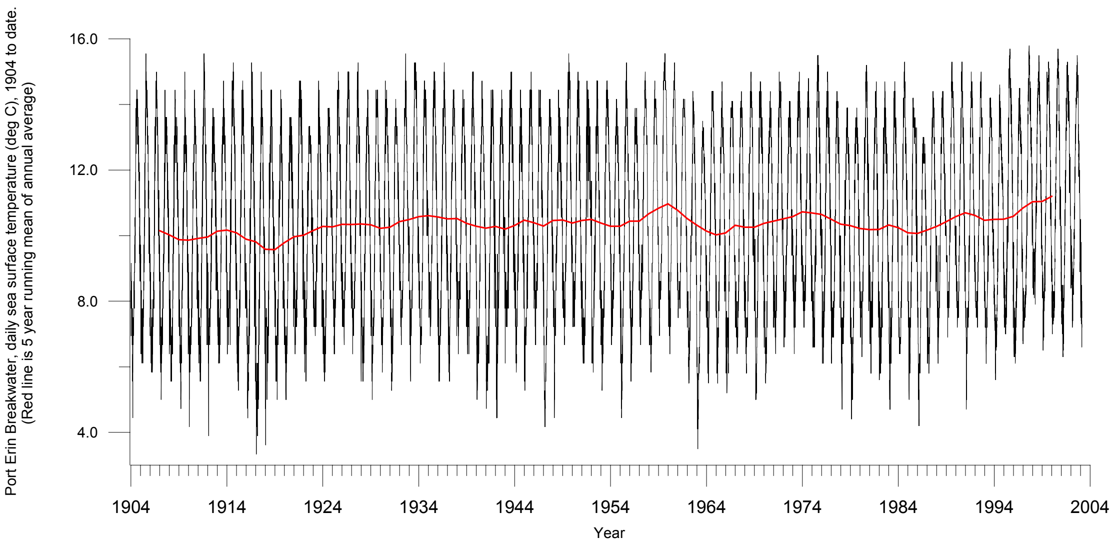


Figure 3 Time series of daily temperature recordings taken from Port Erin Breakwater. Note the increase in winter temperatures since the 1990's. Red line = 5 year running mean.

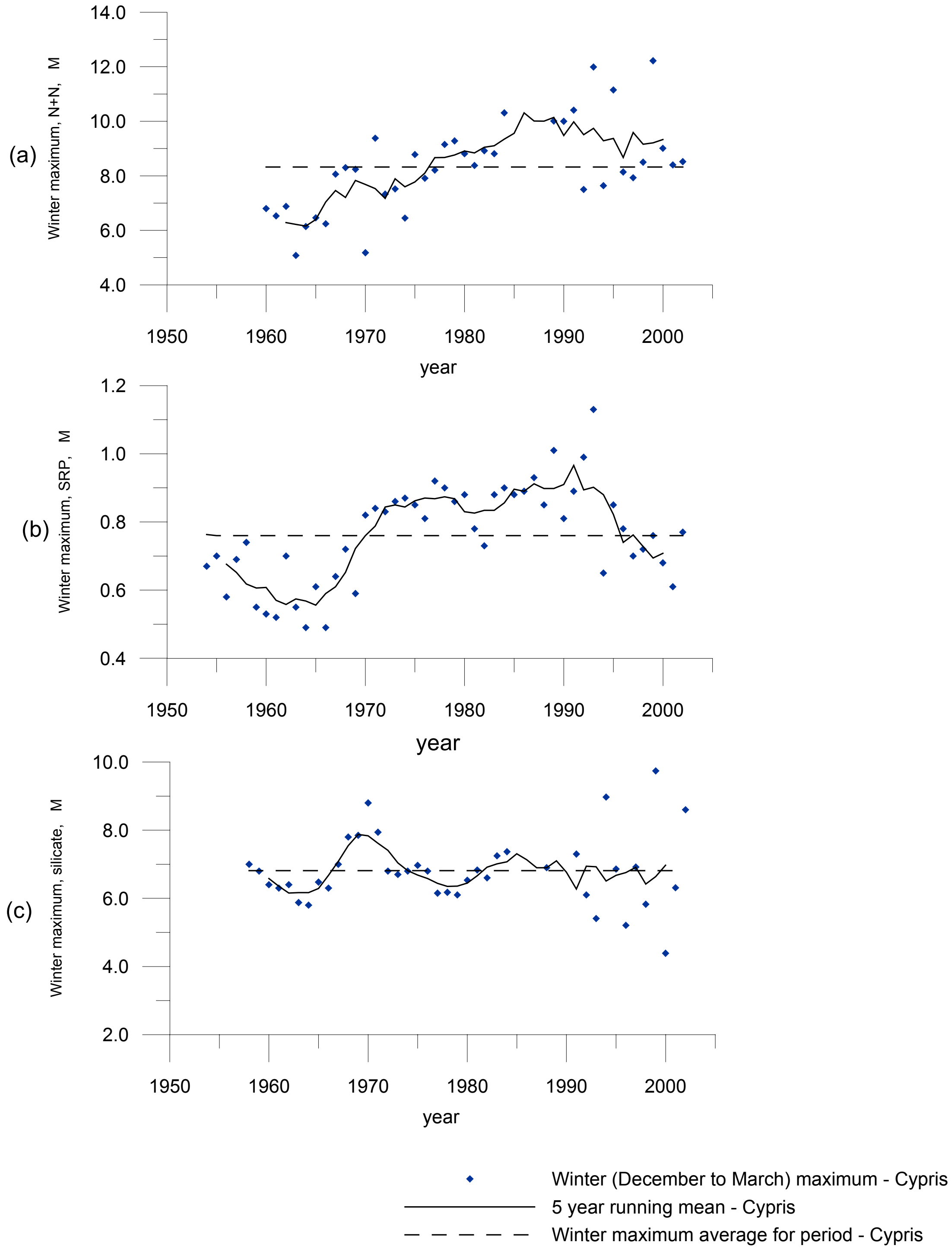


Figure 4 Winter nutrient concentrations of nitrate, phosphate and silicate from the Cypris station, Port Erin, Isle of Man.

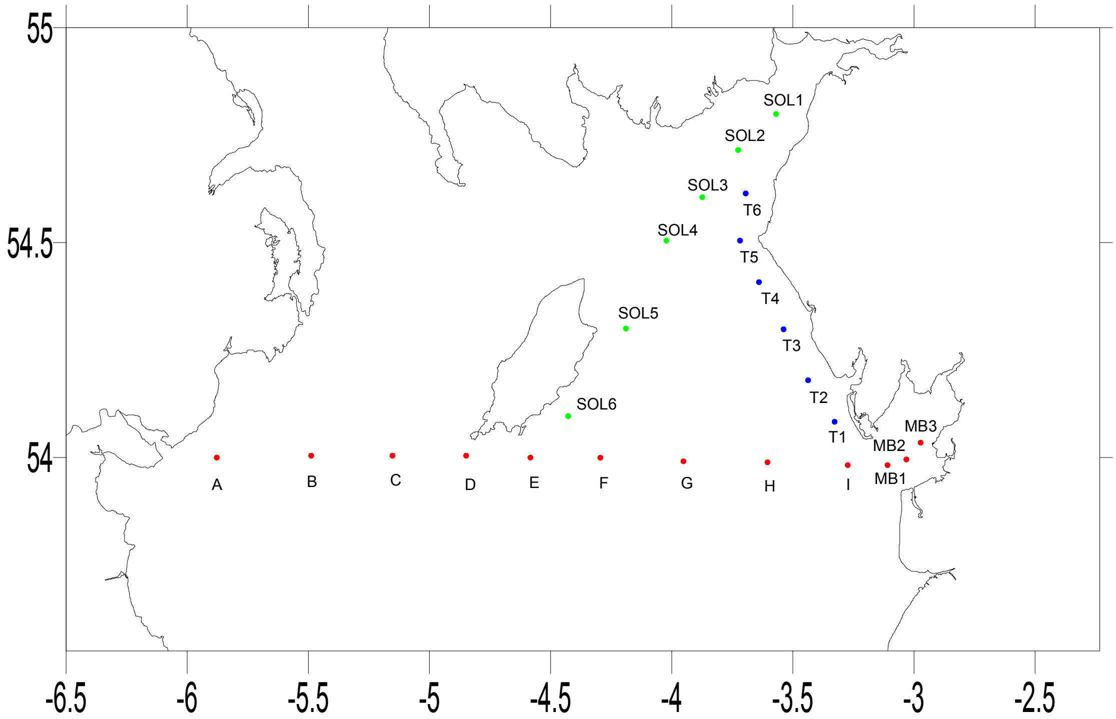


Figure 5 The 54ºN parallel sampling stations and extended north-east Irish Sea Survey stations (as monitored during 2002).

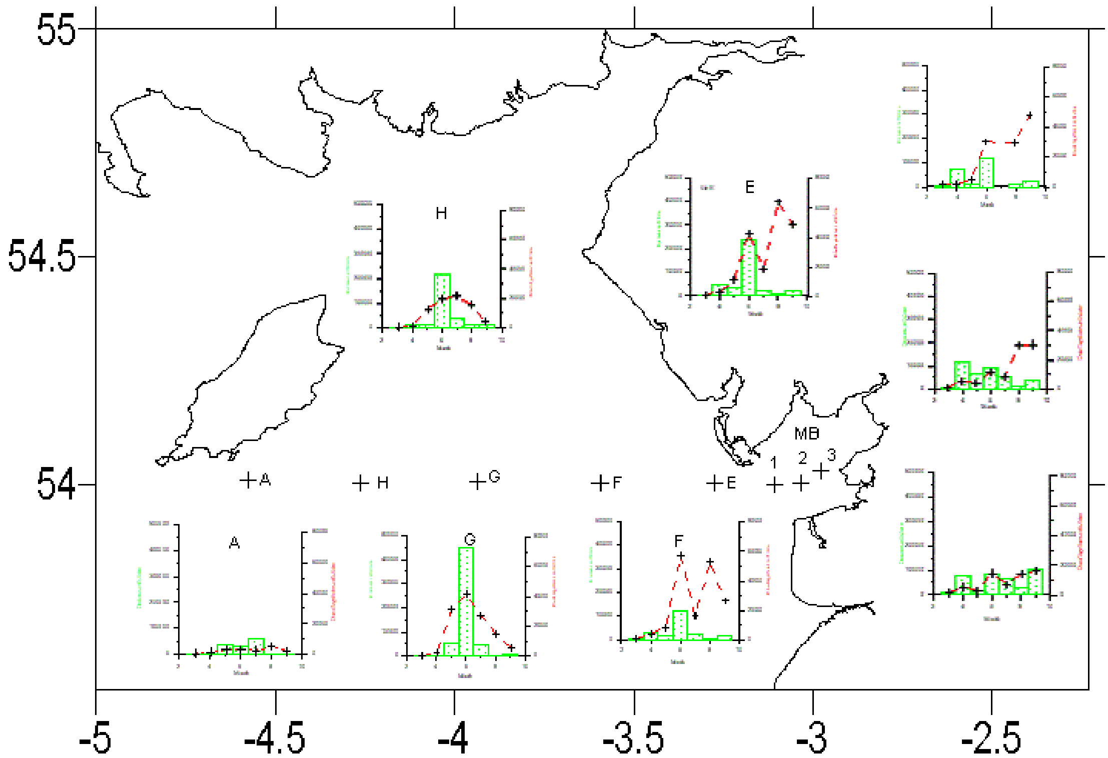


Figure 6 Seasonal cycle of diatoms and dinoflagellates along 54° N in the eastern Irish Sea.

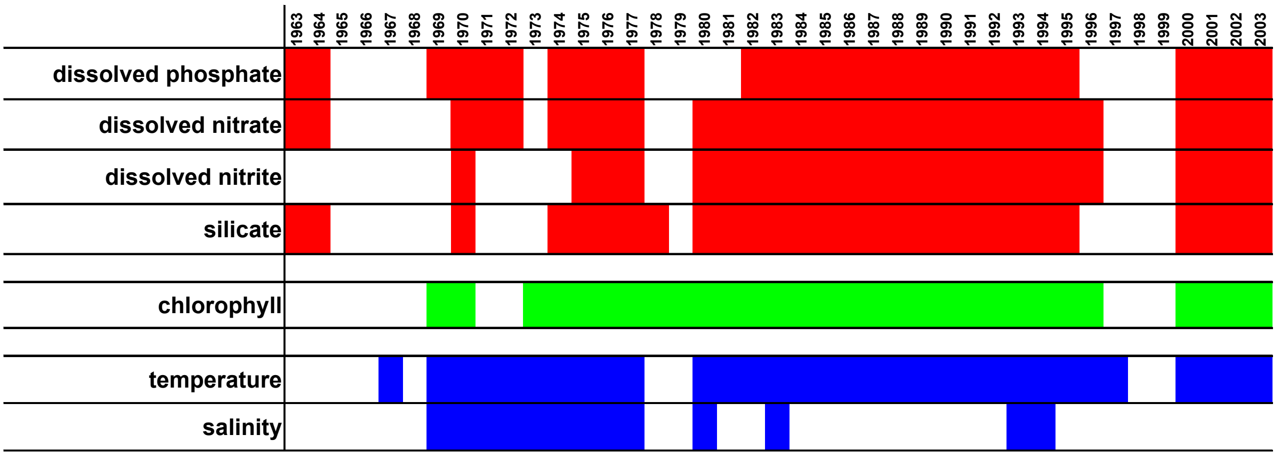


Figure 7 Sampling coverage for the major parameters in the Menai Database

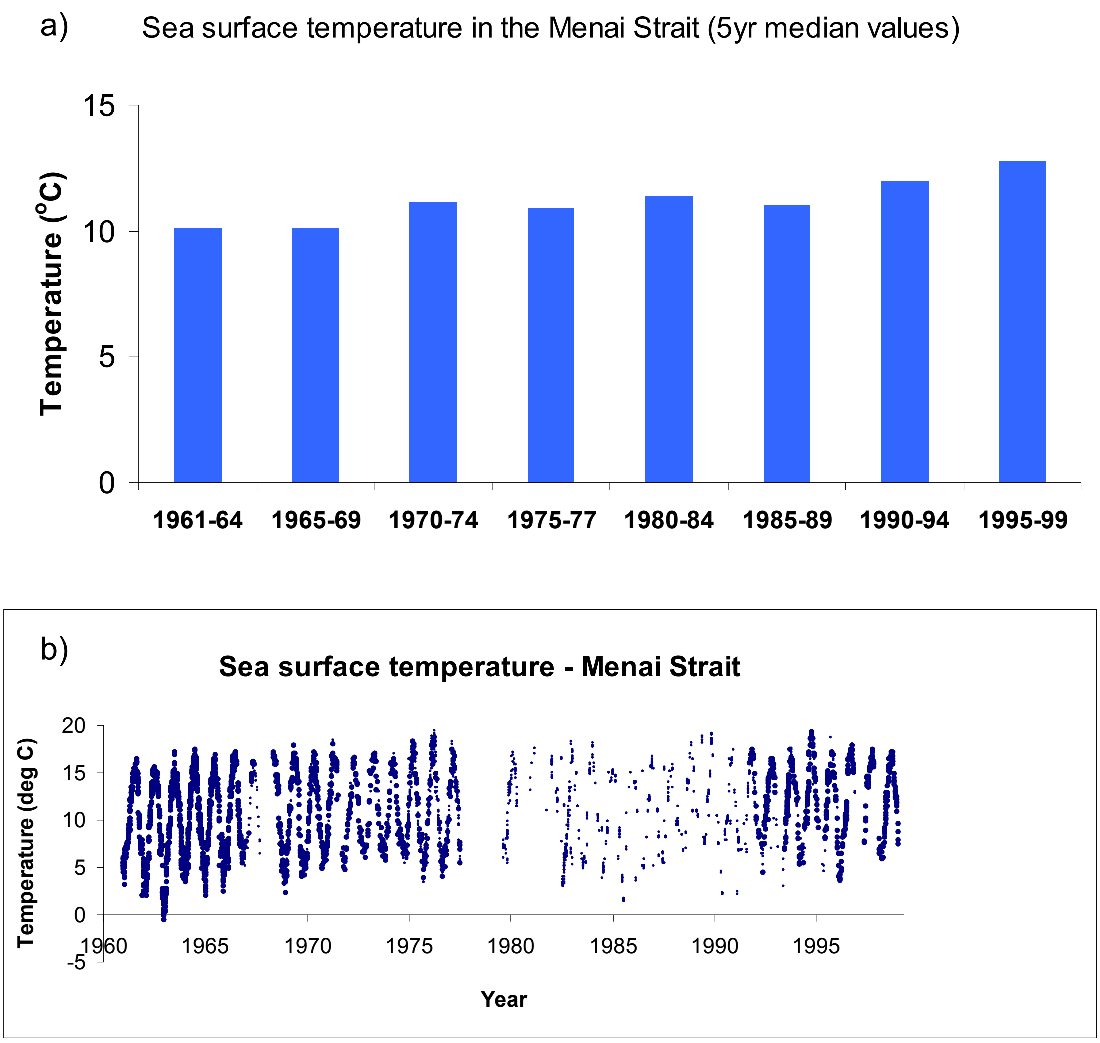
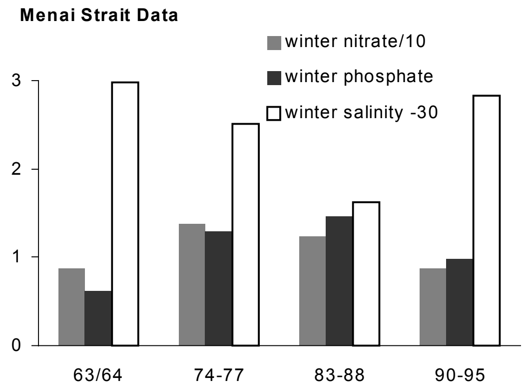


Figure 8 Surface temperature change at the Menai Strait sampling station from 1961-1999; (a) as decadal means, (b) showing all data points.



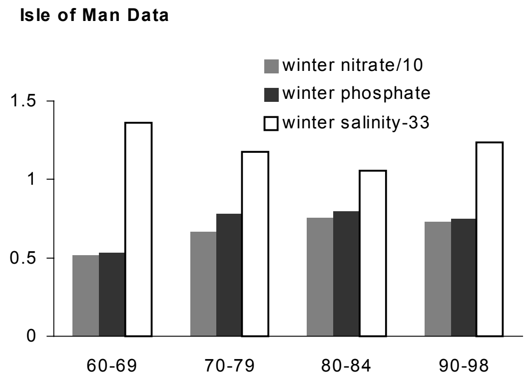


Figure 9 Decadal comparison of the winter nitrate, phosphate and salinity for the Menai Strait and the Cypris stations.

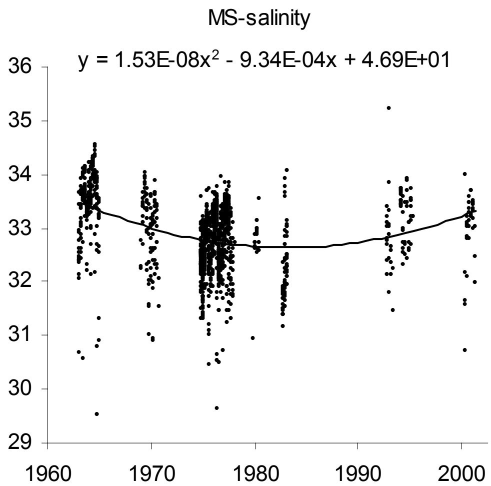


Figure 10 Salinity variation over the period 1963 - 2003.