ENVIRONMENTAL MONITORING IN MANX COASTAL WATERS:
THE ISLE OF MAN TIME SERIES
INCLUDING RESULTS FOR 2005 & 2006

Port Erin Marine Laboratory (University of Liverpool) and the transition to the Government Analysts Laboratory (Department of Local Government and the Environment)

Government Laboratory
thie-scroodie-stoo Yn Reiltys
Ballakermeen Road, Douglas, Isle of Man, IM1 4BR
Website: www.gov.im/dlge/enviro/govlabs

EXECUTIVE SUMMARY

The report presents results for the years 2005 and 2006 for a suite of physico-chemical and biological water quality variables routinely monitored and part of timeseries for the coastal and territorial waters of the Isle of Man.

The variables are temperature; salinity; dissolved oxygen; inorganic nutrients; chlorophyll *a*; phytoplankton. Sea temperature has been monitored since 1904 whilst the other variables have been monitored since the mid-1950s. Until 2006 this monitoring was undertaken by the now defunct Port Erin Marine Laboratory. From 2006 the monitoring has been undertaken by the Government Laboratory.

Local sea temperature was approximately one degree above the longterm mean. 2006 ranked with 1959 and 1998 as the equal warmest on record. Ten of the warmest ranked years for local sea surface temperature have occurred in the decade 1997 to 2006.

Salinity values were low but within ranges for the timeseries and representative for the central Irish Sea.

Dissolved oxygen concentrations were generally excellent.

Chlorophyll *a* concentrations and seasonal fluctuations were not unusual and within ranges for the timeseries. Phytoplankton counts and assemblages were not unusual compared to previous years or the central Irish Sea and exhibited the expected seasonal cycles.

Inorganic nutrients exhibited the expected seasonal fluctuations and cycles and were neither elevated nor unusual.

Algae with the capability of producing shellfish vectored toxins and nuisance algae had a relatively low impact during 2005 and 2006. However, shellfish vectored toxins continue to be a major concern to the Island's shellfish industry.

The measured variables were considered using Oslo Paris Convention (OSPAR) Ecological Quality Objectives (EcoQOs) as a convenient means of interpreting the status of local waters. From a cultural eutrophication perspective the examined waters can be considered of good status and the impact from nutrient enrichment low.

There is significant natural interannual year to year variation in the data. However both anthropogenic and climate forced change can also be discriminated, albeit sometimes subtle.

The upward trends observed from the 1960s through the 1980s for the dissolved inorganic nutrient of nitrogen, phosphorus and also phytoplankton biomass have not been sustained.

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1.0 INTRODUCTION

This report presents results for the years 2005 and 2006 for a suite of physico-chemical and biological water quality variables routinely monitored in the coastal and territorial waters of the Isle of Man.

Physico-chemical conditions in the marine environment support its biology. The marine variables currently monitored are temperature, salinity, dissolved oxygen, dissolved plant (phytoplankton) nutrients, phytoplankton chlorophyll a, and phytoplankton assemblages including toxic, harmful and nuisance algae. These are natural marine variables that have an intrinsic natural fluctuation. Anthropogenic activity such as increased fertiliser use, industry and the burning of fossil fuels have the potential to undesirably disturb natural background levels and detrimentally modify the environment. Fluctuations in environmental variables are also in part driven by local and regional climate fluctuations and also wider global climate change.

The variables can be considered an integrated set relevant to nutrient/eutrophication issues as well as climate change issues and are components that relate to the health and biodiversity of the marine environment. Furthermore the Manx shellfishery is of considerable economic importance to the Island and provides significant employment. The monitoring supports the protection of shellfish growing areas.

In an attempt to demonstrate the dynamic interaction between climate forcing and anthropogenic inputs into the Irish Sea this report also brings together, builds upon and often reworks observations and data collected by Port Erin Marine Laboratory, University of Liverpool and is therefore to some extent a synthesis of Reports 1 -12, Longterm Studies of the Irish Sea: Environmental monitoring and contamination. (1992 – 2005) Reports to the Department of Local Government and the Environment by Port Erin Marine Laboratory, University of Liverpool.

Until June 2006 strategic monitoring in Manx coastal waters was undertaken by the now defunct Port Erin Marine Laboratory, University of Liverpool (PEML). The work which began in the early years of the 20th century had been funded since 1992 by the Department of Local Government and the Environment (DLGE) as part of the Isle of Man Government's commitment to the aims of the Irish Sea Study Group. A full time project officer at PEML plus some of the additional costs of collecting and processing samples were supported by DLGE whilst PEML provided academic supervision, boats, analytical facilities and support staff.

The PEML timeseries were established, respected and important in European Coastal Waters. They are often the benchmark by which other dataseries are compared. The timeseries also represent reference conditions for the Isle of Man and wider Irish Sea waters.

DLGE recognised that this surveillance monitoring should be continued and post-closure of PEML the work plus project officer have been subsumed by the Government Laboratory with FPV Barrule, Department of Agriculture, Fisheries and Forestry (DAFF) assisting with sampling.

Longterm marine environmental data such as the Isle of Man timeseries are important when discriminating anthropogenic impacts, natural fluctuations and global, regional and local environmental change. The Marine Environmental Change Network (MECN) is a collaboration between organisations in England, Scotland, Wales, Isle of Man and Northern Ireland collecting long-term timeseries information for marine waters. It is coordinated by the Marine Biological Association of the UK (MBA) and is funded by the Department of the Environment, Food and Rural Affairs (DEFRA). The goal of the network is to use long-term marine environmental data from around the British Isles and Ireland to separate natural fluctuations from global, regional and local anthropogenic impacts. (www.mba.ac.uk/MECN/) As a result of its association with the Isle of Man timeseries and PEML the Department of Local Government and the Environment is currently a partner in the network.

From an Isle of Man perspective the monitoring data provide a strategic overview and are ultimately a statement of local and wider Irish Sea water quality. Long-term environmental surveillance monitoring data also provide an empirical overview of environmental change.

The Irish Sea is not only of economic and environmental interest to the Isle of Man but also to the UK, Ireland and the EU in general. Within the European Community there are also statutory drivers for continued monitoring of environmental variables, for instance OSPAR (1998) and EU legislation on marine water quality for example the Water Framework (2000/60/EC), Urban Waste Water, Nitrates, Habitats and Shellfish Waters and Hygiene Directives.

The data gathered at PEML have been instrumental in building the Department of the Environment, Food and Regional Affairs (UK) case against the European Union's forthcoming litigation for the Irish Sea infraction under the Urban Waste Water Treatment Directive.

Currently two of the original PEML fixed stations are maintained by DLGE. In August 2006 three further stations in Manx coastal waters and shellfishery areas were added to the monitoring programme. The positions of these sites are indicated in figure 1. Data from these sites will be available for reporting end-2007. A glossary of some of the terms used in this report is presented in appendix A and the metadata for the timeseries in Appendix B.

2.0 THE IRISH SEA – A SUMMARY

The Irish Sea is within OSPAR Region III, the 'Celtic Seas' and comprises territorial waters of the United Kingdom, Eire and the Isle of Man at its centre. Comprehensive reviews of the of the physical, geographical, chemical and biological regimes within the Irish Sea can be found in several publications, for example Dickson & Boelens (1998), The Irish Sea Study Group (1990) or Hartnoll (2000).

The Irish Sea is a relatively small semi-enclosed sea less than one tenth the area of the North Sea and covers an area north of a line across St George's Channel from St Ann's to Carnsore Point in the south, and south of a line across the North Channel from the Mull of Kintyre to Fair Head in the north. It has a calculated volume of 2430 km^3. Four fifths of this volume lies to the west of the Isle of Man. Also to the west of the Isle of Man is a trench with depths up to 275 m. The area east of the Isle of Man is relatively shallow with depths of 50 m or less. Dickson & Boelens (1988) estimated residence times of waters in the Irish Sea to be 6 to 18 months with overall higher residence times in the eastern Irish Sea compared to the western Irish Sea.

Riverine and thus freshwater input volumes into the eastern Irish Sea are considerably greater compared to those of the western Irish Sea. These greater volumes of freshwater input together with shallower waters and longer residence times suggest that the eastern Irish Sea may be more prone to anthropogenic contamination and eutrophication effects compared to the western Irish Sea.

3.0 HYDROGRAPHY AND NUTRIENTS – 2005 & 2006

3.1 PORT ERIN BAY

This environmental timeseries commenced 1st January, 1904 and is continuous. Data is exchanged with the Meteorological Office at Ronaldsway (DoT). Averaged monthly data is also forwarded to the Coastal Temperature Network, a network of 38 stations, at the Centre for Environment, Fisheries and Agriculture Science (Cefas) an agency of the UK Government's Department of the Environment, Food and Rural Affairs (Defra).

Sea surface temperature (SST) at Port Erin Breakwater was recorded once daily at PEML by means of certified mercury thermometers supplied by the Met Office (UK).

Transfer of work to the Government Laboratory in Douglas meant that this method was no longer viable and, since September 2006, temperature autologgers have been deployed in the vicinity of Port Erin Lifeboat slip. Data are downloaded on a monthly basis and are comparable with the daily thermometer data.

Data Archiving for Seabed species and Habitats (www.dashh.uk) (DASSH), an initiative of the UK Marine Biological Association (MBA) and funded by DEFRA (UK) have facilitated a reasonable intercomparison period by funding a person to continue the daily morning recording regime until the end of February 2007.

3.1.1 Port Erin Bay; sea surface temperature

Daily SST at Port Erin Bay together with Cypris data are presented in figure 2a; monthly means of daily SST at Port Erin for the years 2005 and 2006 are presented in figure 2b and also summarised in table 3.1. SST follows a distinct seasonal cycle. Around the Isle of Man sea temperature is at its coolest around end-February/beginning-March and at its warmest around end-August/beginning-September. The timing of these seasonal cyclical changes does vary geographically within the Irish Sea.

SST during 2005 & 2006 followed the expected annual cycles. The 2005 annual mean was 11.3 ^{o}C and the 2006 annual mean was 11.5 ^{o}C. These SSTs are approximately one degree above the 10.4 ^{o}C grand mean (1904-2003) and also fractionally higher than the 11.2 ^{o}C decadal mean (1996-2005).

Overall, 2005 ranked as the 5th warmest for local SST. The coolest month was February (average 7.8^{o}C); the coolest recorded daily SST was 2nd/3rd March (6.5 ^{o}C). The warmest month was August (average 14.9 ^{o}C); the warmest recorded daily SST was 8th September (15.6 ^{o}C). No historical extremes for SST were recorded during 2005. The Meteorological Office at Ronaldsway ranked local mean air temperature for 2005 as the 5th warmest on record (1947 to date).

Overall, 2006 ranked as the equal warmest on record for local SST and equalled SSTs for 1959 and 1998. The coolest month of 2006 was March (average 7.7 ^{o}C); the coolest recorded daily SST was 28th February (6.8 ^{o}C). The warmest month was September (average 15.1 ^{o}C); the warmest recorded daily SST was 28th July (16.1 ^{o}C). The Meteorological Office at Ronaldsway ranked local mean air temperature for 2006 as the warmest on record (1947 to date).

The UK Met Office recorded that autumn 2006 was the warmest on record. The Meteorological Office at Ronaldsway also ranked local mean air temperature for autumn 2006 as the warmest on record (1947 to date). Autumn 2006 (SepOctNov) average local SST was 13.5 °C and equalled 1959, the warmest for the timeseries; September ranked as the warmest for the timeseries with an average SST of 15.1 °C, October ranked as the 2nd warmest for the timeseries with an average of 14.2 °C and November ranked as the 4th warmest for the timeseries with an average of 12.4 °C.

3.1.2 Port Erin Bay; salinity

Daily salinity was added to the Port Erin Bay timeseries on 21 April 1965.

Daily salinity at Port Erin Bay together with Cypris data are presented in figure 3a; monthly means of daily salinity at Port Erin for the years 2005 and 2006 are presented in figure 3b. In line with previous years and in contrast to SST a seasonal cycle for local salinity is a not immediately apparent. The annual mean of daily near-surface salinity readings for 2005 in Port Erin Bay was 34.056 (Practical Salinity Scale 1978); the range was 30.994 to 34.386. The annual mean of daily near-surface salinity readings for 2006 in Port Erin Bay was 33.918 (Practical Salinity Scale 1978); the range was 30.181 to 34.895. Overall salinity for both years was below the longterm annual mean. The grand mean for all years 1966-2006 is 34.176.

During 2005 salinity was below long-term means for all months but within ranges for the timeseries. Overall 2005 ranked as the 11th lowest year (1966-2006) for salinity. During 2006 although just within ranges for the timeseries salinity was notably low. Overall 2006 ranked as the 3rd lowest year for salinity. Spring and autumn 2006 both ranked as the 2nd lowest for the timeseries. Average salinity for both March and April 2006 ranked as the lowest recorded for the timeseries.

3.2 THE CYPRIS STATION

The Cypris Station is located approximately 5 km west of Port Erin Bay and its position is shown figure 1. Monitoring at the Cypris was initiated in 1954 by Mr D.J. Slinn of the Port Erin Marine Biological Station which became Port Erin Marine Laboratory in 1988. Cypris was named after the boat that serviced it and is situated in the area of the Bradda Offshore scallop grounds, area IS 14. As with many if not all longterm timeseries the original emphasis for monitoring was very different from current aims and objectives. In the 1950s Port Erin was the base for one of the biggest scallop fisheries in the British Isles and one of the original and important objectives for monitoring at Cypris was to provide data enabling a basic understanding of local hydrography and water quality for the local scallop grounds. John Slinn retired in 1991 but monitoring at Cypris has continued to the present day.

The aim is to take samples up to 24 times a year. A combination of adverse weather conditions and boat availability means that sampling is more realistically around 18 times per year. Water samples are taken from the surface and near sea-bed (nominally 37 m) for nutrients, salinity, phytoplankton and oxygen, and surface only for chlorophyll *a*. Temperature is recorded at surface, 5 m, 10 m, 20 m and 37 m depths. During the main months for phytoplankton production, that is April to August, and when occurrences of potentially toxic phytoplankton are noted, sampling frequency is increased. Winter sampling is strongly influenced by the often adverse weather conditions in the Irish Sea and is less frequent in many years compared to others.

Sampling at Cypris is Eulerian; the station is fixed geographically and thus the water masses monitored are not constant but highly dynamic and constantly moving back and forth over the site.

The frequency of sampling during 2005 and 2006 is tabulated in table 3.2. Servicing of Cypris was taken over by FPV Barrule (DAFF) from RV Sula (PEML) in August 2006.

3.2.1 Cypris; sea temperature and salinity

SST recorded during 2005 and 2006 at Cypris and presented in figure 2a exhibited the expected seasonal cycles that were in line with those recorded in Port Erin Bay (section 3.1.1).

Salinity recorded during 2005 and 2006 at Cypris and presented in figure 3a was in line with that recorded in Port Erin Bay (section 3.1.2). As in previous years little in the way of a seasonal cycle or haline stratification could be perceived.

During 2005 thermal stratification of the water column with near-bed waters being >0.7^{o}C cooler than near-surface waters was evident at Cypris from mid-May to mid-August. The maximum difference was in the region of 1.5 ^{o}C and was observed by early-August. During 2006 onset of thermal stratification >0.7^{o}C was observed almost a month earlier and was evident from mid-April to mid-August. In 2006 the magnitude and period of stratification was greater compared to 2005 with the maximum stratification in evidence from early-June to mid-July and in the region of

2.5 °C. This spring/summer thermal stratification is not unusual in the water column at Cypris and the thermal gradient is usually small and rarely exceeds 3.0 °C (section 6.3)

3.2.2 Cypris; dissolved oxygen

As in previous years dissolved oxygen (DO) saturations at the Cypris during 2005 and 2006 were generally excellent and mostly 90% or above in both near-surface and near-bed waters (figure 4a).

The solubility of DO in seawater is a function of temperature and salinity and DO saturation is calculated using absolute DO and temperature and salinity values. During 2005 and 2006 and as in previous years DO supersaturation (greater than 100% saturation) was evident in surface waters during the summer. Supersaturation in this case is natural and a result of algal (phytoplankton) photosynthetic activity and growth. Globally the phytoplankton generate most of the planet’s oxygen (Tolmazin, 1985). This seasonal pattern at Cypris of DO supersaturation in surface waters broadly reflects that of phytoplankton chlorophyll *a* production (figure 5 and section 3.2.3), phytoplankton chlorophyll *a* being an index of phytoplankton biomass.

Although not usually observed at Cypris this seasonal supersaturation and algal growth can be followed by oxygen deficiency in the water column due to algal decay and dieback resulting in the death of fish and zoobenthos.

Absolute DO values during 2005 and 2006 are presented in figure 4b. On 13 September 2005 values were 6.5 and 6.3 mgL^{-1} in near-surface and near-bed waters respectively. These reduced values immediately followed the early autumnal algal bloom, reflected natural autumnal decay processes in the water column and did not persist. With the exception of this one occasion absolute DO values during 2005 and 2006 were in the range 7.7 to >10 mgL^{-1} or ppm.

3.2.3 Cypris; (phytoplankton) chlorophyll *a*

Chlorophyll *a* concentrations for the years 2005 and 2006 are presented in figure 5. Concentrations and seasonal fluctuations were not unusual and within ranges for the timeseries.

During 2005 the onset of the vernal bloom was underway by the early-March. The recorded maximum was 2.33 µgL^{-1} on 24th May. The April to August mean concentration was 1.30 µgL^{-1}. A late summer chlorophyll peak of 2.1 µgL^{-1} was noted at the beginning of September. Late-summer/early-autumn phytoplankton blooms fuelled by the onset of late-summer nutrient regeneration in the water column do occur at Cypris. They do not occur annually but are not considered unusual.

During 2006 the onset of the vernal bloom was underway by the end-March. The recorded maximum was 2.86 µgL^{-1} on 23rd May. The April to August mean concentration was 1.39 µgL^{-1}. There are no chlorophyll data for August and September 2006; the move from PEML to the Government Laboratory restricted the analysis of samples at that time.

3.2.4 Cypris; phytoplankton

At Cypris the phytoplankton production season can last 5 to 6 months, with a distinctive spring peak in abundance with diatoms dominating phytoplankton assemblages. Dinoflagellates also show an initial increase in abundance during the spring but tend to become more abundant during late summer forming 50% or more of total phytoplankton.

Seasonal profiles for phytoplankton cell counts in near-surface and near-bed waters during 2005 & 2006 are presented in figures 6 a & b. Counts and assemblages were not unusual compared to previous years or the central Irish Sea. Phytoplankton biomass production exhibited seasonal cycles broadly reflecting chlorophyll cycles (figure 5). As in previous years phytoplankton assemblages were mostly dominated by diatoms (figure 6 c) with dinoflagellates becoming more important during late summer and early autumn when nutrients approached detection levels.

During April 2005 assemblages were dominated by species of *Thalassiosira* with *Skeletonema costatum* also being a notable component. From May to July through the main chlorophyll *a* production period *Leptocylindrus danicus and minimus* were the most abundant species present with *Chaetoceros* spp*, Guinardia delicatula and styliformis, Rhizosolenia* spp and *Pseudo-nitzschia* spp also being important components of the bloom. Notable dinoflagellate groups present especially during July were *Dinophysis acuminata* and *acuta*, *Ceratium furca* and *lineatum*. By the time of the early-September bloom dinoflagellates formed in the region of 65% of phytoplankton assemblages with *Ceratium lineatum, Prorocentrum micans*, *Gyrodinium* spp and small *Peridiniales* being conspicuous dinoflagellate groups present.

During April 2006 around the onset of the vernal bloom phytoplankton assemblages were dominated by *Nitzschia closterium*, *Thalassiosera rotula* and other *Thalassiosera* spp. Between early and mid-may a bloom of *Chaetoceros socialis* was observed with cell counts upto 25 x 10^3 cells L^{-1} noted. During June *Guinardia striata* and *delicatula* dominated assemblages. At end-June the dinoflagellate *Dinophysis acuminata*, associated with DSP intoxication of bivalve shellfish, was observed with cell counts upto 1080 cells L^{-1}. At the same time *Scrippsiella trochoidea* with levels of 55 x 10^3 cells L^{-1} was also observed. At this time dinoflagellates formed in the region of 80% of the total phytoplankton. By early-September dinoflagellates formed in the region of 45% of phytoplankton assemblages.

Nuisance and toxic phytoplankton are discussed further in section 4.

3.2.5 Cypris; inorganic nutrients

The Cypris timeseries is the only longterm nutrient timeseries for the Irish Sea and is amongst the most important for European coastal waters. It is the only means by which changes in the nutrient status of the Irish Sea have been identified.

Both the EU and OSPAR definitions of eutrophication specifically refer to the compounds of nitrogen and phosphorus of anthropogenic origin. It is widely accepted that nitrogen is the limiting nutrient for phytoplankton growth in marine waters with phosphorus being the limiting nutrient in freshwaters. Silicon has few anthropogenic inputs, is an essential requirement for diatoms and may in certain circumstances limit diatom growth. In marine waters nitrate-nitrogen is generally deemed to be the principal driver of eutrophication. An important source of anthropogenic nitrate is via riverine freshwaters. The principal sources of riverine water into the Irish Sea are the major UK rivers that discharge into the eastern Irish Sea, for example the rivers Mersey, Ribble and Eden.

Winter inorganic nutrient concentrations are the criteria used to assess waters from an eutrophication perspective. Nutrient salt concentrations are at a maximum in winter and winter inorganic nutrient data represents the basal or resting state when biological processes have come to a halt and the regeneration of the nutrients is complete.

For this report the inorganic nutrients are considered to be the dissolved inorganic salts of nitrogen, as total oxidised nitrogen or nitrate plus nitrite (N+N), phosphorus as orthophosphate or soluble reactive phosphate (SRP), and silicon as silicic acid (Si).

Nitrogen in nutrient ratios is frequently reported as dissolved available inorganic nitrogen or DAIN (CSST, 1997). DAIN is frequently calculated as ((N+N) + Ammoniacal-nitrogen (NH_4^+/NH_3)). However, NH_4^+/NH_3 data for the Cypris Station were not collected until the 1990s, therefore DAIN is not reported in this report and ratios are calculated using N+N. Concentrations of ammoniacal-nitrogen are in any case generally low at Cypris and in the main <1µM or <10% of the Cypris winter inorganic nitrogen pool.

During 2005 & 2006 inorganic nutrient concentrations, presented in figure 7, exhibited the expected seasonal fluctuations and cycles and were not unusual. In spring, with increasing insolation and phytoplankton growth, stocks of nutrient salts were depleted rapidly, reaching a minimum around late spring to early summer. Levels remained low until late summer and early autumn when organic decay cycles regenerated nutrient salts to the water column. In both years N+N and Si became depleted slightly before SRP.

From June to August 2006 near-surface to near-bed concentration gradients for N+N and SRP but not Si were observed (figure 8). These increased concentrations in near-bed waters relative to near-surface waters coincided with the greater degree of summer thermal stratification observed in 2006 relative to 2005 (section 3.2.1). Such nutrient concentration gradients associated with summer thermal stratification of the water column at Cypris although not annual occurrences are not considered unusual.

Winter inorganic nutrient data for 2005 & 2006 are presented in table 3.3. The observed 2005 winter maxima for inorganic phosphate (SRP), silicate (Si) and total oxidised nitrogen or nitrate + nitrite (N+N) were 0.68 µM, 7.36 µM and 10.22 µM respectively. The 2005 winter N:P ratio was 15.0 and the N:Si ratio was 1.4. The observed 2006 winter maxima for inorganic phosphate (SRP), silicate (Si) and total oxidised nitrogen or nitrate + nitrite (N+N) were 0.67 µM, 6.17 µM and 8.02 µM respectively. The 2006 winter N:P ratio was 12.0 and the N:Si ratio was 1.3. These concentrations and ratios were within ranges for recent years (section 6.5).

4.0 TOXIC AND NUISANCE PHYTOPLANKTON (ALGAE)

4.1 INTRODUCTION

Phytoplankton form the base of the marine food web and are thus essential to the health of the sea. It should be emphasised that most species of this algal group are not harmful and are not associated with toxin production.

Nevertheless, certain marine algae are known to produce toxins harmful to humans that can be vectored into the human food chain by filter feeding bivalve molluscs such as mussels and scallops. Toxin producing algae producing shellfish vectored toxins occur in coastal waters worldwide and in this the Isle of Man is no exception.

This production of algal toxins is a natural occurrence and certainly not a recent phenomenon. The entry for 17th June 1793 in the diary of expedition naturalist and surgeon Archibold Menzies records an eyewitness account, in what is now British Columbia, of the death of seaman John Carter from the consumption of mussels intoxicated with algal toxins. Cooking does not denature the toxins.

Other phytoplankton species do not produce toxins harmful to humans but in ideal conditions can bloom producing dense and vast aggregations causing harmful algal events or 'redtides' that can be aesthetically extremely unpleasant and may also cause fish kills.

One of the earliest references to red tides is the first plague of Egypt which occurred soon after the pyramids had been constructed and documented by the Egyptians in the Ipuwer Papyrus (written about 1780-1600 BCE and now in a museum in Holland), by the Israelites in the Torah and also the book of Exodus in the Old Testament of the Bible.

For the last few decades harmful algal blooms have been the cause of large economic loss to the fishery industry worldwide. From a public health perspective harmful algal blooms can pose a serious poisoning problem. There are three differing opinions on the apparent global increase in harmful algal blooms; 1. they are caused by increased anthropogenic input of nutrients into the marine environment (eutrophication); 2. the putative increase may be an artefact due to increased interest and reporting; 3. any increase is related to climate change (Reid, 2006).

A monitoring programme for algal biotoxins is a requirement of the Shellfish Hygiene Directive amendment 91/492/EEC. This legislation requires EU member states to monitor for the possible presence of toxin producing phytoplankton in production and relaying areas and biotoxins in live molluscs. The Isle of Man although not an EU member state does export shellfish to the EU and thus is required to comply with the legislation.

In the UK the monitoring programmes are operated to comply with the Shellfish Hygiene Directive 91/492/EEC and with current UK implementing legislation, Food Saferty (Fishery Products and Live Shellfish) (Hygiene) Regulations 1998.

In Scotland the monitoring programmes are undertaken by Fisheries Research Services on behalf of the Food Standards Agency (Scotland). In England and Wales the Food Standards Agency (FSA) as the competent Authority has overall responsibility for ensuring that the monitoring programmes are effectively carried out.

Since 1992 and in accordance with the EU directive amendment PEML and, since 2006, the Government Analyst's Laboratory has monitored Manx coastal waters for algae known to be associated with shellfish vectored toxins. From 2002 at least monthly algal reports have been routinely issued to (DLGE) Environmental Health, Fisheries (DAFF) and other interested parties during the main phytoplankton production season, usually March to October.

EU directive 97/61/EC and amendment 91/492/EEC also requires live bivalve molluscs to be routinely monitored for the presence of ASP (amnesic shellfish poisoning) toxins. The Government Analyst's Laboratory and the Environmental Health Food Safety Unit routinely assay samples of scallops from Manx coastal waters for the presence of domoic acid (DA), the causative agent of ASP. The open season for *Pecten maxmus* or king scallops is 1st November to 31st May. During this open season both whole and shucked samples of *P. maximus* are monitored for DA. From 1st June to 31st October *Aequipecten opercularis* (recent synonym *Chlamys opercularis*), queen scallops or 'queenies', which have no close season are monitored for DA.

4.2 ALGAE ASSOCIATED WITH SHELLFISH VECTORED TOXINS

Algae associated with shellfish vectored toxins that have been observed in Manx coastal waters are presented in table 4.1. A summary of results for 2005 & 2006 are presented in appendix C. Organisms associated with Paralytic Shellfish Poisoning (PSP) are to date rarely observed in local waters and PSP toxins at very low levels have been detected in shellfish taken from Manx waters only on one occasion in 2002. PSP and the associated organisms are not considered further in this report.

4.2.1 *Pseudonitzschia* species (associated with ASP)

Pseudonitzschia are diatoms and the genus is represented by about twenty species of which at least nine species are associated with DA, the causative agent of ASP. *Pseudonitzschia* found in European waters include all of the known DA producers. The first documented ASP event was associated with mussels (*Mytilus edulis*) and occurred in Prince Edward Island in 1987. The episode resulted in at least three deaths with more than 100 people becoming ill. Hasle *et* al (1996) recorded that there had been no documented human occurrences of *Pseudonitzschia* derived ASP in Europe and this remains the case.

The warning threshold of organisms in the water column to trigger extra shellfish flesh testing for DA intoxication in shellfish for England, Wales and Scotland is 150000 grouped *Pseudonitzschia* cells per litre of seawater (*eg* Kelly & Fraser, 1999 also Higman and Morris, 1999). Ireland suggests a trigger level is 50000 grouped *Pseudonitzschia* cells per litre (*eg* www.marine.ie/home/). In Manx waters neither of these thresholds was exceeded in either 2005 or 2006.

During 2005 in the waters around the Isle of Man observed grouped *Pseudonitzschia* concentrations did not exceed 30000 cells per litre. During 2006 observed grouped *Pseudonitzschia* concentrations were lower and did not exceed 4500 cells per litre (figure 9 and also appendix C, table C.1).

The highest concentrations of grouped *Pseudonitzschia* were observed in area IS 14 to the west of the Island (figure 1). However it should be noted that Cypris is located in this area and thus monitoring was more intense and also included enumeration of both near-surface and near-bed samples. Only near surface samples were enumerated for areas IS 09, 10, 15 and 21.

Although DA intoxication was detected in samples of whole *P. maxmus* assayed by the Government Analyst's Laboratory (figure 10 and also appendix C, table C.3) there were no observations during either 2005 and 2006 of DA in flesh taken from whole organisms exceeding the EU mandatory threshold of 20 µg g $^{-1}$. DA intoxication in *A. opercularis* taken from Manx waters is at the time of report writing is low and generally <1.0 µg g $^{-1}$. DA depuration in *P. maxmus* is slow and thus toxin retention time is greater compared to *A. opercularis.*

During 2002 and into 2003 DA intoxication in *P. maximus* was above the threshold level in flesh taken from whole organisms. Highest DA intoxication was observed in shellfish taken from grounds to the west and southwest of the Isle of Man. This resulted in fishing ground closures and 'shucking' restrictions. It was early 2004 before DA levels fell below the threshold. *A. opercularis* were and remain relatively unaffected.

A separate and independent survey on scallops collected over a 10 day period during October 2003 confirmed that *P. maximus* from fishing grounds to the west and southwest of the Isle of Man were intoxicated with greater DA concentrations compared to those taken from grounds to the east of the Island. As with DLGE monitoring *A. opercularis* was relatively unaffected (Bogan *et al*, 2007).

Since 2004 DA intoxication has persisted and also fluctuated albeit below threshold levels in *P. maximus* which are notoriously slow depurators of DA, often in excess of two years. This slow depuration rate of DA by does not, however, completely explain the persistence and fluctuation of toxin concentrations in *P. maximus* taken from Manx waters and it would appear that DA levels are seasonally 'topped-up' albeit at a low intensity.

Pseudonitzschia, the genus of algae associated with DA production, are ubiquitous throughout the Irish Sea especially during spring and summer. Although the main peak production season for *Pseudonitzschia* in Manx coastal waters is also during the spring and summer months records (1996 to date) show that observed *Pseudonitzschia* numbers present in the water column at the time of report writing have never exceeded the threshold level of 150000 cells per litre and have only very rarely exceeded the 50000 cells per litre threshold and a link between levels of *Pseudonitzschia* in the water column and DA in scallop tissue has not been established.

Of the twenty or so morphologically very similar *Pseudonitzschia* species at least nine are known to be associated with toxin production. Genetic variability exists amongst some strains of the same *Pseudonitzschia* species from different geographic locations with some strains being associated with toxin production and some not (*eg* Bates *et al*, 1998).

Furthermore, the environmental circumstances that induce DA production remain uncertain. Climate variability and regional climate warming may be a factor. It is also suggested (*eg* Marchetti *et al*, 2004, Fehling *et al*, 2006) that inorganic nutrient limitation by silicate and phosphate in the presence of high available nitrogen allow *Pseudonitzschia* species to out compete other diatoms. Long residence times in well lit waters are also suggested to be an important factor.

In line with other regions waters surrounding the Isle of Man have undergone significant warming in recent years (sections 3.1.1 and 6.1). During the summer months Si, N+N and SRP are present only at low levels often approaching detection limits (section 3.2.5). However, algae including *Pseudonitzschia* species may be capable of utilising ammonium-nitrogen regenerated as part of the natural marine nitrogen cycle. During the summer months day length approaches 18 hours and waters can be considered well lit. These are summer conditions that are common in waters to both the east and west of the Isle of Man.

Hydrodynamic differences between waters on either side of the Island may provide a more plausible explanation for higher DA intoxication in *P. maximus* taken from grounds to the west of the Isle of Man. Overall, waters to the west of the Isle of Man are deeper and during the summer may have longer residence times compared to the shallower, (<50m), waters to the east of the Island (*eg* Ramster & Hill, 1969, Slinn, 1974, Gowen & Stewart, 2005) with little mixing between the two water masses. Deep water combined with weak tidal flows to the south west of the Isle of Man enable the seasonal development of stable stratification. At the same in the western Irish Sea a near-surface gyre develops (*eg* Hill *et al*, 1994, Horsburgh *et al*, 2000) during the summer that may be important in retaining planktonic organisms within the stratified region (*eg* White et al, 1998, Gowen & Stewart, 2005).

There exists only limited information for *Pseudonitzschia* and DA intoxication in Isle of Man waters and thus little or no knowledge of any temporal change. The incidence of DA intoxication in Manx shellfish appears to have increased dramatically post-2001. However, biotoxin monitoring driven by EU Council Directive 97/61/EC also increased around this time also. DA intoxication in shellfish taken from Isle of Man waters was almost certainly endemic pre-2002 but was undetected.

4.2.2 *Dinophysis* species (associated with DSP)

The genus *Dinophysis* consists of around 200 species and the International Oceanographic Commission (2004) list 11 species that are associated with the production of okadaic acid (OA) and *Dinophysis* toxins (DTXs) or Diarrhoetic Shellfish Poisoning (DSP) shellfish vectored toxins. The warning threshold of organisms in the water column to trigger extra shellfish flesh testing for DSP intoxication in shellfish for England, Wales, Scotland and also Ireland is 100 cells per litre of *Dinophysis* species associated with DSP toxins.

In local waters three *Dinophysis* spp. associated with DSP toxins are routinely observed from late–spring to autumn. Most commonly observed are *Dinophysis acuminata* and *D. acuta* with *D. norvegica* being observed less frequently. *Dinophysis rotundata* is observed but rarely.

Data for 2005 and 2006 are presented in figure 11 and appendix C, table C.2.

During 2005 *Dinophysis acuminata* was first observed in the water column during the last week of May with concentrations of *Dinophysis* spp exceeding threshold levels by end-May with a peak of 600 cells per litre at end-July. At this time the *Dinophysis* population was made up of 27% *D. acuminata* and 77% *D. acuta*. These two species formed 48% of the dinoflagellate assemblage and 2% of the total phytoplankton assemblage. Levels of *Dinophysis* fell to detection levels after mid-August. In the autumn, from early-September to early October low levels of predominantly *D. acuta*, 40 cells per litre, were observed. No incidences of DSP intoxication in locally caught scallops were reported during 2005.

During 2006 *Dinophysis* was first observed in the water column during the first week in April, almost two months earlier compared to 2005. Threshold levels were exceeded by mid-May. A monospecific peak of 1080 cells per litre *D. acuminata* was observed during the last week of June 2006. The summer peak was both earlier and greater compared to 2005 with *D. acuminata* forming 82% of the dinoflagellate and 2% of the total phytoplankton assemblages. No *Dinophysis* species associated with DSP shellfish vectored toxins were observed in the water column after end-June.

At Cypris 2006 onset of thermal stratification >0.7°C was observed almost a month earlier compared to 2005 and was evident from mid-April to mid-August. In 2006 the magnitude and period of stratification was also greater compared to 2005 (section 3.3.1).

During July 2006 a large consignment of unshucked Manx 'queenies', *A. opercularis*, taken from IS 14 to the west of the Island and landed at processors in Scotland was condemned for being DSP intoxicated and subsequently destroyed.

DSP events in Manx coastal waters whilst not annual occurrences are not unusual and generally are short lived; depuration seems to be relatively rapid. DSP events tend to occur during the close season for *P. maximus* and in the main the affected organisms are *A. opercularis*.

As with grouped *Pseudonitzschia* spp. the highest concentrations of *Dinophysis* spp.

were observed in area IS 14 to the west of the Island (figure 10 and appendix C, table C.2). Again, it should be noted that Cypris is located in this area and thus monitoring was more intense and also included enumeration of both near-surface and near-bed samples. Only near surface samples were enumerated for areas IS 09, 10, 15 and 21. *Dinophysis* spp. associated with DSP shellfish vectored toxins exceeding threshold levels were observed at end-July 2005 in area IS 21 and at end-June 2006 in areas IS 9 & 10.

4.3 NUISANCE ALGAE AND ALGAE ASSOCIATED WITH 'RED TIDES'

A summary of the algae associated with redtides and other nuisance algae observed in Manx coastal waters presented in table 4.2.

The most conspicuous local red tides are caused by the distinctive orange coloured heterotrophic dinoflagellate *Noctiluca scintillans* and in some years vast slicks are observed in the eastern Irish Sea between the Isle of Man and Morecambe and Liverpool Bays.

Noctiluca red tides are a basically harmless natural phenomenon often mistaken for pollution. They rapidly form during the early summer following prolonged periods of warm, calm sunny weather causing spectacular 'tomato soup' coloured water.
N. scintillans is also bioluminescent and emits light when disturbed. This light is especially visible during the hours of darkness giving rise to the colloquial name of *seasparkle*. The bioluminescence is the source for many sailors' yarns of superstition and magic. Samuel Taylor Coleridge (1772-1834) observed *seasparkle* when crossing the Menai from Caernarfon and is thought to have immortalised it in his epic poem The Ancient Mariner.

> *About, about, in reel and rout*
> *The death-fires danced at night;*
> *The water, like a witch's oils,*
> *Burnt green, and blue and white.*

(verse 130, part II, Rime of the Ancient Mariner, S.T. Coleridge, 1798)

During July 2005 *Noctiluca* red tides were reported by Harbour authorities in Ramsey Bay, Laxey Bay and Garwick. No adverse reports of problems associated with bloom dieback such as deoxygenation or increased ammonia levels in the water column, were observed. No reports of *Noctiluca* red tides were received during 2006.

Species of *Phaeocystis*, a marine haptophyte, may exist as single cells or gelatinous colonies and are regarded as nuisance algae. In suitable conditions *Phaeocystis* can 'bloom' very rapidly sometimes resulting in huge masses of foam being observed on shores and beaches and events may have common names such as *slurry water* or *baccy juice*. *Phaeocystis* is not toxic but can produce acrylic acid, dimethyl sulphide and mucilage. This mucilage may clog the gills of finfish and shellfish. Fishnets may also be clogged. *Phaeocystis* events tend to occur earlier in the year compared to *Noctiluca* blooms.

Although an annual event in many European waters *Phaeocystis* events in Manx waters whilst not unknown are at the time of report writing rare. As in most years *Phaeocystis* species were observed in the local water column during both 2005 and 2006 but at low levels, <5000 colonies per litre.

In August 2005 red, discoloured water was observed around Derby Haven, concentrated in rock pools in the vicinity of the Jetty and St Michaels Island. *Oxyrhis marina*, a heterotrophic flagellate of taxonomic uncertainty within the dinoflagellates, was identified as the causative organism. There were no adverse effects and the problem did not persist.

5.0 ASSESSMENT OF QUALITY AND TROPHIC STATUS IN MARINE WATERS

The Isle of Man currently has no classification system for coastal waters. In the UK a scheme is being developed as part of the Water Framework Directive.

The assessment of the status in marine waters is a complex task that needs to be exercised with caution. In this report OSPAR Ecological Quality Objectives (EcoQOs) (OSPAR, 2005a & 2005b) have been used as indicators and a convenient means of interpreting the status of local waters and applied to dissolved oxygen, dissolved plant (phytoplankton) nutrients, phytoplankton chlorophyll a, and phytoplankton assemblages. These EcoQOs are eutrophication objectives and are similar to the use of biological, physico-chemical and hydromorphological quality elements to assess the ecological status under the Water Framework Directive which rationalises and updates existing water legislation and relates to the effects of all human pressures.

OSPAR has the key aim of achieving "a healthy marine environment where eutrophication does not occur" by 2010. The Water Framework Directive has the key aim of achieving at least good ecological status for all waters, including transitional and coastal waters by 2015. (OSPAR Commission, 2005a)

The UK Comprehensive Studies Task Team (CSST, 1997) also set out guidelines for coastal waters and these have also been referred to where relevant.

- The **EcoQO for dissolved oxygen deficiency** suggests that "*oxygen concentration, decreased as an indirect effect of nutrient enrichment should remain above region-specific oxygen deficiency levels, ranging from 4-6 mg oxygen per litre*." And "*There should be no kills in benthic animal species as a result of oxygen deficiency……*"

Absolute DO concentrations in both near-surface and near-bed at Cypris are rarely <7.5 mgL^{-1} in any season and in Manx territorial waters there are no recorded occurrences of fish kills as a result of oxygen deficiency. Waters cannot be considered to be oxygen deficient and can also be considered to be of good status.

- The **EcoQO for phytoplankton chlorophyll *a*** states "*that elevated maximum and mean levels during the growing season should remain below elevated levels defined as concentrations >50% above the spatial (offshore) and/or historical background concentration*".

CSST guidelines suggest a region to be considered eutrophic if summer chlorophyll *a* concentrations regularly exceed 10 μgL^{-1}. Chlorophyll *a* levels in waters at Cypris have not exceeded this CSST threshold and can be considered of good status and the impact from nutrient enrichment low.

- The **EcoQO for phytoplankton** states: "*Region/area-specific phytoplankton indicator species should remain below respective nuisance and/or toxic elevated levels and/or toxic elevated levels (and increased duration).*" And "*There should be no kills in benthic animal species as a result of oxygen deficiency and or toxic phytoplankton species.*"

Phytoplankton timeseries for the Irish Sea including Isle of Man territorial waters generally cover <15 years. Gowen *et al* (2007) suggest that in the northern Irish Sea there is little or no evidence of increasing trends in the occurrence of toxin producing algae, the closure of shellfish beds or harmful algal blooms. In Manx territorial waters there are no recorded occurrences fish kills as a result of toxic phytoplankton species.

- The **EcoQO for winter nutrient concentrations** states "*winter DIN and/or DIP should remain below elevated levels defined as concentrations >50% above salinity related and/or natural background concentrations*".

DIN is dissolved inorganic nitrogen and for this report equates to N+N and DIP is dissolved inorganic phosphorus and equates to SRP. CSST guidelines suggest that coastal waters are adversely influenced by anthropogenic nutrient inputs if winter concentrations of dissolved available inorganic nitrogen (DAIN) are >12 μM in the presence of >0.2 μM of dissolved available inorganic phosphorus (DAIP).

OSPAR (2002) and also the Environment Agency (UK) in their Technical Assessment Method for nutrient enrichment pressure in coastal waters suggest an area specific threshold background concentration of 12 μM winter DIN for the Irish Sea as indicative of exposure pressure to DIN. Winter Cypris DIN concentration is ≈ 80% of this area specific threshold background concentration.

A winter molar ration of N:Si > 2 was suggested to be indicative of hypernutrified waters by the National Rivers Authority now the Environment Agency (UK) (NRA, 1996). Inspection of the data establishes that waters at Cypris are not hypernutrified.

Current Cypris winter nutrient concentrations meet the above criteria. Waters at Cypris are not adversely nitrogen or phosphorus enriched or detrimentally influenced by anthropogenic nutrient inputs.

6.0 THE ISLE OF MAN TIMESERIES: THE NATURAL FLUCTUATION AND THE ANTHROPGENIC AND CLIMATE FORCING OF VARIABLES.

A detailed discussion of variability and fluctuation within the Isle of Man timeseries is presented in **Appendix D**. Observations both recent and also previously noted in Reports 1 -12 (1992 – 2005), Longterm Studies of the Irish Sea: Environmental monitoring and contamination; reports to the Department of Local Government and the Environment by Port Erin Marine Laboratory, University of Liverpool are brought together and examined with particular reference to the influence of the wider North Atlantic climate on the local marine environment.

The Port Erin Marine Laboratory Isle of Man timeseries, now maintained by the Isle of Man Government Laboratory, provide a unique temporal insight into the variability of physical (temperature, salinity), biological (chlorophyll, phytoplankton) and chemical (nutrient salts) properties in the Irish Sea. The Port Erin Bay temperature timeseries commenced in 1904 and the Cypris timeseries some fifty years later in 1954.

Some variability within the timeseries is undoubtedly attributable to natural background changeability whilst other variability, in for example nutrient salt concentrations, can be linked directly to changes in anthropogenic inputs to the Irish Sea. However some variability in local conditions can be linked to fluctuations in the wider Atlantic and global climate and may be a response to changes in precipitation and storminess. Such climate forced change has implications for the natural biogeochemical properties, equilibria and cycles within the ecosystem.

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FIGURES

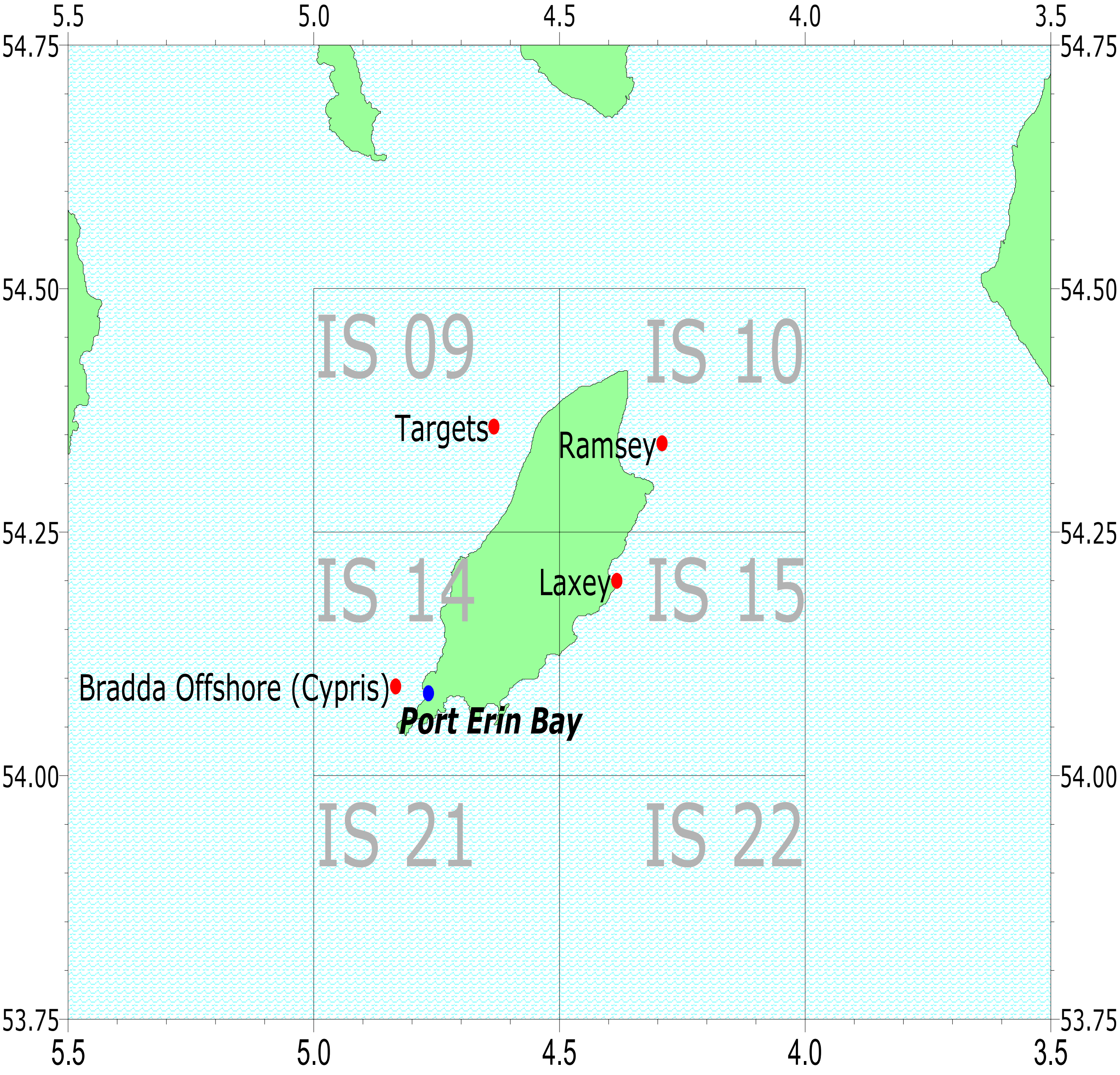

Figure 1. Routine monitoring sites in Isle of Man coastal waters with SERAD Irish Sea (IS) fishery surveillance squares that include Isle of Man territorial waters and scallop grounds. (SERAD = Scottish Executive Rural Affairs Department. Each square = 10 km^2)

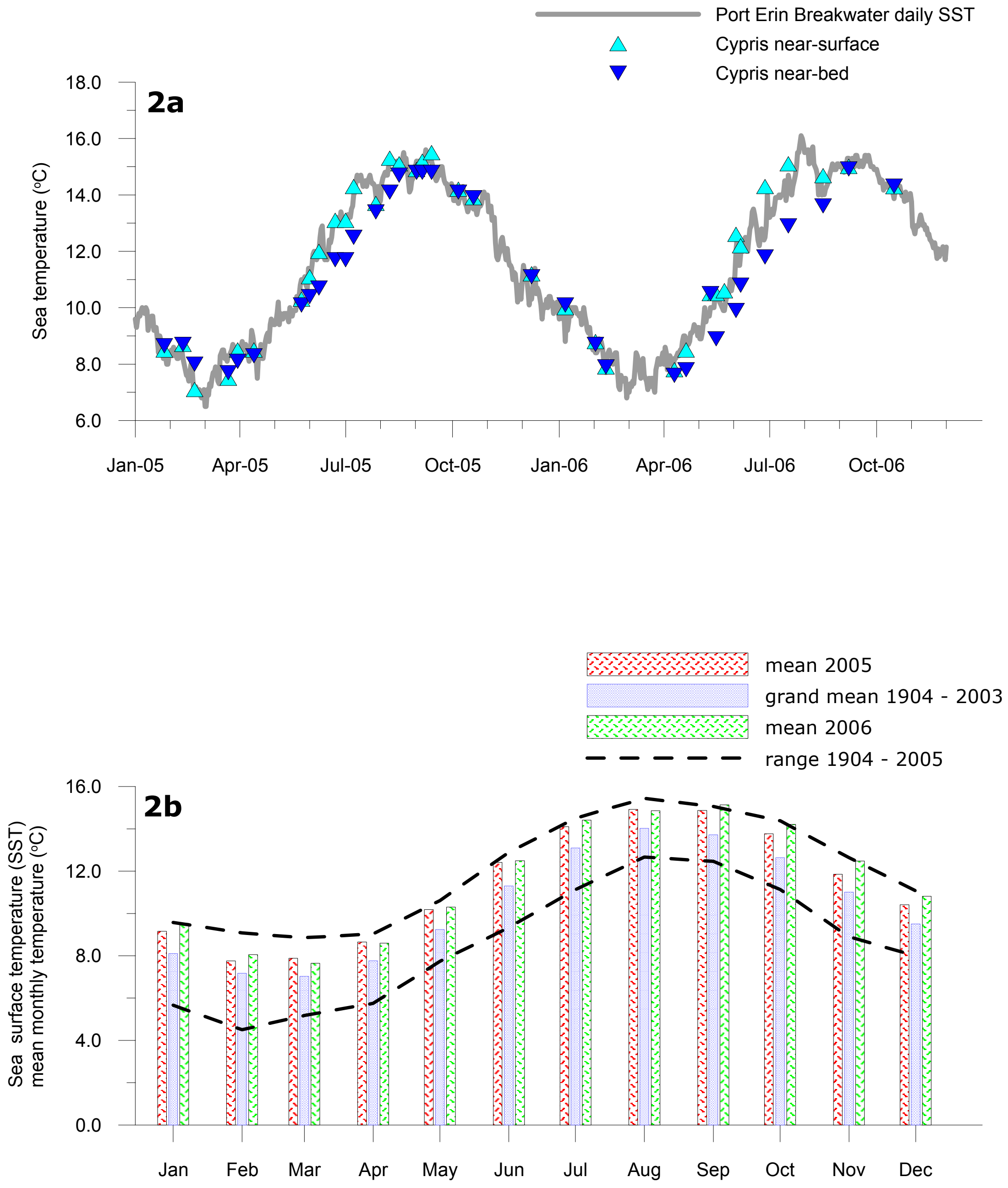

Figure 2. Sea temperature 2005 and 2006. (a) Cypris Station and Port Erin Bay; (b) monthly mean SST Port Erin Bay.

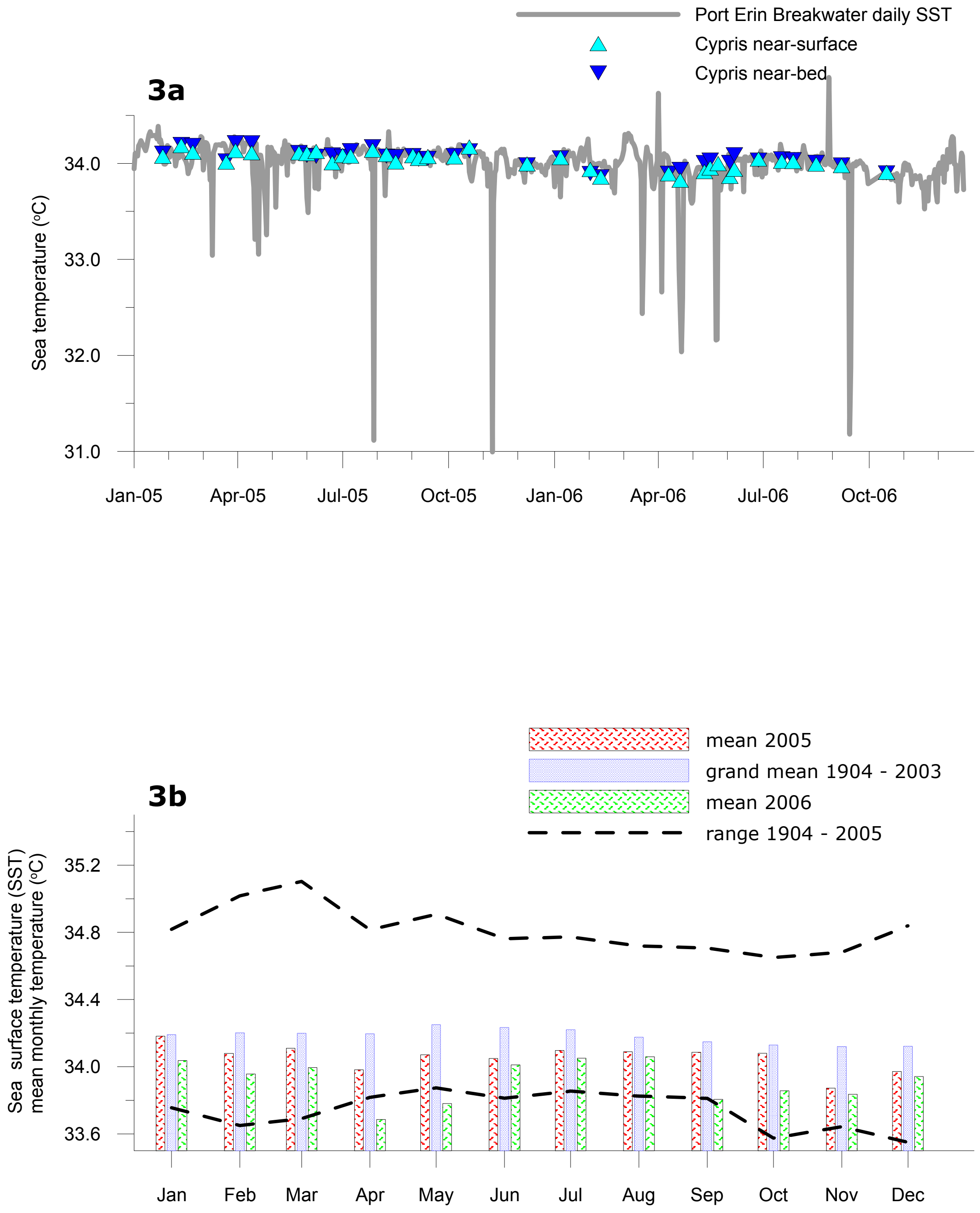

Figure 3. Salinity 2005 and 2006. (a) Cypris Station and Port Erin Bay; (b) monthly mean salinity Port Erin Bay.

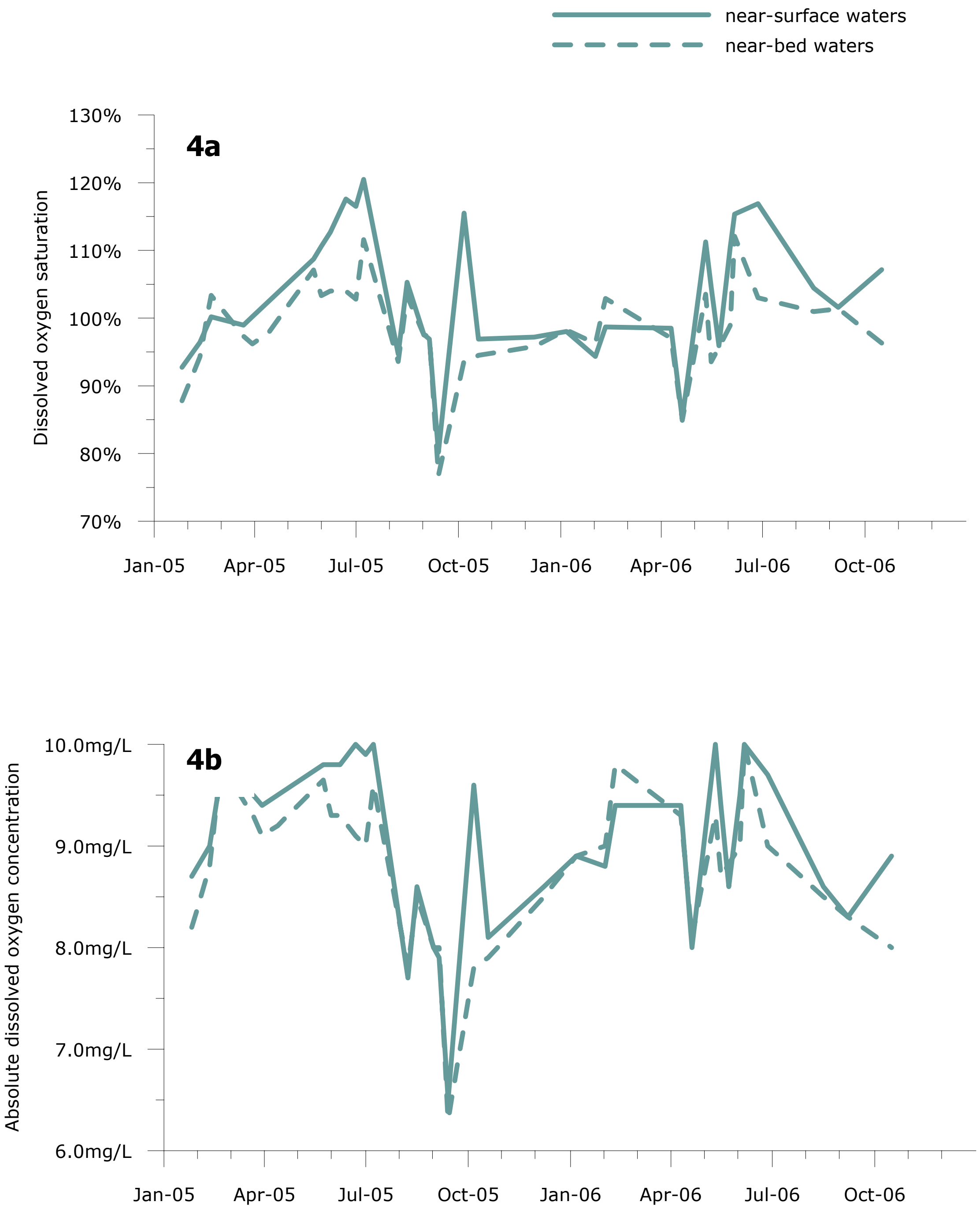

Figure 4. Dissolved oxygen at Cypris during 2005 & 2006. (a) Dissolved oxygen saturation; (b) absolute dissolved oxygen concentration.

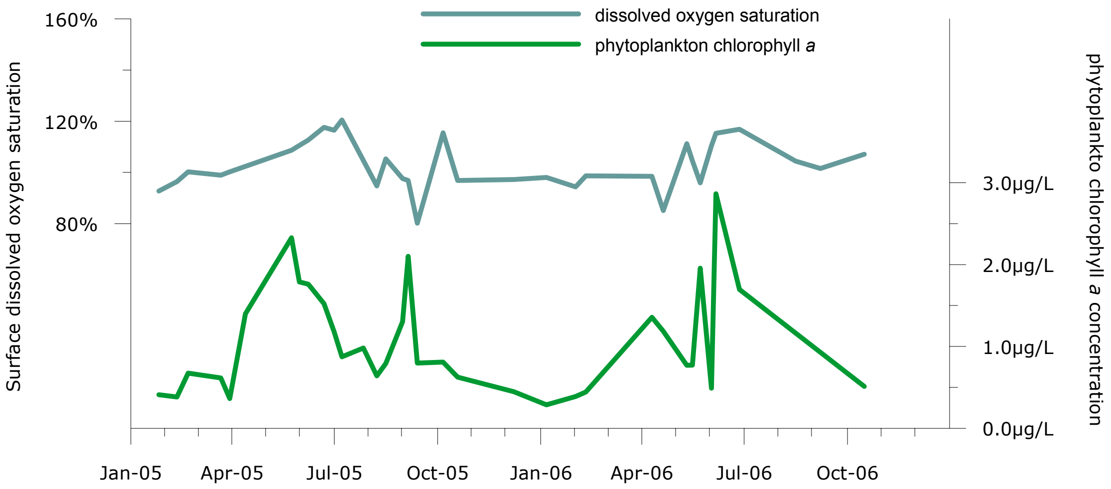

Figure 5. Chlorophyll a concentrations at Cypris 2005 & 2006. Dissolved oxygen saturation included for reference.

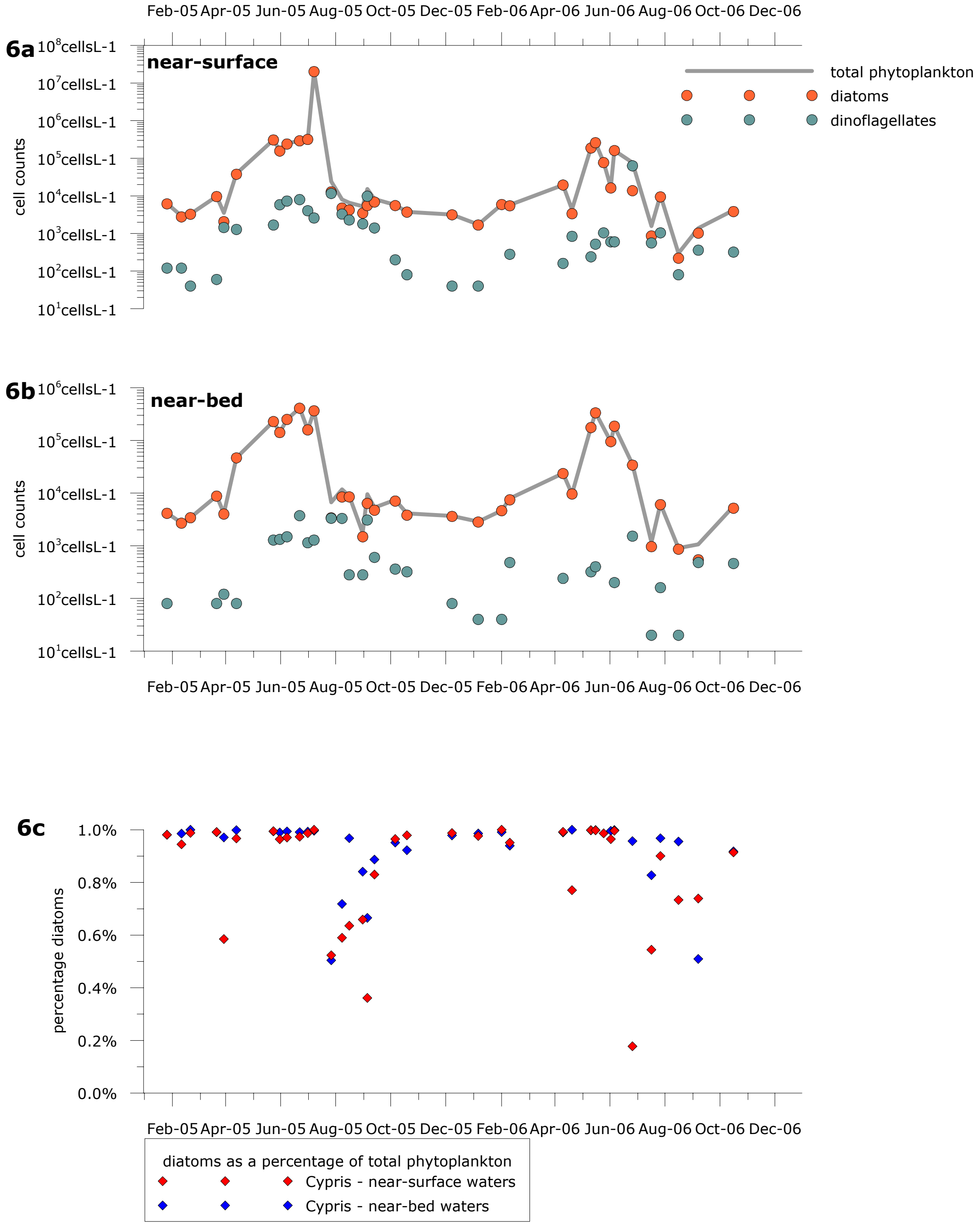

Figure 6. Phytoplankton at Cypris during 2005 & 2006. Seasonal profiles in (a) near surface waters and (b) in near bed waters; (c) diatoms as a percentage of phytoplankton assemblages.

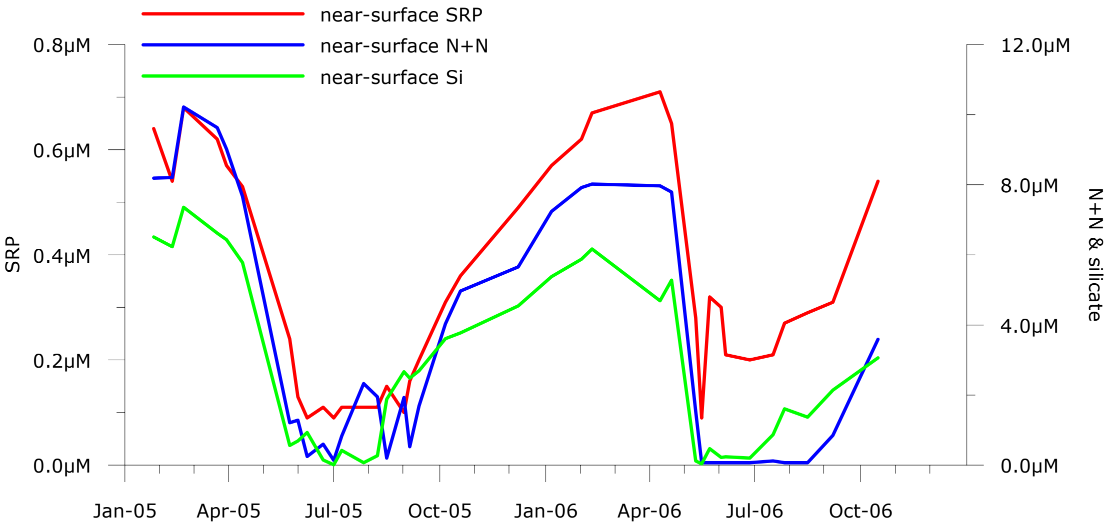

Figure 7. Winter inorganic nutrient concentrations in Cypris near-surface waters during 2005 and 2006.

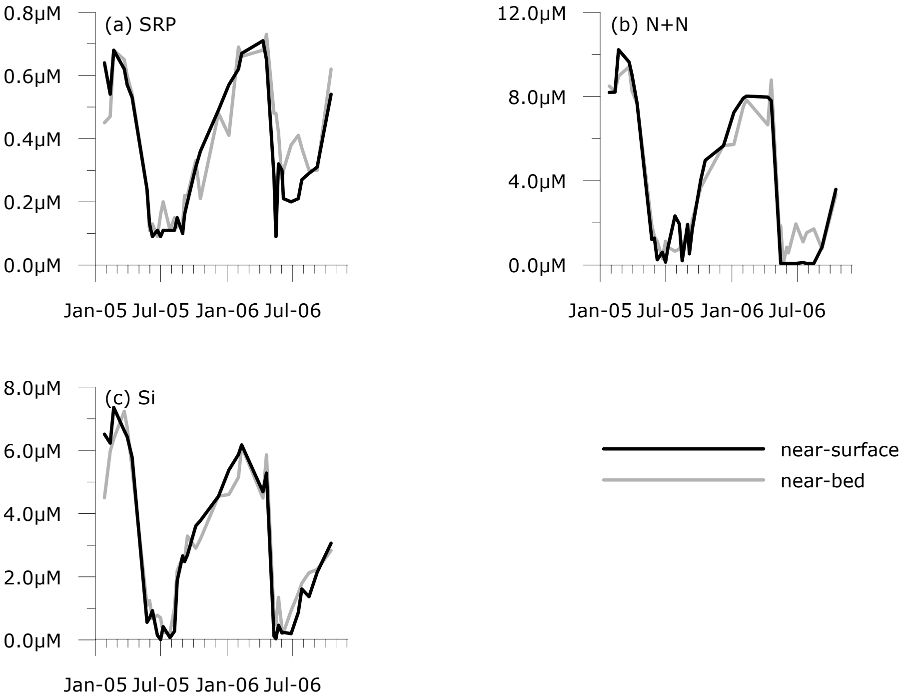

Figure 8. Winter inorganic nutrient concentrations in Cypris near-surface and near-bed waters during 2005 and 2006. (a) Phosphate; (B) nitrite plus nitrite; (c) silicate.

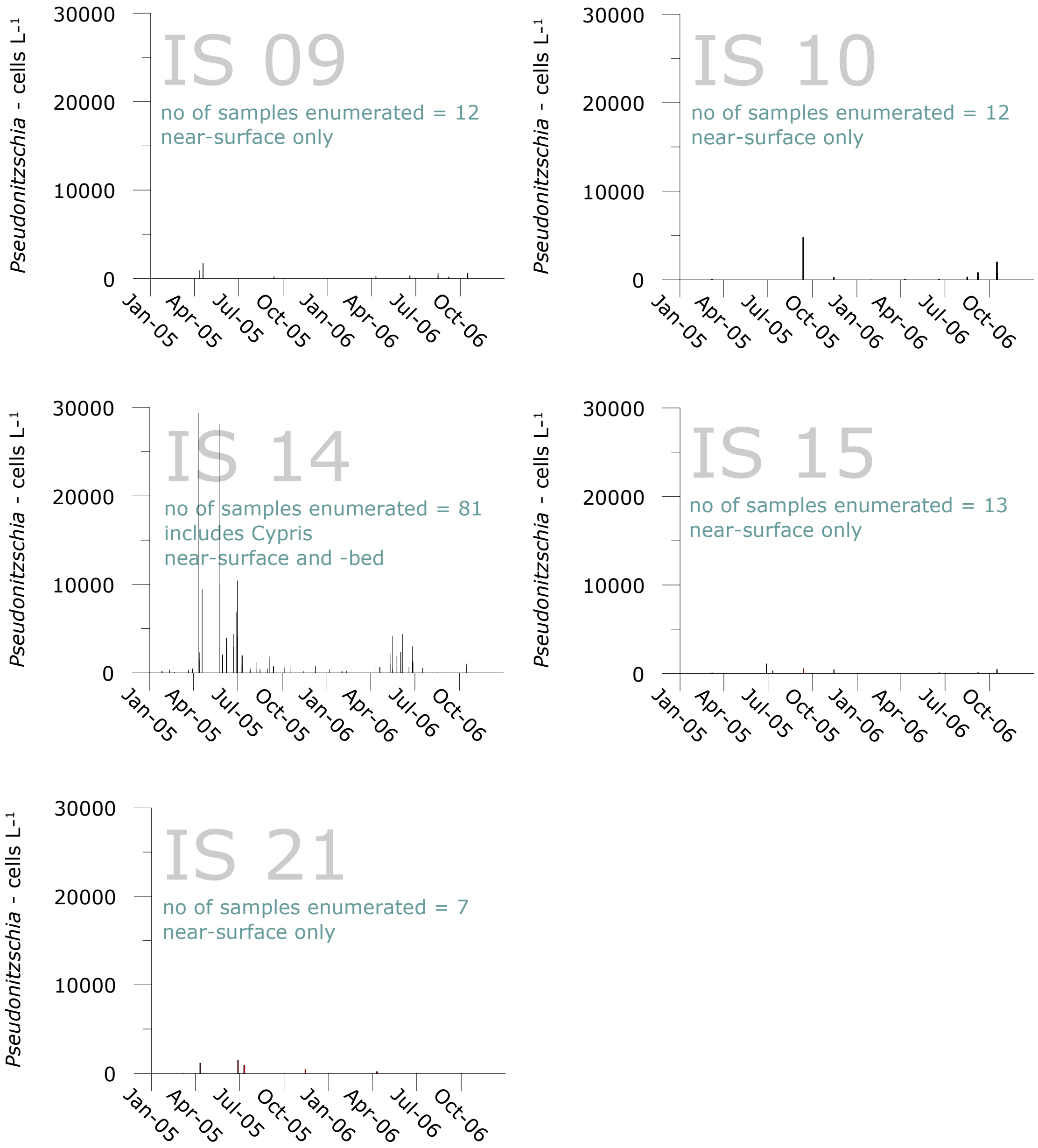

Figure 9. Levels of grouped *Pseudonitzschia* in Isle of Man coastal waters during 2005 and 2006.

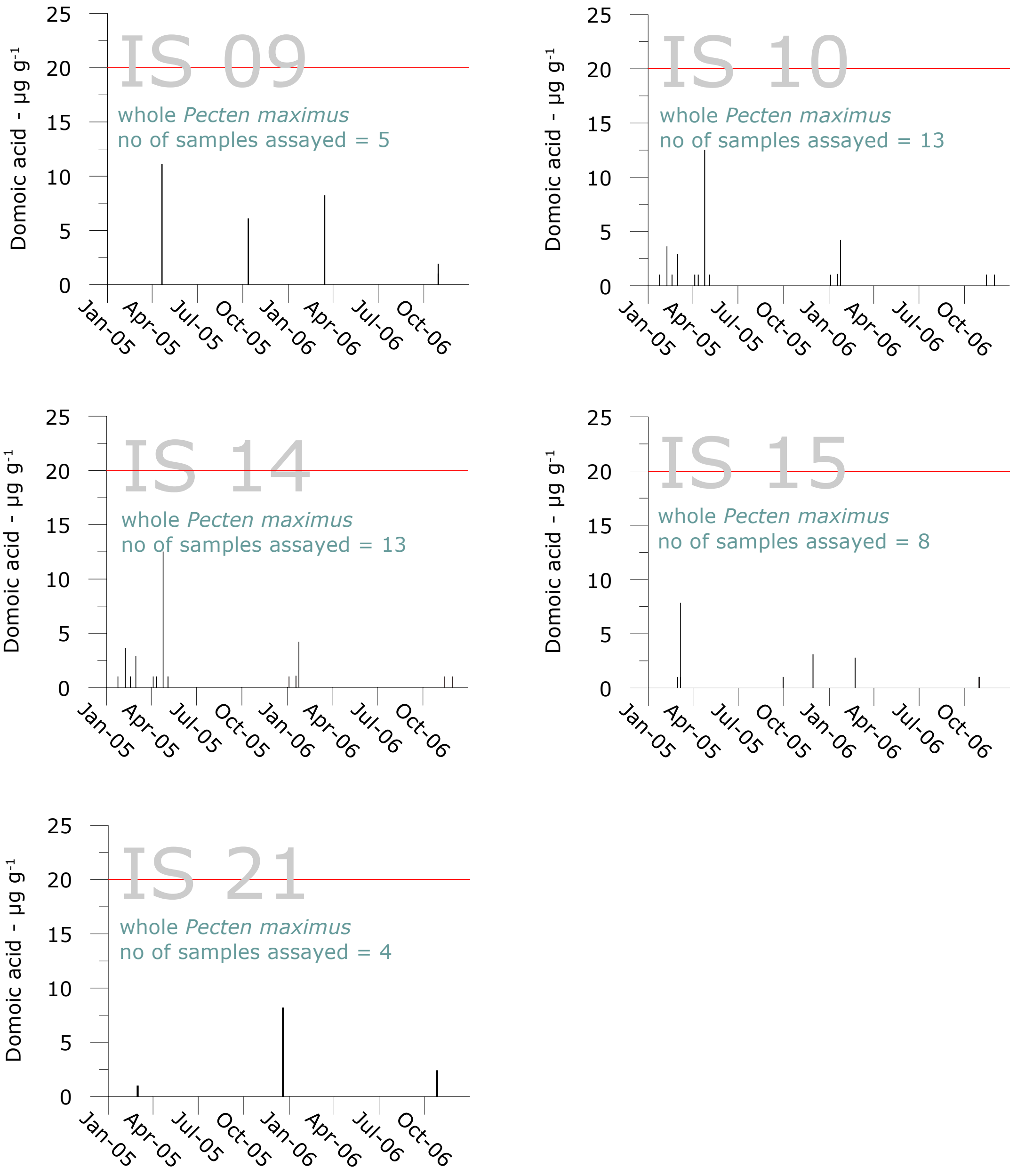

Figure 10. Levels of Domoic acid observed in whole *Pecten maximus* taken from Isle of Man scallop grounds during 2005 and 2006. Red line indicates threshold concentration.

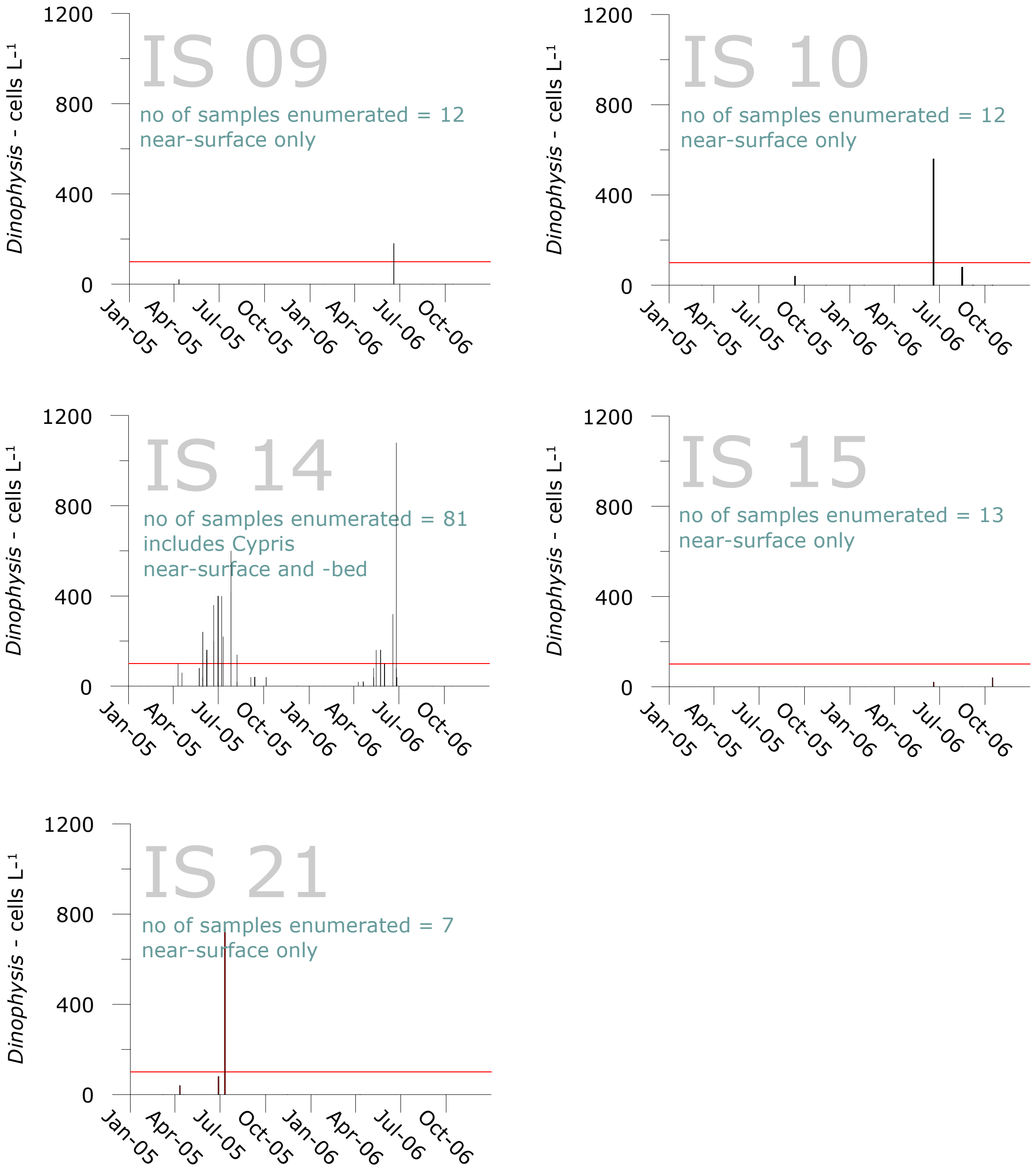

Figure 11. Levels of grouped *Dinophysis* in Isle of Man coastal waters during 2005 and 2006. Red line indicates threshold level that triggers extra sampling.

TABLES

	2005 ^{o}C	2006 ^{o}C	100 year (1903 - 2003) mean (^{o}C)	decadal (1996 - 2005) mean (^{o}C)	maximum ^{o}C	Year	minimum ^{o}C	Year
Jan	9.2	9.5	8.1	8.7	9.6	1998	5.7	1963
Feb	7.8	8.1	7.2	7.9	9.1	1998	4.5	1963
Mar	7.9	7.7	7.0	7.8	8.9	1998	5.2	1947
Apr	8.7	8.6	7.8	8.6	9.0	1959	5.8	1917
May	10.2	10.0	9.3	10.1	10.6	2004	7.7	1917
Jun	12.4	12.5	11.3	12.2	12.9	2003	9.3	1956
Jul	14.1	14.4	13.1	13.8	14.5	1959	11.1	1956
Aug	14.9	14.9	14.0	14.8	15.4	2003	12.7	1986
Sep	14.9	15.1	13.7	14.6	15.1	2006	12.5	1986
Oct	13.8	14.2	12.7	13.4	14.4	1959	11.1	1919
Nov	11.9	12.4	11.0	11.9	12.6	1997	8.9	1919
Dec	10.4	10.8	9.5	10.1	11.1	1997	8.0	1917
Annual mean	11.3	11.5	10.4	11.2	11.5	1959	9.1	1917
Winter mean	9.2	9.3	8.3	8.9	9.9	1998	6.3	1963
Spring mean	8.9	8.8	8.0	8.9	9.5	1998	6.3	1917
Summer mean	13.8	13.9	12.8	13.6	14.2	2003	11.1	1956
Autumn mean	13.5	13.9	12.5	13.3	13.9	2006	10.9	1919

Table 3.1. Sea surface temperature, Port Erin Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cypris													
2005	*	**	**	*	**	**	***	***	**	**		*	21
2006	*	**		**	***	***	**	*	*	*			16

Table 3.2. Frequency of sampling at Cypris, 2005 & 2006

year	**Nutrient**	**Maximum (Jan –Mar)**	**Date of maximum**	**Median (Jan – Mar)**
2005	Phosphate (SRP)	0.68 µM	21 Feb 05	0.62 µM
2006		0.67 µM	10 Feb 05	0.62 µM
2005	Silicate (Si)	7.36 µM	21 Feb 05	6.51 µM
2006		6.17 µM	10 Feb 05	5.87 µM
2005	Total oxidised nitrogen (N+N)	10.22 µM	21 Feb 05	9.02 µM
2006		8.02 µM	10 Feb 05	7.92 µM

Table 3.3. Winter inorganic nutrient concentrations at Cypris during 2005 & 2006

Species	Associated toxins	Symptoms	Comments
Pseudonitzshia species	Amnesic Shellfish Poisoning (ASP) - Domoic Acid (DA)	diarrhoea, nausea, vomiting, abdominal pain, short term memory loss	• Found in all areas of Manx coastal waters • Allegedly, have to occur in numbers in excess of 50,000 plus cells per litre to cause toxicity in shellfish.
Dinophysis acuminata, acuta, norvegica & rotundata	Diarrhoetic Shellfish Poisoning (DSP) - Okadaic acid (OA) & Dinophysis toxins (DTXs)	diarrhoea, nausea, vomiting	• Found in all areas of Manx coastal waters • Observed mostly during the summer months
Alexandrium species	Paralytic Shellfish Poisoning (PSP) - Saxitoxins and Gonyautoxins	headaches, dizziness, diarrhoea, nausea, vomiting leading on to muscular paralysis. In severe cases respiratory failure may occur	• Rarely observed in Manx coastal waters • Can produce toxins in relatively low numbers
Protoperidinium species (possibly)	Azaspiracid Poisoning (AZP) - azaspiracids	similar to DSP but more acute, with headaches and chills	• low numbers observed in Manx coastal waters • studies to confirm that this species are the origin of AZP are ongoing

Table 4.1. A summary of the algae associated with shellfish vectored toxins observed in Manx coastal waters and shellfishery areas.

Species	Comments
Chaetocerous species	Some species are icthyotoxic and can in fish irritate gills, causing excess mucus production and asphyxiation. Farmed fish are especially vulnerable.
Dictyocha speculum	In fish irritate gills, causing excess mucus production and asphyxiation. Farmed fish are especially vulnerable.
Noctiluca scintillans	Blooms cause strong red discolouration of water. Decaying blooms may cause deoxygenation of the water column and ammonia to surge in the water column causing finfish and shellfish mortalities. Blooms are frequently observed in Manx coastal waters during the summer months.
Phaeocystis species	Blooms cause brown-red discolouration of water with foaming. Not toxic but can produce acrylic acid, dimethyl sulphide and mucilage. Blooms have been observed in Manx coastal waters during the spring-early months.
Prorocentrum micans	Has formed red tide discolourations in other parts of the world. To date has not caused problems in Manx coastal waters.

Table 4.2. A summary of the nuisance algae observed in Manx coastal waters.

APPENDIX A

GLOSSARY

Eutrophication is defined the Urban Waste Water Treatment Directive (91/271/EEC) as:

> *the enrichment of waters by nutrients especially compounds of phosphorus and/or nitrogen (nitrate), causing and accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in water and to the quality of water concerned*

and the OSPAR Strategy to Combat Eutrophication adds that eutrophication specifically

> *refers to the undesirable effects resulting from anthrogenic enrichment by nutrients as described in the Common Procedure.*

Eutrophication is a process that requires undesirable disturbance requires to be unambiguously linked to anthropogenic nutrient enrichment.

Great Salinity Anomaly (GSA) refers to the sudden and dramatic decrease in surface salinity observed in progression around the North Atlantic and Nordic Seas in the late 1960s and through the 1970s.

Eulerian sampling considers change over time at a fixed geographic position. Measurements are made at a fixed location and the water 'parcel' at that location is not constant with time but is transported over the site via tidal currents. Lagrangian sampling considers the changes that occur as a water 'parcel' is followed with the geographic sampling position changing over time.

Hypernutrification refers to significant enrichment of waters by nutrients but not necessarily accompanied by accelerated plant growth. What constitutes significant enrichment depends on the nutrient, the concentration in the absence of enrichment and local conditions.

Longterm datasets and timeseries. In this report a longtem dataset is described as a collection of observations or data collected over long periods of time but not with any consistency or regularity over the period of collection. A timeseries is restricted to datasets where consistency and regularity are achieved for the lifespan of the monitoring programme and allows a meaningful evaluation of data from two or more time periods.

North Atlantic Oscillation (NAO) is the dominant influence on climate variability and basic atmospheric meteorological variables (surface wind, temperature, and precipitation) in the Northern Hemisphere, particularly in winter and also a major source of interannual variability in global weather. The NAOI is an index based on the difference in atmospheric pressure between the Icelandic-low and the Azores-high (*eg* www.cru.uea.ac.uk).

High, positive winter NAOI years are characterised by enhanced westerly and southwesterly airflow and in northern Europe warmer winters with increased precipitation and river flow. In lower and negative winter NAOI years westerly airflow is comparatively weaker and in northern Europe winter temperature tends to be colder and precipitation lower.

Routinely monitored variables

Ammoniacal-nitrogen. Ammoniacal-nitrogen, *i.e.* NH_4^+/NH_3, is the most reduced form of dissolved inorganic nitrogen present in seawater and can the preferred form of combined nitrogen for uptake by phytoplankton. It is a product of excretion and decay. In high concentrations ammoniacal-nitrogen is toxic to marine organisms. The un-ionised form, NH_3, is the most toxic. Concerns about ammonia toxicity are greatest in estuarine waters. In general the higher the temperature and pH and the lower the levels of dissolved oxygen and salinity the greater the risk of increased levels toxicity. Ammoniacal-nitrogen when present in low levels is often included in the organic nitrogen fraction. Conversely, it is also frequently included in the inorganic fraction when concentrations are reported as dissolved available inorganic nitrogen.

Chlorophyll and phytoplankton. The plant pigment chlorophyll *a* is measured as an indicator of the standing crop biomass of phytoplankton present at the time of sampling. Marine phytoplankton can be considered basic biological productivity units that reflect the health of the marine environment. The main phytoplankton growth season is during spring/early summer. Sometimes sufficient nutrients regenerate for a smaller secondary summer/early autumn bloom. Increases in nutrient levels have led to increases in phytoplankton biomass in many marine and freshwater areas throughout the world. This increase in biomass is the basis of all problems associated with eutrophication. These problems may include oxygen depletion during phytoplankton die-off, 'blooms' of toxic or nuisance phytoplankton species and a shift from diatom dominance to dinoflagellate dominance in phytoplankton assemblages.

Dissolved inorganic nutrient salts. The inorganic nutrient salts of nitrogen, phosphorus and silicon themselves are not harmful but essential for phytoplankton growth. However, when these salts are present in high concentrations, often referred to as hypernutrification, excessive growth of the microscopic phytoplankton may occur. This process is known as eutrophication. The Irish Sea is a semi-enclosed sea and, as such, is vulnerable to eutrophication. Problems have occurred in other semi-enclosed seas such as the Baltic and Adriatic. Associated with these conditions may be blooms of toxic and nuisance algae, coloration of the waters and depletion of oxygen in the water column during the decay processes of these microscopic plants.

Dissolved organic nitrogen and phosphorus. In the marine systems total dissolved nitrogen and total dissolved phosphorus are partitioned between the dissolved inorganic phase and the dissolved organic phase. The annual cycle in nutrient concentrations represents a balance between uptake, release and regeneration. Inorganic nitrogen and phosphorus are not the only forms of nitrogen and phosphorus. Dissolved organic nitrogen and phosphorus, derived for example from the products of excretion and decay, are important fractions of marine nutrient pools and may be rapidly recycled to supply the summer nitrogen and phosphorus requirements of micro-organisms at a time when inorganic nutrients in the euphotic zone are scarce.

Dissolved oxygen. In semi-enclosed seas where eutrophication is a problem oxygen depletion, particularly in near-bed waters associated with algal die-off, has been recorded. Low oxygen concentrations, anoxia, can result in the mass mortality of bottom dwelling animals. If anoxic conditions develop to the stage where all the nitrate and nitrite-nitrogen has been reduced ammonium-nitrogen becomes the dominant form of nitrogen.

The solubility of oxygen in seawater is inversely proportional to temperature and a longterm increase in seawater temperature could adversely affect absolute oxygen concentration and also result in oxygen depetion.

Nutrient ratios. Changes in the ratios of the essential nutrients may lead to changes in the species present in phytoplankton assemblages and thus to changes in the abundance and composition, and ultimately the bio-diversity of macrobiotic communities. For example, silicon is significant for the growth of diatoms, important members of the phytoplankton community and the usual food for zooplankton and filter feeding fish. Diatoms therefore contribute directly to fishable populations in coastal waters. The flagellate phytoplankton community is considered to be a poor food source for higher organisms. Silicon in the marine environment is almost entirely derived from non-anthropogenic processes and concentrations have changed little with time. Whereas, nitrogen frequently has a large anthropogenic input. Increasing inputs of nitrogen accompanied by an increase in N:Si ratios have the potential to change diatom dominance to flagellate dominance in phytoplankton communities. Nitrogen in nutrient ratios is generally reported as dissolved available inorganic nitrogen, DAIN, which is calculated as ((N+N) + (NH_4^+/NH_3).

Nutrient-salinity relationships. Nutrient-salinity plots can indicate whether nutrients are from riverine origin or other sources. The ideal relationship shows a conservative or inverse linear response with low salinity waters having higher nutrient concentrations and higher salinity waters having lower nutrient concentrations. Lack of linearity indicates other influences; for example phytoplankton uptake, *in situ* regeneration processes or adsorption/desertion by suspended matter, or sources, for example, point sources such as municipal/industrial discharges, affecting nutrient distributions.

Salinity. Long term alterations in the influence of high, for example exchange with the Atlantic Oceans, and low, for example riverine input, salinity water masses may have implications for variables such as nutrient concentrations, and thus exert a substantial impact in the Irish Sea. Precipitation will affect local salinities and prevailing wind conditions will affect the influence of coastal freshwaters. The link between meteorological events and salinity are complex and effects are likely to be short term and of minor importance unless there are longer term climatic changes.

Temperature. Long term changes in the temperature of the water column have the potential to alter the productivity and survival of marine organisms, the dissolved oxygen saturation, ammoniacal-nitrogen concentration and the distribution and composition of communities of marine organisms. Long term change in the relationship between surface sea and air temperature has climatic implications as has climate (thermal) driven modification of marine circulation. Increasing sea-water temperatures can also result in the thermal expansion of the oceans, the raising of mean sea levels and an increased risk of flooding in lowland areas.

APPENDIX B

ISLE OF MAN LONGTERM ENVIRONMENTAL TIMESERIES: metadata and general background information.

The timeseries are continuous and ongoing and were initiated at Port Erin Marine Laboratory formerly (Port Erin Marine Biological Station), University of Liverpool. Upon the closure of Port Erin Marine Laboratory the continuation of the dataseries has been undertaken by the Department of Local Government and the Environment of the Isle of Man Government.

The current data collector and principal investigator is:

(Ms) Theresa M. Shammon MSc CChem MRSC
Scientific Officer – Marine Science
Government Laboratory
Department of Local Government and the Environment
Ballakermeen Road
Douglas
Isle of Man
IM1 4BR

Email: Theresa.Shammon@lab.dlge.gov.im

Telephone: +44 (0)1624 642250

1. PORT ERIN BREAKWATER

Location: Port Erin, Isle of Man. 54 05.113(N), 04 46.083(W)

Variables: Surface sea temperature and salinity.

Frequency: Daily

Initiated: 1 January 1904

Data collected by: Port Erin Marine Laboratory (University of Liverpool).

Methods: Temperature, Meteorological (Sea Ice) Office issue thermometer; Salinity, titration against silver nitrate until 1965, thereafter using inductively coupled salinometers (Autolab salinometer, 6230N Plessey, currently Guildline Portasal).

Other: Until November 1961 temperature was recorded in degrees Fahrenheit; these data have since been converted degress Centigrade.

2. THE CYPRIS DATASETS

(I) D. JOHN SLINN DATASET (1954-1992)

Location: 5km west of Port Erin, Isle of Man. 54 05.50(N), 04 50.00(W). Nominal depth 37m.

Variables (with years of initiation and depths)**:** Temperature (1954: 0, 5, 10, 20 and 37 metres); Salinity (1954: 0 and 37 metres); Dissolved Oxygen (1954: 0 and 37 metres); Phosphate (1954: 0 and 37 metres); Nitrate + nitrite (1960: 0 and 37 metres); Silicate, (1958, 0 and 37 metres); Chlorophyll a, (1966: 0 metres).

Frequency: from weekly to once a month depending on season, boat availability and weather.

Initiated: February 1954

Data originator and principal investigator: D. John Slinn, Port Erin Marine Laboratory (University of Liverpool).

Methods: Samples collected using a Nansen-Pettersen water bottle.

Temperature, insulated thermometer

Salinity, titration against silver nitrate until 1965, thereafter using inductively coupled salinometers (Autolab salinometer, Plessey 6230N).

Dissolved oxygen, Winkler titration as outlined in Jacobsen *et al*, 1950. A review of dissolved oxygen in seawater by the Winkler method. *Association d'Oceanographie Physique. Publication Scientifique* No 11, 1 -22. Conversion to percentage saturation using method from Murray & Riley, 1969, *Deep Sea Research*, **16**:311-320.

Nutrients. Phosphate method 1, method used 1954 to 1971. Reduction with stannous chloride. Slinn, D.J., 1956. Phosphate and oxygen in sea water off the Isle of Man during the years 1952 – 54. *Mar. Biol. Sta. Port Erin, Isle of Man. Ann. Rep.* 68: 30-38; Harvey, H.W., 1948. The estimation of phosphate and total phosphate in sea water. *JMBA* 27: 337-359; A source of error in the absorbtiometric determination of inorganic and total phosphorus in seawater. *JMBA* **28**:701-705.

Phosphate method 2, Reduction with ascorbic acid, (i) February 1958 to October 1961. Murphy, J., & Riley, J.P. 1958. A single solution method for the determination of soluble phosphate in sea water. *JMBA* 37:9-14. (ii) November 1961 onwards, Murphy, J., & Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analyt. Chim Acta.* **27**:31-36.

Silicate Method of Mullin, J.B., & Riley, J.P. 1955. The colorimetric determination of silicate with special reference to sea and natural waters. *Analyt. Chim Acta.***12**:162-176.

Nitrate + nitrite. (i) February 1960 – 1989. Hydrazine method described in Strickland, J., & Parsons, T.R., (1960) *A manual of seawater analysis.* Bulletin. 125, Fisheries Research Board of Canada. 311pp. (ii) 1989 – 1991. Cadmium reduction method described in Morris & Riley, 1963. *Analyt. Chim Acta.***29**:272.

The optical density of coloured solutions was measured using (i) 1954 – 1957 a Hilger 'Spekker' colorimeter using 20cm cells and (ii) 1957 – 1991 Unicam SP500 spectrophotometer using 10cm cells for phosphate silicate and nitrite and 1cm cells for nitrate.

Chlorophyll a. 4 litres of seawater filtered through 90 mm diameter Whatman GF/C filter paper the retentivity of which was improved with a suspension of powdered magnesium carbonate. The filter paper was manually macerated in

90% acetone, extracted overnight, centrifuged and the extinction of the supernatant measured at 750, 663, 645 and 630 nm. Calculation based on trichromatic equations given in Report of Scor-UNESCO (1964) working group 17 on *Determination of photosynthetic pigments* (mimeo), Sydney.

(II) CYPRIS DATASET, 1992 TO MARCH 2006 (continuation of John Slinn's dataset after his retirement in 1992)

Location: 5km west of Port Erin, Isle of Man. 54 05.50(N), 04 50.00(W). Nominal depth 37m.

Variables (with depths)**:** Temperature (0, 5, 10, 20 and 37 metres); Salinity (0 and 37 metres); Dissolved Oxygen (0 and 37 metres); Phosphate (0 and 37 metres); Nitrate + nitrite (0 and 37 metres); Silicate, (1958, 0 and 37 metres); Chlorophyll a, (1966, 0 metres); Ammonia (0 and 37 metres); Total dissolved nitrogen (1996, 0 and 37 metres); Total dissolved phosphorus (1996 – June 2002, 0 and 37 metres).

Frequency: from weekly to once a month depending on season, boat availability and weather.

Initiated: 1992 (after John Slinn's retirement)

Data originator and principal investigators: 1992 to 1994, Janette Allen, Port Erin Marine Laboratory (University of Liverpool), 1994 to 2006, Theresa Shammon, Port Erin Marine Laboratory (University of Liverpool). The work was funded by the Department of Local Government and the Environment, Isle of Man Government.

Methods: Samples collected using a Nansen-Pettersen water bottle or a NIO bottle.

Temperature, insulated thermometer with Nansen Pettersen bottle or mercury reversing thermometers with NIO bottle.

Salinity, inductively coupled salinometer; Autolab salinometer, Plessey 6230N until June 1998, Guildline Portasal from July 1998.

Dissolved oxygen, Winkler method. Conversion to percentage saturation using Ocean Scientific International software until June 1994 and then 'Lab Assistant' software, PDMS Ltd.

Nutrients. Phosphate, Silicate, Nitrate + Nitrite, Ammonia. Using segmented flow analysis and maufacturer's recommended methods which are based on classical 'wet chemistry' colorimetric methods. Alpkem RFA/2 until October 2001, Skalar SAN+System from November 2001.

Total dissolved nitrogen and phosphorus. Persulphate digestion method adapted from Valderama, J.C. (1981) The simultaneous analysis of total nitrogen in natural waters. *Marine Chemistry*, **10**:109-122. Digestion followed by segmented flow colorimetric analysis.

Chlorophyll a. 4 litres of seawater filtered through 90 mm diameter Whatman GF/C filter paper. The filter paper was manually macerated in 90% acetone, extracted overnight, centrifuged and the extinction of the supernatant measured at 750, 663,645 and 630 nm. Calculation based on trichromatic equations given in Report of Scor-UNESCO (1964) working group 17 on *Determination of photosynthetic pigments* (mimeo), Sydney.

Quality control: Analysts participated in QUASIMEME Laboratory Performance Studies (www.quasimeme.org) from 1996 for nutrients in seawater and from 2003 for chlorophyll in seawater.

APPENDIX C

date	depth	ASP – IS 06	ASP – IS 09	ASP – IS 10	ASP – IS 14	ASP – IS 15	ASP – IS 21
26-Jan-05	near-surface				0		
26-Jan-05	near-bed				200		
11-Feb-05	near-surface				240		
11-Feb-05	near-bed				320		
21-Feb-05	near-surface				40		
21-Feb-05	near-bed				80		
08-Mar-05	near-surface			60		60	0
22-Mar-05	near-surface				320		
22-Mar-05	near-bed				160		
30-Mar-05	near-surface				20		
30-Mar-05	near-bed				460		
11-Apr-05	near-surface	200	900		29380		1160
13-Apr-05	near-surface				1520		
13-Apr-05	near-bed				2320		
19-Apr-05	near-surface		1720		9440		0
24-May-05	near-surface				28160		
24-May-05	near-bed				10080		
31-May-05	near-surface				1880		
31-May-05	near-bed				2040		
08-Jun-05	near-surface				2720		
08-Jun-05	near-bed				3960		
22-Jun-05	near-surface				2920		
22-Jun-05	near-bed				4400		
28-Jun-05	near-surface				6900	1080	1480
01-Jul-05	near-surface				4020		
01-Jul-05	near-bed				10400		
08-Jul-05	near-surface				920		
08-Jul-05	near-bed				1880		
11-Jul-05	near-surface				1980	280	900
27-Jul-05	near-surface				480		
27-Jul-05	near-bed				220		
08-Aug-05	near-surface				360		
08-Aug-05	near-bed				1180		
16-Aug-05	near-surface				260		
16-Aug-05	near-bed				460		
31-Aug-05	near-surface				440		
31-Aug-05	near-bed				480		
05-Sep-05	near-surface				1560		
05-Sep-05	near-bed				1920		
12-Sep-05	near-surface		220	4780		540	
13-Sep-05	near-surface				720		
13-Sep-05	near-bed				720		
06-Oct-05	near-surface				480		
06-Oct-05	near-bed				640		

date	depth	ASP – IS 06	ASP – IS 09	ASP – IS 10	ASP – IS 14	ASP – IS 15	ASP – IS 21
19-Oct-05	near-surface				200		
19-Oct-05	near-bed				740		
14-Nov-05	near-surface			260	220	420	440
08-Dec-05	near-surface				760		
08-Dec-05	near-bed				220		
06-Jan-06	near-surface				40		
06-Jan-06	near-bed				400		
30-Jan-06	near-surface		0	0	0	0	
01-Feb-06	near-surface				160		
01-Feb-06	near-bed				120		
10-Feb-06	near-surface				200		
10-Feb-06	near-bed				240		
10-Apr-06	near-surface		260	60	1000		180
10-Apr-06	near-surface				1680		
10-Apr-06	near-bed				1400		
20-Apr-06	near-surface				640		
20-Apr-06	near-bed				240		
11-May-06	near-surface				2160		
11-May-06	near-bed				1040		
16-May-06	near-surface				480		
16-May-06	near-bed				4160		
25-May-06	near-surface				1840		
02-Jun-06	near-surface				320		
02-Jun-06	near-bed				2300		
06-Jun-06	near-surface				100		
06-Jun-06	near-bed				4400		
19-Jun-06	near-surface		320	60	640	80	
26-Jun-06	near-surface				3000		
26-Jun-06	near-bed				1840		
27-Jun-06	near-surface				1320		
27-Jun-06	near-bed				1120		
17-Jul-06	near-surface				160		
17-Jul-06	near-bed				540		
16-Aug-06	near-surface		280	320	80	0	
16-Aug-06	near-bed		600	160	20	0	
07-Sep-06	near-surface		0	800	0	80	
07-Sep-06	near-bed		200	400	0	60	
16-Oct-06	near-surface		600	760	1020	260	
16-Oct-06	near-bed		300	2000	760	480	

Table C.1. Summary of grouped *Pseudonitzschia* concentrations (cells L^{-1}) during 2005 & 2006.

date	depth	DSP – IS 06	DSP – IS 09	DSP – IS 10	DSP – IS 14	DSP – IS 15	DSP – IS 21
26-Jan-05	near-surface				0		
26-Jan-05	near-bed				0		
11-Feb-05	near-surface				0		
11-Feb-05	near-bed				0		
21-Feb-05	near-surface				0		
21-Feb-05	near-bed				0		
08-Mar-05	near-surface			0		0	0
22-Mar-05	near-surface				0		
22-Mar-05	near-bed				0		
30-Mar-05	near-surface				0		
30-Mar-05	near-bed				0		
11-Apr-05	near-surface	20	20		**100**		40
13-Apr-05	near-surface				0		
13-Apr-05	near-bed				0		
19-Apr-05	near-surface		0		60		0
24-May-05	near-surface				80		
24-May-05	near-bed				80		
31-May-05	near-surface				**240**		
31-May-05	near-bed				40		
08-Jun-05	near-surface				**160**		
08-Jun-05	near-bed				**120**		
22-Jun-05	near-surface				**360**		
22-Jun-05	near-bed				**200**		
28-Jun-05	near-surface				0	0	80
01-Jul-05	near-surface				**400**		
01-Jul-05	near-bed				20		
08-Jul-05	near-surface				**400**		
08-Jul-05	near-bed				**100**		
11-Jul-05	near-surface				**220**	0	**740**
27-Jul-05	near-surface				**600**		
27-Jul-05	near-bed				**420**		
08-Aug-05	near-surface				20		
08-Aug-05	near-bed				**140**		
16-Aug-05	near-surface				0		
16-Aug-05	near-bed				0		
31-Aug-05	near-surface				0		
31-Aug-05	near-bed				0		
05-Sep-05	near-surface				0		
05-Sep-05	near-bed				40		
12-Sep-05	near-surface		0	40		0	
13-Sep-05	near-surface				40		
13-Sep-05	near-bed				0		
06-Oct-05	near-surface				40		
06-Oct-05	near-bed				40		
19-Oct-05	near-surface				0		

date	depth	DSP – IS 06	DSP – IS 09	DSP – IS 10	DSP – IS 14	DSP – IS 15	DSP – IS 21
19-Oct-05	near-bed				0		
14-Nov-05	near-surface			0	0	0	0
08-Dec-05	near-surface				0		
08-Dec-05	near-bed				0		
06-Jan-06	near-surface				0		
06-Jan-06	near-bed				0		
30-Jan-06	near-surface		0	0	0	0	
01-Feb-06	near-surface				0		
01-Feb-06	near-bed				0		
10-Feb-06	near-surface				0		
10-Feb-06	near-bed				0		
10-Apr-06	near-surface		0	0	0		0
10-Apr-06	near-surface				0		
10-Apr-06	near-bed				20		
20-Apr-06	near-surface				20		
20-Apr-06	near-bed				0		
11-May-06	near-surface				40		
11-May-06	near-bed				80		
16-May-06	near-surface				**160**		
16-May-06	near-bed				0		
25-May-06	near-surface				**160**		
02-Jun-06	near-surface				**100**		
02-Jun-06	near-bed				0		
06-Jun-06	near-surface				0		
06-Jun-06	near-bed				0		
19-Jun-06	near-surface		**180**	**560**	**320**	20	
26-Jun-06	near-surface				**1080**		
26-Jun-06	near-bed				80		
27-Jun-06	near-surface				0		
27-Jun-06	near-bed				40		
17-Jul-06	near-surface				0		
17-Jul-06	near-bed				0		
16-Aug-06	near-surface		0	80	0	0	
16-Aug-06	near-bed		0	40	0	0	
07-Sep-06	near-surface		0	0	0	0	
07-Sep-06	near-bed		0	0	0	0	
16-Oct-06	near-surface		0	0	0	40	
16-Oct-06	near-bed		0	0	0	0	

Table C.2. Summary of grouped *Dinophysis* concentrations (cells L^{-1}) during 2005 & 2006

date	**Domoic acid IS 09 - µg g^{-1}**	**Domoic acid IS 10 - µg g^{-1}**	**Domoic acid IS 14 - µg g^{-1}**	**Domoic acid IS 15 - µg g^{-1}**	**Domoic acid IS 21 - µg g^{-1}**
24-Jan-05		<1			
08-Feb-05		3.61			
18-Feb-05		<1			
01-Mar-05		2.9			
01-Mar-05				<1	
01-Mar-05					<1
07-Mar-05				7.84	
07-Mar-05				<1	
24-Mar-05			2.96		
05-Apr-05		<1			
12-Apr-05		<1			
21-Apr-05	11.1				
25-Apr-05		12.5			
05-May-05		<1			
12-May-05			3.53		
19-May-05			12.9		
30-Sep-05				<1	
05-Oct-05			11.2		
12-Oct-05	6.08				
09-Nov-05			11.94		
22-Nov-05			11.23		
29-Nov-05				3.08	
19-Dec-05					8.19
04-Jan-06		<1			
18-Jan-06		1.06			
24-Jan-06		4.2			
07-Feb-06			5.4		
22-Feb-06				2.79	
08-Mar-06			7.72		
15-Mar-06	8.21				
10-May-06			2.71		
25-Oct-06			5.6		
25-Oct-06			3.4		
25-Oct-06			4.7		
26-Oct-06			10.5		
26-Oct-06					2.4
26-Oct-06					2.2
30-Oct-06	<1				
30-Oct-06	1.9				
30-Oct-06				<1	
30-Oct-06				<1	
14-Nov-06		<1			
30-Nov-06		<1			

Table C.3. Domoic acid in whole *Pecten maximus*, 2005 & 2006, Manx waters

APPENDIX D

Appendix D: THE ISLE OF MAN TIMESERIES: THE NATURAL FLUCTUATION AND THE ANTHROPGENIC AND CLIMATE FORCING OF VARIABLES.

D.1 Sea temperature

Differentials or anomalies of annual mean SST in Port Erin Bay, 1904 – 2006 with reference to the 1904 to 2003 mean, are presented in figure D1a. Differences between SST as recorded at Port Erin Bay and as recorded at Cypris are minor (report section 3.2.1) Although there is pronounced interannual variability an overall significant increase of 0.75 ^{o}C or greater is indicated for the 103 year timeseries. This local increase in SST strongly reflects increasing global temperatures.

Figure D1 a demonstrates that the increase is not consistent for the period. Local-SST in the early 20th century was characterised by a cool period with five of ten of coolest ranked years occurring during the decade 1914 - 1923. A relatively stable period occurred between the mid-1920s and mid-1990s. Raised SST is most conspicuous for the decade at the end of the 20th into the 21st century. Ten of the warmest ranked years for local sea surface temperature have occurred in the decade 1997 to 2006.

Cumulative interannual differences for individual seasons (figure D2) indicate that SST increase in autumn (SepOctNov) may be greater compared to other seasons. This would broadly concur with the reasoning of Evans *et al* (2001) who applied a similar approach to Cypris SST data. Interannual variance (σ^2) for individual seasons also is not consistent throughout the year (also figure D2) being least in summer (JunJulAug) and greatest in winter (DecJanFeb).

Figures D1 a & b not unexpectedly demonstrate that interannual variability in local-SST strongly reflects that of local annual mean air-temperature as recorded by the Meteorological Office at Ronaldsway. A highly significant relationship exists between local annual mean air and sea temperature with the two variables having 77% of their interannual variation in common (table D.1).

Air-sea heat interactions have an impact, both globally and locally, on weather patterns. Air heats more rapidly compared to seawater. Because of the high density and specific heat capacity it takes more energy to raise the temperature of seawater compared to air.

The local sea-air temperature differential exhibits a distinct annual cycle. Sea temperature is warmer compared to air temperature for around seven months of the year from autumn through winter to early spring. Conversely from late spring to late summer/early autumn local air temperature is warmer compared to sea temperature. Overall local annual mean sea temperature exceeds local annual mean air temperature.

Sea-air temperature differentials, that is the difference between air temperature and sea temperature for the period 1948 to 2006 are presented in figure D1c. It is intuitive from this graph that the local sea-air differential has decreased over that period. Figure D3 demonstrates that local air temperature is increasing at a faster rate compared to sea temperature and table D.1 confirms a statistically significant decrease in the local sea-air differential since 1948 most notably during winter but also during spring and autumn.

One possible consequence of this shifting sea-air temperature differential is a change in the number of days fog recorded around the coast of the Isle of Man. The number of days with fog observed by the Meteorological Office at Ronaldsway is closely correlated with the sea-air differential. (Hiscott, A. 2005) The number of days with fog in summer has increased since the mid-1970s whereas the number of days with fog in winter has decreased during the period 1947 – 2004. Hiscott suggests that changes in the occurrence of fog have implications for the Island's transport and also the ecology, both terrestrial and aquatic, of the Island. For the article Hiscott divided the data into only two seasons, not four as presented in table D.1, with the 'winter season' being defined as October to March and the 'summer season' as April to October.

The dynamics of sea temperature change are complex. Local sea temperature is likely to be influenced to a certain extent by the advective transport of North Atlantic waters into the Irish Sea. The major influences will be local air-sea exchange processes. These processes in turn depend on North Atlantic atmospheric circulation which can be described by the North Atlantic Oscillation (NAO).

A strong inverse linear relationship exists between winter North Atlantic Oscillation Index (NAOI) and the local winter sea-air temperature differential with the two variables having 50% of their variation in common (table D.1). During the warmer, wetter NAOI positive years the sea air differential tends to be lower compared to cooler, dryer NAOI negative years.

There are significant positive relationships between local SST and the NAOI for all seasons (table D.1) reflecting the tendency to warmer European winters during NAOI positive years. NAOI is most closely related to SST during autumn.

Averaged SST cycles for NAOI negative and positive years, presented in figure D4 indicate that winter/spring-SST during negative years tends to be cooler compared to positive years but with minimal differences during summer/autumn. This may reflect the tendency to cooler winter temperatures during NAOI negative years. Furthermore in NAOI negative years there is an indication that the vernal warming of local waters maybe delayed compared to NAOI positive years.

D.2 Salinity

Differentials or anomalies of annual mean Port Erin Bay salinity with reference to the 1966 – 2005 grand mean are presented in figure D5a which emphasises the interannual variation in local salinity. Unlike SST no significant long-term trend has been established for the 41 year dataset. This also applies for the relatively few long-term timeseries for salinity in the British Isles.

The timeseries shows evidence of decadal fluctuation. Although there was some interannual variability salinity through the 1970s was relatively stable with little evidence of the Great Salinity Anomaly that was noted in other areas of the North Atlantic region. There was a noteworthy period of low salinities through the 1980s into the early 1990s. The 1990s was generally a period of higher salinity followed by a salinity decrease in the early 2000s and to date. A similar temporal fluctuation pattern has also been noted in data collected by the University of Wales, Bangor for the Menai Strait.

Salinity in the Irish Sea is not heterogeneous. All regions of the Irish Sea are to some extent influenced by freshwater. Low salinity waters are largely confined to the north-eastern Irish Sea corresponding to high riverine freshwater loadings with highest salinities being observed in offshore western Irish Sea waters. Isle of Man waters at Port Erin and Cypris have a salinity typically in the range 33.8 – 34.8. The North Atlantic has a salinity in the region of 35.5 and is the source water for the Irish Sea.

Oceanic water from the North Atlantic enters the Irish Sea and is modified by local evaporation/precipitation changes and diluted by freshwater via riverine discharge from the surrounding land masses of England, Wales, Scotland and Ireland. The ingress of oceanic water from the North Atlantic, the extent of freshwater discharge and the geographical position of the mixing zone are all modified by climatic factors. Although mechanisms are complex and often speculative, salinity at any given zone in the Irish Sea represents the extent of this freshwater/seawater mixing.

A negative correlation or inverse relationship exists between the NAOI and Port Erin Bay salinity (figures D5 a & b and table D.2) for the winter, spring and autumn but not summer. The relationship is relatively strong for NAOI negative years when winter precipitation and thus runoff from land and westerly winds are less persistent. Salinity in these years tends to be higher and more impacted by oceanic water ingressing from the North Atlantic and less impacted by freshwater inputs. Port Erin Bay salinity does tend to be lower during NAOI positive years but the relationship is somewhat weak and local and regional effects seem to have a much greater impact on salinity. In NAOI positive years westerly and southwesterly airflow tends to be enhanced and in Northern Europe winters tend to be warmer with increased precipitation and airflow. Salinity would be expected to be more impacted by freshwater inputs and thus lower in these years.

D.3 Thermal stratification

Spring/summer thermal stratification is not unusual in the water column at Cypris. The thermal gradient is usually small and rarely exceeds 3.0 ^{o}C. Stratification at Cypris is relatively weak and unstable compared to the much deeper waters of the western Irish Sea Trench.

Thermal stratification depends on the stability of the water column and is a function of depth, convective mixing and turbulence due to wind intensity, frequency and the duration of periods of high winds. Stable thermal stratification inhibits the replenishment of nutrients in the near surface euphotic or production zone from near-bed waters

There is considerable interannual variation in the timing of vernal onset, duration and magnitude of this thermal stratification at Cypris (figures D6 a, & b).

There is a weak but nevertheless statistically significant indication that the vernal onset of thermal stratification at Cypris is occurring later in the year and a stronger statistically significant decrease over time in the duration of this seasonal stratification (table D.3). A long-term change in the onset of this seasonal stratification has implications for the onset of the vernal phytoplankton bloom.

D.4 (Phytoplankton) chlorophyll *a*

Maxima and mean levels during the growing season considered to be April to August in the waters at Cypris for the years 1966 to 2006 are presented in figure D7. For the 41 year time series there is much interannual variation.

Figure D7 offers little evidence that the modest but significant increase in chlorophyll *a* at Cypris for the period 1966 to 1991 suggested by Allen *et al* (1998) using Man-Kendall methods has been maintained. The assumption was that changes in anthropogenic inputs of the nutrient salts of nitrogen and phosphorus were in part responsible for the increase. Recent analysis of data upto and including 2005 also using Mann-Kendall methods shows no significant trend for levels of chlorophyll *a* at Cypris during the production season. Since the mid-1970s there has been no significant increase in inorganic nitrogen and since 1988 there has been a significant decrease in inorganic phosphate at Cypris (section D.5).

There is some evidence that chlorophyll *a* production at Cypris may be impacted by climate variability. A weak but just significant positive relationship (table D.4) exists between median summer (April to August) chlorophyll *a* levels and NAOI indicating that in NAOI positive years overall chlorophyll *a* production and thus phytoplankton biomass may be increased in these years. A positive relationship also exists between NAOI and the timing of though not the magnitude of the chlorophyll *a* maximum at Cypris; in NAOI positive years the maximum is recorded later in the year compared to NAOI negative years.

Within the Irish Sea there are regional variations in the timing of production onset and also season length brought about by geographic differences in depth and tidal mixing. The onset and duration of the phytoplankton chlorophyll *a* production season is controlled by the quality of light penetrating the sub-surface waters.

White *et al* (2003) observed a positive relationship between turbidity in the Irish Sea and wind strength, storm index and NAOI. During NAOI positive years water clarity was decreased and turbidity (reflectance) was increased thus reducing light penetration into sub-surface waters. During NAOI positive years Northern Europe winters tend to be warmer with increased precipitation westerly and southwesterly airflow tends to be enhanced. Wind stress causes change in turbidity through the generation of waves which can suspend sediment from the seabed especially in shallower waters <50m.

Furthermore, during NAOI positive years cloud cover may be increased compared to negative years and thus light reaching sub-surface waters would be decreased compared to NAOI negative years.

Chlorophyll *a* production is an index of phytoplankton biomass and primary production. Phytoplankton forms the base of the marine food web. Evaluating the effects of changes in phytoplankton dynamics as a result of longterm climate change and the effect on equilibria within the system and the access of higher trophic levels to prey is beyond the scope of this report.

D.5 Inorganic nutrients

Nutrient concentrations at Cypris exhibit a pronounced seasonal cycle typical of northern temperate shelf seas. At Cypris the winter nutrient maxima are usually observed between January and March. There is considerable interannual variation in the timing of the maxima. In some years nutrients concentrations are still increasing at the commencement of the vernal phytoplankton production season and winter nutrient maxima are frequently observed towards the end of March. Furthermore, within any one year the timing of the winter nutrient maxima for individual nutrients is also not always concurrent.

The timing of winter nutrient maxima 1954 to 2006, that is the day of the year that the maxima were observed are presented in figure D8. Winter nutrient maxima 1954 – 2006 are presented in figure D9.

During the mid to late 20th century there were increases at Cypris, a central Irish Sea site, in both N+N and SRP but not Si concentrations. Cypris data to 1991 were examined in Allen *et al* (1998) and the increases in winter N+N and SRP were found to be statistically significant. The increases coincided with a significant rise in phytoplankton biomass, measured as chlorophyll a (section D.4). Anthropogenic inputs were identified as the most likely cause of the increased concentrations of N+N and SRP.

It is widely accepted that Si in the marine environment is almost entirely derived from natural, non-anthropogenic processes although this is not an entirely correct assumption. Kennington *et al* (2006) record that in 2003 an industrial plant at Warrington discharging 1739 tonnes of silica (as SiO_2) into the north eastern Irish Sea.

Inspection of figure D9 indicates that the increases have not been maintained; N+N concentrations have stabilised and SRP concentrations have decreased. Gowan *et al* (2007) have re-analysed the timeseries using identical statistical methods and included data upto 2005. At Cypris since the mid-1970s there has been no significant increase in N+N and since 1988 there has been a significant decrease in SRP. Fluctuations in nutrient concentrations and salinity generally reflect those observed for the Menai Straight (Evans *et al*, 2003) and the trends are consistent with riverine inputs into the Irish Sea for the period (Gowen *et al*, 2002).

The decrease in SRP concentrations can be linked to a decline in the use of phosphate in detergents and the consequent reduction in load to the Irish Sea from sewage and industry. Also during the 1990s the dumping of sewage sludge ceased in the north-eastern Irish Sea and there were industrial process changes at a phosphate rock processing plant at Whitehaven on the Cumbrian coast.

Averaged Cypris winter nutrient data for 1960 – 1964, representative of early data, 2000 – 2004, representative of recent data taken from the Isle of Man timeseries, winter Atlantic data collected at the Celtic Sea shelf break, winter data for the inshore and offshore western Irish Sea and the eastern Irish Sea reproduced from Gowen *et al* 2007 are presented in table D.5. It is clear from the table that considerable nutrient heterogeneity exists within the Irish Sea and no single set of values typifies the entire Irish Sea. Highest concentrations of winter nutrients are observed in the lower salinity waters of the north eastern Irish Sea reflecting higher riverine freshwater inputs with lower concentrations being observed in the central and offshore western Irish Sea.

The source water for the Irish Sea and therefore also Cypris is Atlantic seawater entering across the Celtic Sea shelf break. It is unlikely that there has been longterm change in Celtic Sea winter nutrient concentrations. Because all regions of the Irish Sea, including Cypris, are influenced to some extent by freshwater and thus potentially anthropogenic nutrients Gowen *et al,* 2007 suggest that nutrient status should be assessed against (Atlantic) source water.

Cypris, both currently and in the past, is enriched with SRP compared to the shelf break and as discussed earlier this can be linked to anthropogenic enrichment via freshwater riverine loadings. Cypris and the Irish Sea generally are Si enriched compared to the shelf break. This is not unexpected as riverine water is naturally high in Si.

Recent data show that Cypris and also the Irish Sea in general is enriched with N+N. However, it was not until the late-1960s that Cypris winter N+N concentrations reached and exceeded those at the shelf edge suggesting substantial denitrification, a component of the marine nitrogen cycle, balancing anthropogenic inputs of nitrogen. The European shelf is widely regarded as a net sink for nitrogen and in view of this Gowen *et al* (2007) suggests that denitrification mitigates anthropogenic nitrogen enrichment in the western Irish Sea. Mills & Hydes (2006) advise that microbiological studies and a model suggest that increasing temperatures may decrease denitrification and increased concentrations of nitrate may lead to phosphate becoming the limiting nutrient in the marine environment. Furthermore, not only would denitrification decrease but the product of microbial processing would be ammonia which could enhance rates of plankton production.

Data presented in table D.6 indicate that conservative or inverse relationships can be established between winter salinity and winter N+N and SRP but not Si at the Cypris Station. At the same time positive relationships can also be established between winter N+N and SRP but not Si at the Cypris Station and climate in the form of winter NAOI. Relationships between local salinity and climate were established in section D.1.

Salinity in the central Irish Sea represents a mixing of Atlantic Ocean water entering via the St George's Channel and freshwater riverine loading from the surrounding landmasses of the United Kingdom and Ireland. In NAOI positive years there is a tendency during winter towards higher precipitation and thus increased freshwater runoff, stronger winds, more intense mixing and thus reduced winter salinity. Freshwater riverine inputs into the Irish Sea have high anthropogenic nitrogen and phosphorus loadings. Intensification of mixing and shifts in the saline/freshwater mixing zone will result in decreased salinity and winter increases in N+N and SRP concentrations in the central Irish Sea.

It is reasonable to conclude that both anthropogenic loadings of the inorganic nutrients of nitrogen and phosphorus and climate influence the longterm fluctuations in nutrient concentrations in the Irish Sea. However, it is beyond the scope of this report to determine the relative influence of either.

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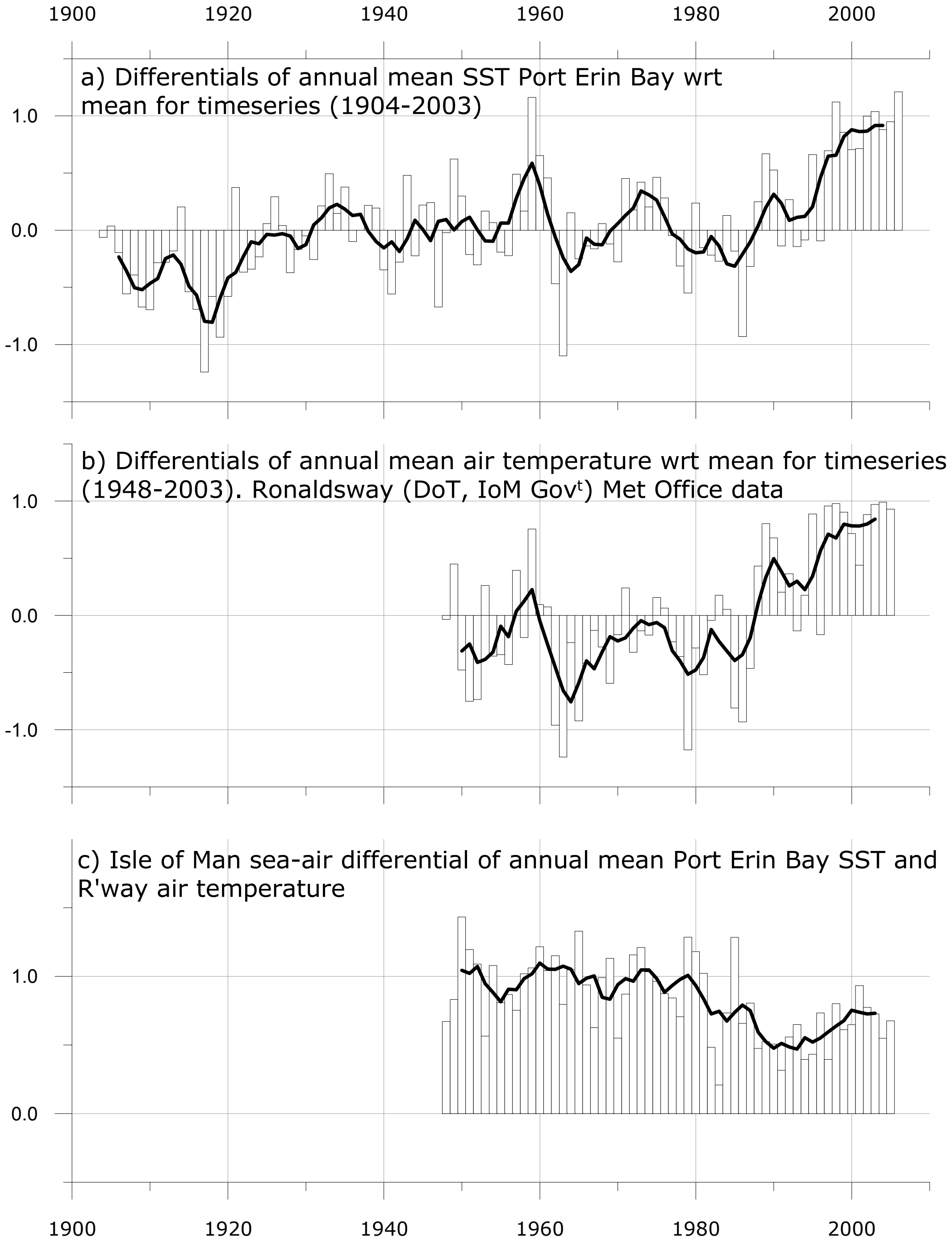

Figure D1. Annual mean sea and air temperature differentials or anomalies. (a) SST Port Erin Bay 1904 – 2006; (b) Air temperature, Ronaldsway Meteorological Office 1948 – 2006; (c) Isle of Man sea-air differentials, 1948 – 2006. Continuous black line represents 5 year running mean.

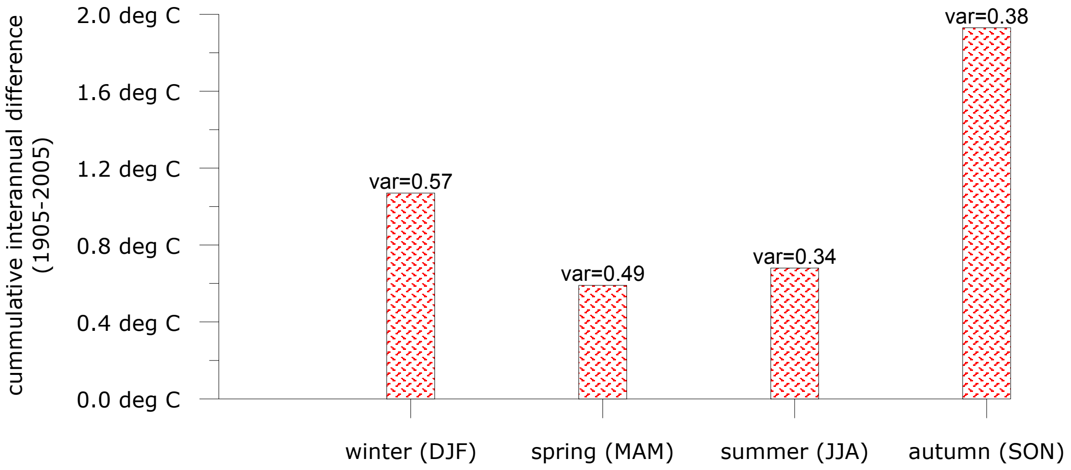

Figure D2. Port Erin Bay sea temperature - cumulative interannual difference for individual seasons with interannual variance.

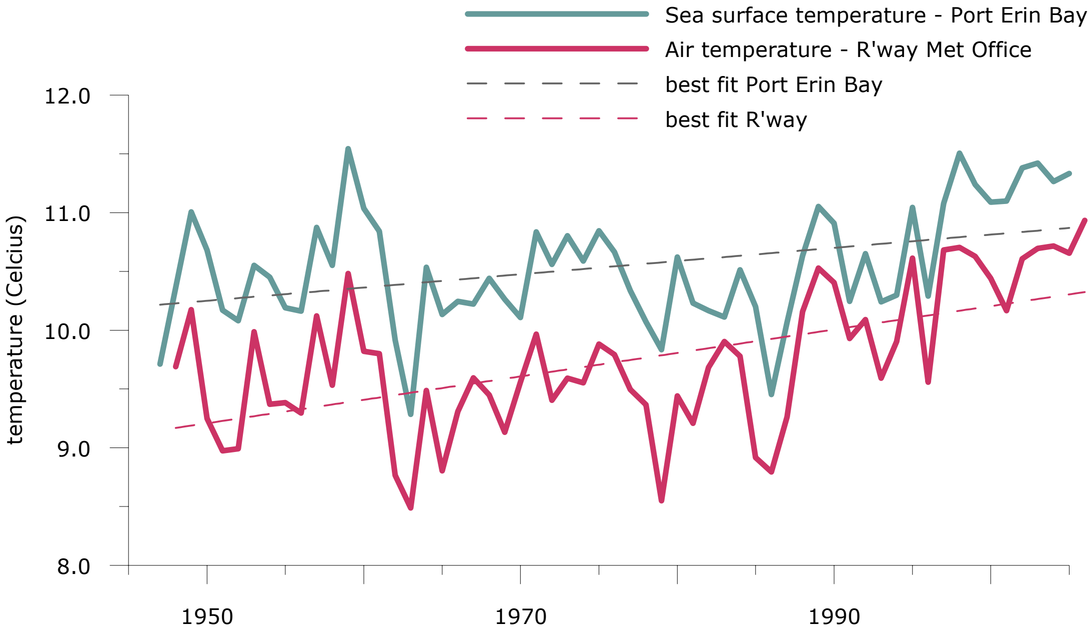

Figure D3. 1948 – 2006 annual mean of Port Erin Bay sea surface temperature and local air temperature as recorded by Ronaldsway Meteorological Office.

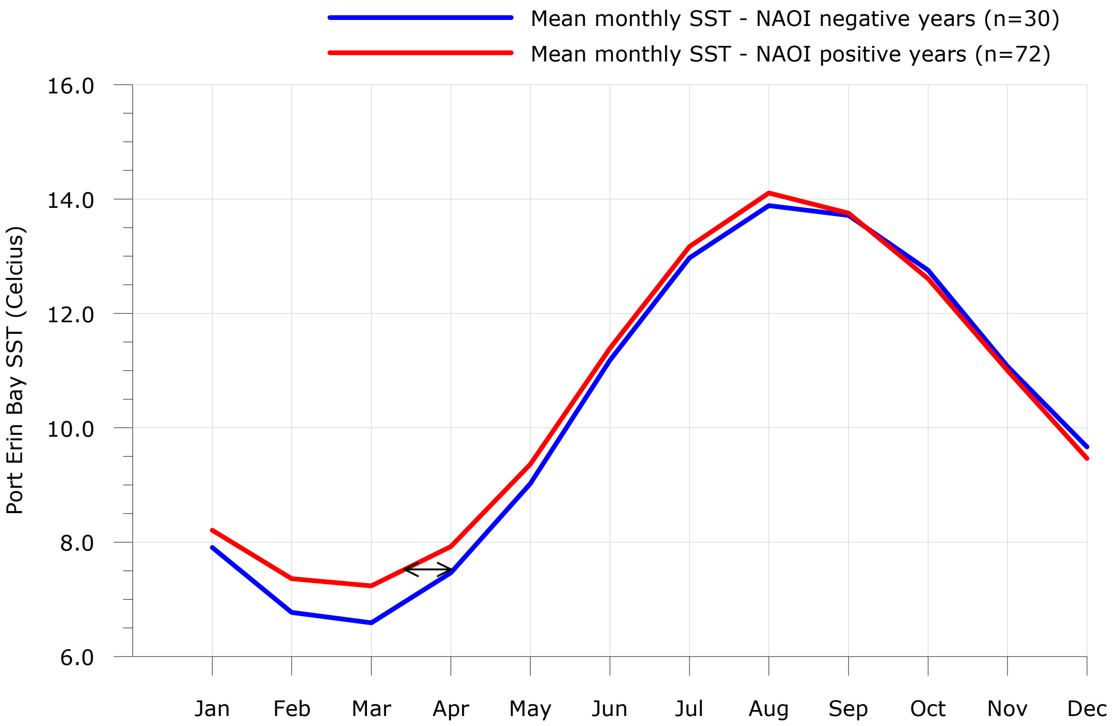

Figure D4. Port Erin Bay, averaged annual cycles for NAOI negative and positive years.

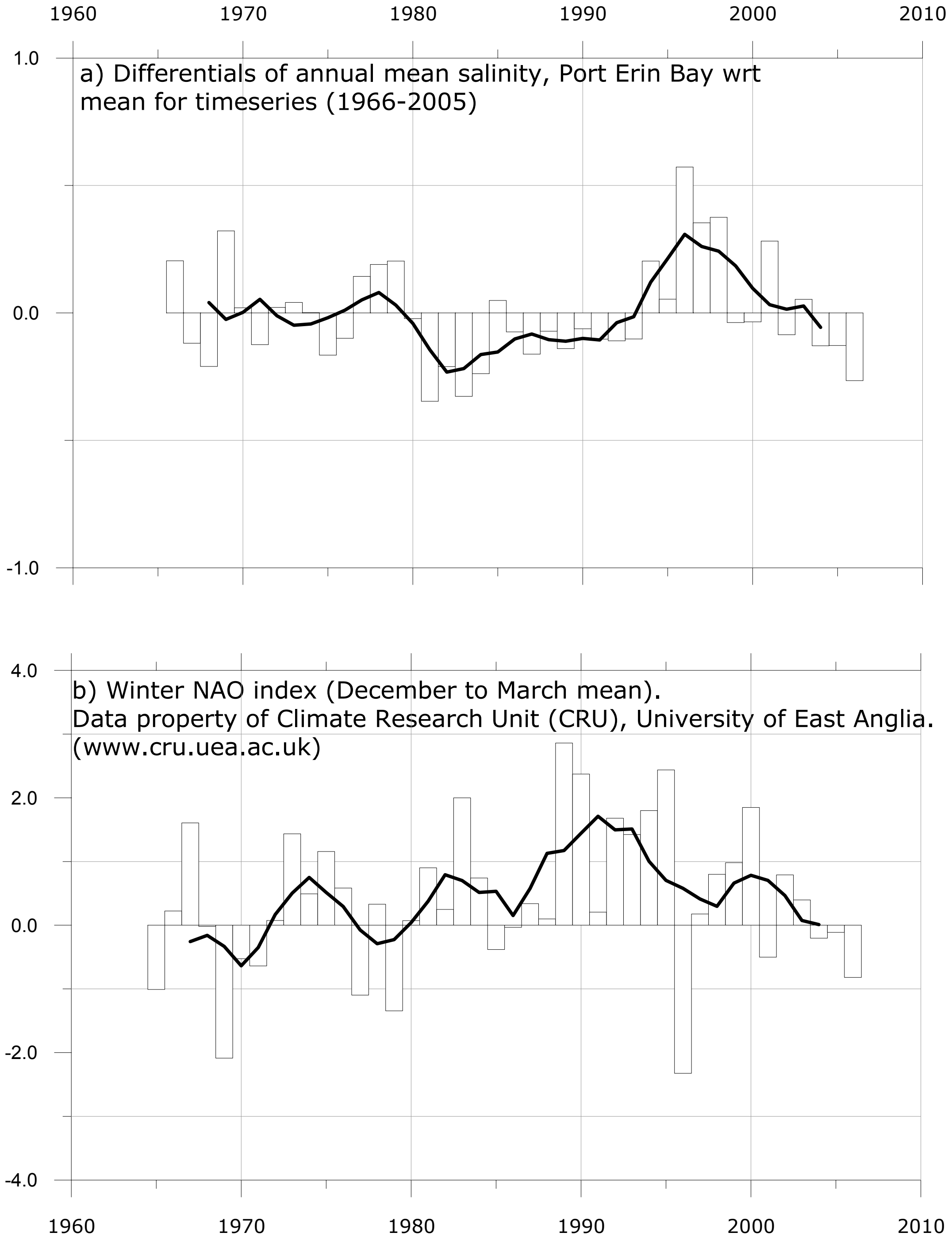

Figure D5. (a) Differentials or anomalies of Port Erin Bay salinity annual means and (b) winter North Atlantic Oscillation winter (December to March) index.

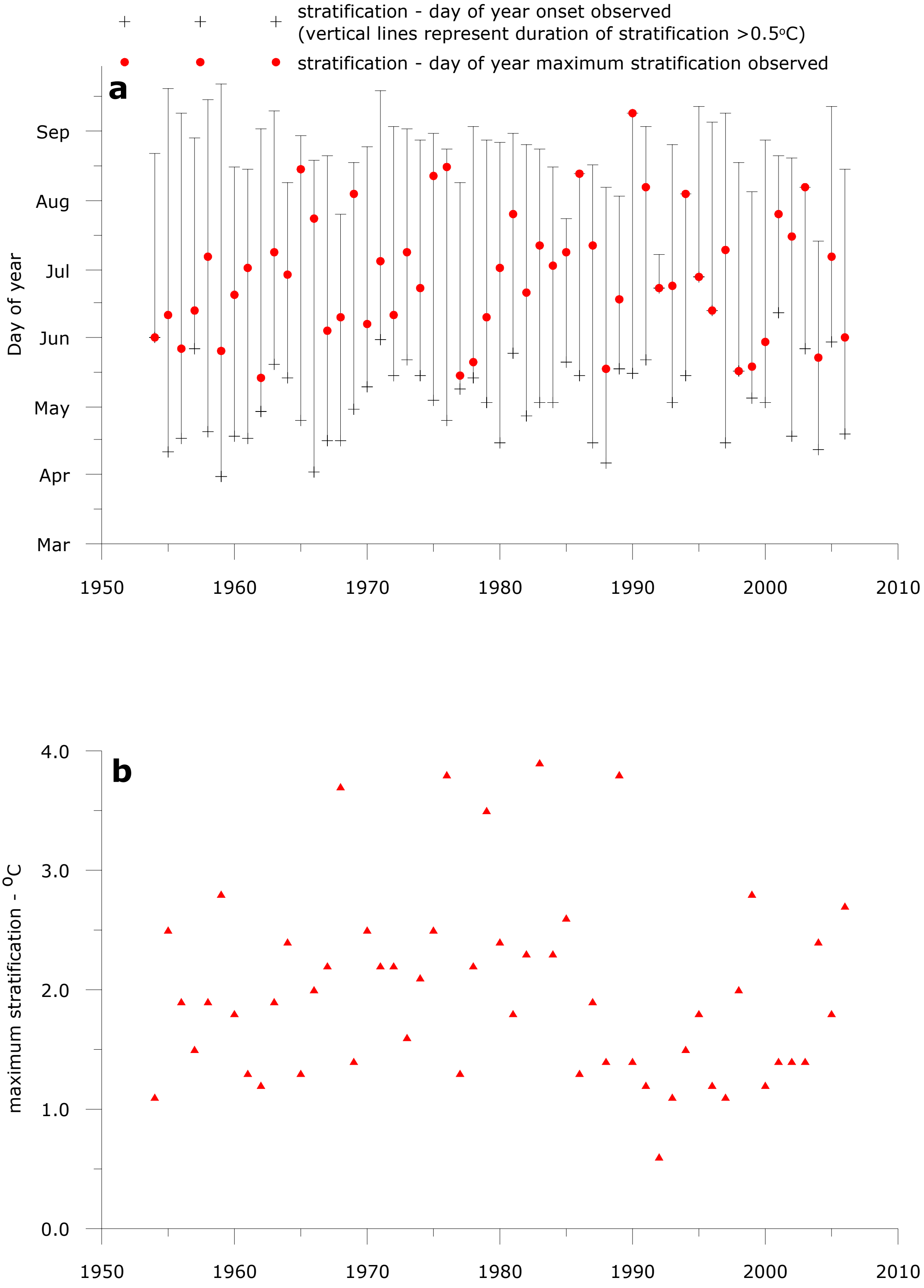

Figure D6. Spring/summer thermal stratification at Cypris. (a) Day of year of onset, maximum stratification and duration of stratification; (b) magnitude of maximum stratification.

Figure D7. Chlorophyll a concentration at Cypris (1966 2006). (a) Maximum (Apr – Aug) recorded concentration; (b) mean summer (Apr – Aug) concentration.

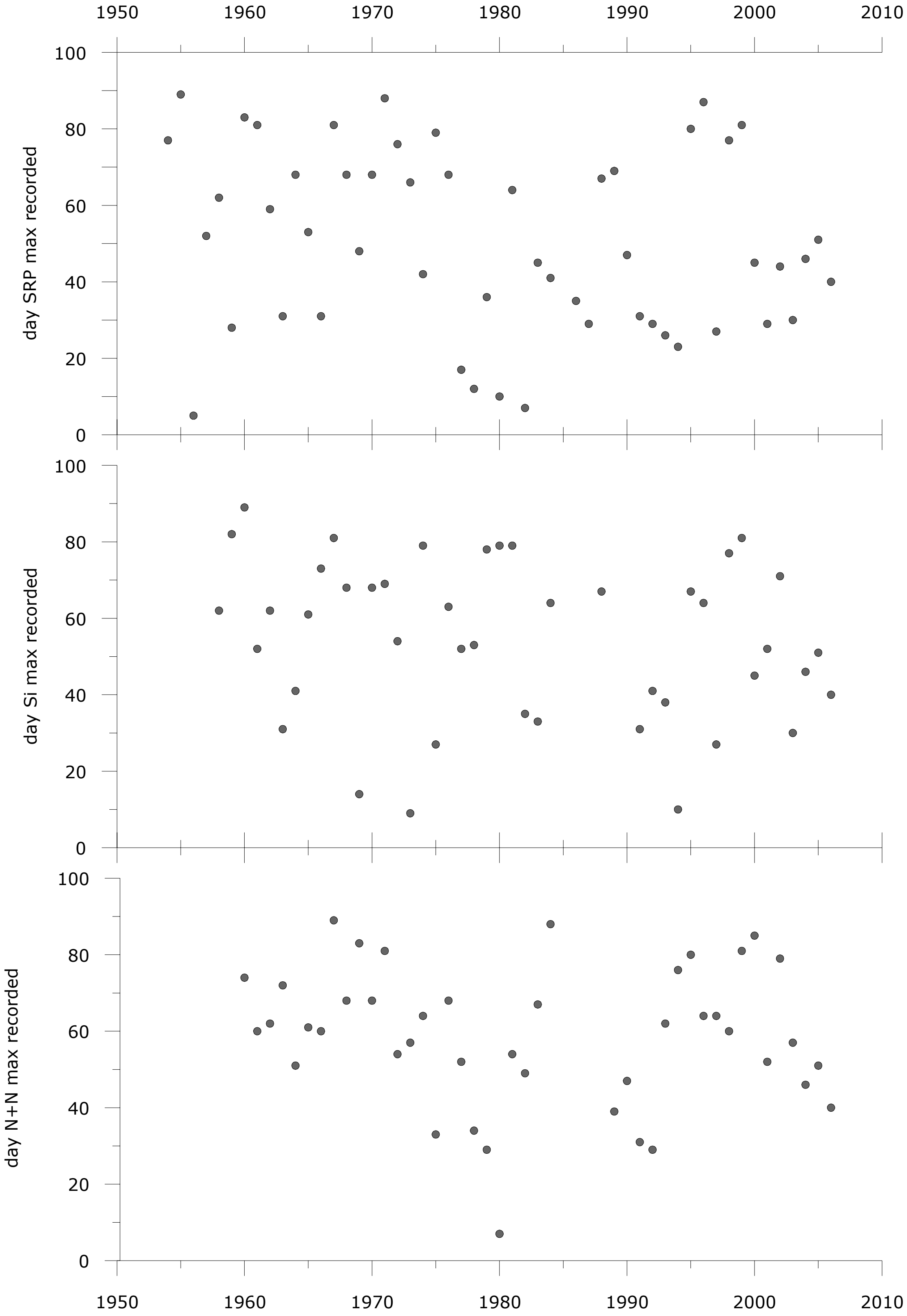

Figure D8. Timing of winter (Jan – Mar) inorganic nutrient maxima at Cypris.

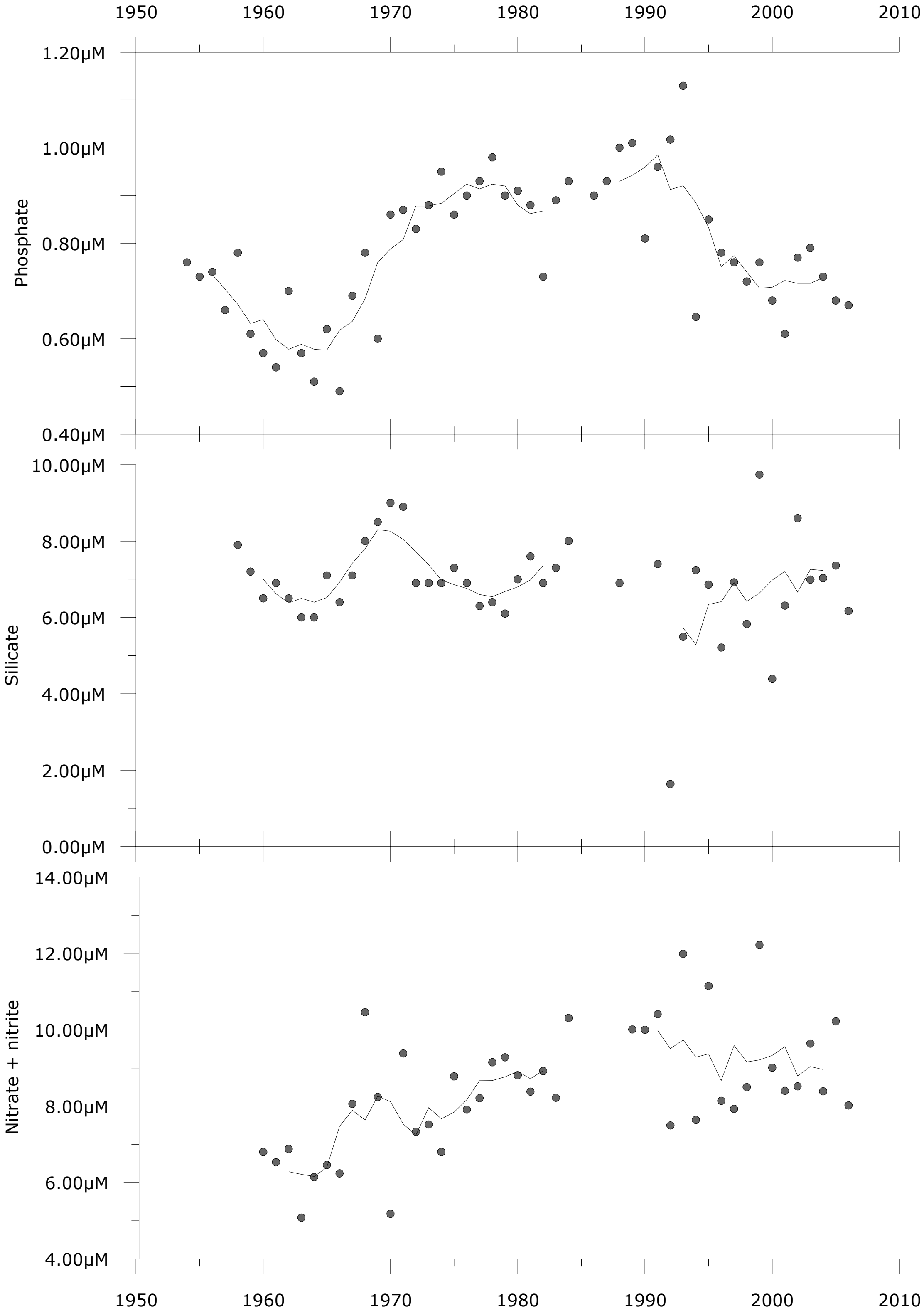

Figure D9. Winter (Jan – Mar) inorganic nutrient maxima recorded at Cypris. Continuous black line represents 5 year running mean.

x	***y***	***r***	R^2	***n***	***P***
Annual mean – PE Bay SST	Annual mean - R'way air temp	0.880	0.775	58	0.01
Local sea-air differential - winter	Year	-0.386	0.149	59	0.01
Local sea-air differential - spring	Year	-0.285	0.081	59	0.05
Local sea-air differential - summer	Year	-0.161	0.026	59	NS
Local sea-air differential - autumn	Year	-0.293	0.086	60	0.05
Local sea-air differential - winter	Winter NAOI	-0.708	0.501	59	0.01
Winter mean PE Bay SST	Winter NAOI	0.338	0.145	102	0.01
Spring mean PE Bay SST	Winter NAOI	0.412	0.169	103	0.01
Summer mean PE Bay SST	Winter NAOI	0.459	0.211	103	0.01
Autumn mean PE Bay SST	Winter NAOI	0.504	0.254	103	0.01

Table D.1. Relationships between Port Erin Bay sea temperature as recorded by PEML, Isle of Man air temperature as recorded by Ronaldsway Met Office and the North Atlantic Oscillation.

x	y	r	R^2	n	P
Winter mean salinity – Port Erin Bay	Winter NAOI	-0.311	0.097	41	0.05
Spring mean salinity – Port Erin Bay	Winter NAOI	-0.415	0.172	41	0.05
Summer mean salinity – Port Erin Bay	Winter NAOI	-0.270	0.073	41	NS
Autumn mean salinity – Port Erin Bay	Winter NAOI	-0.351	0.123	42	0.05
Winter mean salinity – Port Erin Bay	Winter NAOI - negative years	-0.677	0.459	13	0.05
Spring mean salinity – Port Erin Bay	Winter NAOI - negative years	-0.698	0.487	13	0.01
Summer mean salinity – Port Erin Bay	Winter NAOI - negative years		0.000	13	NS
Autumn mean salinity – Port Erin Bay	Winter NAOI - negative years	-0.798	0.637	14	0.01
Winter mean salinity – Port Erin Bay	Winter NAOI - positive years	-0.118	0.014	28	NS
Spring mean salinity – Port Erin Bay	Winter NAOI - positive years	-0.265	0.070	28	NS
Summer mean salinity – Port Erin Bay	Winter NAOI - positive years	-0.179	0.032	28	NS
Autumn mean salinity – Port Erin Bay	Winter NAOI - positive years	-0.152	0.023	28	NS

Table D.2. Relationships between Port Erin Bay salinity as recorded by PEML and the North Atlantic Oscillation.

x	*y*	*r*	R^2	*n*	*P*
Year	Onset of stratification	0.281	0.079	53	0.05
Year	Duration of stratification	-0.417	0.174	53	0.01
Year	Magnitude of stratification	-0.110	0.012	53	NS
Year	Timing of maximum stratification	0.114	0.013	53	NS

Table D.3. Relationships between thermal stratification at Cypris and year.

x	*y*	*r*	R^2	*n*	*P*
Timing within year of chlorophyll *a* maximum	Winter NAOI	0.342	0.117	41	0.05
Magnitude of chlorophyll *a* maximum	Winter NAOI	0.009		41	NS
April to August chlorophyll *a* median	Winter NAOI	0.260	0.068	41	0.10
Timing within year of chlorophyll *a* maximum	Timing within year of winter SRP maximum	0.351	0.123	40	0.05
Timing within year of chlorophyll *a* maximum	Timing within year of winter Si maximum	0.032	0.001	36	NS
Timing within year of chlorophyll *a* maximum	Timing within year of winter N+N maximum	0.161	0.026	37	NS

Table D.4 Relationships between chlorophyll *a* and winter NAOI and between the timing of the summer chlorophyll *a* maximum and the winter inorganic nutrient maxima.

Location	**SRP** µM - P	**Si** µM - Si	**N+N** µM - N	**N:P** molar ratio	**N:Si** molar ratio
Cypris 1961 -1964 - mean winter maxima	0.6	6.4	6.3	10.3	0.9
Cypris 2000 -2004 - mean winter maxima	0.7	6.7	9.6	13.7	1.6
Celtic Sea shelf break*	0.5	2.7	7.7	15.4	2.9
Inshore western Irish Sea (2000 – 2004 DARD data)*	0.8	8.7	12.8	17.1	1.5
Offshore western Irish Sea (2000 – 2004 DARD data)*	0.7	6.6	7.4	10.4	1.1
Eastern Irish Sea (2003 – 2005 Cefas data)*	1.6	12.3	20.0	12.5	1.6

* data reproduced from Gowan *et al*, 2007

Table D.5. Range of winter nutrients in the Irish Sea and at the Celtic Sea shelf break.

x	***y***	***r***	***R^2***	***n***	***P***
Winter SRP maximum - January to March	Winter salinity - median	0.373	0.139	52	0.01
Winter Si maximum - January to March	Winter salinity - median	0.197	0.039	44	NS
Winter N+N maximum - January to March	Winter salinity - median	0.383	0.147	43	0.01
Winter SRP maximum - January to March	Winter NAOI	0.245	0.062	52	0.10
Winter Si maximum - January to March	Winter NAOI	-0.105	0.011	44	NS
Winter N+N maximum - January to March	Winter NAOI	0.322	0.104	43	0.05

Table D.6. Relationships between Cypris winter inorganic nutrient maxima (Jan – Mar), salinity and NAOI.