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Temporal and spatial monitoring of eutrophication variables in CEMP

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Temporal and spatial monitoring of eutrophication variables in CEMP

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Contents

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1 Abstract

The OSPAR Revised Eutrophication Monitoring Programme (ETG 05/3/Info.1-E) requests that nutrient “monitoring should include sufficient samples to confirm that the maximum winter nutrient concentration has been determined”, while *para.* 7 of the Terms of Reference for the preparation of guidance on the spatial and temporal resolution of monitoring for nutrients and eutrophication effects (ICG 003) states that “there are at least nine different water types covered by the OSPAR Maritime Area”…”guidance must, therefore, be at least complex enough to cover each type with sufficient clarity to guide contracting parties in their evaluation of the temporal and spatial coverage required to adequately assess the relevant water body”.

This document summarises the national reports submitted to the OSPAR Intersessional Correspondence Group on Eutrophication Monitoring, and highlights common problems faced in the monitoring of (primarily) inorganic nutrients and chlorophyll. In addition, it presents tests of different approaches to solving the spatial and temporal sampling problems associated with delivering marine eutrophication data.

Based on tests of model data, monthly sampling appears adequate to give a good estimate of annual mean concentrations. Buoy data suggests that this would not be sufficient where there is tidal variability. It was not possible to determine maximum concentrations through a practical ship sampling scheme, or by using extreme value statistics.

The optimum sampling programme to observe rapid events is likely to be a combination of ferrybox systems, which appear to be reliable and give both good spatial and temporal coverage, combined with buoy observations. To ensure data of sufficient quality, these must be controlled against conventional research vessel observations. Research vessels still have a role in seasonal mapping, and in providing data of sufficient quality for trend analysis from a large area. This is likely to remain so, at least until technologies such as gliders and optical nutrient sensors become widely available and capable of delivering reliable, high quality data.

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- CEFAS, for the use of data from the SmartBuoys operated at Warp (TH1), Gabbard and West Gabbard.

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3 Aim

The OSPAR Strategy to Combat Eutrophication seeks to achieve 'a healthy marine environment where eutrophication does not occur' by 2010. According to the strategy, countries should be able to report on the effectiveness of actions taken to minimize the flow of nutrients to the marine environment. To do this requires that it should be possible to indicate which areas are at risk from eutrophication, based on output from their respective monitoring programmes and related evaluation criteria. On the basis of national reports to OSPAR, the Intersessional Correspondence Group on Monitoring (ICG-Mon) is developing general advice on the requirements for temporal and spatial resolution of eutrophication variables in the various OSPAR marine areas.

For each parameter, it is necessary to determine the change in variance with increasing sampling frequency. The sampling frequency must be sufficiently high to allow the maximum concentration to either be observed, or determined. This requires knowledge on the level and duration of the winter nutrient maximum.Because nutrient concentrations also vary spatially, it is necessary to understand over what area a mean or maximum nutrient concentration can be considered to be representative.

These problems have been formulated into the following questions:

1. What does the pattern of winter nutrient maximum/growing season chlorophyll maximum/growing season plankton maximum and autumn oxygen minimum look like?
2. What does the statistical distribution of winter nutrient concentrations looks like?
3. Is it possible to calculate the maximum winter nutrient concentration, even if it cannot be measured?
4. How many data points are necessary to estimate the maximum winter nutrient concentration with x% confidence?
5. How does the timing of sampling affect the calculation of average and maximum values?

6. Can all data be used, or should data be restricted to certain depth intervals?
7. Over which horizontal length scales are data representative?
8. What problems can disrupt these calculations (for example; tides, internal waves, currents etc)?

This report updates the overview of information on national practices for the monitoring of eutrophication variables in CEMP (previously presented in Axe, 2006) based on new information on the web sites ICG Eutrophication Monitoring and ICG Common Procedure. Similarities and differences for the different types of environment (estuaries, coastal waters and open sea) in terms of temporal and spatial variability are highlighted, using examples from different sea areas.

The report aims to make recommendations for the necessary time intervals and spatial scales which should be used for the monitoring of DIN, DIP, chlorophyll, phytoplankton and oxygen in different types of marine environments within the convention area.

Finally, the report recommends statistical methods to evaluate the spatial and temporal coverage of the various national monitoring programmes.

4 National eutrophication monitoring

Previously, in EUC(1) 06/3/3, the eutrophication monitoring programmes adopted by Belgium, Denmark, Germany, the Netherlands, Norway, Sweden and the United Kingdom were summarized, based on documents listed in the Intersessional Correspondence Group on Eutrophication Monitoring document ICG 0000. Since then, national assessments have been submitted describing the application of the Common Procedure. The report from Spain (ICG 00110_ES COMP 2 Report, 2007, referenced as Anon, 2007) includes a description of the national monitoring activities, while the Portuguese report (00102_PT draft assessment Mondego_OSPAR_Mar2007) describes monitoring in the vicinity of the Modego estuary.

Table 5 summarizes the different environments sampled by each country.

4.1 Portugal

Portugual presented a draft assessment report to the Eutrophication Monitoring ICG (00102_PT draft assessment Mondego_OSPAR_Mar2007, referenced as MARETEC, 2007). This report describes the application of the Common Procedure to the Mondego Estuary in north western Portugal. The estuary is covered by 25 sampling stations spaced at approximately 1 km intervals. Observation results were interpreted with the assistance of the MOHID biogeochemical model, developed at the Technical University of Lisbon.

Nutrient loading, DIN, DIP, chlorophyll a, oxygen and organic carbon concentrations were reported based on monthly measurements. Eutrophication status was assessed on the basis of:

- monthly mean nutrient loads,
- winter nutrient concentrations (mean and 90th percentile)
- winter- autumn N/P ratios (mean and 90th percentile)
- maximum (90th percentile) and mean chlorophyll a concentrations during spring and summer
- spring-summer oxygen concentration (mean and 90th percentile)

as well as phytoplankton indicator species, macrophytes, zoobenthos, fish mortality and evidence of harmful algal blooms.

The report indicates that the residence time in the estuary is too short to allow phytoplankton blooms to develop, and the supply of nutrients from land is governed by the operation of the Pranto river sluice. The reported salinity range in the estuary is from 0 to 36, although there is no indication whether stratification occurs in the estuary and if it affects the observation data.

4.2 Spain

The Common Procedure for the evaluation of eutrophication status was first applied in Spain in 2000. No regions were classified as Problem Areas, although the coastal area in the vicinity of Cadiz was identified as a Potential Problem Area. Of the fifteen areas assessed in the second application of the Common Procedure (2006 – 2007) three were classified as Non-Problem Areas, twelve as Potential Problem Areas, and there were no Problem Areas. This generally good status is explained by the exposed nature of much of the coast, the narrow and steep continental shelf and tidal mixing combined with a lack of run-off from land. Eutrophication is restricted to estuaries and bays with restricted water exchange combined with significant human settlements. Along the north coast, wind induced upwelling can raise nutrients up to the photic zone.

Responsibility for eutrophication monitoring in Spain is devolved to the regional administrations of the Autonomous Communities. Five communities have the responsibility for monitoring in the OSPAR area. The monitoring networks consist of 233 stations in total. The report states that spatial coverage is good, although temporal coverage along the Cantabrian coast has only recently been improved.

No information is given on the actual frequency of sampling and only Galicia reports the sampling methods used. In Galicia, these are hose samples from 0 – 5, 5 – 10 and 10 – 15 metres, which are analysed for phytoplankton, chlorophyll –a and nutrients. A vertical plankton net cast is used for a rapid assessment of the phytoplankton community, to warn of the presence of toxic or potentially harmful species. Water bottle samples are used for determination of dissolved organic carbon.

In addition to the sampling carried out by regional authorities, the Ministry of Education and Science's Institute of Oceanography (Instituto Español de Oceanografía) have offshore monitoring data from monthly cruises which started in 1993. These cruises collect data (temperature, salinity and nitrate) from a transect off Santander, and a station off Vigo. These data are reported to ICES. Phytoplankton data are held by IEO in La Coruña, and come from four transects: off La Coruña, Cudillero, Gijon and Santander. Chlorophyll a records extend back to 1989 from one station. (http://www.seriestemporales-ieo.net/en/index.htm)

4.3 Belgium

The report refers to a previously submitted case study (ETGMON/04/3/3) which demonstrated that undersampling of cholorophyll-a in Belgian waters during the spring phytoplankton bloom period could lead to an area being erroneously classified as a non-problem area. The report also highlights two difficulties in sampling eutrophication variables, where:

1. the dominant scales of variability are not always well-known and,
2. sampling strategy is severely constrained by the resources that can be allocated to sample acquisition and processing.

Belgian coastal waters are generally shallow (predominantly 0 – 10 m) and well mixed, due to tidal and wind mixing. Weak stratification may be found near the mouth of the Scheldt estuary (haline) and in the deeper (~40 m) offshore waters during calm warm weather (thermal). This leads to limited vertical variability in the [near] conservative parameters, such as winter nutrient concentration, though even chlorophyll-a and phytoplankton show small vertical variation. As a result, Belgian sampling takes place at a single depth. This is usually 3 metres, which is expected to give a ‘worst case’ result for phytoplankton and chlorophyll-a, and even DIN and DIP.

Horizontal variability is an issue in Belgian waters, due to the significant point sources (major European rivers) combined with the effects of wind and tidal advection. This variability is usually large scale. Some small scale variability exists around small bathymetric features, and close to isolated minor discharges.

Shipborne sampling occurs at fixed stations within the Belgian continental shelf. Twenty stations are used for the national eutrophication assessment. Using underway fluorimetry measurements, some chlorophyll variability has been observed on scales smaller than the measuring grid.

Some assessment of the spatial coverage of the monitoring programme has been using satellite data. In practice, because of cloudiness problems, a new complete satellite image is available once a week during the spring bloom season.

The monitoring programme is relatively poor inshore, because of draught limitations of the research vessel. The offshore region is considered to be well covered from with regards to eutrophication.

Short term temporal variability in DIN, DIP and chlorophyll may occur because of advection due to tidal currents. This problem is minimised by binning data into larger areas. Any local nutrient ‘hotspot’ is expected to remain within a binned area, and be observed. Alternatively, the variability may be reduced by analysing a five year time series from a specific point.

Variability in chlorophyll-a concentration can be as much as 50% from day to day at a fixed point. The exact scales of both temporal and spatial variability are not well known. It is considered that the monitoring of phytoplankton species, in particular *Phaeocystis Globosa*, is probably adequate for the purposes of the OSPAR Comprehensive Assessment.

4.4 The Netherlands

The Dutch continental shelf is divided into seven zones. The four inshore zones cover the Western Scheldt and Ems-Dollard estuaries, the Wadden Sea and coastal waters (shorewards of the mean 34.5 isohaline). The offshore region comprises the Southern Bight, the Oyster Ground and Dogger Bank. Mean winter nutrient concentrations are reported for each area, based on monthly sampling (December – February). Winter sampling is at one depth only (1 metre), as the area is not then stratified. Total, dissolved and particulate organic carbon are observed. Chlorophyll a is assessed using the mean and 90^{th} percentiles of data collected twice monthly between March and September, with sampling at three depths: surface, mid-water and bottom. Phytoplankton indicator species are observed twice monthly throughout the year at the same depths. Oxygen concentrations are measured throughout the year at two depths: 3 metres above the bottom and 1 m below the surface. The minimum observed concentration is used as the assessment parameter.

Between 1991 and 1998, additional samples were taken for the analysis of DIN and DIP. These data were analyzed together with those from the standard monitoring programme, to see if their inclusion in trend analysis led to a significant improvement.

A significant improvement was not seen when including the additional data. Given the expected size of changes in DIN and DIP concentrations, between 25 and 40 winter DIN samples are needed each year to detect a change of 10 – 15% per year. Between 30 and 35 winter DIP stations are required to identify the same size change in DIP concentration. On the basis of this analysis, the existing Dutch monitoring programme is considered to be adequate

4.5 Germany

The German Bight consists of wide shallows, with inter-tidal mudflats and barrier islands, cut by the valleys of the rivers Ems, Jade, Weser and Elbe. These deliver significant amounts of fresh water, and nitrogen. The boundary of the Water Framework Directive lies about 35 km offshore, while marine conditions (annual mean salinity greater than 34.5) lie approximately 100 km offshore. The Wadden Sea is considered to consist of about 12 different regional water type/water bodies.

The German National Monitoring Programme (Bund-Länder- Messprogram, or BLMP) for the North Sea is compiled by the Bundesamt für Seeschifffarht und Hydrographie (BSH) using data collected by both monitoring activities (collected by the German Oceanographic Data Centre, DOD) and research projects.

Nutrient sampling occurs in most of the OSPAR areas – that is estuaries (including the Wadden Sea), coastal and offshore waters.

In the Elbe, Weser and Ems estuaries, sampling occurs between 6 and 26 times per year. Over the tidal flats, sampling occurs only 2 – 4 times per year, while at Helgoland sampling occurs on every weekday. The offshore area is sampled once per year, during winter. BSH have recently started a summer cruise covering a large area of the North Sea. Additional nutrient measurements are made during the ICES Young Fish Survey, and during the summer fish survey.

Inorganic nutrients are measured in the surface waters (together with salinity and temperature). Analyses by ARGE Elbe and ARGE Weser also include total nitrogen. The BLMP operational monitoring is summarised in Table 4.

Historical data availability in the offshore region is relatively poor. Between 1980 and 2001, there is an average of only 5 measurements per year in each of the 700 km^2 grid cells that are used for data averaging.

Chlorophyll measurements in estuaries and coastal waters stopped in 1997. Prior to this, observations were made during the growing season (March – October). In the Wadden Sea, sampling started in 1988, and reached 50 stations per year before sampling stopped.

Inorganic nutrient data were sampled up to 80 times per year in the estuaries, though this has recently been reduced to around 30. The 12 water bodies of the Wadden Sea are sampled less than 40 times per year (total). Regular monitoring of the remaining coastal waters started in 1985 and is restricted to about 20 samples per year.

Total nitrogen and phosphorus has been measured in the estuaries and Wadden Sea. Approximately 100 samples per year are taken in the estuaries. Including data made available from research cruises, about 50 samples per year come from the Wadden Sea. There are very few total nitrogen or phosphorus measurements from offshore.

Data were analysed based on annual mean nutrient concentration, to reduce the variability caused by local run-off variability. Annual means and standard deviations were calculated based on weekly or daily measurements. Annual means showed significant decreasing nutrient trends from all rivers from 1977 to 2001, although trends during the 1990s were not significant. In estuaries, data were corrected for salinity variations using mixing diagrams. Data were analysed year by year, and the resulting mixing diagram gradients plotted against time. Linear regression indicated that the decrease in total nitrogen was significant for the Elbe and Weser. The decrease in total phosphorus was significant for the Weser. In the Ems, there was a significant increasing trend in total phosphorus. A similar analysis was carried out on data from the Wadden Sea and coastal waters. A weak (non-significant?) decreasing trend in both total nitrogen and total phosphorus could be identified in the waters off Lower Saxony. There was also a general decrease in winter DIN concentration. The high variability of annual slope estimates did not appear to be related to variability in run-off, or to another nutrient variability.

The authors conclude that winter nutrient data are insufficient to allow trends to be determined in open water, because of the high variability. Only by comparison with data from 1936 can significant differences be detected.

Standard deviations of annual total nutrient concentrations exceeded 100% [of the mean] immediately offshore of the rivers. Even away from the rivers, they still exceeded 40%. The variability of winter DIN and DIP was similar. This makes the determination of trends extremely difficult.

In the stratified summer waters of the the deep Elbe valley, high frequency monitoring of organic, inorganic and particulate nutrients during the growing season is necessary for source apportionment. The monitoring programme does not include samples that are sufficiently close together to resolve the presence of strong gradients, so is not considered adequate to meet the JAMP requirements. These requirements are fulfilled for chlorophyll in the Wadden Sea and at some near coast stations. High resolution phytoplankton observations have been made in research projects. These showed great spatial variability in chlorophyll concentration, such that an estimate of the spatial mean concentration had a standard deviation of greater than 70%.

4.6 Denmark

The hydrography of Danish marine waters varies from shallow, brackish semi-enclosed bays with poor water exchange, to open sea areas with marine conditions and short residence times. The offshore region also varies from brackish to marine. Phytoplankton growth is nutrient limited from late winter to late autumn, and analyses of data from Danish fjords show a close correlation between nutrient concentrations and changes in the biology. There is also a significant correlation between nutrient inputs and their concentration in coastal waters. Several fjords act as nutrient filters, retaining nitrogen but exporting phosphorus to the neighbouring marine waters. Several fjord systems suffer seasonal anoxia, releasing phosphorus from sediment to the water column.

Seasonal variation is large giving rise to the need for frequent monitoring to determine nutrient mass balances. Primary production in fjords is often phosphorus limited in early spring, though in general plankton biomass is closely regulated by nitrogen availability, and a 50% reduction in nitrogen concentration results in a 25% reduction in chlorophyll concentration. Eutrophication monitoring is defined through the NOVANA programme, which also describes Danish monitoring requirements in terrestrial and aquatic environments.

The NOVANA programme runs from 2004 – 2009. Compare to previous programmes, the monitoring of nutrients and the effects has been reduced. The statistical review of the previous monitoring programme recommended that:

> ‘A number of marine stations should be continued in order to ensure sufficiently long time series to be able to demonstrate any trend. In general, approximately 30 years of monitoring will be needed to demonstrate a trend of the order of 1 – 2% per year.’

A need for improved climate corrections was also identified, further reducing the variance of time series which in turn reduces the amount of data needed to allow trend determination. Monitoring is divided into two classes: Intensive monitoring occurs frequently at a small number of stations. ‘Frequent’ means once or several times per year. This monitoring is intended to determine the seasonal and interannual variability, and to determine the relationship between pressure and state. Extensive monitoring occurs nationwide, and occurs every third or sixth year.

The NOVANA programme description (Part 1) indicates some concern that the programme may lead to some shortfalls in Denmark’s compliance with relation to HELCOM and OSPAR, although whether this is regarding eutrophication assessment is not clear. The marine monitoring programme now covers 14 intensive offshore stations. Summer monitoring cruises in the Skagerrak and North Sea have been discontinued. Offshore monitoring is almost exclusively carried out by NERI, while coastal monitoring is carried out by local county administrations.

Part 2 of the report describes the marine programme in more detail. In coastal waters, eutrophication monitoring is carried out in 34 areas (35 according to Table 9.4, though with 0 or 1 stations per area). These stations are monitored 20 – 33 times per year, with samples taken from 1 – 4 depths. Twenty areas have been identified for flux measurements, for example to look at the exchange of nutrients between coastal waters and fjords. These are sampled at one or two depths, between 11 and 47 times per year. Offshore, 26 stations are visited 5 times per year, with samples taken from between 3 and 23 different depths. In addition, one winter cruise each year visits 50 stations for nutrient mapping. Eleven additional marine stations are monitored by local authorities, at up to 10 depths, between 6 and 47 times per year. These activities are supported by numerical modelling efforts and the operation of six automatic buoys.

Table 9.26 suggests that NERI do not believe that the offshore monitoring programme is adequate to meet the national obligations and requirements described.

4.7 Norway

Reference levels for nutrient concentrations in marine and brackish waters are published centrally by the National Pollution Board. The sampling strategy is based on local conditions, and so varies from station to station. In general however, sampling takes place at standard depths of 0, 5, 10, 20 and 30 metres. Integrated sampling is also used: typically 0-2 m or 0-10 m. Standard depths are used when sampling nutrients. The uncertain depth associated with the chlorophyll fluorescence peak makes this unsuitable for chlorophyll analysis. At Flödevigen, an open bay in the northern Skagerrak, it has been found that twice weekly sampling is necessary to get a reasonable record of the annual phytoplankton and chlorophyll concentrations. This result is site specific however, and cannot be immediately assumed to suit other locations.

The report recommends the use of standard depths, but suggests their application should be sufficiently flexible to adapt to local circumstances, such as the presence of a 3 metre thick surface layer. A sampling frequency of every second week is recommended for inorganic nutrients in winter and during the growing season. Coefficients of variation were used to understand whether, or when, sampling was adequate to the calculation of trends. The high variability in the chlorophyll record requires both a higher temporal and spatial resolution.

The second report makes use of hydrographic and nutrient data collected along a transect across the Skagerrak, as well as numerical model results. Data were presented showing the apportionment of variance into different timescales (from less than 3 months, 3 – 12 months and inter-annual). Higher frequency data obtained from a mooring were also analysed, showing that most of the signal variance was associated with longer time periods (> 28 days). This result was confirmed by analysis of data from a 3D hydrodynamic model. The report also refers to a study by Ottersen et al (1998), which reported on a temporal correlation analysis of stations in the Skagerrak.

4.8 Sweden

The Swedish report presents a brief overview of the National and Regional monitoring programmes in the Skagerrak and Kattegat. National monitoring cruises take place monthly, visiting a mixture of coastal and offshore stations, including a transect of stations across the Baltic current as it enters the Skagerrak. Additional chlorophyll measurements are taken from 2 m at the Läsö E buoy in the northern Kattegat, for calibration purposes. Measurements taken at Släggö, a coastal station, and Anholt E, in the southern Kattegat occur twice a month. CTD profiles are taken at all stations, and at all stations bar two, samples for the analysis of inorganic and total nutrient concentrations are taken from standard depths. Chlorophyll concentrations are now analysed at all stations, though this was not the case prior to 2006. In addition to these monthly cruises, more intensive sampling occurs in winter for nutrient mapping, in autumn for mapping the extent of low oxygen levels, and in association with the ICES Young Fish surveys.

Monitoring of nearshore, estuarine and fjord stations is organised by Vattenvårdsförbund. These are associations of regional stakeholders, such as county administrations and the larger polluters. These organise monthly sampling at 14 stations within and north of the Göta Älv, the river with the largest catchment in Sweden, which enters the sea close to the southern boundary of the Skagerrak. An additional station is taken south of the estuary, as a form of control. Along the Swedish Kattegat coast, monthly measurements are made within fjord systems and in the large bays in the south of the region (Laholm Bay and Skälderviken). Nutrient loads entering the region are obtained by monthly observations in the Sound, which transports Baltic water into the Kattegat.

Statistical analysis of long time series of data, using the Mann-Kendall tests, showed that including full years of data, rather than simply winter nutrient concentrations, increased the statistical strength of the trend estimates. A problem with this approach was identified however: In summer, when both inorganic nitrogen and phosphorus concentrations are very low, correcting for salinity generates unreasonable values.

Analysis of the spatial resolution of the data set took the form of probability mapping. This involved dividing the study area up into several areas, based on prior knowledge of the hydrography and bathymetry, and then testing to see if each area differed significantly from the others for each parameter. The monitoring programme should have at least two stations in each sub-basin.

4.9 United Kingdom

The United Kingdom presented a case study on winter DIN concentrations and chlorophyll in the Thames region, and a report on annual cycles of nutrient concentrations in Scottish waters. Only the cover page of the Scottish report was available.

Data come from two CEFAS SmartBuoys, located offshore of the Thames. In addition, spot data, gathered from ships were collected at a range of sites. Data come from the National Marine Monitoring Programme, the Environment Agency Monitoring Programme (coastal and estuarine data) and CEFAS research.

The original data analysis involved the determination of mean winter DIN levels. Trends were determined by linear regression. Significant differences between slopes were tested for using modified T-tests. Trends were accepted when slopes differed significantly from 0 ($P < 0.05$). Analysis of variance was used to identify statistical differences between different periods.

In the reanalysis, the study area was divided into three distinct salinity zones. Data were tested for skewness using Box plots. Skewed data sets were transformed logarithmically to reduce the impact of extreme values, and the means and 95% confidence levels were calculated from the transformed data.

Mixing diagrams of chlorophyll suggest that these values should either be normalised to a reference salinity, or binned by salinity, before a reasonable assessment can be made. In the coastal Thames assessment, the variance explained by regression against salinity was poor for the data set as a whole, and it was recommended that each year of data be analyzed separately, and then a mean winter DIN level (corrected to a reference salinity) be generated based several years of data.

Experiments with data buoys in the coastal and offshore Thames highlight the more intense spatial variability found inshore, or alternatively, the more homogenous offshore conditions. Thus in the offshore southern North Sea, a limited number of stations is considered sufficient. In coastal areas, the higher variability demands a different approach. The authors propose that in coastal waters, where variability is high, the chance of a value occurring which exceeds a certain threshold is high – even though that value may not be representative of the area as a whole. It may therefore be worth reducing sampling effort in this area, and instead concentrate on sampling in the region of lower variability, where additional samples have a meaningful effect on the confidence limits of the resulting data.

In regions of strong spatial variability with high winter nutrient concentrations, it is important to sample across the entire salinity range. Failure to do this can lead to strongly skewed populations. A suitable spread of observations may be achievable by sampling a single point over an entire tidal cycle. Nutrient measurements from the SmartBuoys indicated that much of the sub-daily variability was attributable to tides

4.10 Similarities and differences of the various environments

Estuaries

In Spain and Portugal, low rainfall means that nutrient discharges to estuaries from agricultural run-off are less of a problem than discharges from point sources. Around the North Sea, all countries report problems measuring at sufficient spatial and temporal scales to resolve the effects of salinity gradients, river plumes and topographical effects. In Germany, inorganic and total nutrients were measured 80 – 100 times per year in estuaries, although this has since been reduced. Belgian sampling occurs at 3 metres depth, which is considered to give a "worst case" picture of nutrients and chlorophyll.

Coastal waters

Spanish coastal waters were considered in general to be problem free, with signs of eutrophication constrained to a few bays with poor water exchange. The remainder of the coastal environment benefited from the lack of run-off from land, and good exchange with the offshore.

Around the North Sea, horizontal variability causes problems. In the UK, the decision was taken to avoid sampling where the variability was large, as it could not be known how representative individual values were, and they may have an unreasonable effect on any annual mean. Belgium combines underway chlorophyll observations with point measurements to get some idea of small scale variability, and complements ship borne observations with satellite based estimates of chlorophyll-a during the growing season. To avoid the effects of 'hot-spots' data are spatially averaged, or a minimum 5 year record is considered. A particular problem in Belgian waters is that the depth is frequently insufficient to allow access to oceanographic vessels. Both Germany and Denmark consider their monitoring programmes to be inadequate for their international obligations.

Offshore waters

While North Sea countries reported that variability was reduced offshore, so is the frequency of ship-based sampling. The UK reports more homogenous conditions in the southern North Sea, reducing the number of stations needing to be sampled. BSH (Germany) carry out offshore sampling ine winter and summer, with spatial sampling every 5 years. The German report however concluded that variability was so high in open water that winter nutrient data were not sufficient to allow trends to be determined.

Several countries maintain high frequency nutrient and chlorophyll measurement platforms in coastal and offshore areas. The UK Smartbuoy system operates in the outer Thames, BSH operates the MarNet system of platforms at Ems and Deutsche Bucht.

5 Time intervals for monitoring DIN, DIP, Chlorophyll-a, phytoplankton and Oxygen

This chapter describes the tests carried out to determine suitable temporal and spatial scales for monitoring. These tests were carried out using data supplied by CEFAS (UK), MUMM (BE), GKSS (DE) and SMHI (SE).

5.1 Data availability

Time series of inorganic nitrate, ammonium, DIP (silicate) chlorophyll-a and Phaeocystis biomass were made available by MUMM from three stations in the domain of the 3D biogeochemical model MIRO&CO (described in Lacroix et al, 2007). Daily values from one depth were provided, being representative of the entire water column (as discussed in 1003_BE monitoringpractice 16_01_2006).

Total oxidised nitrogen (the sum of nitrite and nitrate) data were made available from the buoys at Gabbard, West Gabbard and Warp by CEFAS (Greenwood, pers. comm.). These data had a temporal resolution at best of 20 minutes.

Ferrybox data (Petersen et al, 2003) were made available by GKSS on the routes between Cuxhaven and Harwich (2002 - 2005) and Cuxhaven and Immingham (September 2006 -). These systems provide data on (among others) chlorophyll fluorescence, and algal classes (from a multi-fluorescence analyser). Nutrient data had not yet been quality controlled, so were not available. Chlorophyll fluorescence data were also available from 1992 – 2002 in the Kattegat and Skagerrak from U/F Argos.

5.2 What are the patterns of the winter nutrient maximum/growth season chlorophyll & phytoplankton maxima, and autumn oxygen minimum?

Figure 1 shows an example of the annual cycles of the sum of nitrate and ammonium (as a proxy for DIN) and DIP generated by MIRO&CO for the three stations representing the nutrient gradients from coastal to offshore. Data are shown for one year only. Both parameters show a decrease in variability (measured using the ratio of variance to mean) of an order of magnitude with increasing offshore distance. DIN exhibits more variability than DIP. The winter nutrient maximum is reached for only a short period at the end of February at all stations. At the coastal and central sites, a secondary maximum occurs after the the onset of the spring bloom. This may be due to land run-off, as the same signal is not seen offshore. DIP data do not show a clear winter nutrient maximum near the coast or in the central area. Offshore, maximum DIP concentrations in 1994 occurred during October so would have been missed by conventional December-January-February assessment of winter nutrient concentrations.

Figure 2 shows the annual cycle for total oxidised nitrogen (the sum of nitrate and nitrite) observed by the CEFAS buoy at the Warp site. These data exhibit a more conventional winter nutrient maximum than is observed in the Belgian data, though there is more high frequency variability apparent than is seen in the daily Belgian model data – in part due to the measurements resolving tidal influences (Figure 3). The Warp data show that in 2005, the nutrient maximum occurred in April.

Chlorophyll observations were available from the CEFAS Smartbuoys (Figure 4) and from the GKSS ferrybox operating Cuxhaven - Harwich, and Cuxhaven – Immingham (Figure 5). Chlorophyll data from the Smartbuoy showed the short duration of the spring bloom. It is not possible to see if bloom magnitude was consistent from year to year. A pronounced autumn bloom was not apparent in these data. The ferrybox data indicates the spatial variability of the spring bloom – varying an order of magnitude in 2005 between 2-3°E and 5-6°E. The duration of both the spring and autumn blooms were apparent, as is the variability and timing of the bloom between years.

High frequency oxygen data are seldom available. BSH were approached for data, but did not feel the data quality the MARNET stations at Ems or Deutsche Bucht was sufficient to allow them to be used. Near surface oxygen data were available from the CEFAS buoy at WARP (Figure 6). Despite these data coming from the surface

5.3 What is the statistical distribution of nutrient data during winter?

Distributions of winter nutrient concentrations were plotted for each site. Examples for DIN at the inshore and offshore Belgian stations are shown in Figure 8 and Figure 9. Total oxidised nitrogen from West Gabbard and Warp are presented in Figure 10 and Figure 11. Winter was defined as being December – February, inclusive. The shape of the distributions varied from winter to winter. Offshore the distributions were positively skewed, so may be better described by a log-normal, rather than normal distribution.

The growing season was identified as between April and November. Histograms showed the data to be positively skewed. Skewness was reduced by plotting the histogram of the logged concentrations (Figure 12) but the resulting distribution were still significantly different from a normal distribution (Kolmogorov-Smirnoff test and Lilliefors test, both at 0.05 significance level).

5.4 Is it possible to calculate the maximum winter nutrient concentration even if it is not possible to measure it?

The annual nutrient cycles indicate that the winter maximum nutrient concentration is of such short duration as to be practically impossible to observe from monitoring ships. It is common to use extreme value analysis to estimate the magnitude of rare events based on the characteristics of the observed data distribution. To test whether the method showed promise for nutrient observations, the following tests were completed:

Daily estimates of nutrient (nitrate, ammonium, orthophosphate and silicate) were subsampled from the MIRO&CO biogeochemical model, to simulate monthly, twice-monthly, weekly and twice weekly sampling. Data were tested from the coastal, central and offshore locations and were fitted to a Weibull distribution. The cut-off value of the distribution was tuned to the input data, through optimising the coefficient of determination (R^2) value. The quality of the prediction was assessed by use of a cost function:

$$\cos t = \frac{abs(N_{predicted} - N_{MIRO\&CO})}{\sigma}$$

$N_{predicted}$ and $N_{MIRO\&CO}$ are the maximum nutrient concentrations predicted by the Weibull distribution and the MIRO&CO model respectively, σ the standard deviation of the data. Tests were repeated up to 5 times for each sampling schedule, using slightly different input data obtained by shifting the subsampling by 1 day.

Tests were then repeated using only winter data (December to February). These tests included sampling on alternate days.

Tests were repeated for each year.

The tests were unsuccessful. It was rare that the cost function was less than 1 (i.e. that the estimated concentration was within one standard deviation of the model value). Best results were obtained using daily observations (as expected) or from alternate days sampling, but even this was not consistently reliable for all years.

5.5 How many data points are necessary to make an assessment with x% confidence?

This is a problem, as observation data do not appear to fit to a standard distribution, and the data distribution is not constant from year to year. A better approach may be that outlined in 5.6.

5.6 How does the timing of sampling affect the calculation of the average and maximum values?

The influence of different sampling regimes on estimates of mean and maximum concentrations was tested for nitrate, ammonium, orthophosphate, silicate, chlorophyll and phaeocystis, using the Belgian model data from MIRO&CO.

For each station (coastal, central or offshore) and parameter, the annual maximum and mean concentration was calculated, as was the standard deviation. The time series of daily concentrations were then subsampled according to different sampling programmes. The programmes used were:

- 4 x per year (quarterly)
- 12 x per year (monthly)
- 24 x per year (twice monthly)
- 52 x per year (weekly)

- 104 x per year (twice weekly)
- 183 x per year (alternate days)

Each sampling was repeated five times, with the actual sampling time randomized, so the sampled values could vary by up to a week.

On the basis of the subsampled data, the annual mean and the annual maximum concentrations were estimated. A cost function was used to describe the quality of the estimate in terms of the standard deviation of the whole year of data. The results for the estimate of the mean are presented in Figure 13 to Figure 15 and maximum in Figure 16 to Figure 18.

Estimates of the annual mean concentrations do not appear to pose a problem for shipborne observations, if the sampling frequency is better than or equal to monthly. At this frequency, estimates of the annual mean concentration are of the order of 0.1 standard deviations from the actual mean. This result appears valid for each of the modelled stations, from coastal to offshore.

Reliable estimates of the maximum concentration require more sampling effort. Offshore, estimates of the maximum nitrate concentration require weekly sampling if the result was to be within 1σ of the annual maximum. Estimates of the maximum chlorophyll concentration only came within 1σ with sampling on alternate days.

5.7 Can all data be used, or should they be restricted to specific depth intervals?

Data from CEFAS, MUMM and GKSS were all from single depths, near the surface. In Belgian waters it was explained that stratification is seldom important except near the Schelde estuary, or offshore during summer. Where stratification occurs, monitoring should describe both activity in the euphotic zone and processes in the lower layers. Deeper water is more prone to problems related to hypoxia, and is also a nutrient bank, supplying nutrients to the euphotic zone when stratification breaks down in the autumn, as well as trickle feeding them across the pycnocline during the growing season.

To determine suitable vertical intervals for monitoring, cross correlations or semivariograms can be used. Figure 19 shows the cross correlations between surface observations from Anholt E., in the southern Kattegat, and observations taken from the 'standard' Kattegat depths[1]. The southern Kattegat is permanently stratified due to the Baltic outflow. The halocline occurs at about 15 metres, although this varies depending upon the state of the internal tide. Parameters tested were temperature, salinity, oxygen, orthophosphate, total phosphorus, nitrite, nitrate, ammonium, total nitrogen, dissolved inorganic nitrogen, silicate and chlorophyll. Observations from 1999 to 2007 were used.

[1] Standard depths in the Kattegat are 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80 and 90 metres. The water depth at Anholt E. is 55 metres

The degree of correlation between different layers varied for different parameters, although the common assumption of assessing data from 0 – 10 metres appears reasonable.

5.8 Over which horizontal length scales are data representative?

Representative horizontal length scales can be assessed by looking at the correlation length. The correlation length is a measure of the distance over which a signal from one point is correlated with the signal observed at another. It can be determined by studying the cross correlation between stations or where data are collected along a transect (such as from a ferrybox system) through autocorrelation. Analysis using a semivariogram is also possible, where the semivariance is assessed in relation to the distance between sampling points.

Chlorophyll fluorescence data from the GKSS Ferrybox system, operating between Cuxhaven and Immingham, were binned by month and into 1° longitude bins. The mean autocorrelation of each binned series was calculated, and the correlation length scale determined as the distance over which the mean correlation fell to 1/*e*. Results for one longitude bin are presented as Figure 20. Table 8 and Figure 21 show the calculated correlation length scales. These vary between 5 and 14 km. It is possible to detect a shortening of the correlation length in the summer (June – August) and winter length scales appear shorter in the central areas.

The analysis was repeated using a simple semivariogram, although not all months showed the typical plateau form. Instead, in many case semivariance continued to increase with distance.

6 Discussion

The national reports indicate that the problems of the spatial and temporal representativeness of nutrient and chlorophyll data are non-trivial. However, a number of common themes occur:

The problem of variable salinity and dilution remain. Mixing diagrams are particularly useful where data are evenly spread throughout a wide salinity range, and there is a strong dilution effect. This gives trends with narrow confidence intervals. During the spring bloom, nutrient levels may be close to exhausted along the lower reaches of an estuary, and nutrient concentration is no longer conservative. To use these data for assessment purposes, or in the analysis of trends (such as a seasonal Kendall approach) it may be advisable to bin data by month and salinity. Thus, instead of analysing all data from January, then February etc, and combining the trends from each of the twelve months, it may be valuable to analyze trends for January between 25 and 30 psu, between 30 and 35 psu, then February between the same limits and so on through December, before combining the 24 trend results in the final trend estimate. Such an analysis requires a large dataset – although non-parametric methods such as Mann-Kendall are reasonable at handling data sets with gaps, albeit with a loss of statistical strength.

The relation between salinity and chlorophyll concentration is less well defined than that between nutrients and salinity. It may be advisable to bin chlorophyll data according to salinity, and analyze each bin separately.

Few reports detail how the national sampling programmes guarantee that the winter nutrient maximum has been observed. The SmartBuoy delivers nutrient data at such high frequency that the peak should be observable.. The UK report highlighted the problem of extremely high temporal variability in nutrient levels, even at sub-daily levels. This would appear to be a particular problem in strongly tidal waters and could be expected to be a problem offshore of the Rhine and in the German Bight. That report recommended that a ship should remain on station for a complete tidal cycle to ascertain whether this is a problem. The tests using model data indicate that annual means should be determinable from monthly sampling. This result may however be over optimistic, as the model data were daily means and do not show the same sub-daily variability seen in the SmartBuoy data, where the total oxidised nitrogen varied from 20 to 60 mmol/m^3 within one tidal cycle.

Every country has the problem of identifying the timing and location of the spring bloom. Studies from Belgium, Germany and Norway indicate that the bloom maximum lasts about a week, which requires observations at least every three days to be sure of recording the maximum chlorophyll concentration. Norway's report also stated that this sampling regime was needed throughout the growing season to obtain a good estimate of the annual mean chlorophyll concentration, although this is not supported by the analysis of MIRO&CO model data in 5.6. There was no discussion as to whether the chlorophyll maximum was to be obtained from a surface water sample, from a mixed sample (for example a hose lowered to 10 metres) or from a water sample taken at the fluorescence maximum identified during a CTD cast, or what the effect of these different sampling approaches would be.

Given that using a research ship to catch the spring bloom is prohibitively expensive, Belgium suggested the use of satellite remote sensing data, though accepted that cloudiness is frequently a problem at just the time of the spring bloom. This reduces the effective sampling rate to approximately weekly. The SMHI Seawatch Buoy at Läsö East is equipped with a fluorimeter at two metres depth. This sensor may over-estimate in-situ chlorophyll fluorescence during daytime (a relatively common problem), but is controlled against accredited shipborne observations each month. This approach can offer the temporal resolution required. A more significant problem with this sensor has been biofouling however. The GKSS ferrybox system does appear to be reliably delivering data with both high spatial and temporal resolution. If the sensor calibration can be maintained, then this technique is most promising, at least for delivering near-surface data.

Length scales were assessed for chlorophyll fluorescence based on the ferrybox data. The resulting correlation length scales were short: around 10 km. The analysis was based on many transects across the North Sea, and appears robust.

The Netherlands and Germany have contributed a document on the recommended spatial distribution and frequency of monitoring (ETG 05/3/5-E). According to these recommendations, areas should be mapped to indicate the extent of sub regions. These sub regions should be sampled such that the distance between adjacent sampling points is 10% of the total length of the sub region. If the sub region is a front, then the 10% rule should be used to ensure sufficient resolution across the front. The subregion should be divided into squares, where each square does not exceed 2% of the total area, and each square is then sampled. Any deviations from this should be justified on the basis of cross correlations. Sampling should be intensified where differences between adjacent stations are more than 10%. Resolution may be decreased once the region is shown to be a non-problem area. A similar process should be adopted in the vertical

It is not clear that this method would deliver the 10% confidence that is claimed, because the underlying probability distribution is not known. The initial intensive sampling could allow the confidence interval to be determined, though it is not clear that the processes are stationary (the statistical properties of the model and buoy data appear to vary from one season to the next) so the validity of that confidence interval one month later is not guaranteed.

Advice on temporal sampling resolution is similar. If one week is a typical time scale for a eutrophication effect, such as a phytoplankton bloom, and the growing season is for example 32 weeks, then by sampling 90% of the weeks, (29 times over the season) a sufficient frequency is assumed. This assumes that the occurrence of the eutrophication event is what is to be observed. Where the parameter is the maximum chlorophyll concentration, this occurs at a timescale that is much shorter than the bloom itself, and so requires much greater sampling effort.

Within the EU FP6 project ECOOP, ecosystem models, combined with in situ observations, are being set up to cover the English Channel and the Baltic. These will be run for a full annual cycle, to generate a proxy ocean – the best estimate of the biogeochemical status. The proxy ocean will be used to test different nutrient and chlorophyll sampling strategies, to indicate areas which lack observations. The proposed strategies are the effective data coverage and the explained variance methods. The effective data coverage is defined as the area (and time) represented by a single observation. The explained variance method uses the proportion of variance associated with each principle component to identify the primary scales to be observed.

7 Conclusions

Reports from the contributing parties indicate that common problems are:

1. Variation of nutrient/chlorophyll concentration with salinity

2. Temporal and spatial variability of nutrients in shallow, near coastal water (which may in part be related to the previous point)

3. The amount of data required to allow the determination of trends

4. Identification and observation of the spring phytoplankton bloom.

Point 1 may be tackled as it is now, by the use of mixing diagrams, based on the assumption that the mixing of nutrients is conservative. This is a reasonable assumption outside of the growing season. Alternatively, data may be binned into different salinity ranges. While this may help trend analyses, it may make comparison with reference levels more problematic. Chlorophyll concentration does not lend itself to salinity correction by mixing diagram, and so a binning approach may be useful.

In general, most countries considered their programmes to deliver adequate nutrient data for trend analysis, although some did identify shortcomings, particularly in terms of plankton-related analyses. In coastal waters and close to large rivers, the large coefficients of variation made trend determination difficult.

The Danish programme found that variability could be reduced by correcting for climatic factors, including run-off. In the German Bight however it was difficult to account for variation in the concentration of total nitrogen using run-off. Temporal variability was not considered a significant problem in Belgian waters, with the exception of the area around the Scheldt and very close to small rivers. The UK report suggested that the additional effort reqired to reduce the uncertainty in coastal waters may be better used improving confidence in areas of lower variability. The identification and measurement of the spring phytoplankton bloom remains a problem for all countries, with the possible exception of Norway in the vicinity of Flödevigen. To sustain sampling every three days throughout the growing season is not practical at a large number of stations.

Temporal variability can only be tackled by modelling, or by very high sampling frequencies, as with the SmartBuoy system. This is sufficient to resolve signal (tidal) noise of 40 mmol/m^3 superimposed onto a 30 mmol/m^3 signal. Buoy systems are demanding to operate however, and the data records often suffers from gaps. The ferrybox system appears to be most reliable, particularly if good quality nutrient data can be obtained. Both ferrybox and Smartbuoy only sample surface waters.

The spatial sampling problem can be addressed, in surface waters, by ferrybox systems, at least along the ferry route. In stratified waters, buoy observations at multiple depths or conventional ship observations appear to be the only available technology, if exotica such as gliders and optical sensors are excluded.

A coordinated programme of ferrybox systems, supplemented by buoys, with quality assurance through monthly control observations is necessary for observation of high frequency events such as the spring bloom. Oceanographic vessels still have a role producing high quality data for trend analysis and seasonal mapping campaigns. This is likely to remain so at least until novel technologies, such as gliders and optical nutrient sensors become widely available and capable of delivering high quality data.

8 References

In addition to the reports listed in Table 1 and Table 2, the following documents have been referenced:

Lacroix G., K. Ruddick, P.Youngje, N. Gypens & C. Lancelot, 2007, "*Validation of the 3D biogeochemical model MIRO&CO with field nutrient and phytoplankton data and MERIS-derived surface chlorophyll a images*", Journal of Marine Systems, v 64 (2007), pp 66 - 88

MARETEC, 2007, "2nd Application of Comprehensive Procedure: Mondego estuary - Portugal", ICG Report 00102_PT draft assessment Mondego_OSPAR_Mar2007, 15 pp

Ottersen, G., Aure, J., Danielssen, D., Ostrowski, M., Skjoldal, H.R., Svendsen, E., Søiland, H., Aasen, S.E., Tangen, K., Johnsen, T., Magnusson, J., Molvær, J. and Sørensen, K. 1998." *Utarbeidelse av et program for overvåkning av eutrofitilstand og –utvikling i norske kystfarvann basert på både tradisjonelle og høyteknologiske metoder. (Development of a program to monitor eutrophication status and trends in Norwegian coastal waters based on traditional and high-technological methods.)*" Fisken og Havet No. 1 – 1998. Institute of Marine Research. ISSN 0071-5638. 114 pp. (In Norwegian).

Petersen W.; Petschatnikov, M.; Schroeder, F.; Wehde, H., 2003, "*Application of a FerryBox: automatic measurements in the North Sea*", in: Proceedings of OCEANS '04. MTTS/IEEE TECHNO-OCEAN '04, 1399- 1401 Vol.3, 1399- 1401 Vol.3

9 Appendices

9.1 Tables

Reported national assessments		
00101	Norway – national assessment report	20 April 2007
00102	Portugal – DRAFT assessment report	5 April 2007
00103	Sweden – national assessment report	3 April 2007
00104	Sweden – assessment report – Appendix	3 April 2007
00105	Sweden – assessment report – reporting format	3 April 2007
00106	Netherlands – assessment report	30 May 2007
00107	Belgium – assessment report	22 June 2007
00108	Germany – national assessment report	14 June 2007
00109 a-g	Germany – assessment report - Annex	14 June 2007
00110	Spain – national assessment report	22 June 2007
00111	UK – national assessment report (draft)	7 August 2007

Table 1 Reported national assessments

1 National contributions					
1001	Frequency and spatial resolution of a monitoring programme for the application of the comprehensive procedure – summary of case studies	Convenor of the ICG	ETG/MON 2004	ETGMON 04/3/1	November 2004
1002	Analysis of sampling frequency and spatial and temporal processing of Belgian chlorophyl data for the purpose of eutrophication assessment	Belgium	ETG/MON 2004	ETGMON 04/3/3	November 2004
1003	Belgian monitoring practice relating to horizontal and vertical length scales and time scale for variation of DIN, DIP, chlorophyll and phytoplankton	Belgium	ICG	Follow-up to EUC(2) 2005	16/01/2006
1004	Nutrients and Eutrophication in Danish marine waters - A challenge for science and management (Common Procedure)	Denmark	EUC	EUC 02/2/9	December 2002
1005	Statistical optimization of the current Danish National Programme for Monitoring the Aquatic Environment	Denmark	ETG/MON 2004	ETGMON 04/3/6	November 2004
1006	Danish National Monitoring and Assessment Programme for the Aquatic and Terrestrial	Denmark	EUC	EUC(2) 05/3/Info.1	December 2005

	Environments (NOVANA)				
1007	Eutrophication Monitoring in the German Bight	Germany	ETG/MON 2004	ETGMON 04/3/2	November 2004
1008	Optimalisation Nutrient Monitoring in Dutch Marine Waters	Netherlands	ETG 2005	ETG 05/3/6	October 2005
1009	Some inputs to the consideration of spatial and temporal scales related to nutrients and eutrophication monitoring	Norway	ETG/MON 2004	ETGMON 04/3/8	November 2004
1010	Spatial and temporal resolution of monitoring	Norway	EUC(2) 2005	EUC(2) 05/3/4	December 2005
1011	The Swedish National Monitoring Programme in the Kattegat and Skagerrak	Sweden	ETG/MON 2004	ETGMON 04/3/5	November 2004
1012	Case study on winter DIN and chlorophyll in the Thames region	UK	ETG/MON 2004	ETGMON 04/3/4	November 2004
1013	Annual cycles of physical, chemical and biological parameters in Scottish waters	UK	ETG/MON 2004	ETGMON 04/3/7	November 2004
1014	Monitoring of nutrients, chlorophyll and phytoplankton in Norwegian coastal waters	Norway	EUC(2) 2005	EUC(2) 05/3/4	December 2005

Table 2 National contributions to ICG

Region	Offshore/open coast stations	Nearshore/estuarine stations	Total
The Basque Country	19	32	51
Cantabria	21	53	74
Asturias	3	20	23
Galicia	16	39	55
Andalusia	13	17	30
Total	72	161	233

Table 3 Distribution of stations in the Spanish eutrophication monitoring network, derived from figures in Anon, 2007)

Institution	Location	Sampling events/year	Additional Analyses
ARGE Elbe	Elbe Estuary	7	TN, TP
ARGE Weser	Weser Estuary, 2 stations,	26	TN
	Profile	6	TN, TP
BAH, Station Helgoland	Helgoland Roads,	Weekdays	
	Sylt,	52	
	Transects German Bight	6, 6, 12	
BSH	German Bight	1 (1^{st} quarter), spatial every 5 years	
LANU	Wadden Sea North	2- 12 (9 stations)	TN
NLÖ	Wadden Sea West, Ems Estuary	2- 26 (1 station)	TP, SPM

Table 4 Sampling frequencies for nutrients in the German Bight

Land	Region	Issues and characteristics
Portugal	Estuarine	Eutrophication problems are limited where estuaries have short residence times and low inputs. Management changes in the Mondego estuary have caused problems due to the discharge of nutrient rich water into a branch of the estuary with poor water exchange.
	Coastal	No information
	Offshore	No information
Spain	Estuarine	Problems generally occur due to point discharges, as river run-off is very low.
	Coastal	Generally good status, due to low levels of run-off from land, and a narrow, exposed continental shelf with significant tidal mixing. High nutrient levels can occur in bays with poor water exchange, and due to upwelling of oceanic water
United Kingdom	Estuarine	Strong salinity gradients
	Coastal	Intense spatial variability, with salinity a poor explanatory variable for the variation in DIN.
	Offshore	Less spatial variability than in coastal waters. Tides account for much of the sub-daily variability in nutrient concentrations
Belgium	Estuarine	Weak stratification near the mouth of the Scheldt. Horizontal variability is important – particularly around estuarine plumes
	Coastal	Well mixed.Horizontal variability influenced by freshwater discharges from nearby rivers, small point sources and from small bathymetric features
		Problem for deep draught research ships to enter shallow coastal waters
	Offshore	Some thermal stratification where water depth exceeds 40 metres. Horizontal variability – as for coastal
	Summary	Weak stratification gives limited vertical variability, so sampling occurs at a fixed depth (3 m).Need for high spatial resolution because of horizontal variability. Use underway fluorimetry measurements to solve problem of horizontal chlorophyll variability. Also tried using satellite imaging.
		Temporal variability due to tidal currents solved by

		binning data into larger periods or by studying a long time series. Exact scales of chlorophyll a variability are not well known
The Netherlands	Estuarine	The National Montiroing Programme (MWTL) operates a station in the outer Ems-Dollard estuary.
	Coastal	Figure 1 of the Netherlands OSPAR CP report indicates 7 stations in the coastal waters. These waters are not stratified, so a surface sample is considered representative for the whole water column. The area is assessed using annual/seasonal mean concentrations (90th percentile fpr chlorophyll-a). Stations are sampled up to twice monthly, depending upon the parameter.
	Offshore	The offshore regions lie offshore of the 34.5 [psu] halocline. The deeper water of the Oyster Grounds, and over the Dogger Bank becomes stratified in summer, so the water column is sampled at the surface, at the thermocline and near the bottom. Otherwise, only the surface waters are sampled. The offshore regions are characterised based on annual or seasonal means derived from between one and three stations per area. These are usually sampled monthly in winter, and twice monthly in summer.
	Summary	Sampling frequency is monthly for winter nutrients, and twice monthly during the growing season (Category II and Category III) parameters. The sampling regime is adjusted to take the seasonal stratification into consideration. An increase in sampling frequency during a seven year period did not significantly improve the results of a trend assessment, so the existing sampling programme is considered adequate.
Germany	Estuarine	Wide shallow intertidal mudflats, barrier islands, crossed by rivers delivering large quantities of fresh water and nutrients. Within the estuaries and coastal waters, strong gradients require high frequency and dense monitoring networks.
	Coastal	The inshore limit for coastal waters lies 35 km offshore. There are strong gradients and high variability. High frequency studies of the chlorophyll a concentration showed a standard deviation of more than 70% when calculating the spatial mean.
	Offshore	The offshore limit of coastal waters (taken as the offshore location of the 34.5 [psu] halocline) lies approximately 100 km from the shore.

	Summary	Standard deviations of annual mean total nutrient concentrations exceeds 40% throughout the area,
Denmark	Estuarine	Seasonal anoxia in fjords.
	Coastal	Monitoring occurs approximately fortnightly (20 – 33 times per year)
	Offshore	Brackish to marine environment. Summer monitoring in the Skagerrak and North Sea have been discontinued. On the Kattegat side, Danish waters are shallow (~10 metres deep over a large area)
	Summary	Significant correlation between nutrient inputs and their concentration in coastal waters. Large seasonal variation
Sweden	Estuarine	River run-off is significant, and residence times short. The principle estuary (Göta Älv) is regulated, so variation in run-off is limited.
	Coastal	Coastal regions are affected by local run-off. In the shallow bays of the southern Kattegat, hypoxia can occur during calm conditions in late summer, where stratification causes the bottom water volume to be reduced at the same time as oxygen consumption is highest. Further north, the coast is relatively open, though salinity and thermal stratification occur. Within the inner fjords, permanent and seasonal anoxia occur.
	Offshore	There is permanent salinity stratification due to the Baltic outflow. A substantial internal tide exists in the Kattegat. Sampling at 5 metre intervals in the vertical down to 30 metres resolves this variability. Autumn hypoxia can occur in the southern Kattegat, but is exceptional. The offshore Skagerrak is separated from coastal waters by the front associated with the Baltic current. Sampling occurs along a transect from the coast to offshore of the front
Norway	Coastal	Twice weekly sampling at Flödevigen necessary to make a reasonable estimate of chlorophyll-a concentrations
	Offshore	Strong horizontal gradients due to the complex hydrography of the Skagerrak, resolved using transects. Most variance occurs on time scales greater than 28 days.

Table 5 Summary of estuarine, coastal and offshore characteristics

	Parameter	Sampling regime (per year)					
		4 x	12 x	24 x	52 x	104 x	183 x
Coastal	Nitrate	0.256	0.085	0.045	0.032	0.029	0.032
	Ammonium	0.220	0.070	0.040	0.031	0.031	0.029
	Orthophosphate	0.324	0.080	0.054	0.038	0.034	0.030
	Silicate	0.269	0.073	0.049	0.038	0.035	0.031
	Chlorophyll	0.363	0.075	0.067	0.039	0.031	0.027
	Phaeocystis	0.446	0.128	0.056	0.033	0.036	0.028
Central	Nitrate	0.253	0.089	0.072	0.037	0.033	0.032
	Ammonium	0.196	0.063	0.041	0.029	0.028	0.024
	Orthophosphate	0.318	0.090	0.059	0.034	0.043	0.030
	Silicate	0.258	0.082	0.053	0.040	0.037	0.031
	Chlorophyll	0.299	0.091	0.055	0.040	0.028	0.027
	Phaeocystis	0.434	0.094	0.058	0.042	0.030	0.027
Offshore	Nitrate	0.184	0.066	0.049	0.040	0.038	0.033
	Ammonium	0.138	0.063	0.037	0.025	0.024	0.028
	Orthophosphate	0.219	0.069	0.038	0.029	0.029	0.028
	Silicate	0.169	0.061	0.047	0.032	0.032	0.025
	Chlorophyll	0.256	0.087	0.053	0.044	0.029	0.027
	Phaeocystis	0.452	0.123	0.074	0.044	0.033	0.029

Table 6 Results of the cost function for estimates of the mean concentration, derived from different sampling frequencies

	Parameter	Sampling regime (per year)					
		4 x	12 x	24 x	52 x	104 x	183 x
Coastal	Nitrate	1.575	0.422	0.164	0.101	0.070	0.024
	Ammonium	1.468	1.088	0.616	0.579	0.291	0.242
	Orthophosphate	0.864	0.447	0.259	0.138	0.124	0.081
	Silicate	1.546	0.601	0.221	0.170	0.066	0.046
	Chlorophyll	2.178	2.047	1.203	0.541	0.448	0.211
	Phaeocystis	2.286	3.716	1.671	0.768	0.544	0.194
Central	Nitrate	2.141	0.904	0.615	0.391	0.326	0.235
	Ammonium	0.880	0.556	0.430	0.202	0.168	0.103
	Orthophosphate	1.053	0.523	0.365	0.262	0.206	0.096
	Silicate	1.978	1.141	0.627	0.412	0.394	0.251
	Chlorophyll	2.274	2.006	1.192	0.841	0.439	0.309
	Phaeocystis	2.225	3.725	2.292	0.997	0.469	0.401
Offshore	Nitrate	2.767	1.810	1.334	1.089	0.558	0.443
	Ammonium	0.120	0.106	0.083	0.064	0.048	0.028
	Orthophosphate	1.233	0.914	0.713	0.508	0.309	0.246
	Silicate	1.907	1.225	1.055	0.711	0.496	0.280
	Chlorophyll	3.298	2.430	1.798	1.286	0.941	0.524
	Phaeocystis	4.229	4.595	3.338	1.955	1.430	1.409

Table 7 Results of the cost function for estimates of the maximum annual concentration, derived from different sampling frequencies

Longitude bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 – 1°E	10	7	10	8	7	6	7	6	8	9	10	5
1 – 2°E	7	5	8	7	8	6	7	6	6	8	10	11
2 – 3°E	7	10	10	9	9	10	10	5	7	7	13	14
3 – 4°E	6	5	10	7	6	7	7	6	8	9	7	8
4 – 5°E	5	10	7	8	7	9	7	6	7	8	10	7
5 – 6°E	6	7	6	9	7	9	11	8	8	11	8	12
6 – 7°E	5	10	9	8	5	7	6	9	6	10	10	10
7 – 8°E	5	9	11	8	8	9	7	9	5	11	6	7
8 – 9°E	8	10	10	8	6	6	7	5	6	8	7	8

Table 8 Correlation length scales (in km) for each month and longitude bin, based on chlorophyll fluorescence data collected by the GKSS ferrybox system between Cuxhaven and Immingham

9.2 Figures

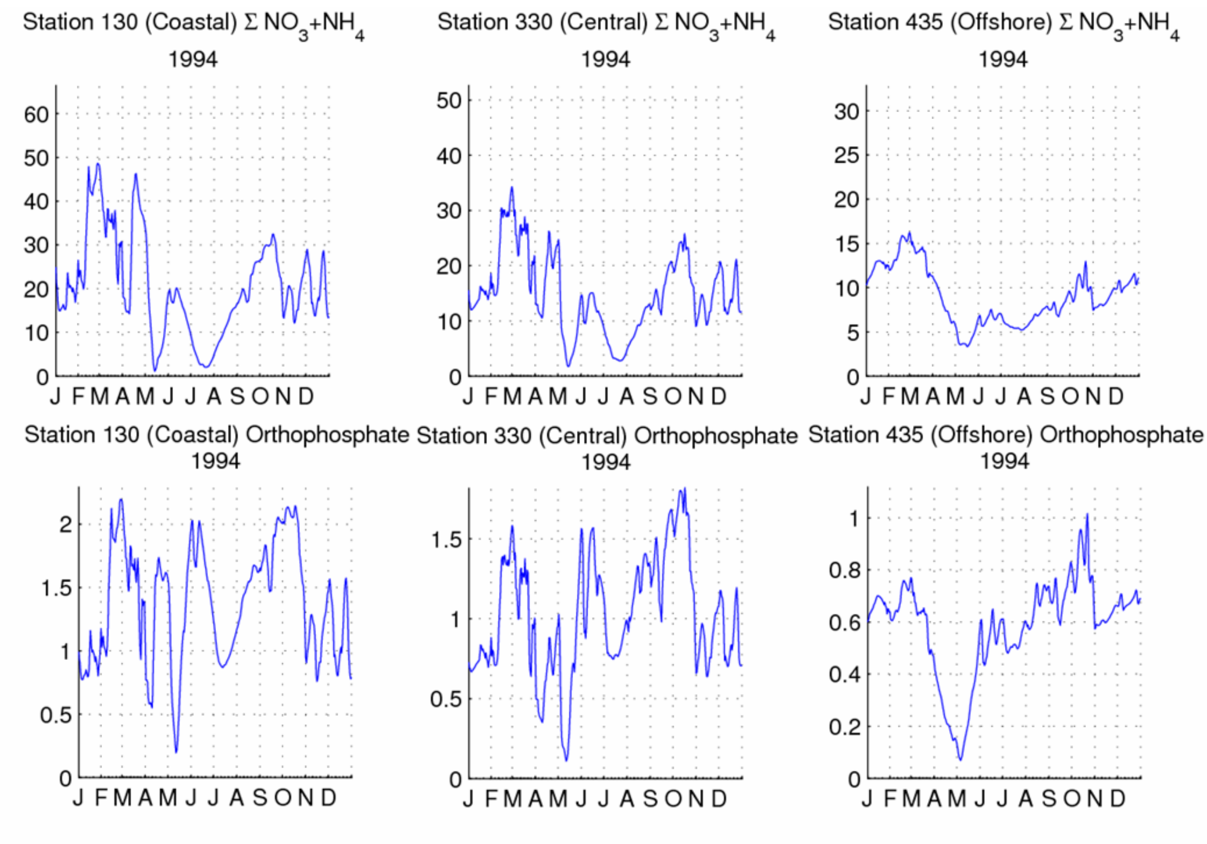

Figure 1 Nutrient cycles (the sum of nitrate and ammonium and DIP) for coastal, central and offshore Belgian waters, 1994. Concentration units are mmol/m³

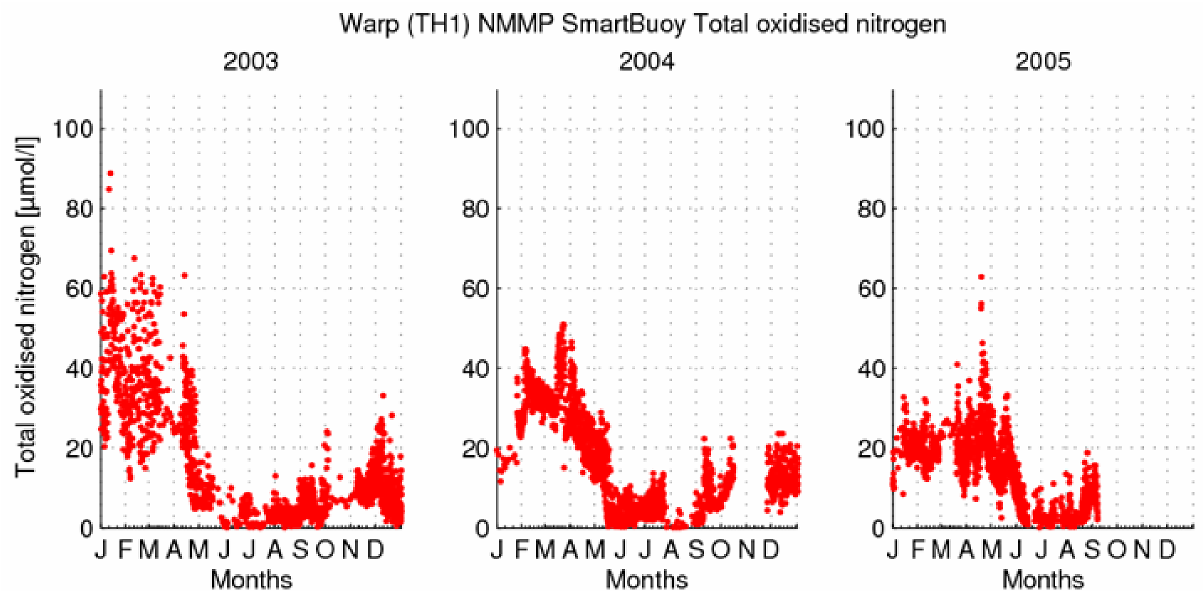

Figure 2 Annual cycles of total oxidised nitrogen (Σ nitrite + nitrate) observed by the CEFAS Smartbuoy at Warp.These data are Crown Copyright.

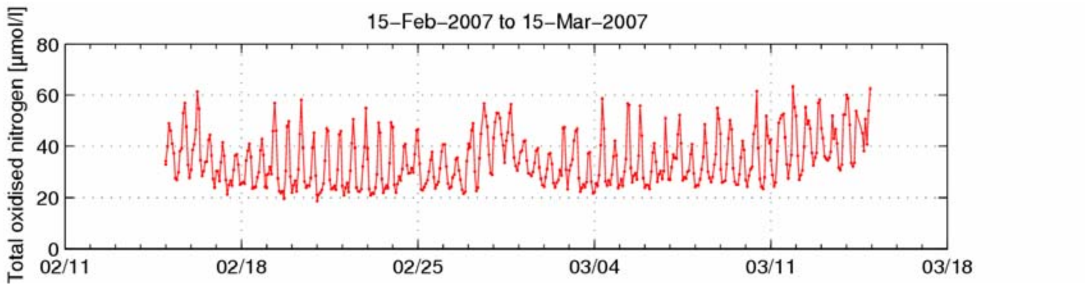

Figure 3 Time series of total oxidised nitrogen, showing the tidal influence on the observations. Data are Crown Copyright

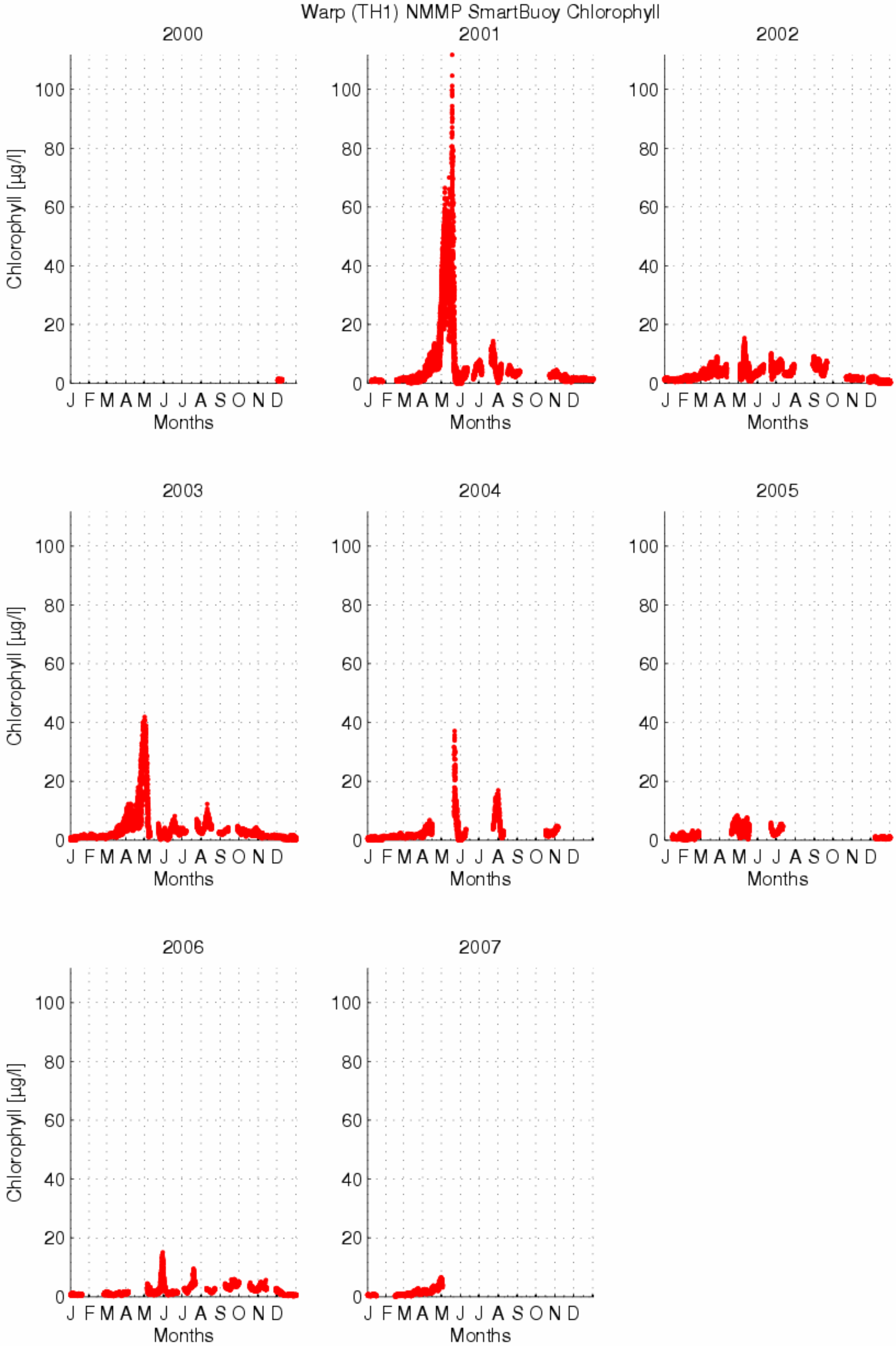

Figure 4 Annual cycles of chlorophyll a concentration, from the CEFAS Smartbuoy at Warp. Data are Crown Copyright.

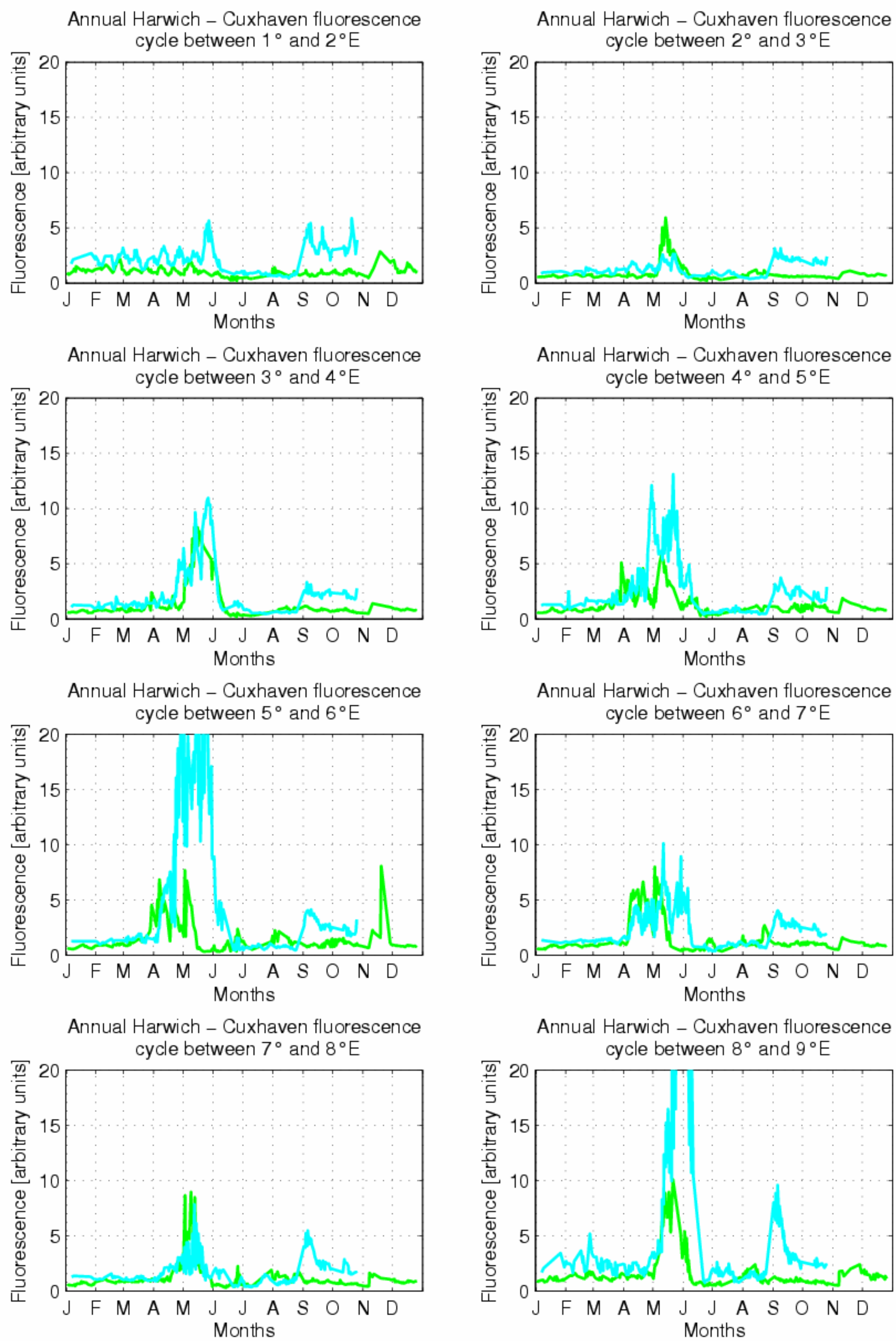

Figure 5 Annual cycles of chlorophyll a fluorescence from the GKSS ferrybox, 2004 & 2005

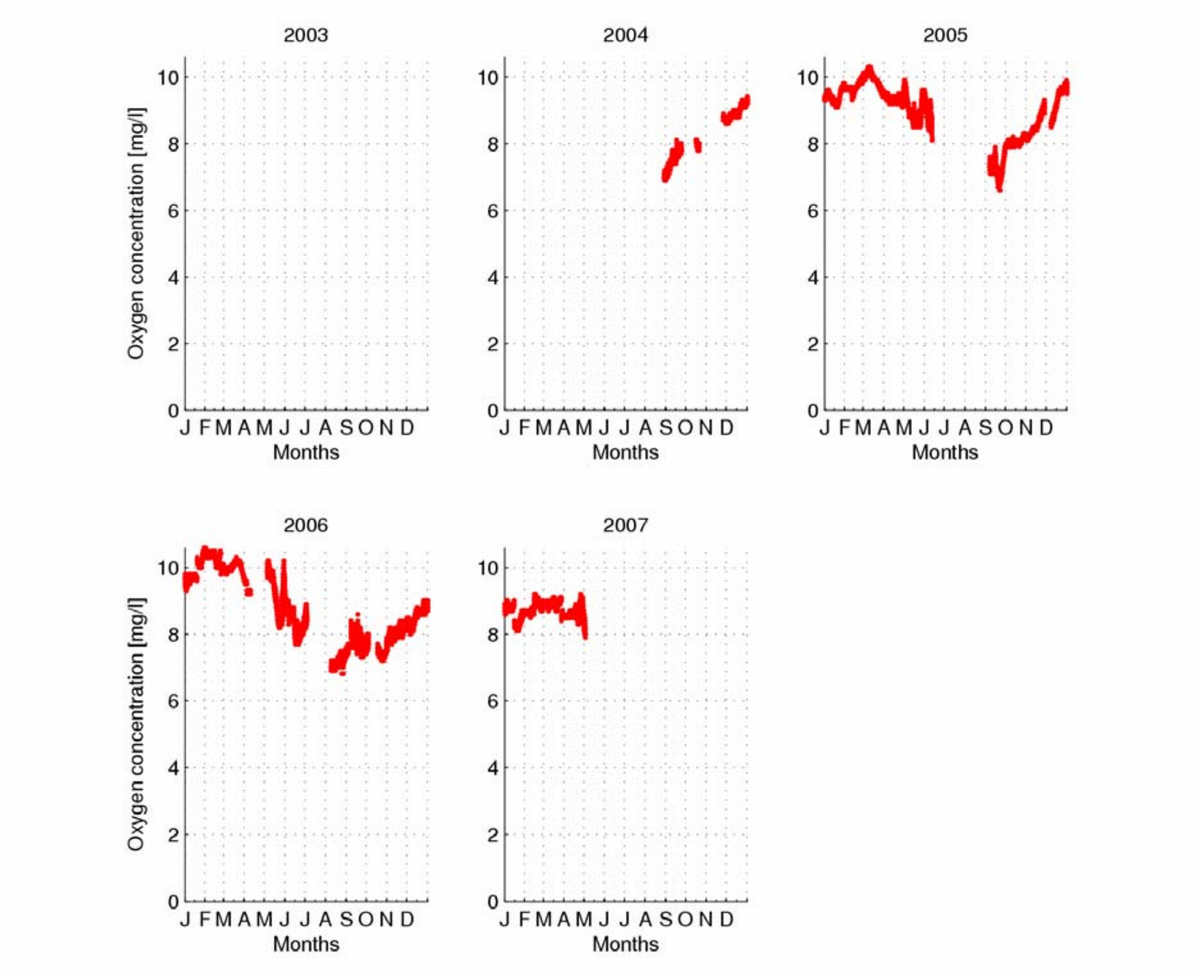

Figure 6 Annual cycles of oxygen at 1 m depth, from CEFAS Smartbuoy at Warp. These data are Crown Copyright.

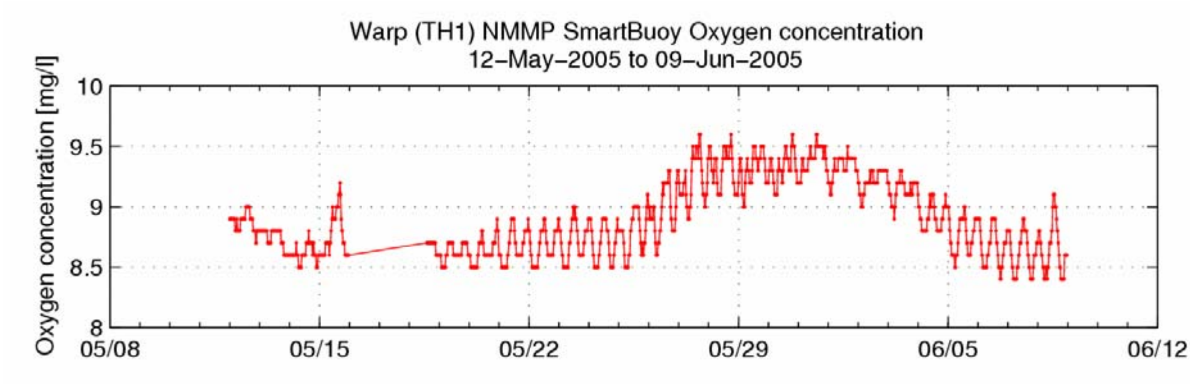

Figure 7 Part of the oxygen time series from Warp, showing the tidal influence. Data are Crown Copyright.

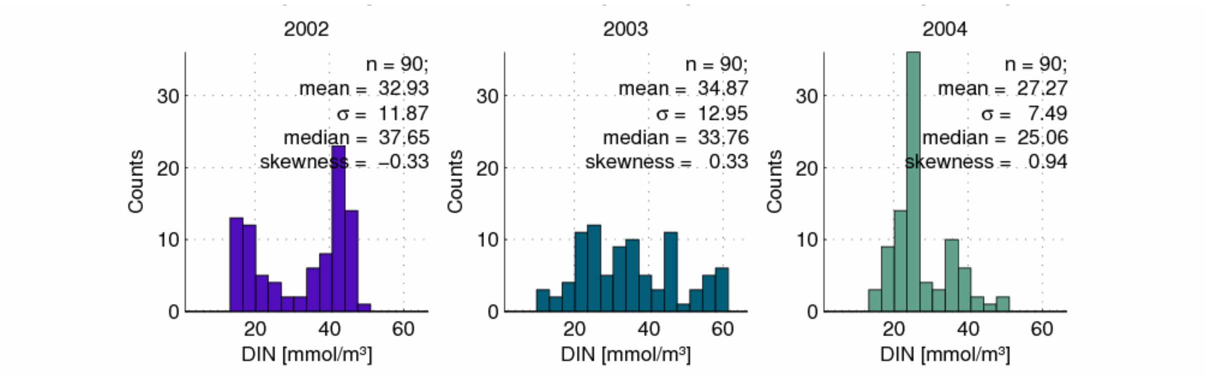

Figure 8 Distributions of winter inshore DIN concentrations, 2002 - 2004. Belgian data

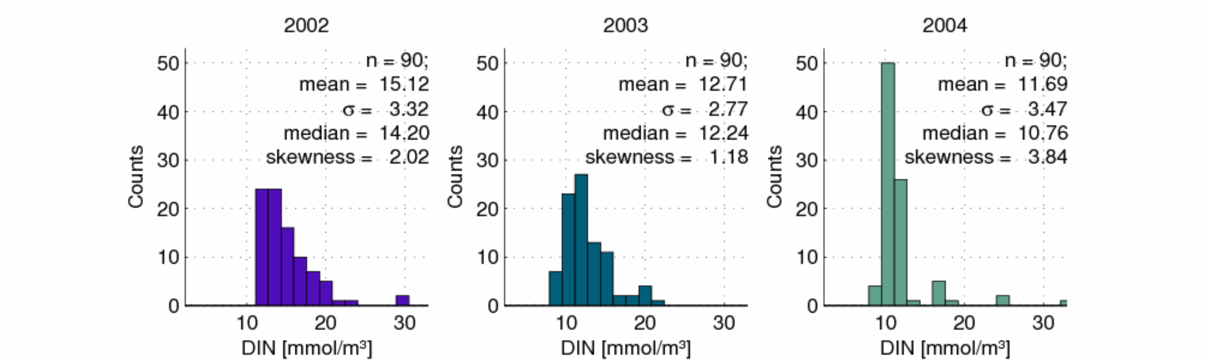

Figure 9 Distributions of offshore winter DIN 2002 - 2004. Belgian data

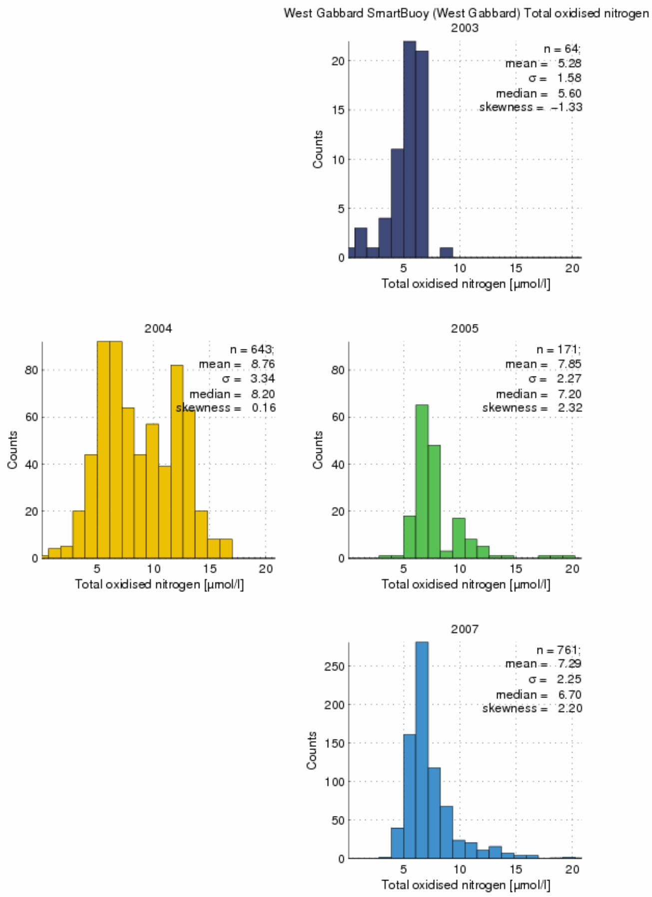

Figure 10 Distributions of Total Oxidised Nitrogen during winter at West Gabbard

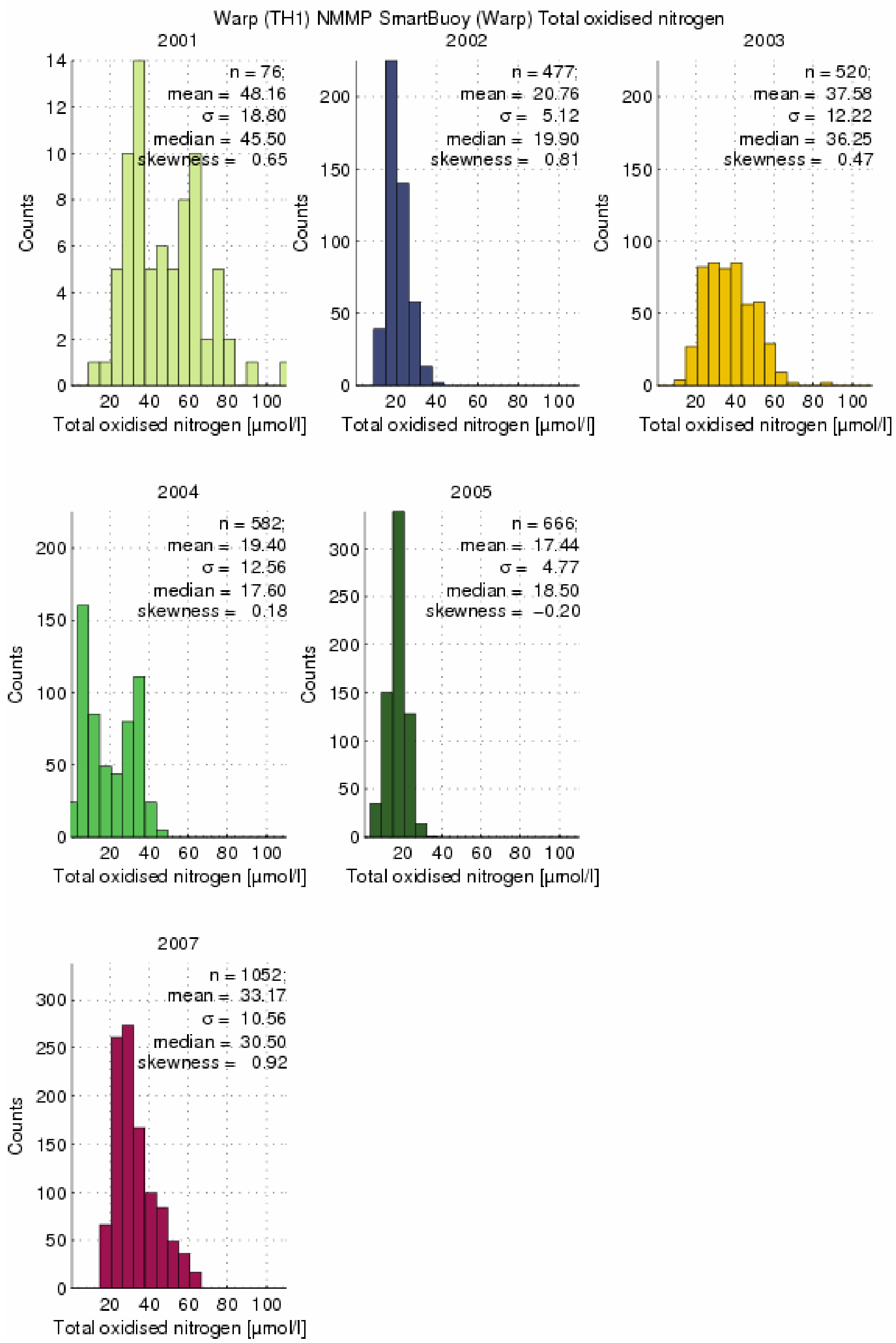

Figure 11 Distribution of winter Total Oxidised Nitrogen at Warp

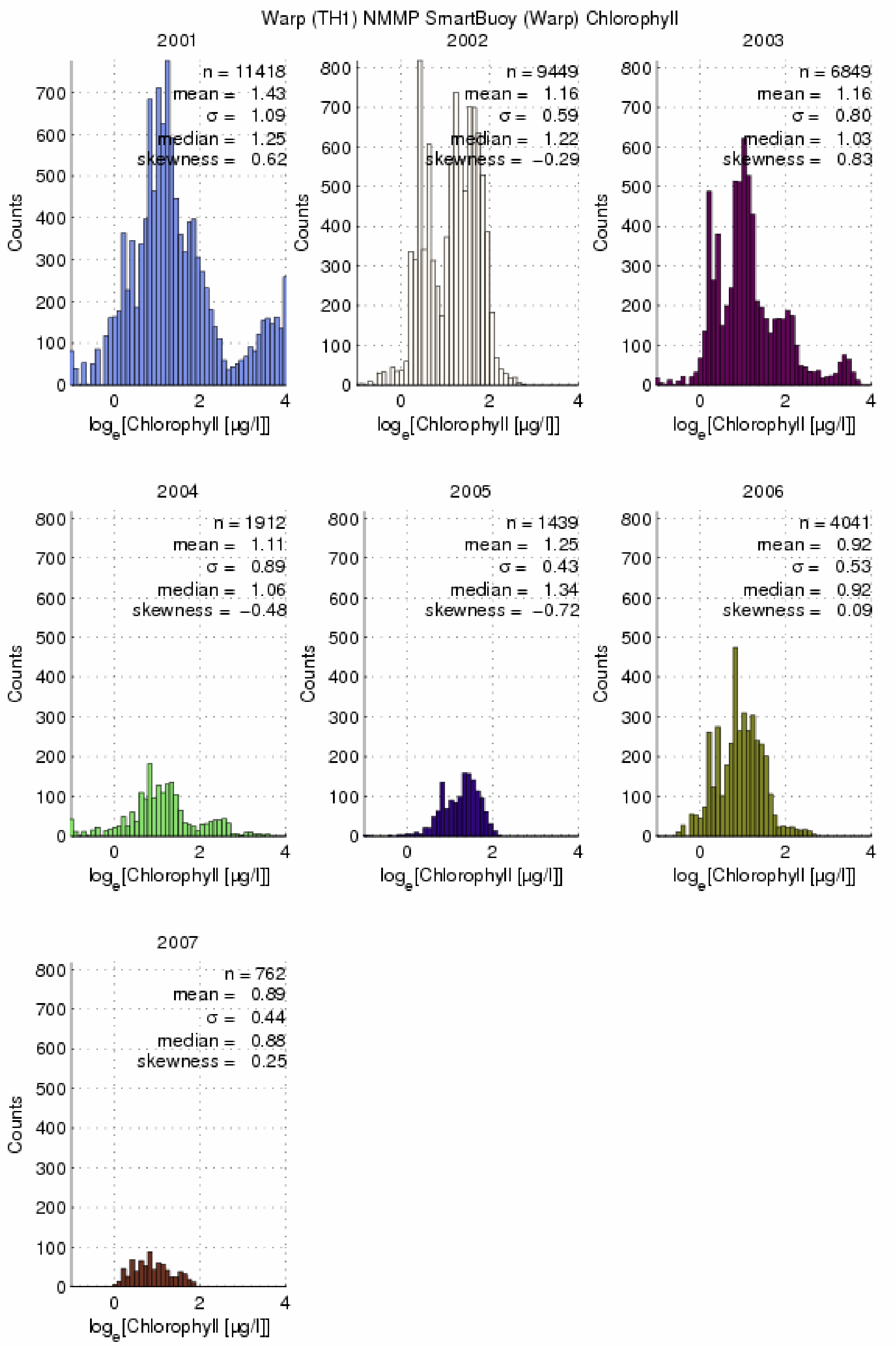

Figure 12 Distribution of the log$_e$ chlorophyll concentrations from Warp

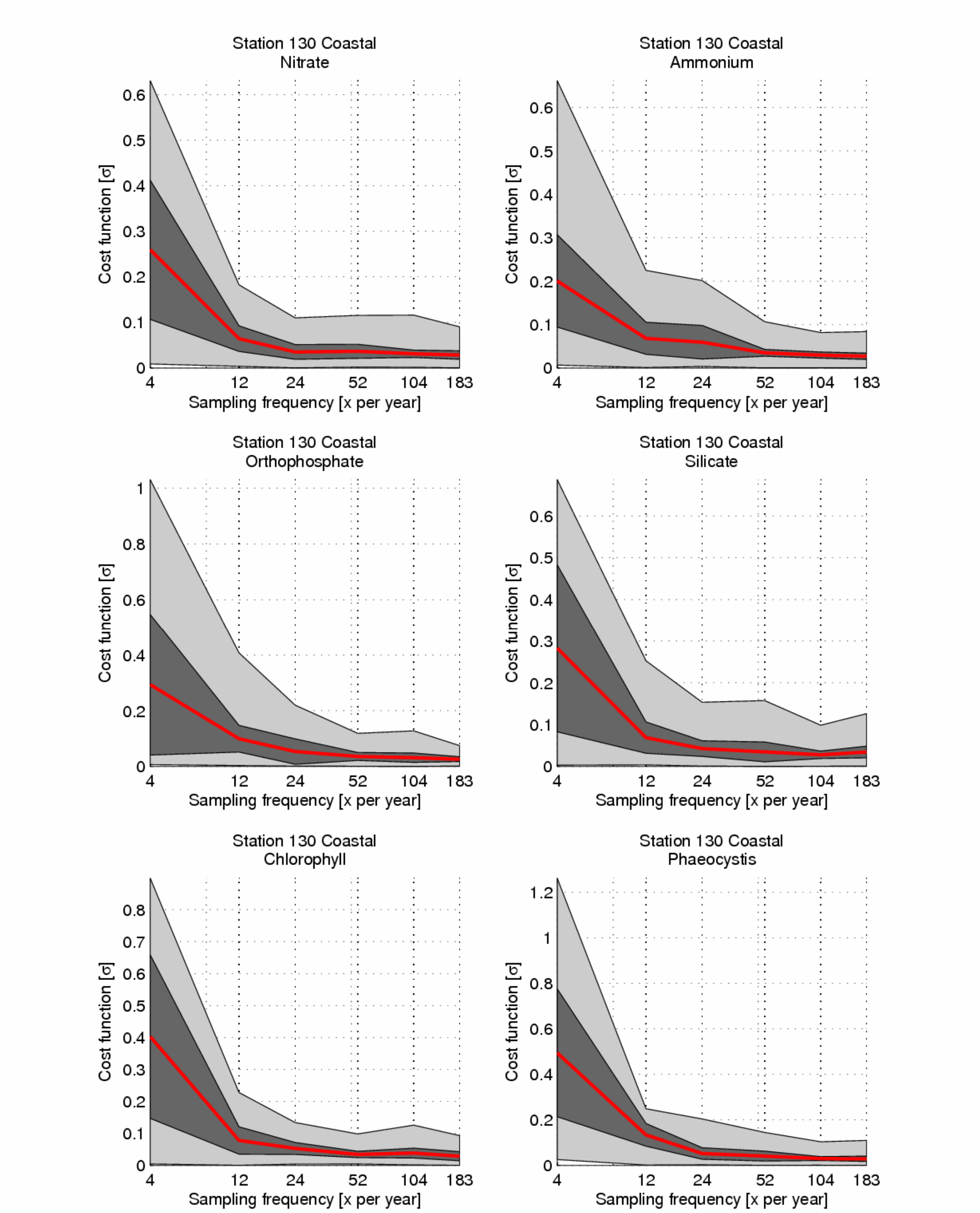

Figure 13 Effect of different sampling strategies on estimates of the mean (Coastal waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

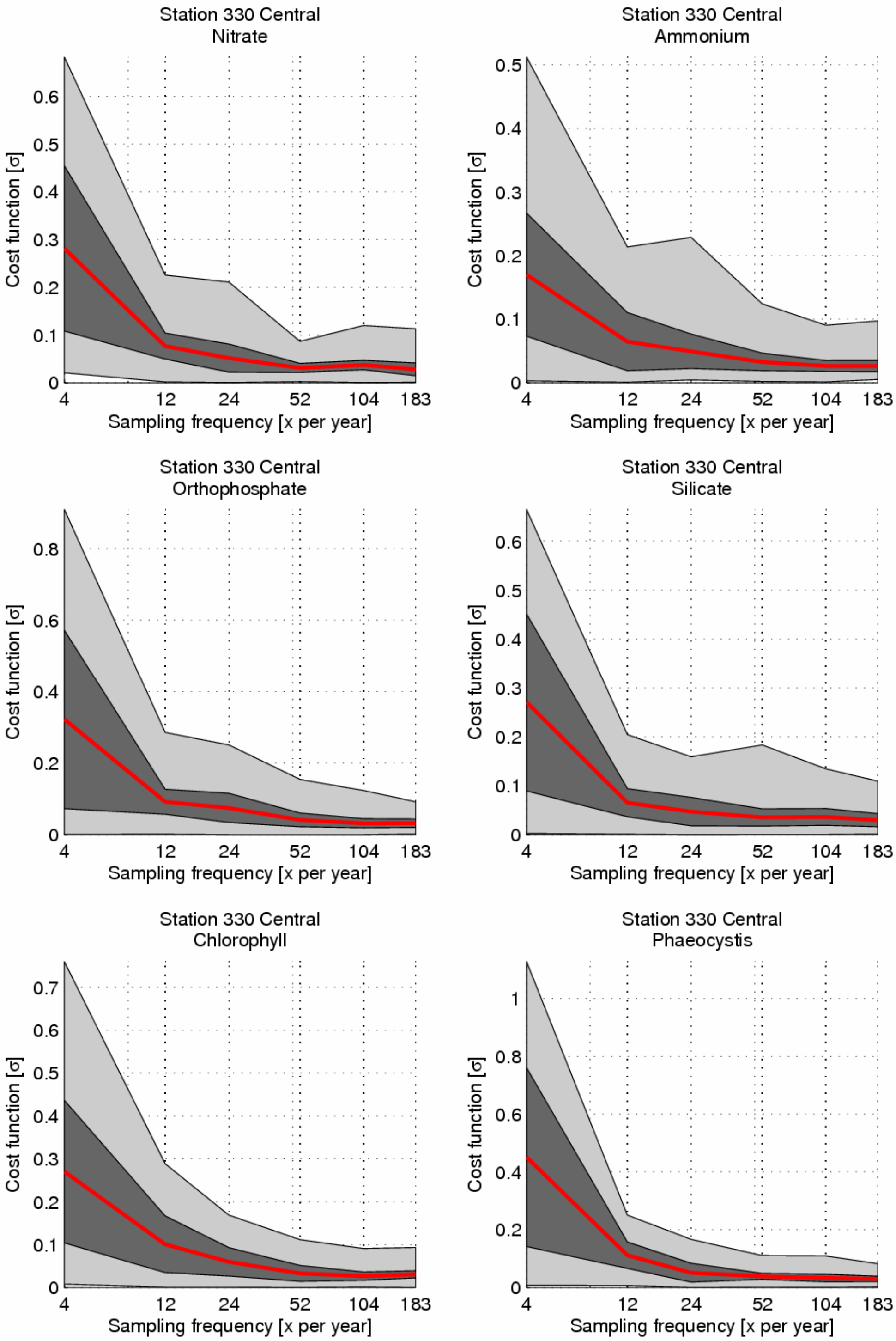

Figure 14 Effect of different sampling strategies on estimates of the mean (Central waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

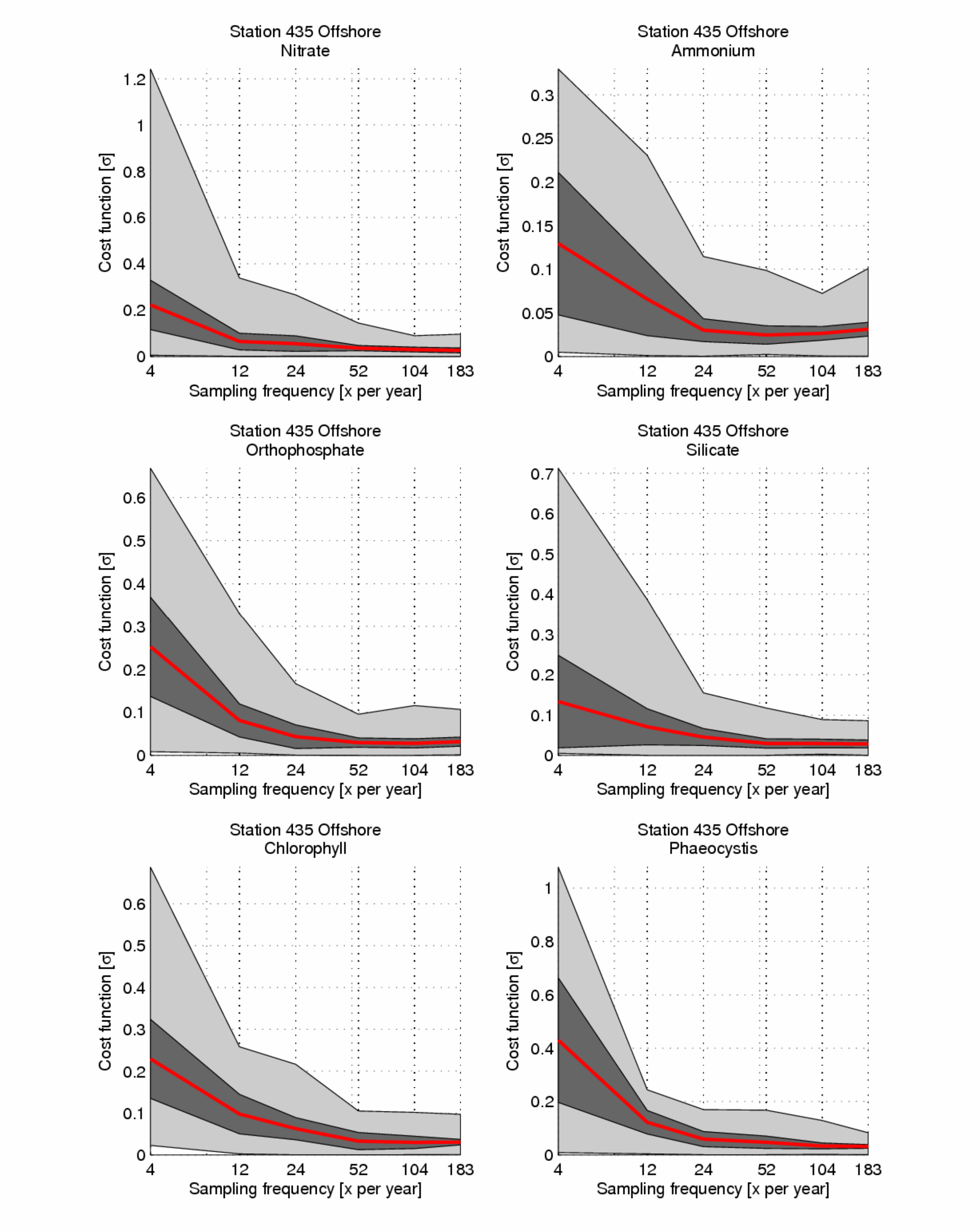

Figure 15 Effect of different sampling strategies on estimates of the mean (offshore waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

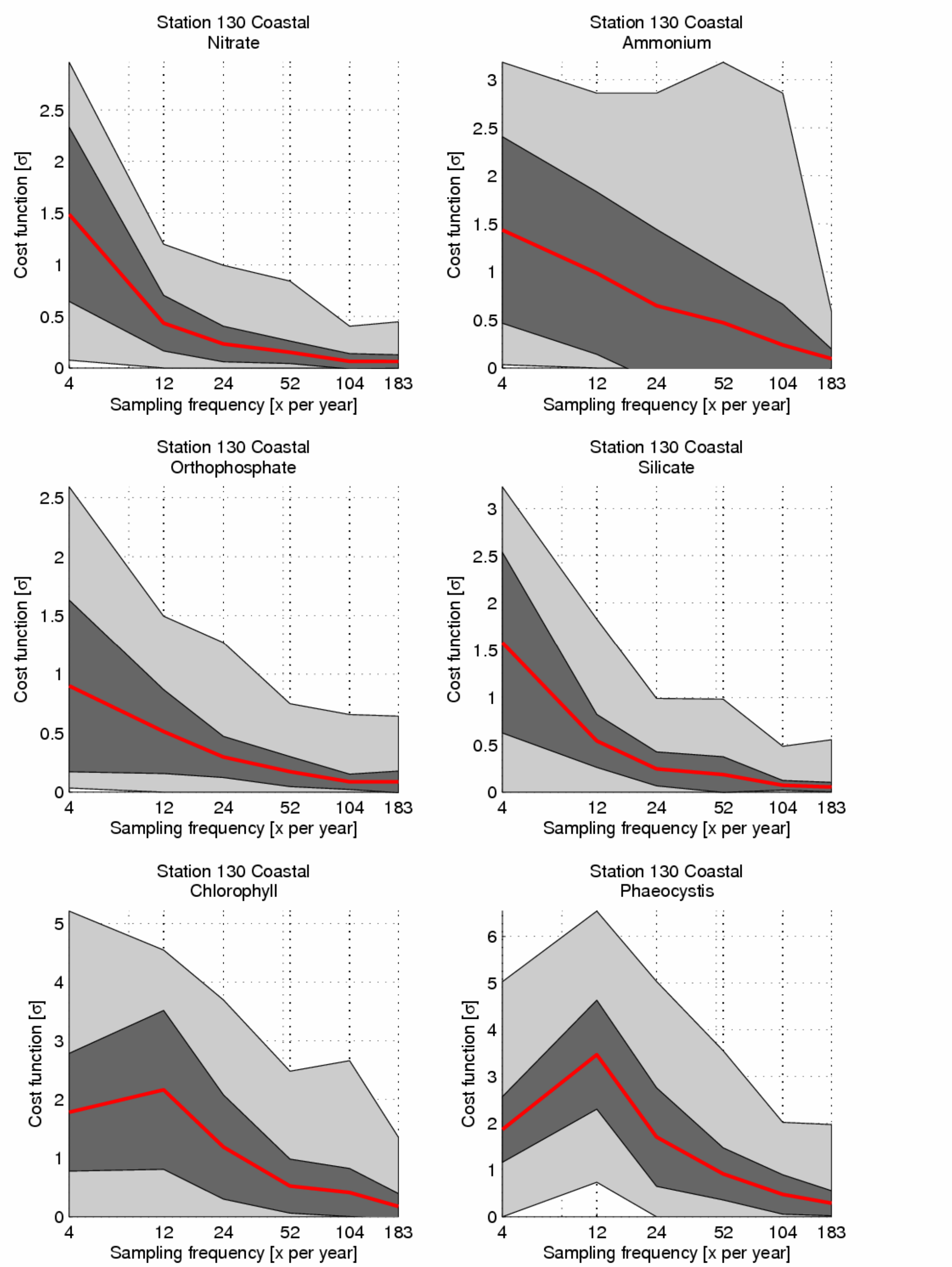

Figure 16 Effect of different sampling strategies on estimates of the maximum concentration (coastal waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

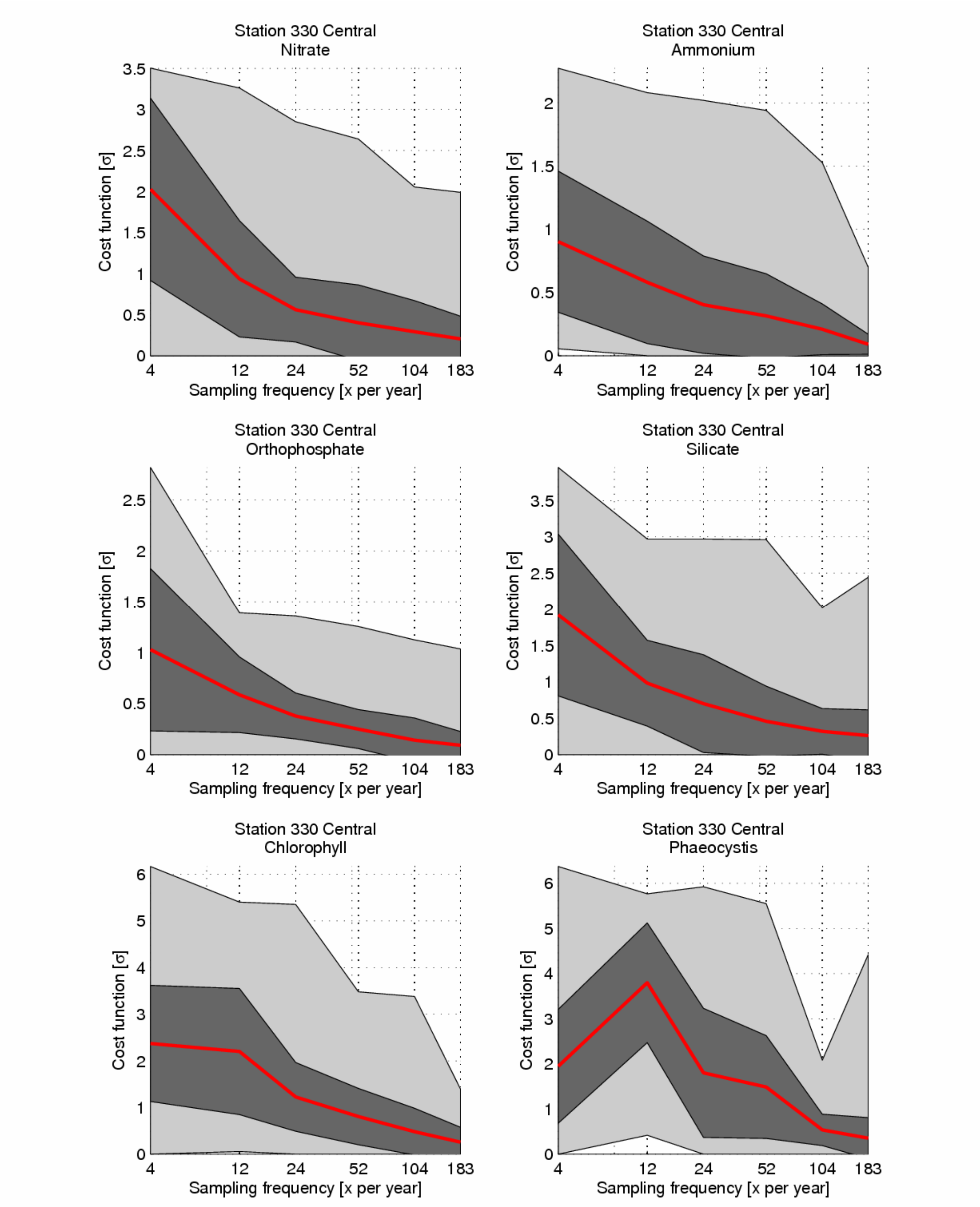

Figure 17 Effect of different sampling strategies on estimates of the maximum concentration (central waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

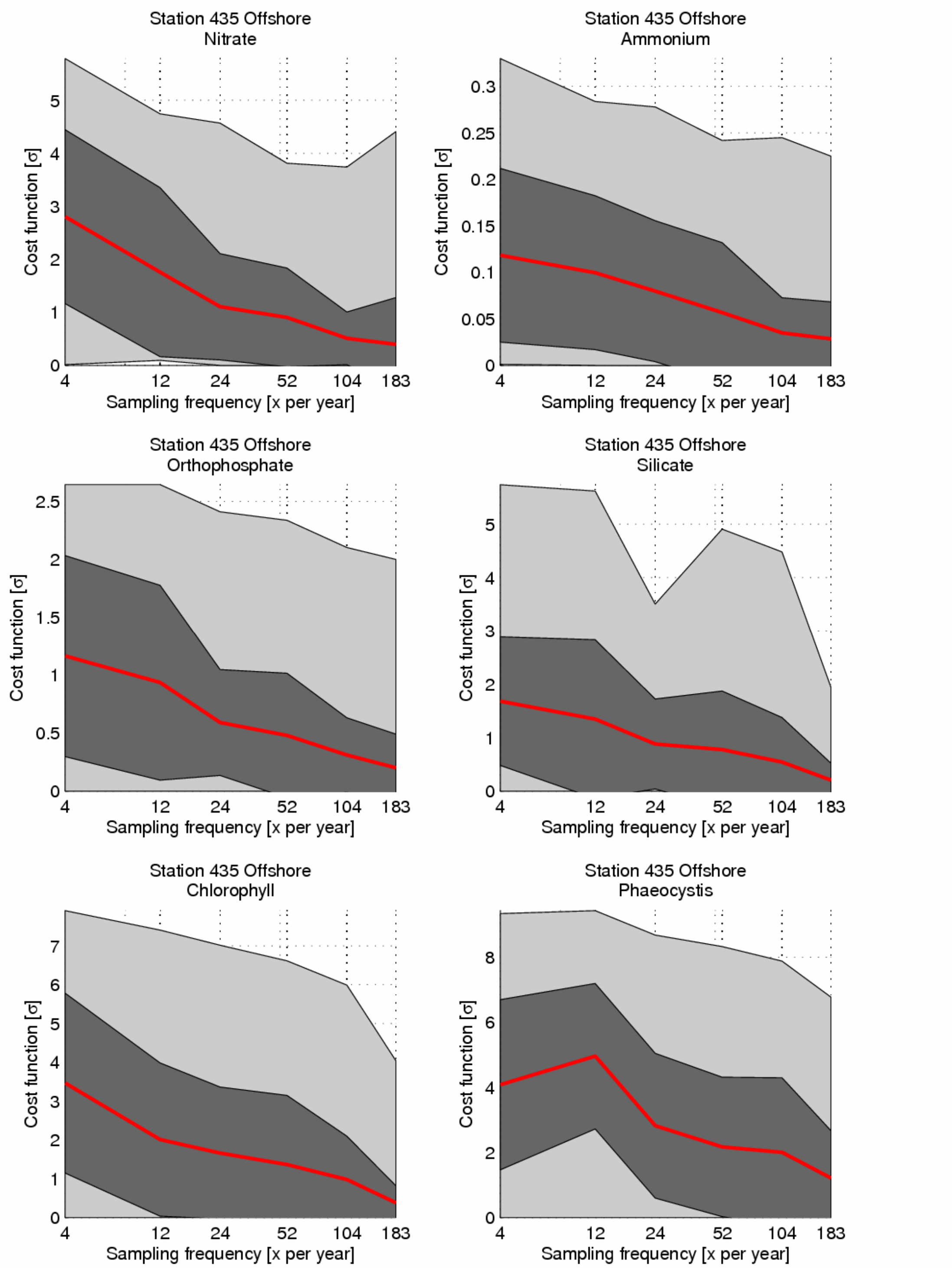

Figure 18 Effect of different sampling strategies on estimates of the maximum concentration (offshore waters). Light grey indicates the entire range of estimates. Dark grey is the standard deviation of the estimate quality. Red is the mean quality (after 5 tests per sampling frequency, repeated for 10 years of data)

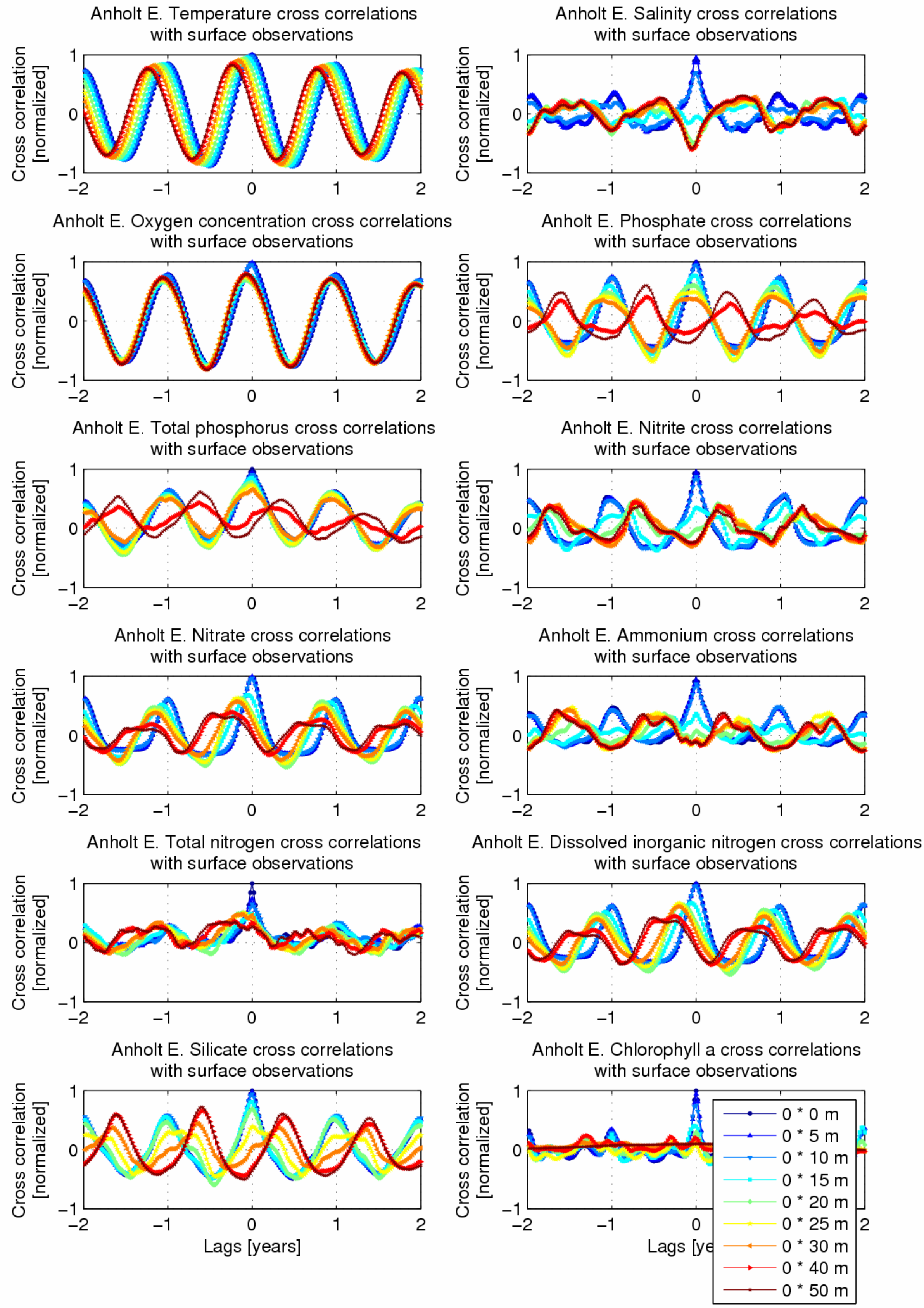

Figure 19 Cross correlations between surface data and data from standard depths, at Anholt E. in the southern Kattegat

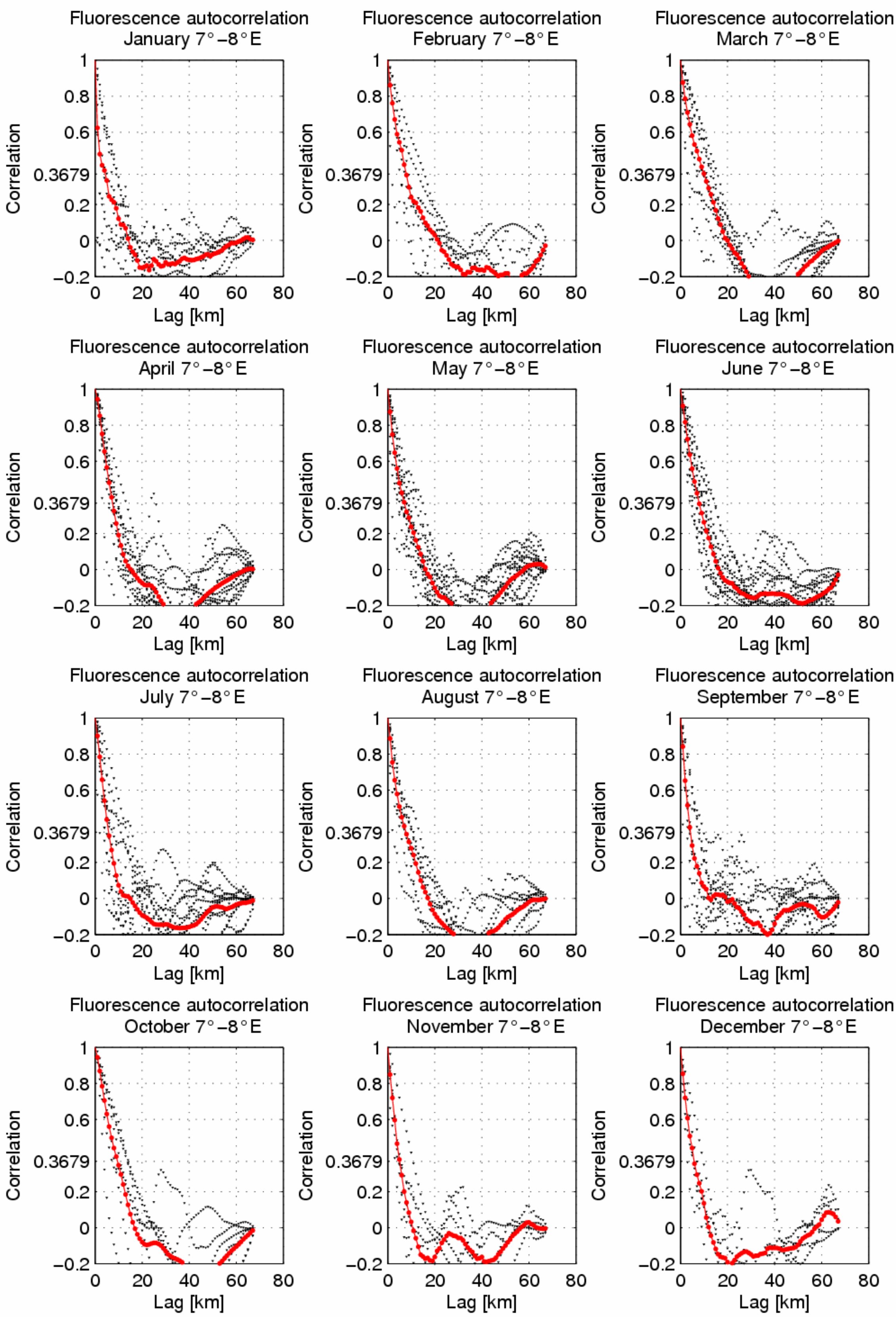

Figure 20 Autocorrelation of chlorophyll fluorescence from GKSS Ferrybox, between 7 & 8°E, January to December

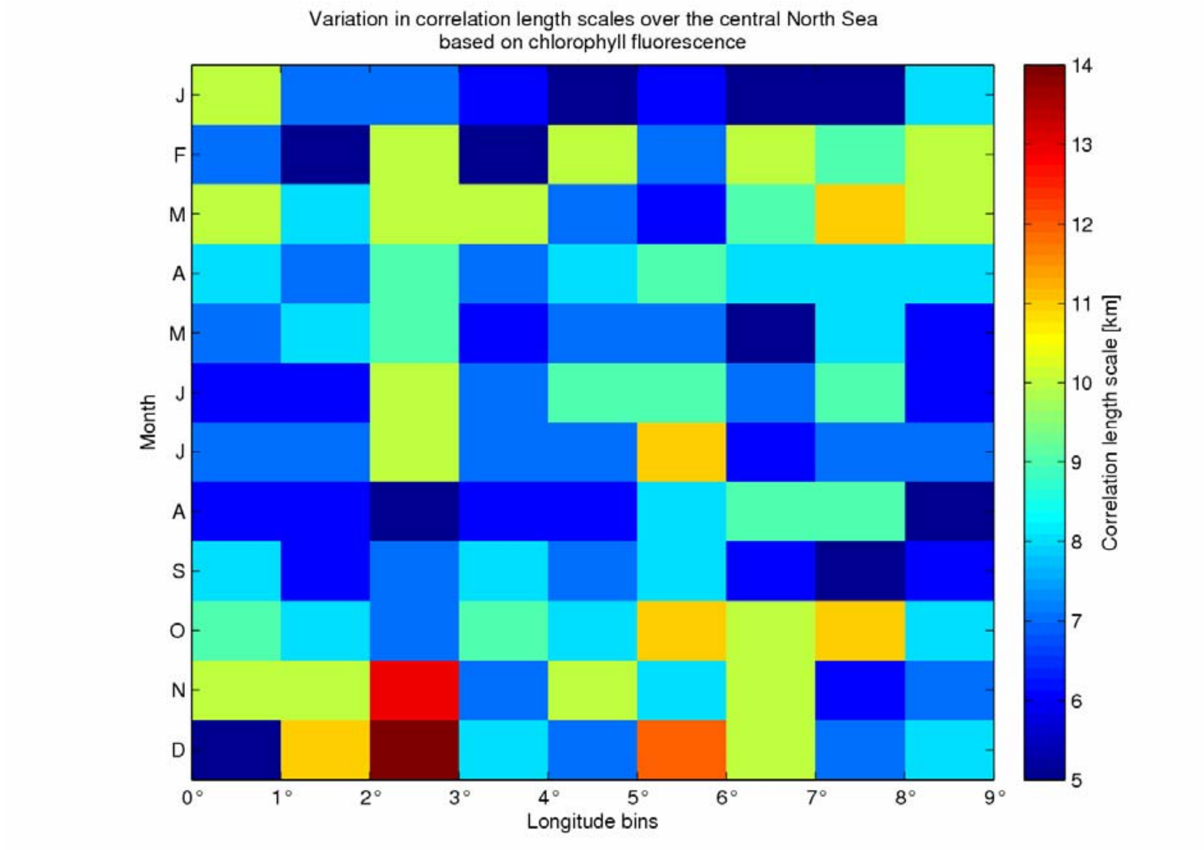

Figure 21 Summary of variation in correlation lengths by longitude and month, based on GKSS ferrybox chlorophyll

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