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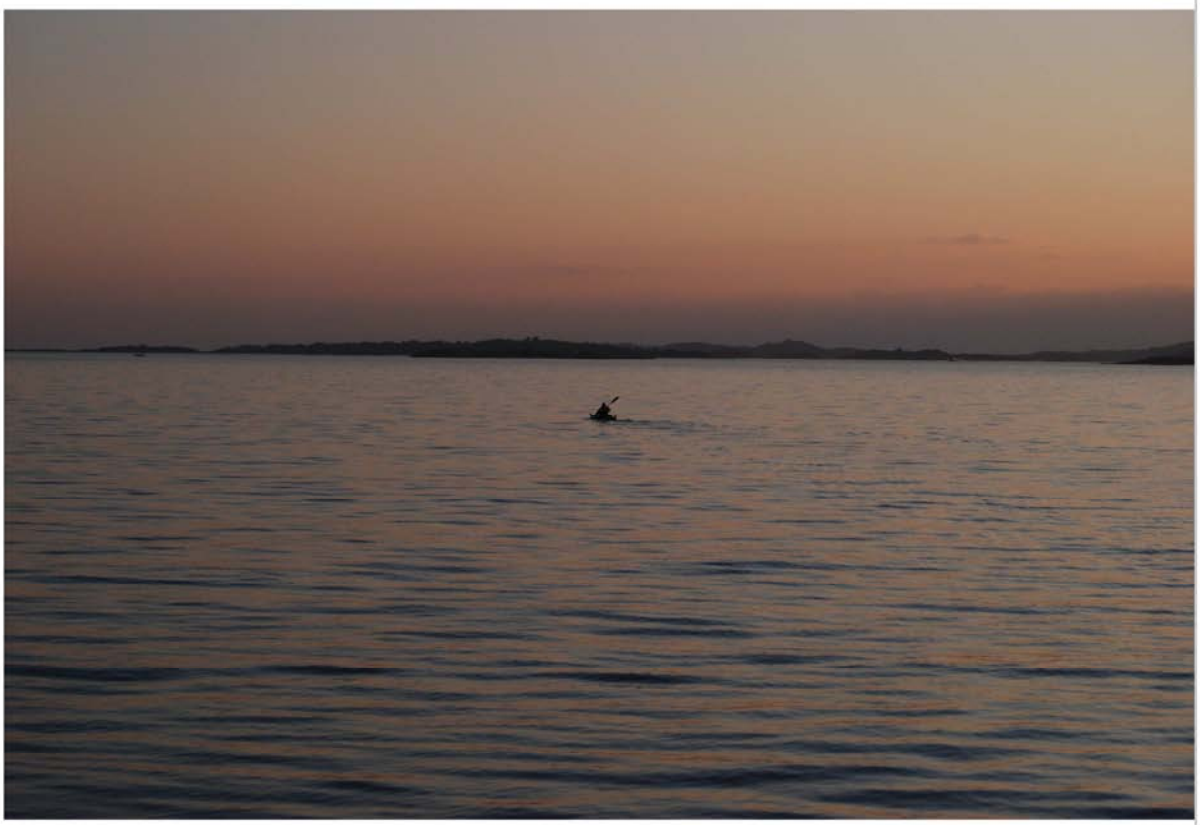
Confidence rating for OSPAR COMP



Pärmbild.
Bilden föreställer en novemberkväll i nordöstra Kattegatt

A November evening in the north eastern Kattegat

RO 43

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Confidence rating for OSPAR COMP

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1 Summary

With the adoption of the Marine Strategy Framework Directive and the Water Framework Directive, EU Member States are obliged to achieve “Good” or “Good Environmental” Status within a certain time frame, or be obliged to take remedial action. There is therefore a need to quantify the quality of the monitoring programmes on which such status assessments are based, as a part of assessing the confidence in the status assessment.

Within the framework of the OSPAR Convention on the Protection of the North East Atlantic, Germany and the Netherlands presented a suggestion for how such an assessment could be made. This report documents the application of this methodology to stations in the Swedish National Monitoring Programme within the OSPAR area, and also within the Sound, which may in future be included in the Greater North Sea region under the Marine Strategy Directive.

The variability of eutrophication parameters with salinity was examined. In the Kattegat, inorganic nutrient variability was least at the highest salinities, suggesting that a reliable status assessment could be made more easily with data from this region, for example, rather than in the dynamic near coast region.

Assessing the coverage of the existing monitoring programme, it was found that horizontal gradients in assessment parameters (generally seasonal averages) varied by less than about 30% between stations, which suggests that the programme has reasonable spatial coverage, though additional stations would improve matters. Looking at each station individually, the current vertical sampling resolution appears adequate for most parameters, apart from chlorophyll *a* and inorganic nutrients during the growing season. Temporal coverage is adequate for the total nutrient concentrations, but is insufficient for the inorganic nutrients and chlorophyll *a*, as well as for the deep water oxygen concentration in the Sound.

The poor temporal coverage of chlorophyll *a* and inorganic nutrients could be relatively easily improved by the addition of a two channel (nitrate + nitrite, and orthophosphate) autoanalyser onto the existing ferrybox platforms in use in these waters. Addressing these problems using traditional measuring platforms and buoys would be more costly.

2 Sammanfattning

Medlemsländerna inom EU har undertecknat Havsmiljödirektivet samt Ramdirektivet för Vatten och har därmed förpliktat sig att uppnå ”God” eller ”God miljö-” status inom sina marina miljöer inom en viss tid, eller ta fram åtgärder. Det finns därför ett behov att utvärdera mätprogrammen som levererar data till sådana statusbedömningar, som en del av konfidensbedömningen av hela statusbedömningen.

Inom OSPAR Konventionen för Skyddet av Nordost Atlanten, har Tyskland och Nederländerna presenterat ett förslag för hur man skulle kunna utföra en sådan utvärdering. Den här rapporten beskriver resultat när metoden användes med svenska data från Västerhavet (inklusive Öresund, som möjligtvis ska ingå i Större Nordsjöns region under Marina Strategin).

Övergödningsvariablernas salthaltsvariation undersöktes. I Kattegatt var den oorganiska närsaltsvariabiliteten minst vid den högsta salthalten, detta tyder på att en pålitlig bedömning av övergödning kan göras enklare med utsjödata än med data från den mer dynamiska kustzonen.

När man tittar på mätprogrammets täckning, syns det att horisontala gradienter i bedömningsvariabler (ofta säsongsmedlen) varierar med mindre än 30 % mellan stationer. Detta visar på en rimlig täckning, även om flera stationer skulle förbättra programmet. Om man tittar på varje station för sig, är nuvarande provtagning i djupled tillräcklig, förutom för klorofyll *a* och oorganiska närsalter under växtsäsongen. Provtagningsfrekvensen räcker för totala

närsaltshalter, men är inte tillräcklig för oorganiska närsalter samt, i Öresund, för koncentrationen av syre i djupvattnet.

Den otillräckliga provtagningen av klorofyll *a* och oorganiska närsalter kan förbättras ganska enkelt om en autoanalysator med två kanaler (nitrit + nitrat, samt ortofosfat) monteras på de nuvarande ferryboxsystem som används. Alternativet att använda bojar och traditionella mätplattformar skulle vara dyrare.

3 Background

The OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic commissioned an inter-sessional correspondence group (ICG) to review the Common Procedure which member countries use to describe eutrophication status in OSPAR waters.

Germany and the Netherlands presented a discussion paper at a meeting of the ICG in January 2011 (document ICG COMP 11/2/2-E; presented by Brockmann 2011). This document recommends a more explicit confidence rating of eutrophication status in the next application of the Common Procedure, considering the data coverage (in terms of area and time), variability and steepness of gradients. The variability affects the natural background conditions, the assessment levels and the actual eutrophication status.

The document recommends the use of numerical modelling to determine background nutrient concentrations, based on known concentrations at the fresh and saline limits. Background concentrations of other nutrients are then determined by their relation to the nutrients used in the modelling exercise.

Confidence in eutrophication assessment will be affected by data availability in relation to the variability and strength of concentration gradients: if sufficient data are available to resolve gradients, and to capture the natural variability of the system, then confidence in the final assessment of that particular parameter will be satisfactory. In order for the overall eutrophication status to be satisfactory, gradients and variability will need to be represented across all the parameters used.

The document also proposes that all regions where the quantitatively assessed confidence is unsatisfactory should be classified as '*Problem Areas*'[1].

The German / Dutch proposal was illustrated using a test case of the German Bight over a 5 year period. Data confidence was determined by the number of samples per assessment unit, the standard deviation and the ranges of the (means of) measured parameters reflecting the steepness of gradients within the areas.

Confidence was scored on the 1 -3 scale used in HEAT (Andersen et al, 2010). Table 1 shows the various conditions defining the confidence scores. Highest confidence was awarded if there were more than 100 observations, and if the coefficient of variation (ratio of standard deviation to the mean) was less than 50%. Alternatively, 50 samples would suffice if the sample range was less than the mean. An intermediate confidence would be obtained if the range ratio was greater than 100 or the coefficient of variation was between 50 and 100%. If the coefficient of variation was greater than 100%, or fewer than 50 samples were available, then the lowest confidence rating was given.

The method also highlighted changes in variability with salinity. In the coastal waters of the German Bight, variability is much greater than in the offshore German Bight. This has implications for monitoring and assessment: to obtain the same confidence in both offshore and inshore regions, the inshore region will require a greater monitoring effort. Similarly, if the assessment criterion is expressed in terms of "95% of samples are below the threshold", then the

[1] This recommendation was not adopted at the ICG-EUT meeting in autumn 2011

mean concentration must be considerably lower than the threshold in the variable zone than it would need to be in the less variable, offshore zone (Figure 2).

The discussion paper also proposed a method for evaluating the spatial coverage of the monitoring programme, using pairs of stations and examining the concentration gradients between them, expressed as a percentage of the mean of the two concentrations – a form of variation coefficient. This method is also applicable to assess the sampling resolution with depth, and also temporally at individual stations. At present, no criteria have been adopted to say what are acceptable or unacceptable gradients, so the results are a qualitative guide to the variability of the assessment parameters, and the ability of the monitoring programme to capture the variability.

The Annex V of the Marine Strategy Framework Directive requires that monitoring programmes are adequate to demonstrate distance from, and progress towards good environmental status. Within OSPAR, Contracting Parties have committed to assess ‘Distance to Target’ for Problem and Potential Problem areas identified in the integrated OSPAR eutrophication report (OSPAR, 2008). In the case of Sweden, this covers the inshore and offshore Kattegat, and the inshore and offshore Skagerrak. The calculation of nutrient budgets, including transboundary inputs, is beyond the scope of this report. However, time series of observation data are presented (winter nutrient concentration, growing season chlorophyll *a* concentration and autumn bottom oxygen) and compared to the assessment levels used in Håkansson et al, 2007.

4 Aim

The aim of this work is to gain a better understanding of the variability in the data used for eutrophication assessments in the waters off the Swedish West Coast, by using the proposals in the German / Netherlands document. As there are ongoing discussions about including the Sound in the Greater North Sea region of the Marine Strategy Framework Directive, the national monitoring station West Landskrona was included.

The work also provides a basis for discussion of ‘Distance to Target’ to achieve ‘Good Environmental Status’ or ‘Non-problem Status’. This is proposed through the presentation of time series of the principle hydrographic eutrophication parameters.

5 Method

5.1 Variability as a function of salinity

The German / Netherlands proposal (Brockmann, PDF document, appendix 1) uses salinity as a tool to understand dilution effects and to define background values in different regions (Figure 1). It also illustrates an apparent reduction in variability with increasing salinity, when the standard deviation is used as the measure of variability, as conditions tend towards the offshore ‘background’. The coefficient of variation does not reflect the same reduction in variability however (Figure 2). This has implications for determining whether an assessment target has been met (the black line): are assessment criteria met when the mean concentration is below the threshold level, or when (for example) 95% of observations are below the threshold? The ability to determine whether the Good Environmental Status criterion has been met will depend therefore on the data variability, and on the ability of the monitoring programme to capture this variability.

The Kattegat and Skagerrak have more complex hydrography than the German Bight (two large mesohaline outlets from the Baltic Sea; nutrient loading from large fresh water point sources, from inflowing saline water and from additional diffuse sources; multiple dynamic frontal regions). It is possible that the description of variability in the German Bight presented in Figure 2 is not applicable to Swedish waters. To test this, mixing diagrams are plotted, showing variation of mean winter nutrient concentrations (DIN, DIP, Total N, Total P), mean growing season chlorophyll, mean Secchi depth and mean oxygen concentrations with salinity. Parameter choice is summarized in Table 2.

Results are presented as means plus and minus one standard deviation for each salinity bin, and as coefficients of variation per bin. The size of the salinity bins is selected as a tradeoff between having sufficient data to estimate the mean in each bin, yet a sufficient number of salinity bins to make any trend with salinity apparent. Data from 2006 – 2010 are used.

Discussion of results covers the suitability or otherwise of the present regional subdivision (Water Framework Directive water types as opposed to the ‘classic’ OSPAR / HELCOM Kattegat / Skagerrak /Inshore /Offshore delineation).

5.2 Horizontal, vertical and temporal gradients

Increased sampling effort is necessary in regions with strong horizontal and vertical gradients, in order to resolve these gradients so that data are correctly interpreted. Brockmann proposes a method to do this in both the horizontal and the vertical, while the method is also applicable to assess the sampling frequency.

Horizontal and vertical concentration gradients have been determined for dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), total phosphorus (TOT P), total nitrogen (TOT N), chlorophyll *a* , O_2, O_2 saturation, and Secchi depth for the time period 2006-2010. Time series from the following monitoring stations in Kattegat and Skagerak were used: West Landskrona, Anholt E, N14 Falkenberg, Fladen, P2, Släggö, Å13, Å15, and Å17, as these stations are monitored frequently (monthly or more frequently) in the Swedish national monitoring programme[2]. The location of these stations is indicated in Figure 4.

Horizontal gradients between sampling sites were assessed by taking the difference between two stations (e.g. station A and station B) and expressing this difference as a fraction of the mean of the same two values ($\overline{V}$). The resulting gradient magnitude expressed in percentage terms is:

$$Horizontal\ gradient = \frac{V_{station\ A} - V_{station\ B}}{\overline{V}_{station(A,\ B)}} * 100$$

where V denotes ‘value’. Horizontal gradients were determined for each parameter using data from the same depth intervals and seasons as used in the assessment. These are described in Table 2. All nine monitoring stations were compared with each other. Results are presented for each year and the mean for the time period in Figure 7-Figure 12.

[2] Additional monthly monitoring stations exist as part of the regional coastal monitoring programme in these regions, but are not part of the national monitoring programme.

Similarily, the vertical concentration gradient between consecutive depths (z(i)) has been determined according to:

$$Vertical\ gradient = \frac{V_{z(i)} - V_{z(i+1)}}{\overline{V}_{z(i,\ i+1)}} * 100$$

To see wether temporal resolution is sufficient, temporal concentration gradients have been calculated for each standard depth on each station by comparing consecutive samplings (t):

$$Temporal\ gradients\ = \frac{V_{t(i)} - V_{t(i+1)}}{\overline{V}_{t(i,\ i+1)}} * 100$$

5.3 Distance to target

To assess ‘Distance to target’, eutrophication indicators need to be compared to reference levels. In the case of OSPAR, the reference levels are called the ‘Elevated status’. Nutrient and chlorophyll concentrations below the elevated status are considered to be ‘Non-problem’, as are bottom oxygen conditions above this level. In order to account for dilution effects, the Comprehensive Procedure proposes that nutrient concentrations are ‘corrected’ to a salinity of 30 using mixing diagrams.

Winter DIN, DIP, total nitrogen, total phosphorus, growing season chlorophyll *a* and autumn bottom oxygen concentrations have been plotted using data from 2001 to 2010. Data are presented as box plots, to show the full distribution of data. Mean concentrations for each year are also indicated. The distance of annual mean and median values from the ‘elevated status’ is reported, as is the percentage number of data points under the status level.

Two sets of time series are presented. The first uses the OSPAR correction to 30 [psu] (Figure 31Figure 34), while the second set shows the original data, and are included purely to illustrate the impact of the salinity correction.

6 Results

6.1 Variability as a function of salinity

Figure 5 shows how the concentration of OSPAR Common Procedure ‘Causative Factors‘ (winter nutrient concentrations) vary with salinity in the Kattegat and Skagerrak. In the Kattegat, very high DIN concentrations are associated with very low salinity (below 7). Salinities this low are associated with rivers discharging directly into the Kattegat. The standard deviation of the mean DIN in these salinity bands is large, although the coefficient of variation (shown in Figure 5 as the standard deviation in percentage terms) is small, due to the high DIN concentration.

Between salinities of 7 to 16, the DIN concentration is fairly constant, as is the standard deviation. This salinity range is fairly typical of the coastal waters and of the discharge from the Sound. Above 16, DIN decreases to a minimum of about 5 µmol/l around a salinity of 20, before increasing towards again (to about 10 µmol/l) with higher salinities, as Skagerrak water (including DIN from the southern North Sea via the Jutland Coastal Current) becomes apparent. The standard deviation within each salinity bin decreases steadily above a salinity of 16. The increasing DIN concentration, combined with the reduction in standard deviation, causes the coefficient of variation to fall rapidly.

In the Skagerrak, DIN behaves differently: there is very little data below salinity 12. Between 12 and 22, DIN concentration decreases steadily, from above 20 µmol/l to about 6 µmol/l. At greater salinities, DIN concentration remains rather constant. The coefficient of variation is highest in the more saline waters, although at between 30% and 80% is similar to the most saline parts of the Kattegat.

The behaviour of DIP also differs between the Kattegat and Skagerrak. In the Kattegat, there is a rapid increase in concentration from the transitional to coastal waters. Above a salinity of 7, DIP concentration remains fairly constant, with averages in the salinity bins varying from 0.5 to 0.8 µmol/l. Lowest concentrations occur in the middle of the range, at salinities between 17 and 25. Variability is also fairly steady: There are peaks in both the standard deviation and coefficient of variation at salinities of 5 and 15. Otherwise, the variation coefficient is fairly constant, between 10 and 40%. In the Skagerrak, there is a steady increase in DIP concentration with salinity, and also increasing variability. Particular peaks in variation coefficient occur at salinities of 20 and 30 (similar to DIN). Aside from these, the coefficient of variation is between 20 and 40% above 15 [psu].

In both the Kattegat and Skagerrak, total nitrogen decreases with increasing salinity. In the Kattegat, the standard deviation decreases quickly too, causing the coefficient of variation to decrease as salinity increases. At the offshore end, the coefficient of variation is around 10%. In the Skagerrak, the coefficient of variation remains fairly constant as the salinity exceeds 20, except around 30, where there is a small increase in the standard deviation, and a larger increase in the coefficient of variation, from 20% to 40%.

Total phosphorus shows little relation to salinity. In the Kattegat, above a salinity of 7, concentrations are steady at about 1 µmol/l, and the standard deviation is also steady. In the Skagerrak, concentrations are also steady at about the same level. The standard deviation reaches a maximum at a salinity of around 30 (as for total nitrogen). This causes the coefficient of variation to increase to 60%, rather than the 10% which is normal for salinities of 15 – 20, and above 33.

Figure 6 shows the variation with salinity of eutrophication effects, such as growing season chlorophyll *a* concentration and summer Secchi depth, as well as the summer total nitrogen and phosphorus concentrations.

In the Kattegat, away from transitional waters, salinity does not appear to influence the chlorophyll *a* concentration, except possibly above a salinity of 28. The standard deviation is also fairly constant, giving a variation coefficient of about 100%. In the Skagerrak, chlorophyll *a* does appear to decrease with increasing salinity. The standard deviation also decreases, causing the coefficient of variation to remain constant, also at 100%. Summer Secchi depth follows a similar pattern, with no noticeable salinity effects in the Kattegat, but an increase from about 5 to 8 metres in the Skagerrak as salinity increases from 15 to 35. The coefficient of variation for the Secchi depth in both basins is around 30 – 40%, irrespective of salinity.

Summer total nitrogen behaves in a similar way to the winter concentration, with decreasing concentrations as salinity increases, in both the Skagerrak and Kattegat. The coefficient of variation also decreases with increasing salinity in the Kattegat, but not the Skagerrak.

6.2 Horizontal and vertical gradients

6.2.1 Horizontal gradients

Horizontal gradients between the monitoring stations were determined for the seasons and depth intervals in Table 2 and are illustrated for each year and the mean year in Figure 7 to Figure 12. The variability between years is large. There are considerably larger gradients for inorganic nutrients in 2010 than in previous years, suggesting that the spring bloom has already started during the winter. Interpretations are therefore made on the averaged results (Figure 12). Gradients for adjacent stations are confined along the diagonal and according to the mean image they are small, ~20 %, for all parameters apart from winter DIN. There are especially small gradients between the station pairs Å17 - Å15, Å13 - P2 and Fladen – Anholt E. Stations further away from each other have larger gradients, as would be expected. Generally, there are larger horizontal gradients for the total concentrations of nutrients in summer than in winter and gradients for inorganic compounds are larger than for the totals.

Perhaps surprisingly, differences between stations for chlorophyll *a* concentration were generally small – often less than 30%. Oxygen differences were also small: the worst differences between adjacent stations were between Anholt E. in the southern Kattegat and West Landskrona in the Sound, and between the coastal Skagerrak station Släggö and the adjacent offshore stations P2 and Å13.In particular years, the differences could exceed 70%, although usually the difference was much smaller.

6.2.2 Vertical gradients

Vertical gradients for each of the nine monitoring stations and parameters are presented in Figure 13 - Figure 21. In general, for all parameters, vertical gradients are smaller in winter because of mixing and less biological activity. Largest gradients are found in the surface layer and particularly in the pycnocline where concentrations are more variable. For both inorganic and total nutrient concentrations, it is most difficult to resolve the vertical gradients in spring/summer when the nutrients are intensively used and thermal stratification has begun. Gradients for the total nutrients are mostly less than 50 % while gradients for the inorganic compounds often approach 100 % at the pycnocline and during the spring/summer months. At the stations P2, Släggö, Å13, and Å15, gradients for nutrients are large deeper down in the water column than the other stations.

Chlorophyll *a* is a difficult parameter to resolve vertically that results in large vertical gradients even though the 0-5 m layer is better. Vertical gradients for O_2 are overall low, ~20 % except for W. Landskrona, in the Sound, where larger gradients are common.

6.2.3 Temporal gradients

Temporal gradients for each station and parameter are presented in Figure 22 - Figure 30. For nutrients, sufficient temporal resolution can only be guaranteed below the surface layer and possibly in the winter months. Time periods with the largest problems to resolve temporal variations in nutrients are when the bloom season starts and stops. Generally, gradients for DIP are slightly lower than for DIN and gradients for the total concentrations are better than the inorganic gradients. Chlorophyll *a* seems to be a problematic parameter with overall large gradients approaching 100 %. Temporal gradients for the concentration and saturation of O_2 is low, ~20 %, except at W. Landskrona that has larger gradients below 5 m. The Secchi depth needs to be observed in particular during the growing season. Because of sampling problems (avoiding ship shadowing, and with the sun higher than 15° above the horizon) it is measured less often than other parameters. Despite this, the temporal gradient for Secchi depth is often below 50 %.

6.3 Distance to target

Dissolved inorganic phosphorus and total phosphorus concentrations in the inshore Kattegat (Figure 31) lie close to the assessment level (after salinity correction, which increases apparent concentrations compared to what was actually observed). During winter 2010, both median and mean DIP concentrations were below the assessment criterion. For total phosphorus, the median concentration was below the assessment level during four winters, and the mean was below during two winters. The furthest the median and maximum concentrations were from the assessment level was 0.23 µmol/l, which is about 20% of the assessment concentration. About 20 – 30% of DIN observations, and 30% of total phosphorus observations lie below the assessment level.

Dissolved inorganic nitrogen and total nitrogen concentrations are generally below the assessment level, helped in part by the salinity correction. Bottom oxygen concentrations are generally above (i.e. better than) the assessment level, although between 1% and 5% of observations lie below. The worst result (5%) occurs during 2002, which was a particularly bad year for hypoxia in the Kattegat. Growing season chlorophyll lies close to the assessment level, although the spread of data is very large, with about 40% of observations lying above.

In the offshore Kattegat (Figure 32), the picture is similar. DIP lies close to the assessment level, although acceptable status is only observed during two years, or three if the median is used. Total phosphorus is similar, with the first half of the time series having good status, the second having bad, although rarely being more than 0.1 µmol/l above the assessment level. DIN also straddles the assessment level, while total nitrogen is generally below: usually only the 75th – 95th percentiles exceed the criterion. With the exception of 2002, when 15% of observations were below the threshold, oxygen concentration lies well above, with typical mean and median values around 7 mg/l. Growing season chlorophyll lies close to the assessment level, with the median below during seven of the ten years, although the mean was only acceptable during one year. Mean values typically lie 0.8 µg/l above the assessment level, which is 50% over.

In the inshore Skagerrak (Figure 33) the spread in the phosphate (DIP) and total phosphorus data is greater than in the Kattegat, although this appears to be a result of the salinity correction (c.f. Figure 37) which also results in median concentrations occasionally exceeding the assessment level. Mean concentrations exceed the assessment level with or without correction, due to the skewed nature of the data.

Salinity correction has little effect on the nitrogen data (dissolved inorganic and total nitrogen). Median concentrations are consistently under the assessment level, and mean values only rarely (two winters in ten) exceed it. Mean and median oxygen concentrations exceed the threshold, but the presence of hypoxia and anoxia in the coastal fjords is apparent, and the on no occasions does the 5th percentile exceed the threshold.

Mean chlorophyll *a* concentrations lie very close to the assessment level, while the median concentrations are consistently under. Despite this, approximately 40% of observations each year exceed the threshold.

Finally, in the offshore Skagerrak (Figure 34) only chlorophyll *a* indicates any eutrophication problems. For eight of the ten years, the median lies below the assessment level (good status) though when using the mean value, only two years are ‘good’. Approximately 40% of observations remain above the assessment level.

7 Discussion

The Kattegat generally exhibits estuarine behaviour in a similar way to the German Bight. For both DIN and DIP however, concentrations increase with increasing salinity. This suggests that offshore nutrient reductions are necessary, and local actions are likely to have only local effects. In the Skagerrak, the mixing diagram is normal for DIN and Total Nitrogen, with higher concentrations in the coast and lower in the more saline waters. There is no apparent mixing relation for total phosphorus in the Skagerrak.

The reduction in both the standard deviation (and coefficient of variation) with increasing salinity in the Kattegat suggests that fewer observations will be required offshore to determine eutrophication status compared to the coastal zone. Similarly, the low coefficients of variation for winter DIN and DIP in the offshore Kattegat suggest that significant trend detection is most likely in these regions, rather than in the coastal zone.

The coefficients of variation for chlorophyll *a* show no variation with salinity, so there are no particular regions that can be focused on to permit better status or trend assessments. The variation coefficients in both the Kattegat and Skagerrak are large – often more than 100% - so the likelihood of a significant trend being detectable is small. Whether increased measurement frequency from ships of opportunity can reduce this apparent variability is not yet clear. With the existing research vessel data, Secchi depth has a coefficient of variation less than half that of chlorophyll *a*, so is better able to give a confident status assessment than can be made using chlorophyll *a*.

Horizontal gradients suggest that seasonal differences between adjacent stations are rarely more than about 30%, suggesting that the monitoring programme has moderately good coverage in this area. It should be noted however that the winter nutrient mapping network was not assessed: this network includes more stations, but these are only visited once during each winter season. While individual years do stand out – 2010 in particular – by combining information on chlorophyll, oxygen saturation and nutrient concentrations it is possible to detect when an early spring bloom disrupts the winter nutrient sampling. Differences in oxygen concentrations between coastal and offshore stations were also larger than other differences. This could be addressed by an additional station linking the coastal and offshore areas. In the case of Släggö and its adjacent stations, there is a monthly monitored station, part of the regional monitoring programme, between Släggö and Å13.

Both horizontal and vertical gradients indicate that inorganic nutrients and chlorophyll *a* are the most problematic parameters on the Swedish west coast. Total nutrients, oxygen, and Secchi depth are the most acceptable. More efforts could be needed during certain seasons and depth interval. The most sensitive time period is during spring and summer and especially when the seasonal bloom starts and ends. It is however impossible to know in advance when a bloom will set off and it would not be feasible to design the monitoring programme to meet this criterion specifically. Since biological production takes place in the surface layer this is also a sensitive region and in particular the pycnocline. The rather small horizontal gradients between adjacent stations indicate that the horizontal station resolution is good.

Winter nutrient concentrations appear to be well sampled (in the vertical) at each of the monitoring stations. More problematic conditions occur in the spring and summer, as thermal stratification and biological activity strengthens the vertical gradients.

Temporal gradients suggest that the existing monitoring programme has most difficulty measuring inorganic nutrients with sufficient frequency. Even at Anholt E., which is sampled 24 times per year, differences between successive measurements of both DIN and DIP greater than 100% occur – no doubt at the onset of the spring bloom (given that it is possible in Figure 23 to follow the undersampled zone as it cycles in depth during each of the five years). Chlorophyll *a* is the most undersampled temporally. There are rarely periods when successive measurements are within 100% of each other at many stations.

Given that inorganic nutrients and chlorophyll *a* are of interest in the surface waters, and (relatively) easily measured with automatic sampling systems, the problems identified with these parameters may be eased by ensuring that two- channel autoanalysers and good quality fluorimeters are included on the existing ferrybox platforms in operation.

The problem of rapid changes in oxygen concentration in the Sound could be addressed by means of a buoy system or landers equipped with oxygen sensors.

Studying the time series, there is a problem concerning which metric should be used in assessment: median concentrations are often lower than the means, because of skewness in the data. Can ‘Good Environmental’ or ‘Non-problem’ status be said to have been achieved when perhaps 40% of observations lie on the wrong side of the assessment level. This is particularly relevant for oxygen, when short term hypoxic events may be missed during monitoring, yet have serious consequences for benthic and pelagic communities. The large assessment units used within the Swedish OSPAR eutrophication work also causes problems: mean oxygen levels in the inshore Skagerrak appear good, but the presence of anoxic fjords and some hypoxic areas indicate problems, even though they are insufficient to affect the overall oxygen status if regional means are used.

The time series show that observations are very close to the accepted assessment levels used in the OSPAR Comprehensive Procedure, making the classification into ‘Problem’ or ‘Non-problem’ area difficult. The German / Dutch (Brockmann) proposal recommends that sampling effort is increased as the assessment level is approached, to ensure that a confident status assessment can be made. An increase in sampling effort, particularly for inorganic nutrients and chlorophyll *a*, such as that recommended to solve the temporal sampling problem would also facilitate the overall status assessment.

8 Conclusions

1. The reduction in both the standard deviation (and coefficient of variation) of DIN and total nitrogen with increasing salinity in the Kattegat indicates, if nitrogen is the principle causative factor, fewer offshore observations are required to determine eutrophication status with a particular degree of confidence compared to when using data from the coastal zone.
2. Winter nutrient variation coefficients are lowest at salinities of about 15 in the Skagerrak, so status determination and trend detection is likely to be most successful in this region, rather than offshore.
3. Inorganic nutrients are under-sampled at each station
4. Chlorophyll *a* concentration is extremely variable, and in addition is under-sampled at each station. This makes chlorophyll *a* particularly problematic as an indicator for determining whether Good Environmental or Non-Problem Status has been reached.
5. Whether high frequency (ferrybox and / or satellite) data can be used to reduce the apparent variability in chlorophyll *a* concentration should be assessed.
6. Temporal under-sampling should be addressed by instrumenting the existing ferrybox lines with nutrient autoanalysers for DIN (or at least nitrate + nitrite) and DIP, and fluorimeters for chlorophyll *a*. This also has the possibility of improving the spatial coverage as well.
7. The spatial coverage of the existing monitoring programme is close to adequate for providing seasonal mean concentrations, although gradients of about 30% between adjacent stations suggest that much information is currently missed, and any reduction in the number of stations will lead to much greater uncertainty in any status assessment.
8. Analysis of time series shows eutrophication status to be very close to OSPAR Non-problem status: to facilitate confident status assessment so close to this boundary, the assessment criteria should be clarified and sampling effort increased to determine which side of the boundary we are on, and whether additional nutrient reductions are necessary. The increased sampling effort identified in point 6 would facilitate the status assessment.

9 References

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10 Figures and tables

Score	**Number of samples**	**Sample range, compared to mean**	**Coefficient of variation**
1	> 100	[> 100%]	< 50%
1	> 50	< 100%	
2	> 50	> 100%	50 – 100%
3	> 50		> 100%
3	< 50		

Table 1 Examples of confidence scoring used in the German Bight, after Anon 2011

Parameter	**Unit**	**Depth range [metres]**	**Time period**
Dissolved inorganic nitrogen	*µmol/l*	0 – 10 m	Dec - Feb
Dissolved inorganic phosphorus	*µmol/l*	0 – 10 m	Dec – Feb
Total nitrogen	*µmol/l*	0 – 10 m	Dec – Feb
Total phosphorus	*µmol/l*	0 – 10 m	Dec – Feb
Total nitrogen	*µmol/l*	0 – 10 m	Jun - Aug
Total phosphorus	*µmol/l*	0 – 10 m	Jun – Aug
Secchi depth	*m*		Jun – Aug
Chlorophyll *a*	*µg/l*	0 – 10 m	Feb - Oct
Bottom oxygen concentration	*mg/l*	Bottom	Aug - Oct
Bottom oxygen saturation	*%*	Bottom	Aug - Oct

Table 2 Assessment parameters

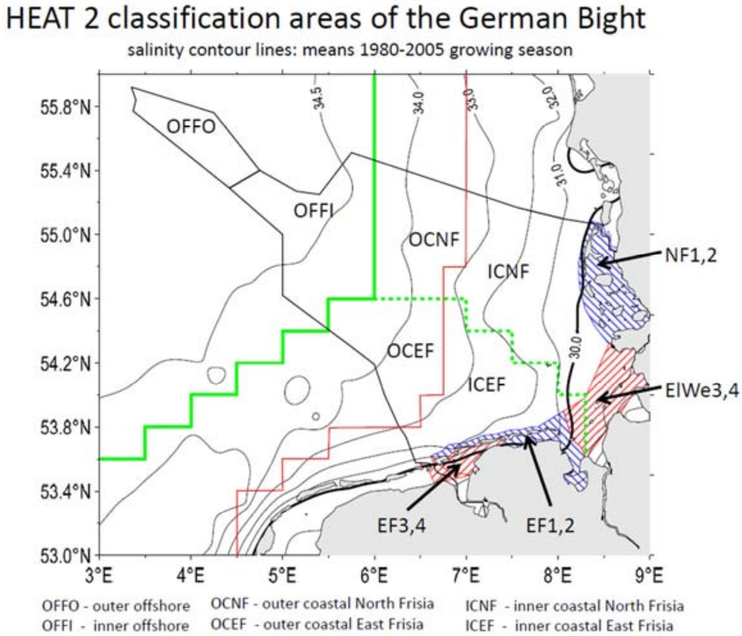


Figure 1 Designation of assessment units based on salinity (from Brockmann, 2011)

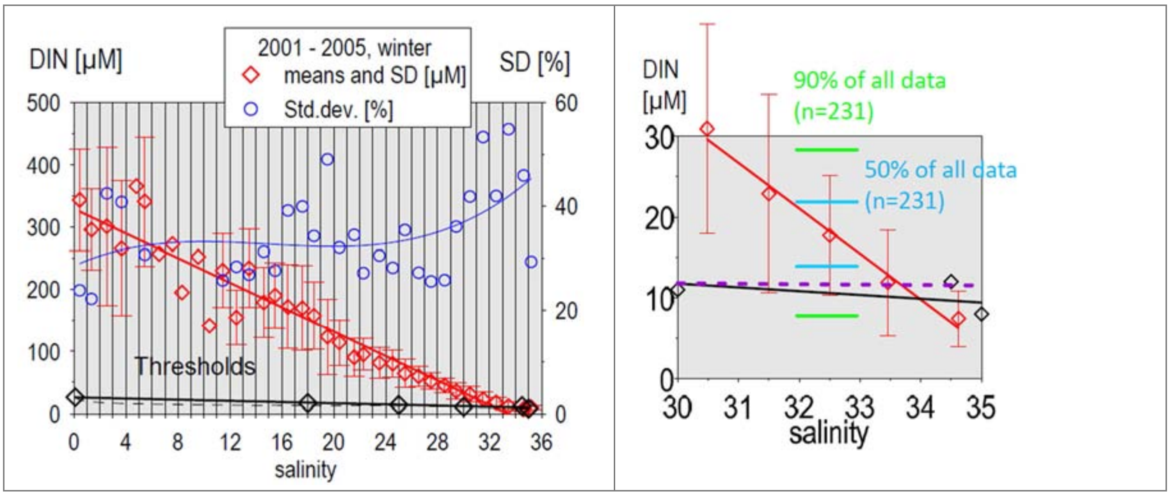


Figure 2 Changes in variability (expressed as standard deviation and coefficient of variation)with salinity (from Brockmann, 2011)

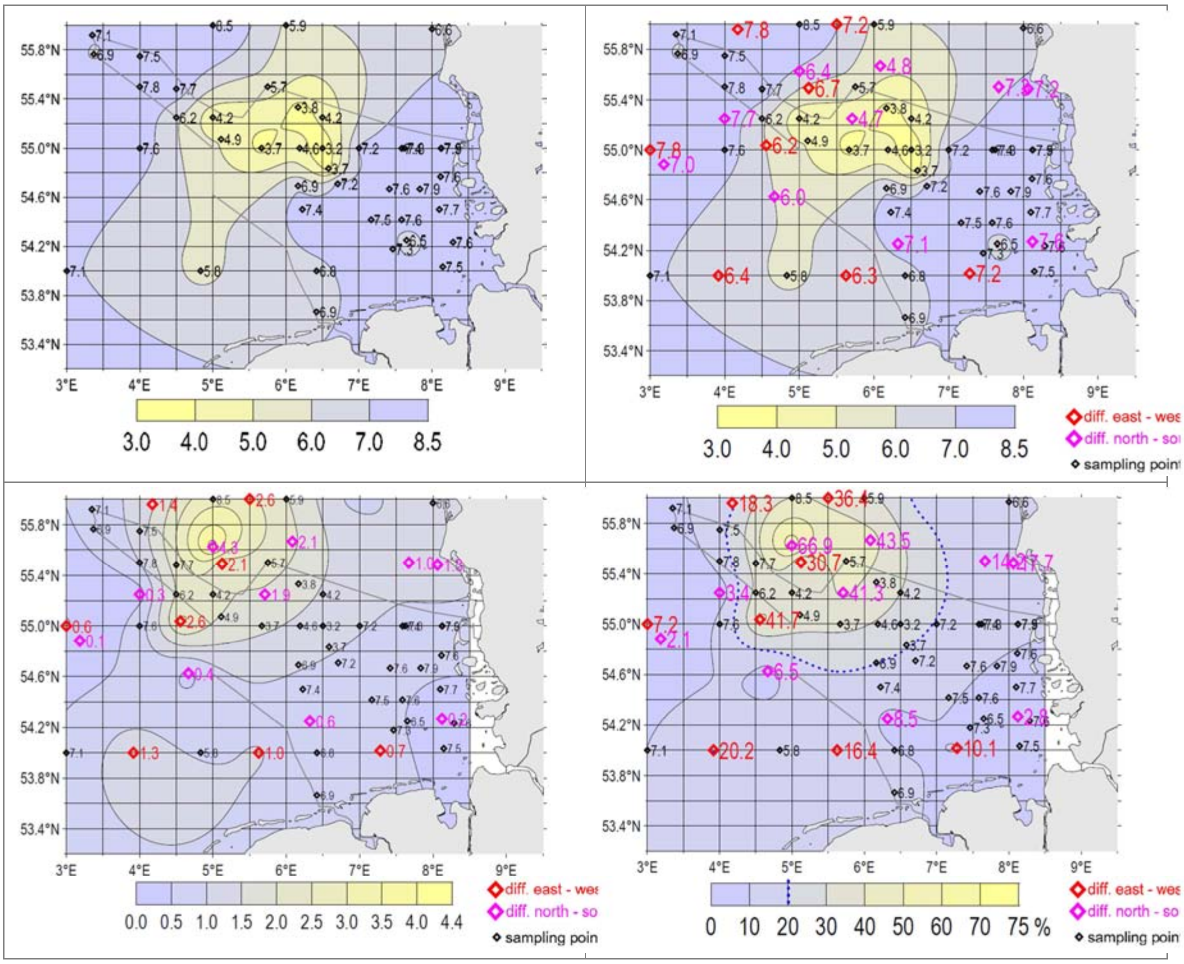


Figure 3 Method for assessing the horizontal coverage of bottom oxygen observations concentrations [top left], using the mean between adjacent observations [top right], the difference between adjacent observations [lower left] with the difference expressed as a percentage of the mean [lower right. Only observations more than 1° apart in longitude or 0.4° apart in latitude, were evaluated.

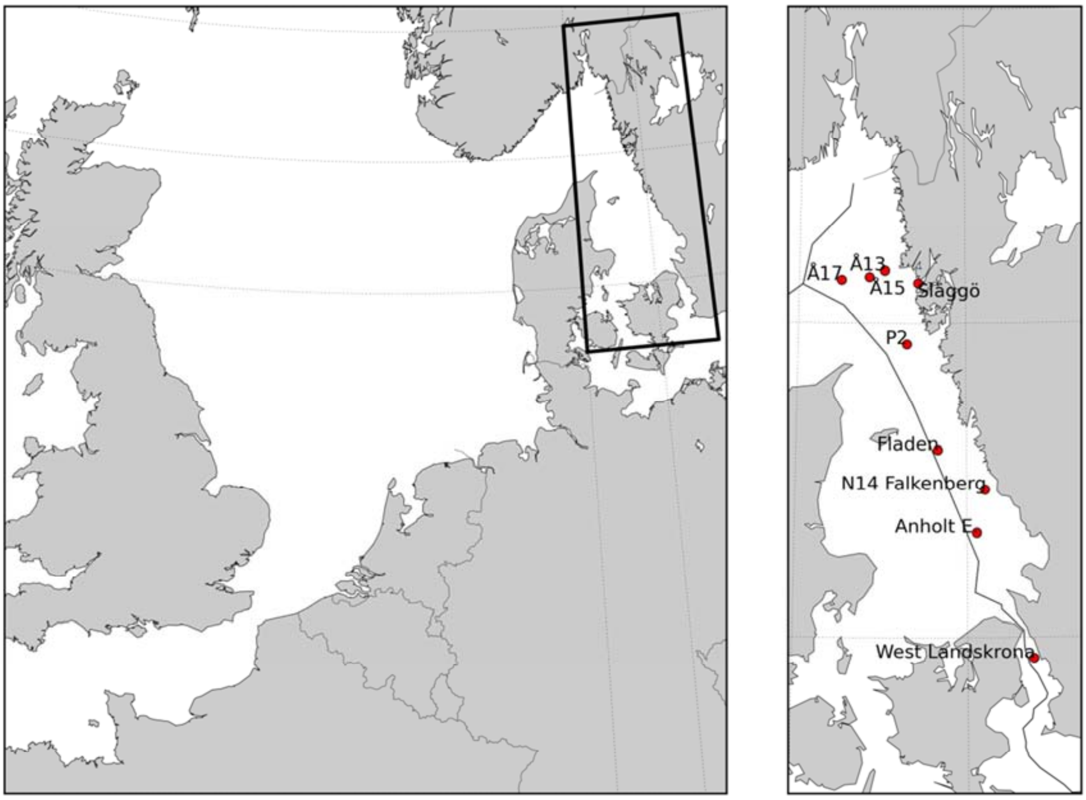


Figure 4 Station map (right) showing Swedish waters as a part of the Greater North Sea (left)

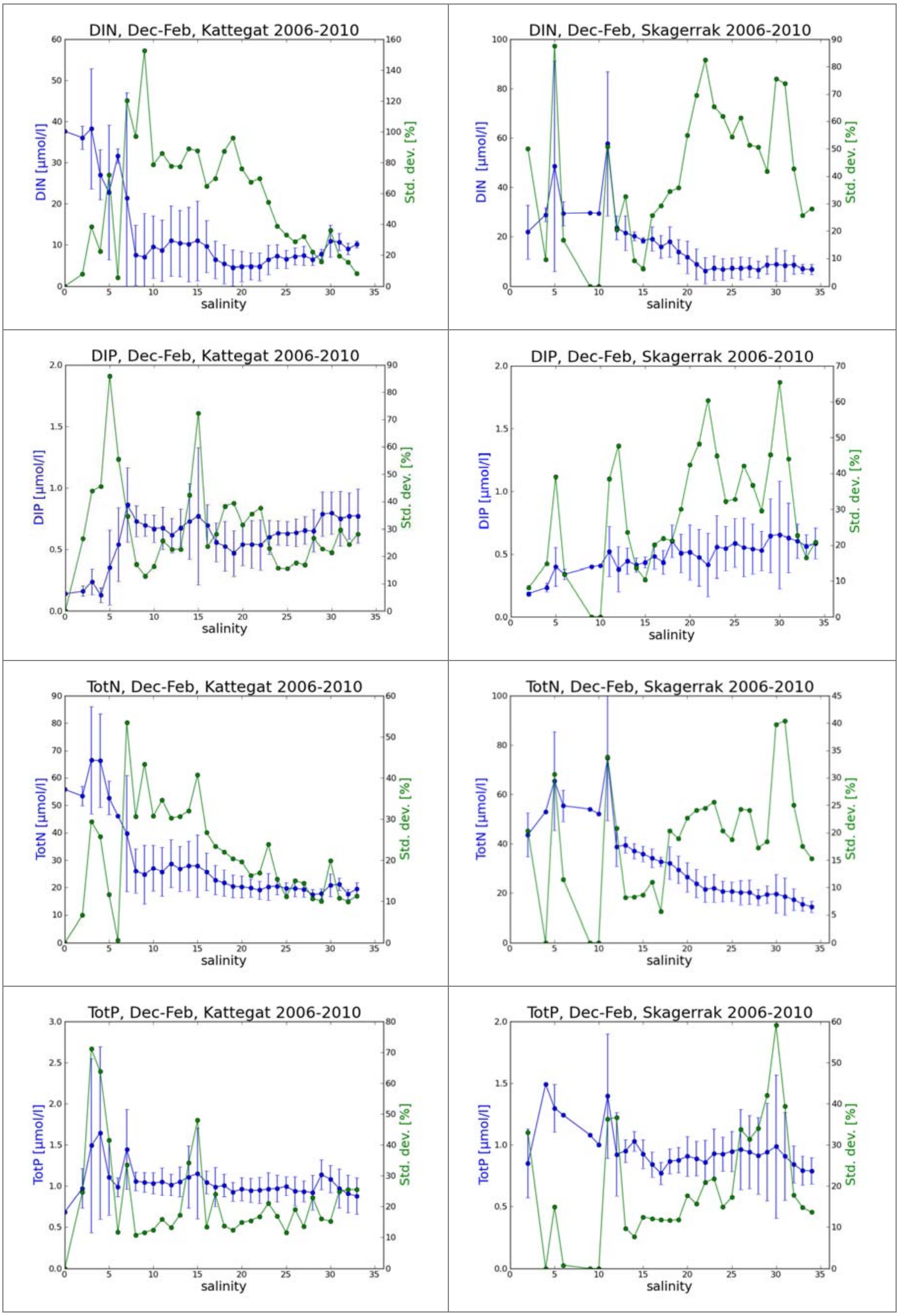


Figure 5 Variability of Causative Factors (winter nutrient concentrations, 0 – 10 m) with salinity in the Kattegat (left) and Skagerrak (right)

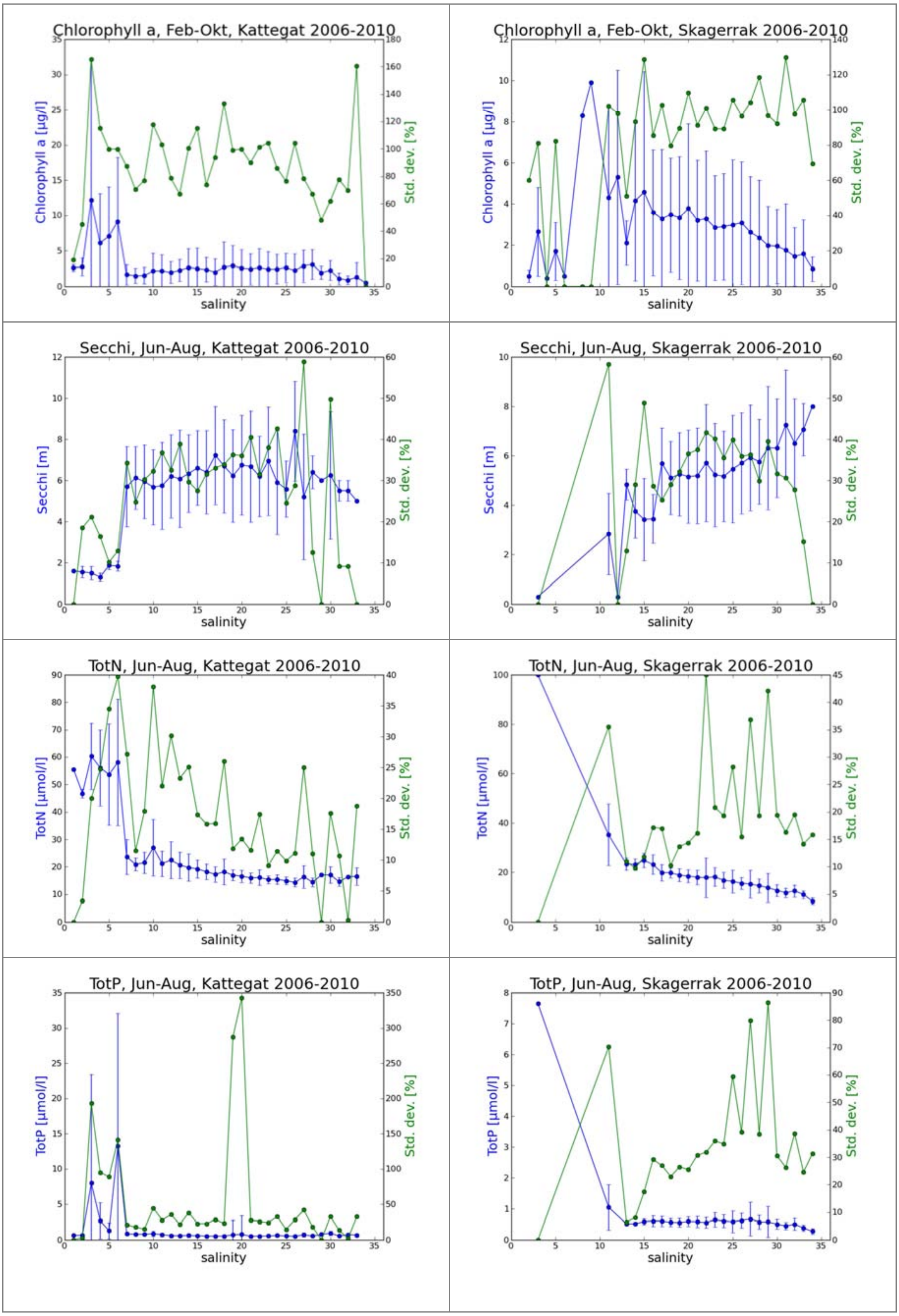


Figure 6 Variability of chlorophyll a, Secchi depth and summer total nutrient concentrations, with salinity, in the Kattegat (left) and Skagerrak (right)

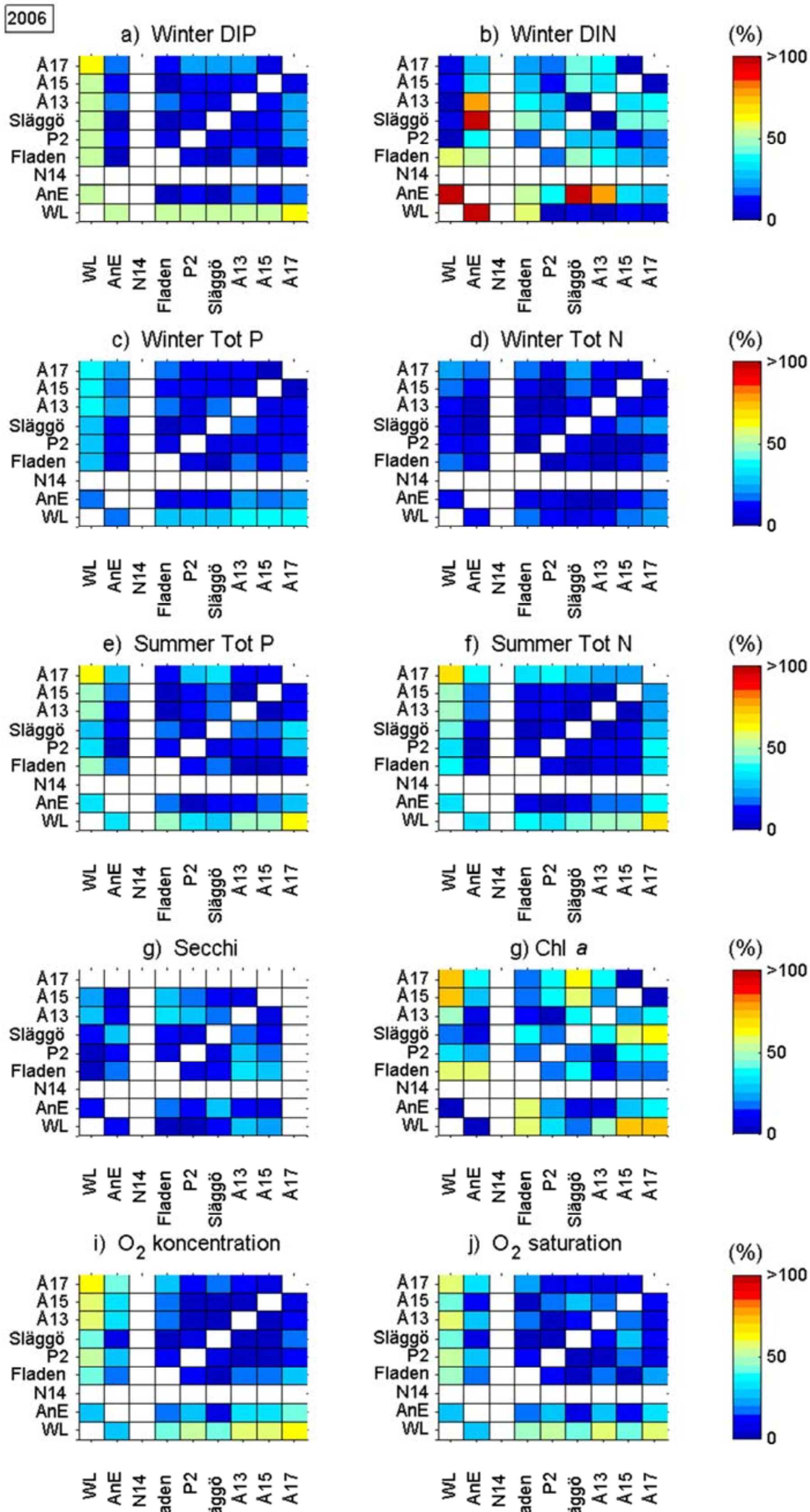

2006
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl a
i) O2 koncentration
j) O2 saturation
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL
(%)
>100
50
0

Figure 7 Horizontal gradients between stations for 2006. Time periods and depth intervals according to Table 2

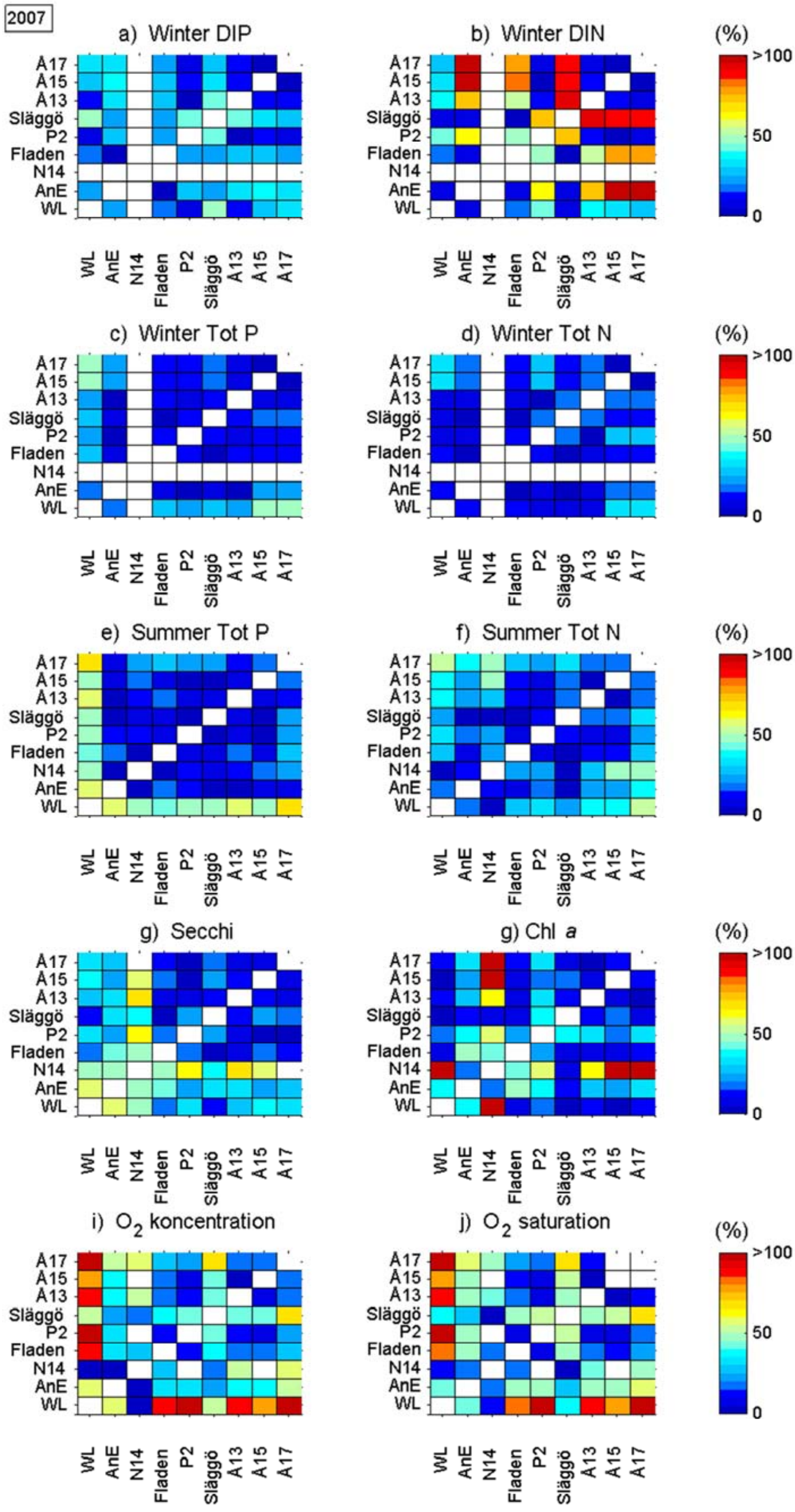
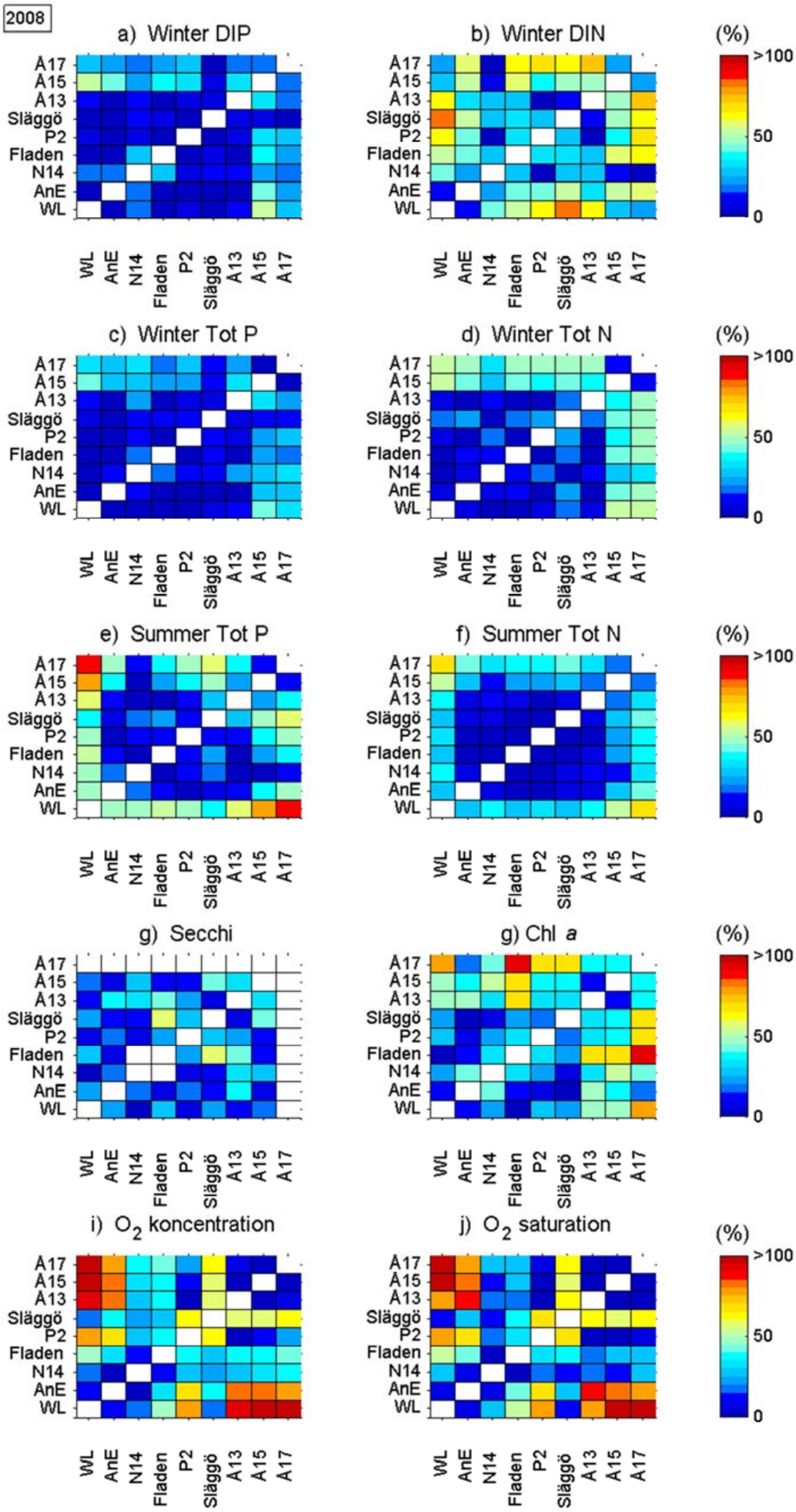

2007
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl a
i) O2 koncentration
j) O2 saturation
(%)
>100
50
0
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL

Figure 8 Horizontal gradients between stations for 2007. Time periods and depth intervals according to Table 2



2008
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl a
i) O2 koncentration
j) O2 saturation
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL
(%)
>100
50
0

Figure 9 Horizontal gradients between stations for 2008. Time periods and depth intervals according to Table 2

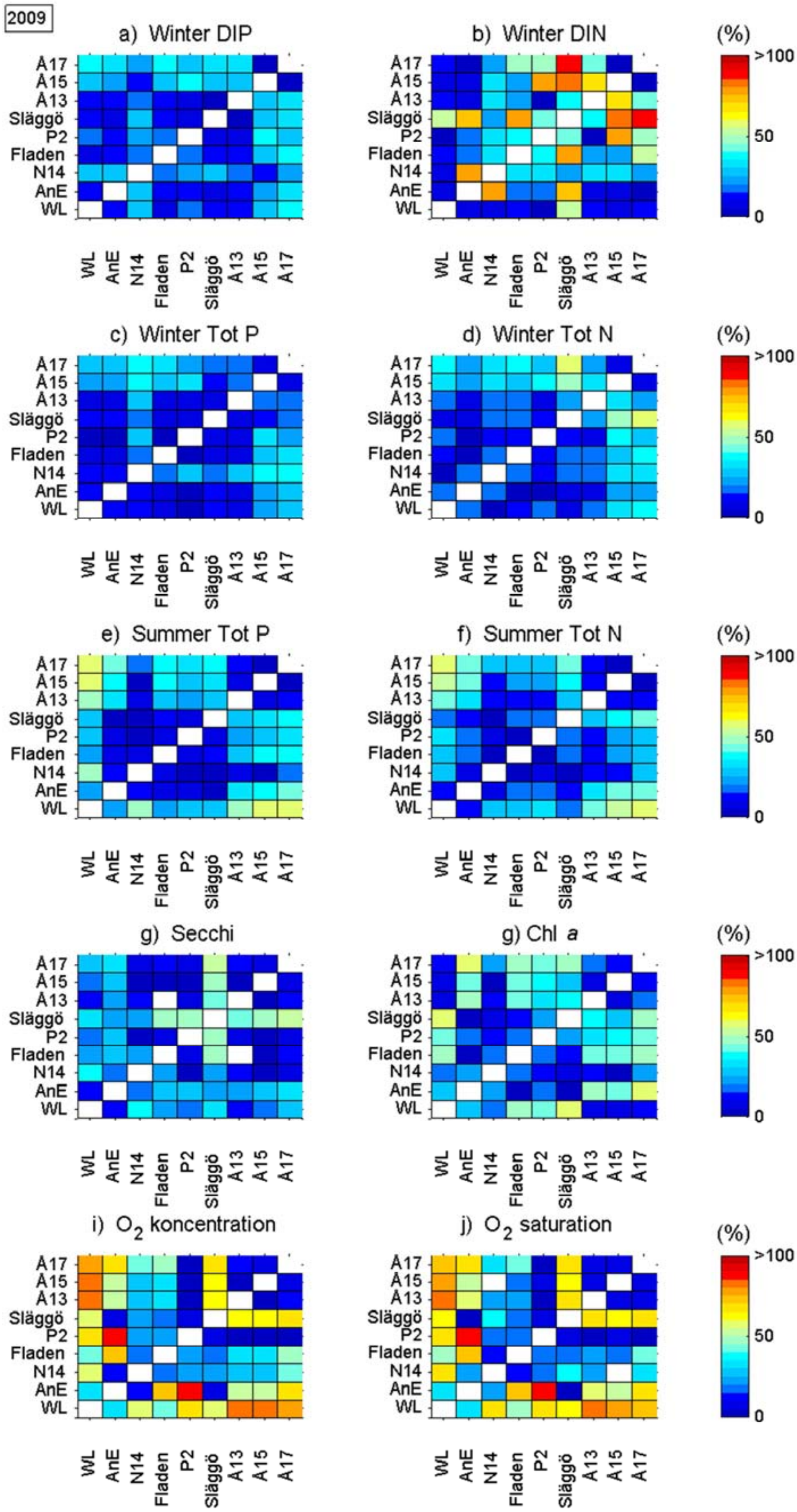
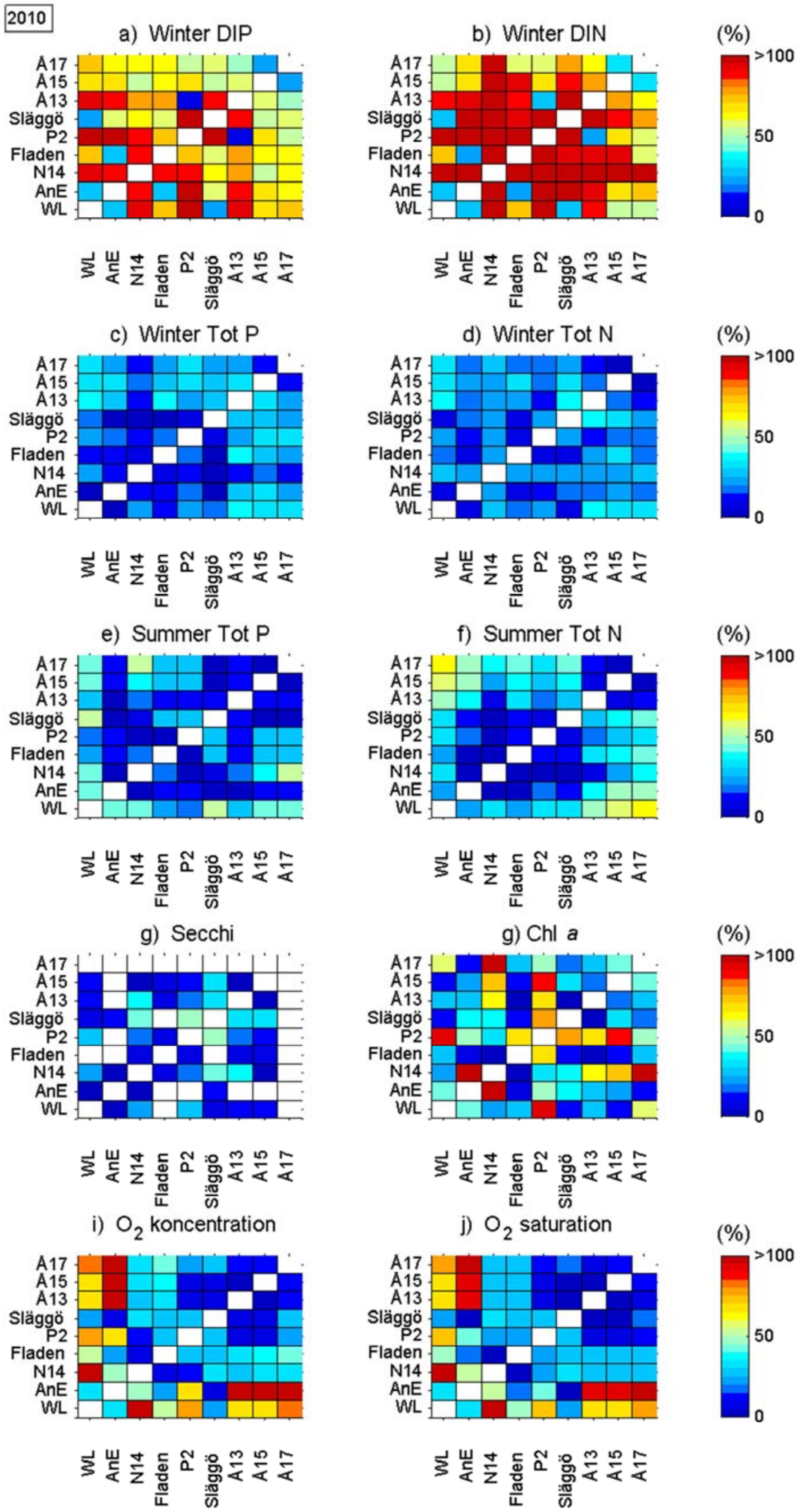
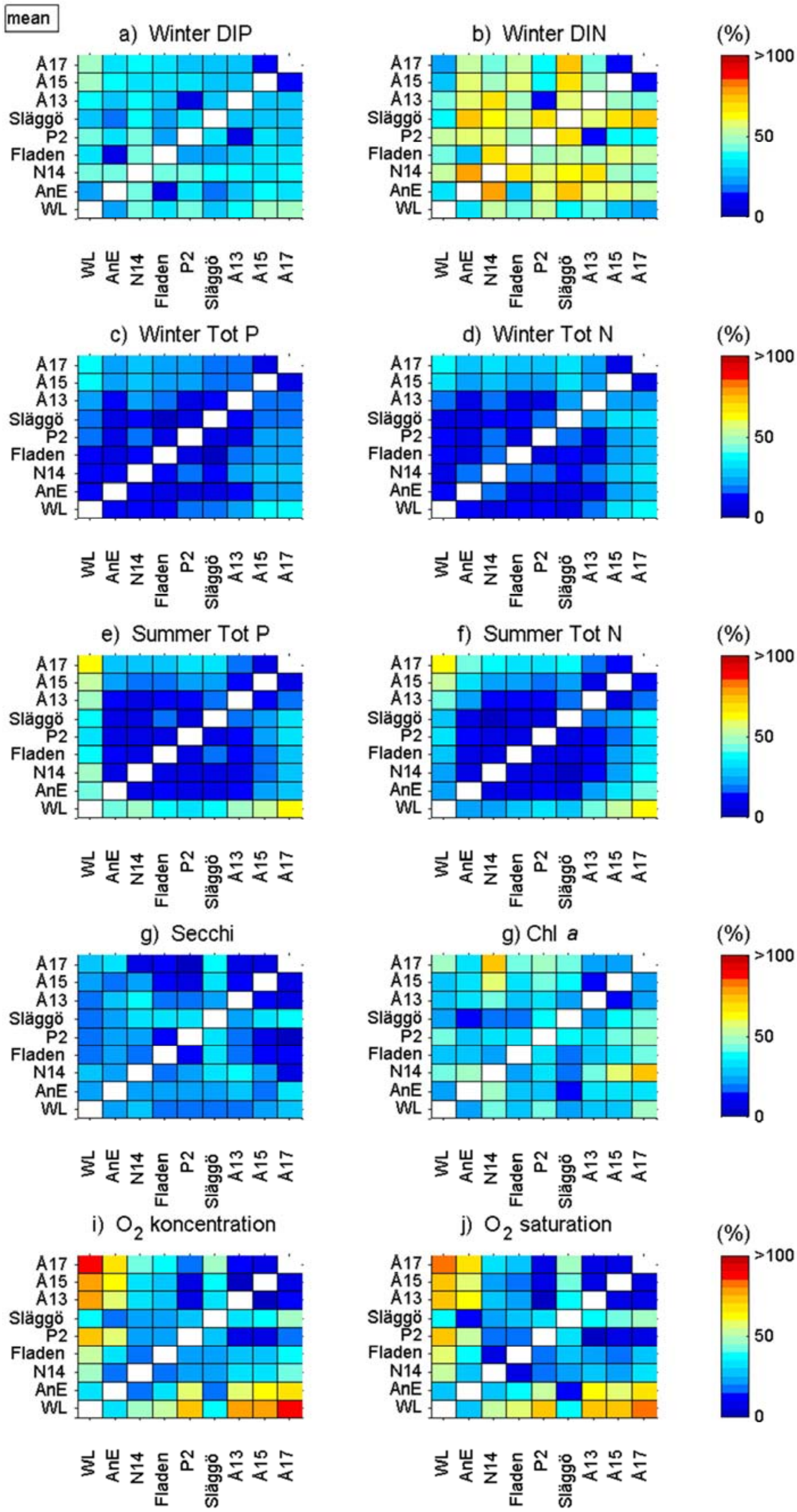

2009
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl *a*
i) O_2 koncentration
j) O_2 saturation
(%)
>100
50
0
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL

Figure 10 Horizontal gradients between stations for 2009. Time periods and depth intervals according to Table 2



2010
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl a
i) O2 koncentration
j) O2 saturation
(%)
>100
50
0
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL

Figure 11 Horizontal gradients between stations for 2010. Time periods and depth intervals according to Table 2



mean
a) Winter DIP
b) Winter DIN
c) Winter Tot P
d) Winter Tot N
e) Summer Tot P
f) Summer Tot N
g) Secchi
g) Chl a
i) O2 koncentration
j) O2 saturation
(%)
>100
50
0
Å17
Å15
Å13
Släggö
P2
Fladen
N14
AnE
WL

Figure 12 Horizontal gradients between stations: mean of results for 2006 - 2010. Time periods and depth intervals according to Table 2

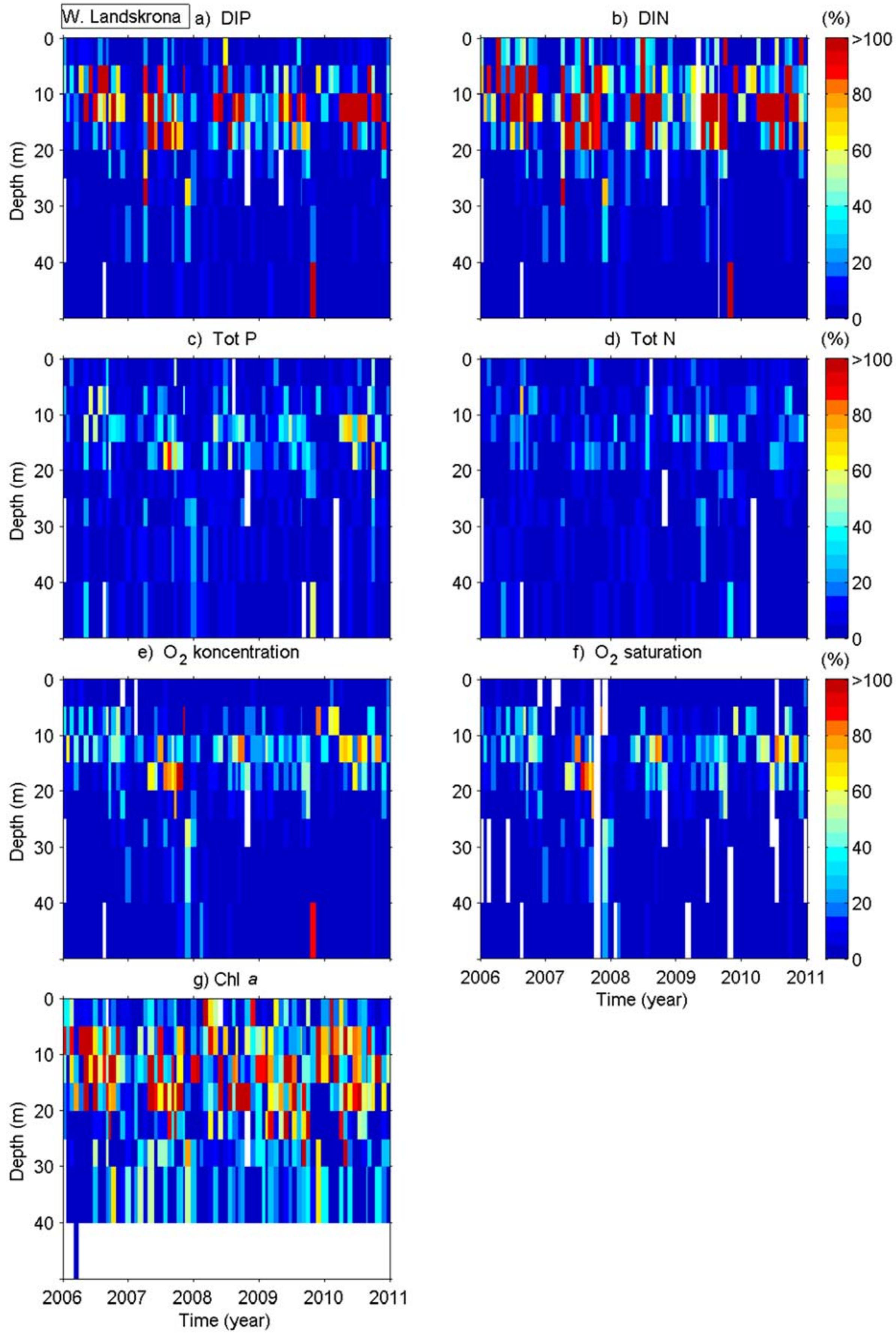


Figure 13 Vertical gradients at West Landskrona

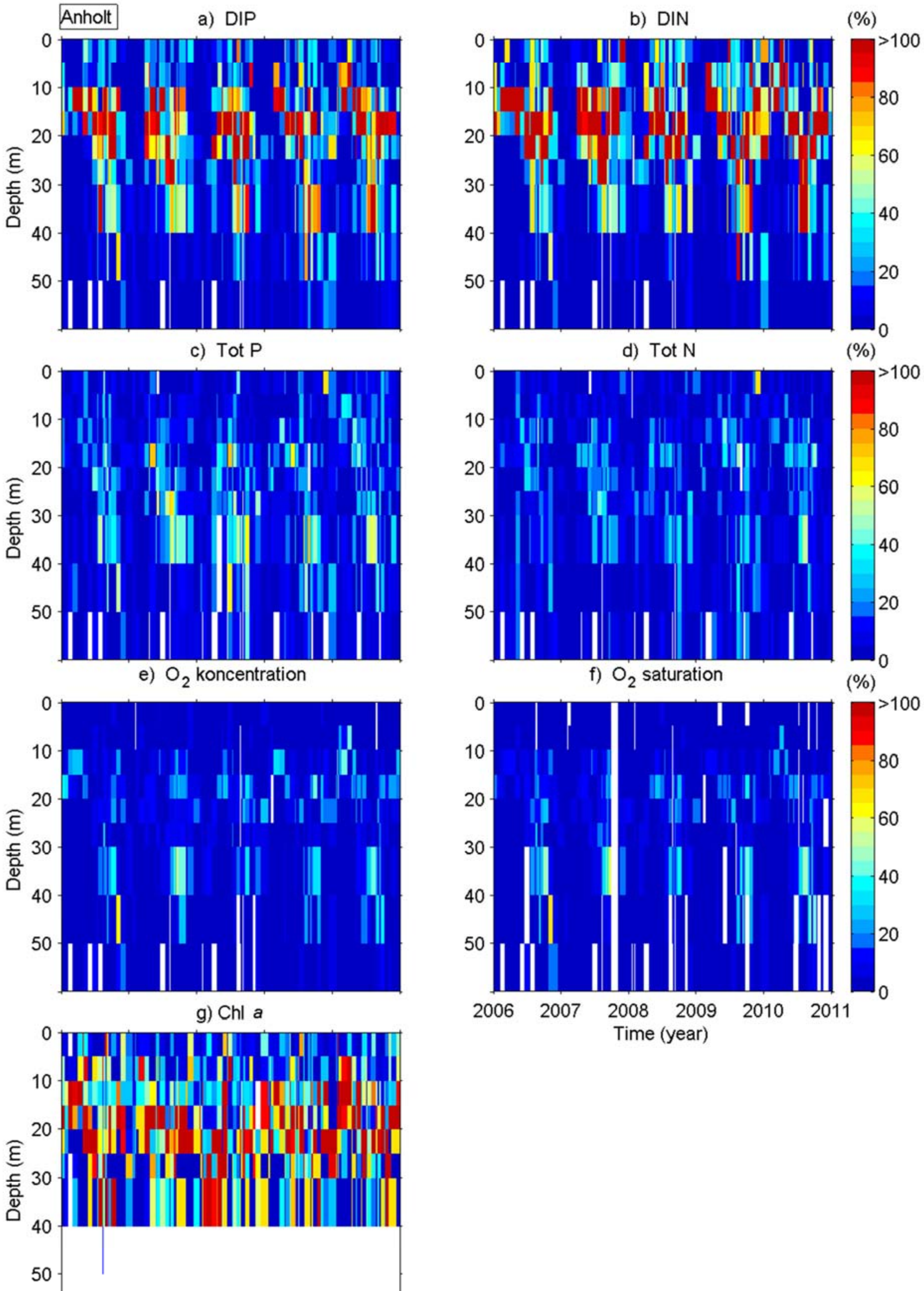


Figure 14 Vertical gradients at Anholt E.

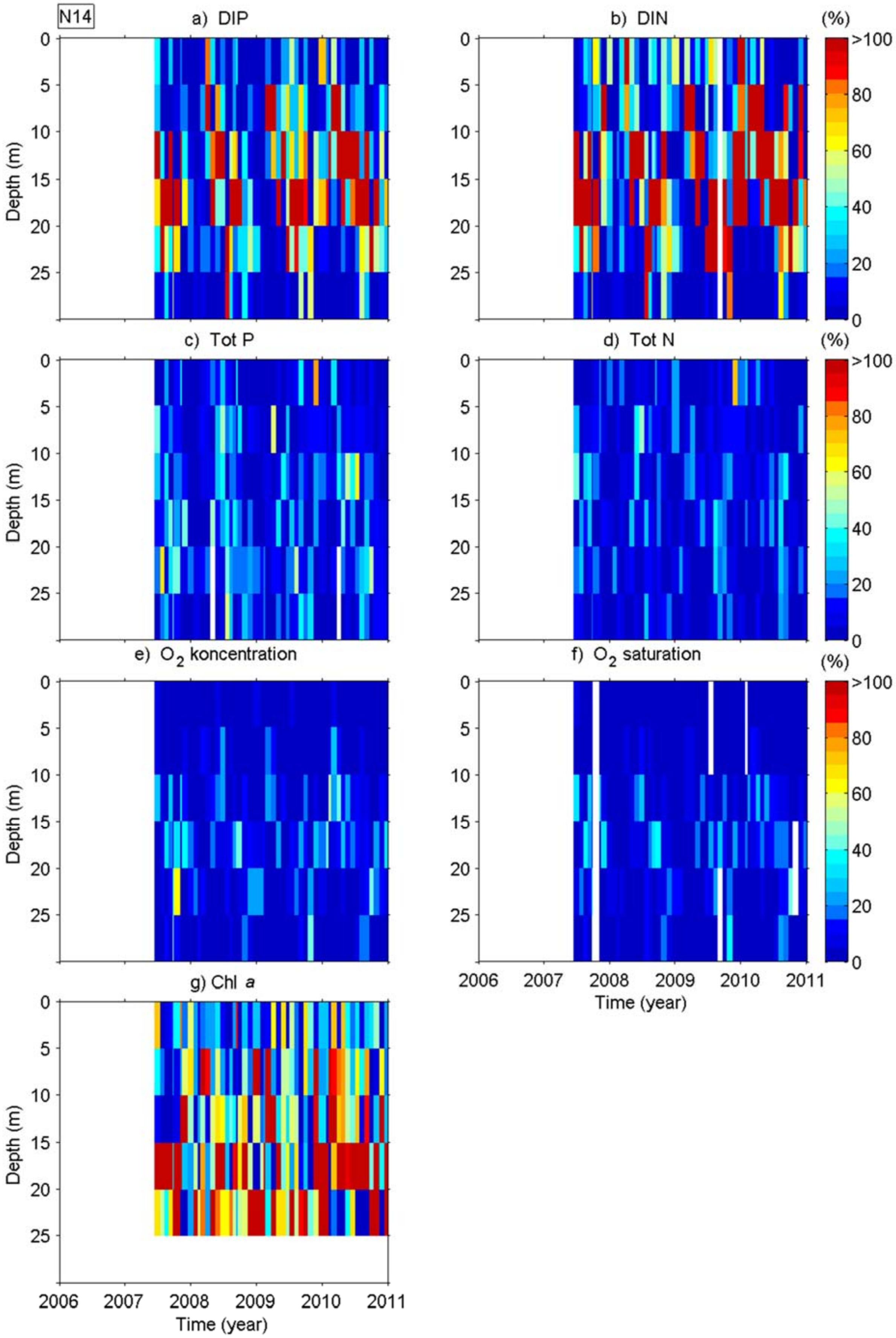


Figure 15 Vertical gradients at N14 Falkenberg

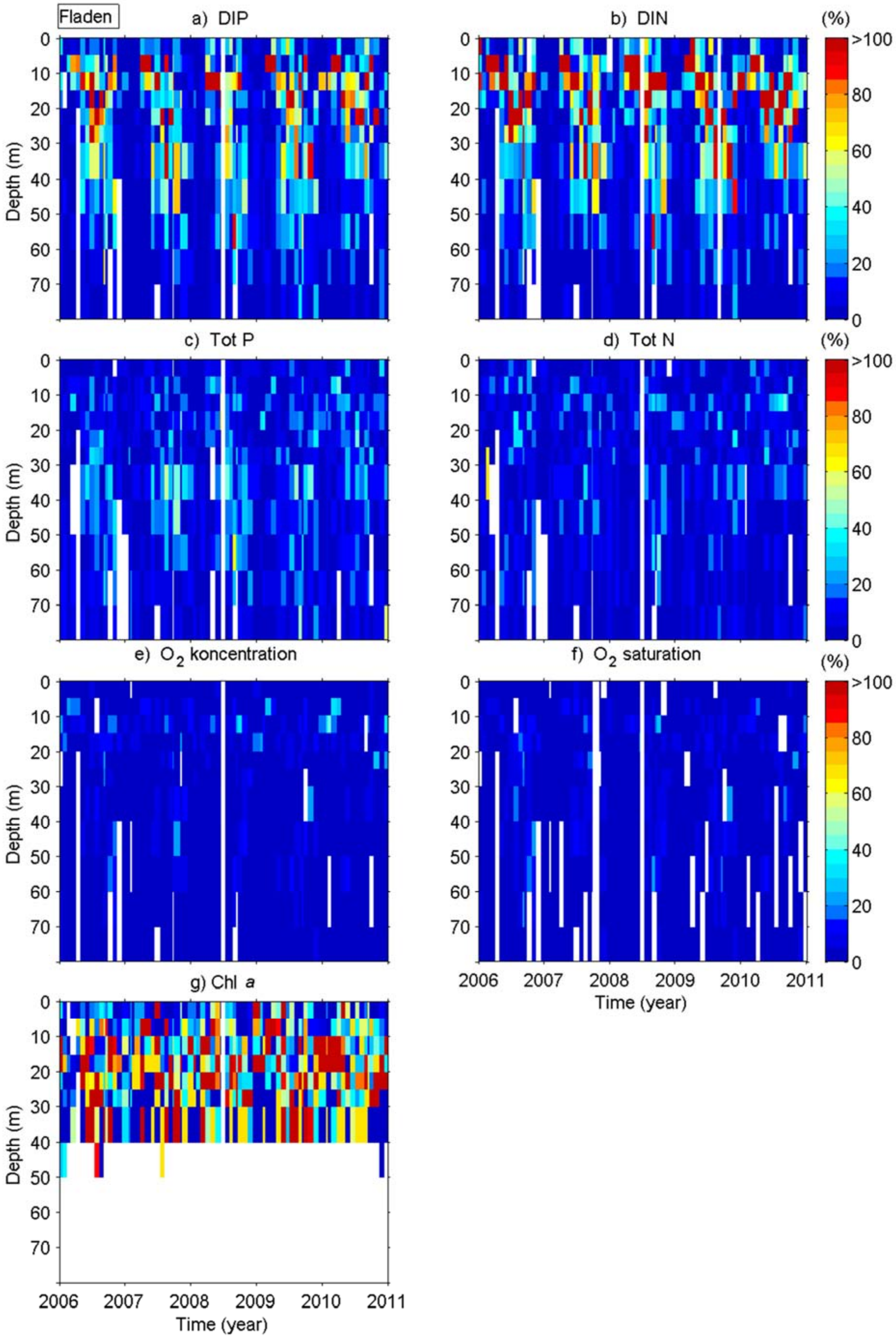


Figure 16 Vertical gradients at Fladen

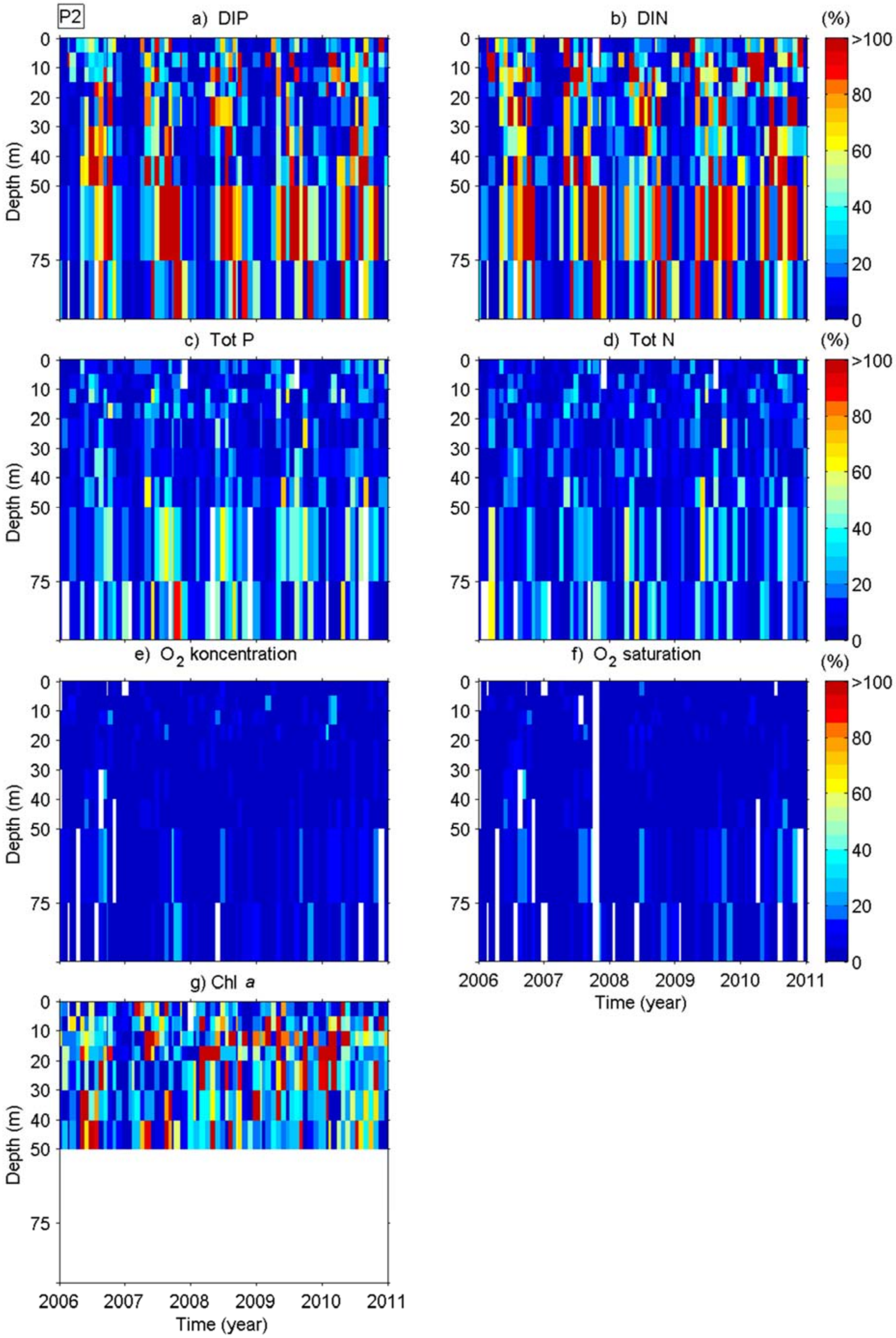


Figure 17 Vertical gradients at P2

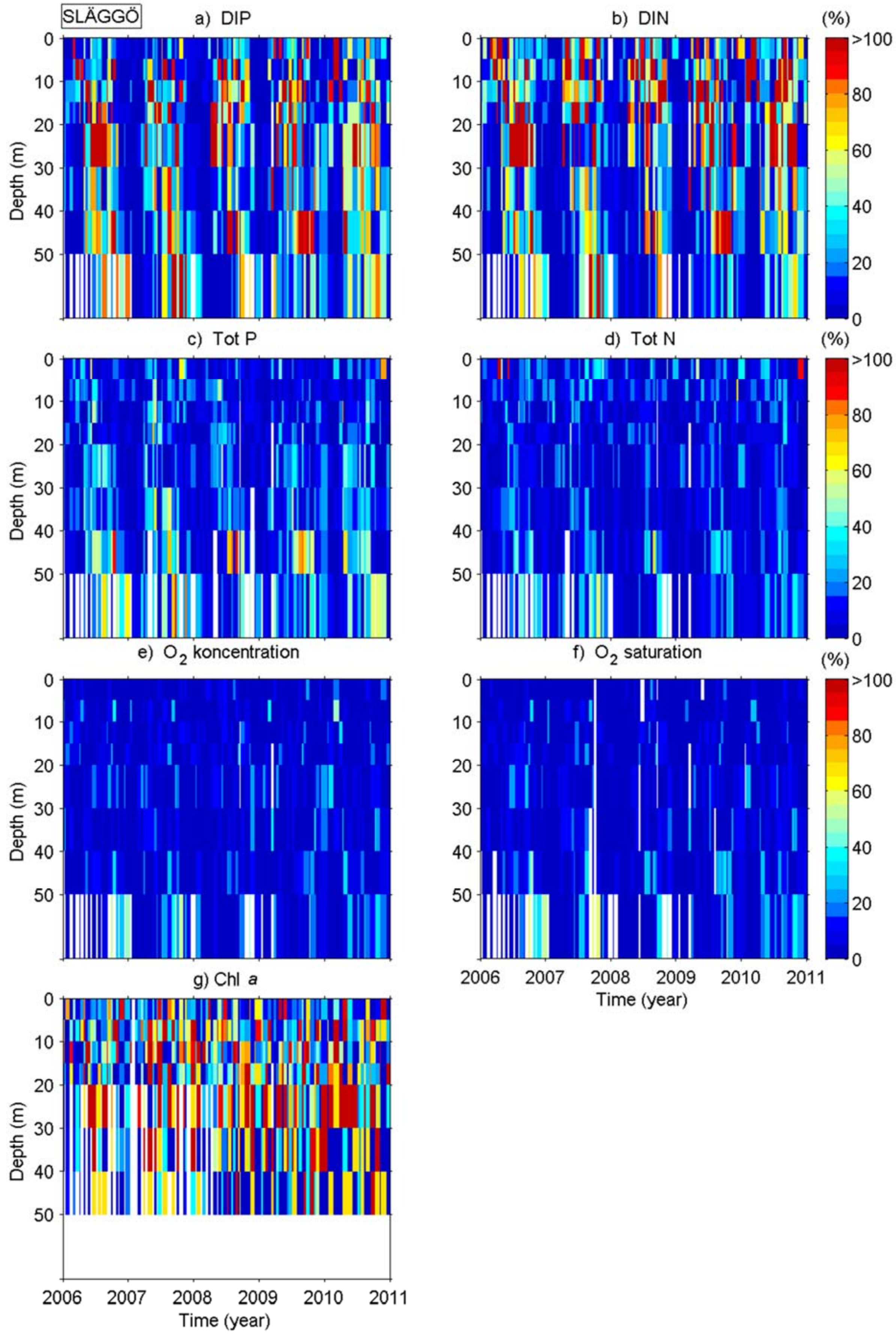


Figure 18 Vertical gradients at Släggö

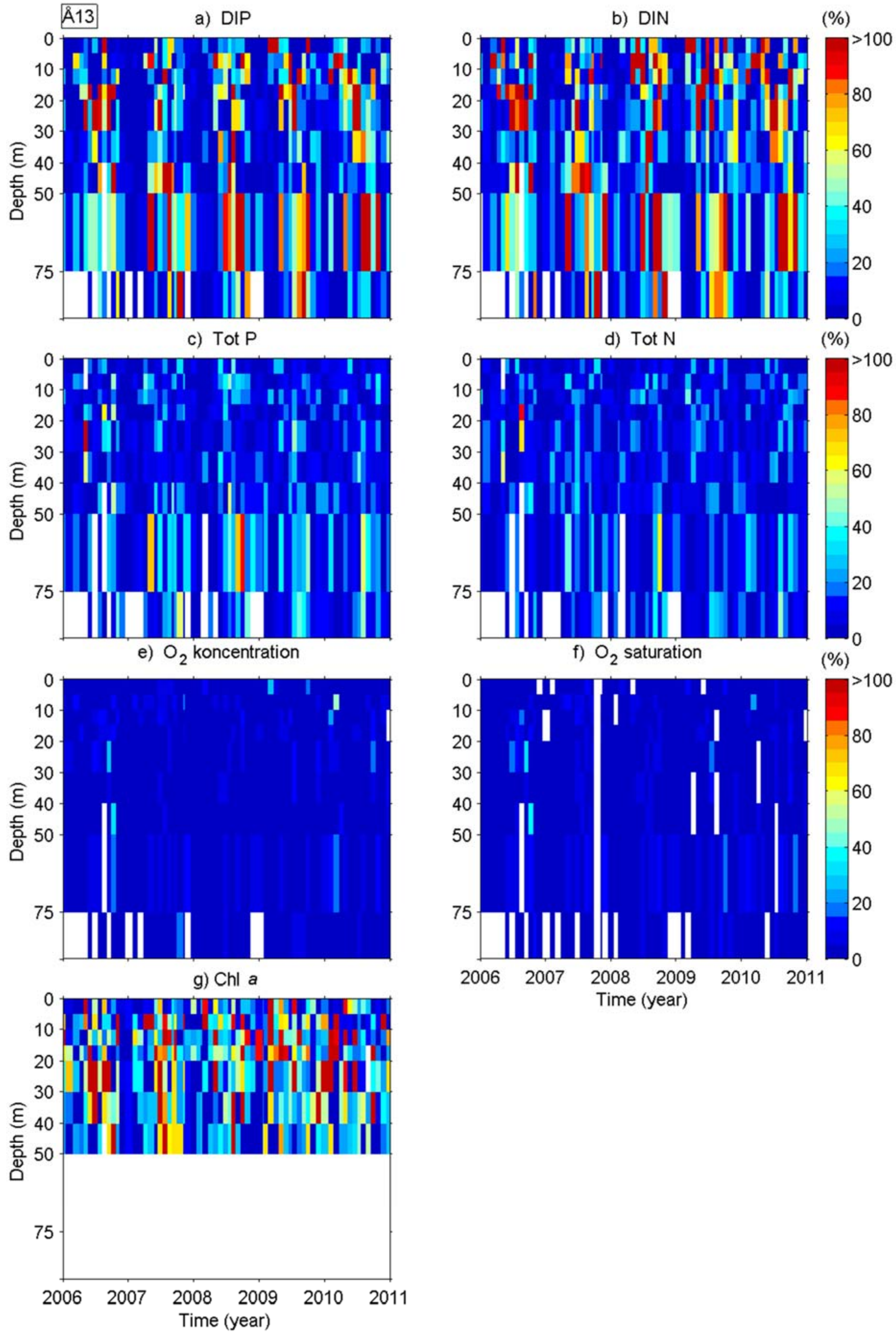


Figure 19 Vertical gradients at Å13

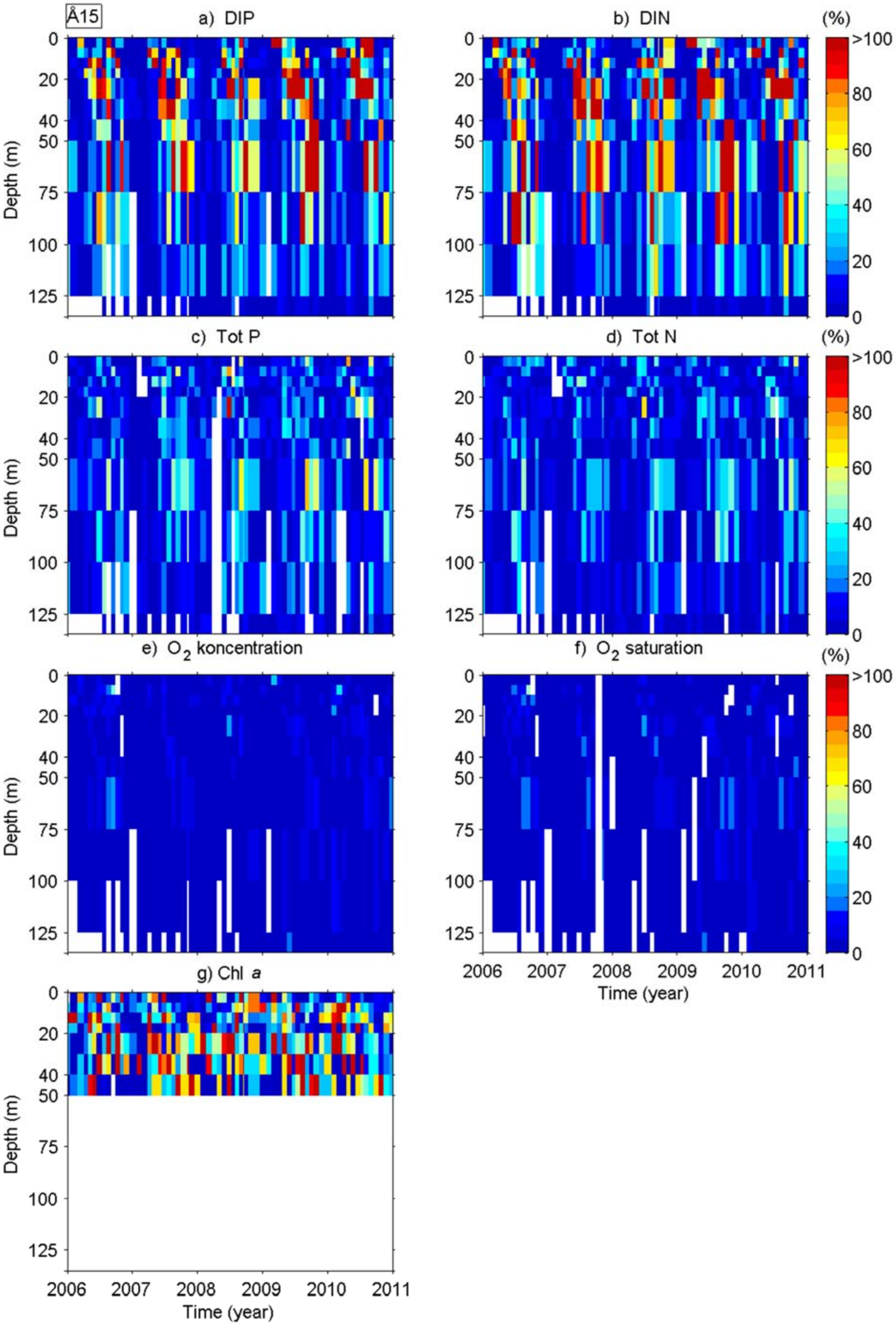


Figure 20 Vertical gradients at Å15

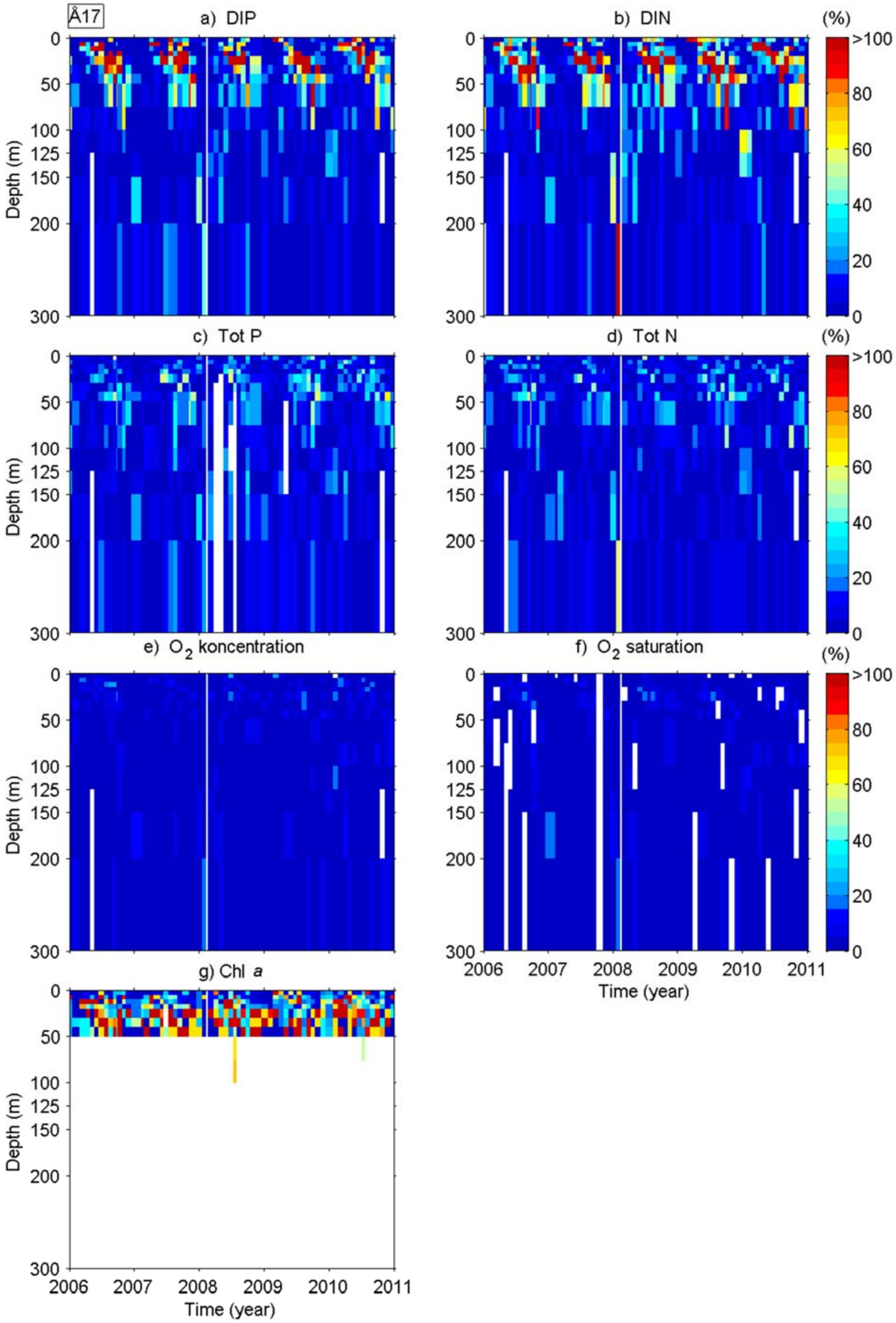
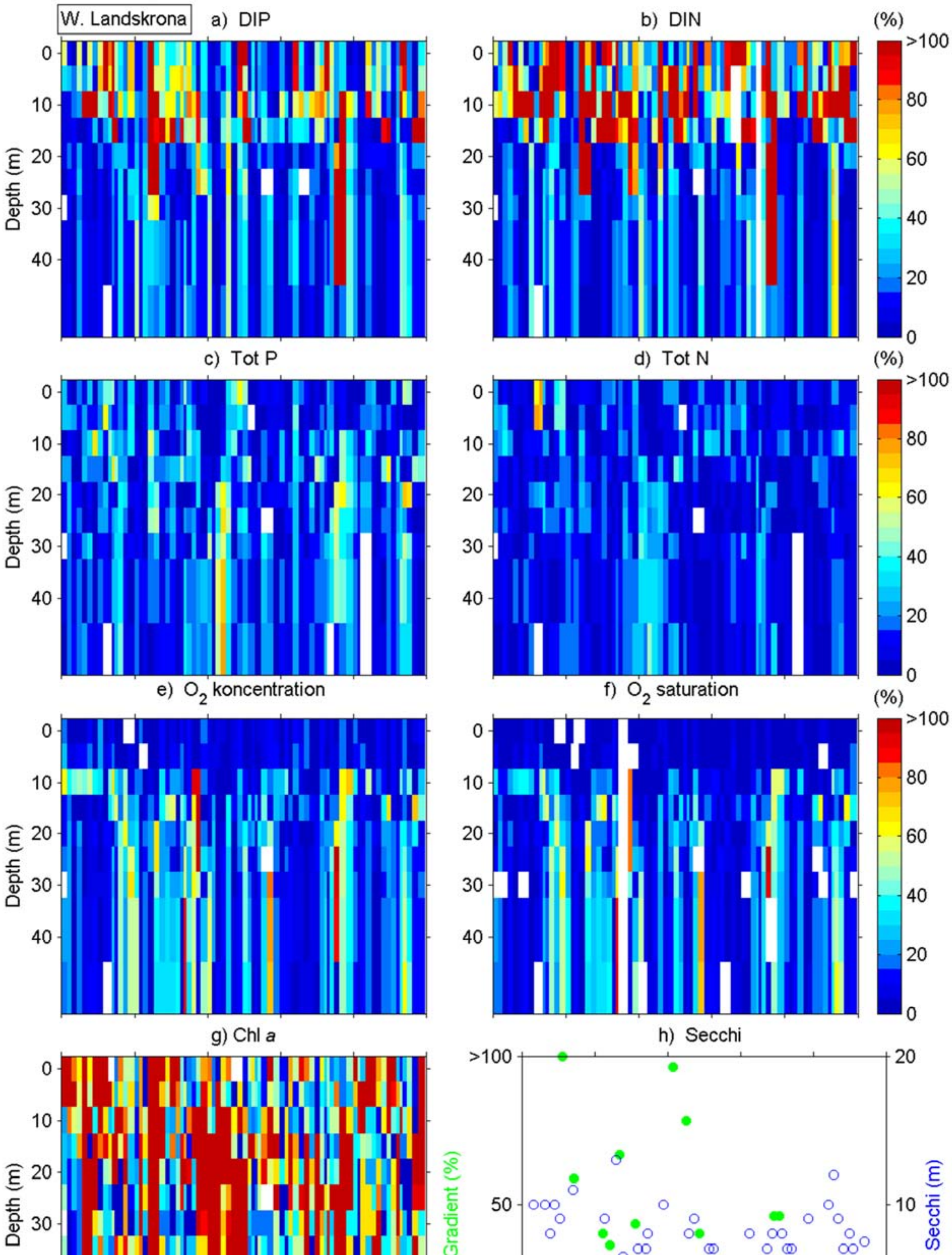
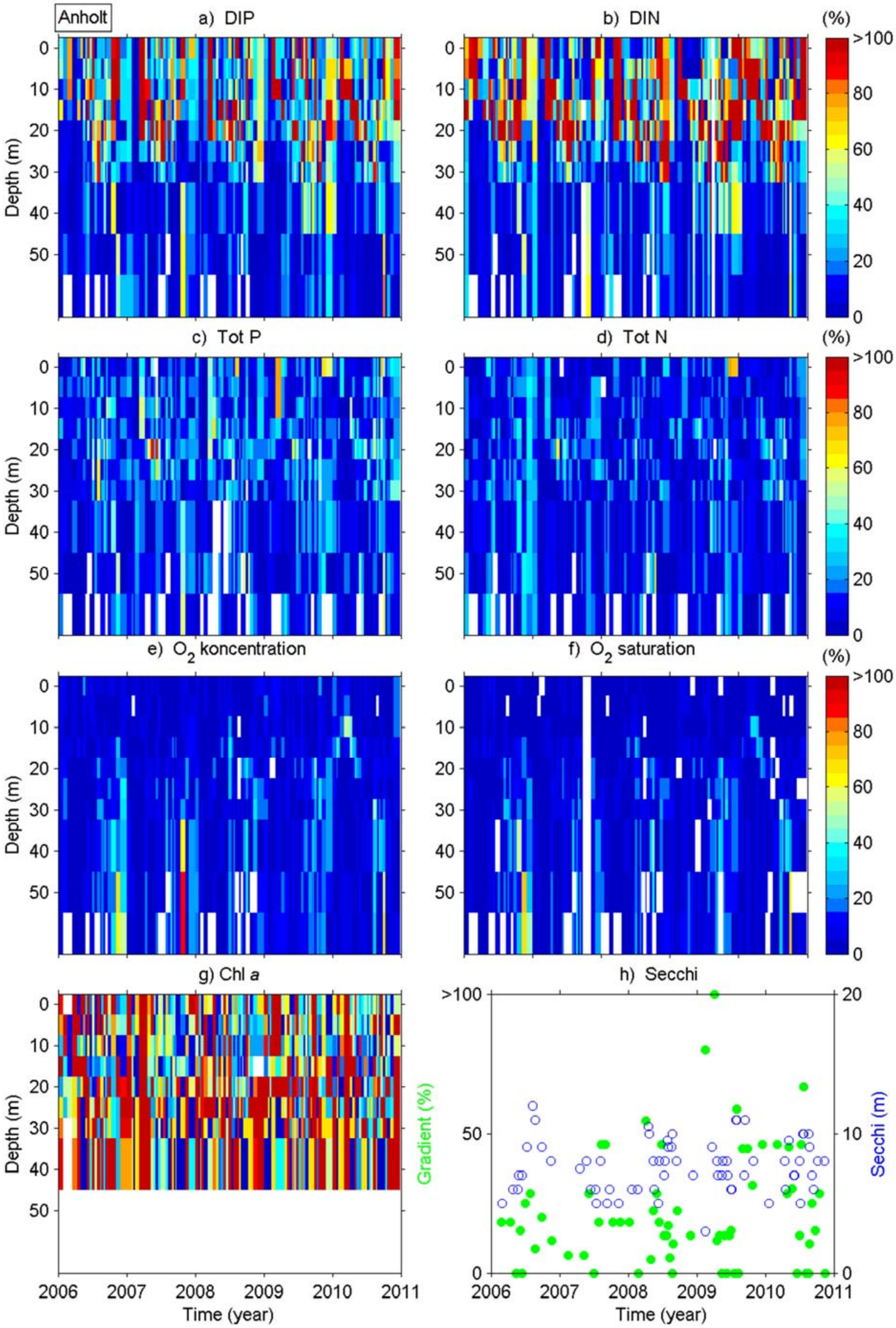


Figure 21 Vertical gradients at Å17



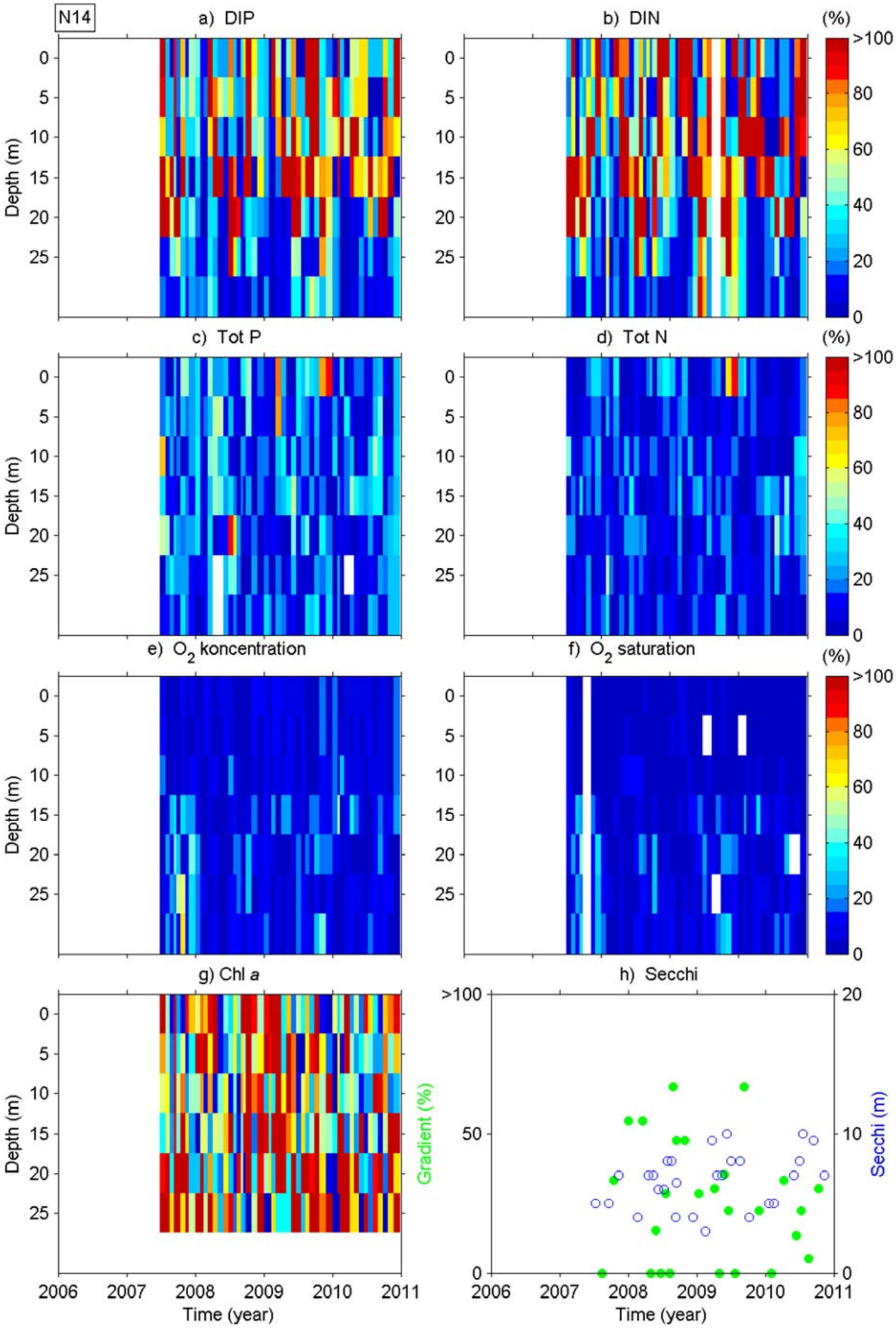
W. Landskrona
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O_2 koncentration
f) O_2 saturation
g) Chl *a*
h) Secchi
Depth (m)
(%)
Gradient (%)
Secchi (m)
Time (year)

Figure 22 Temporal gradients in concentration at West Landskrona. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



Anholt
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O2 koncentration
f) O2 saturation
g) Chl a
h) Secchi
Depth (m)
(%)
>100
Gradient (%)
Secchi (m)
Time (year)
2006
2007
2008
2009
2010
2011

Figure 23 Temporal gradients in concentration at Anholt E.. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



N14
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O_2 koncentration
f) O_2 saturation
g) Chl *a*
h) Secchi
Depth (m)
Time (year)
Gradient (%)
Secchi (m)
(%)
>100

Figure 24 Temporal gradients in concentration at N14 Falkenberg. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.

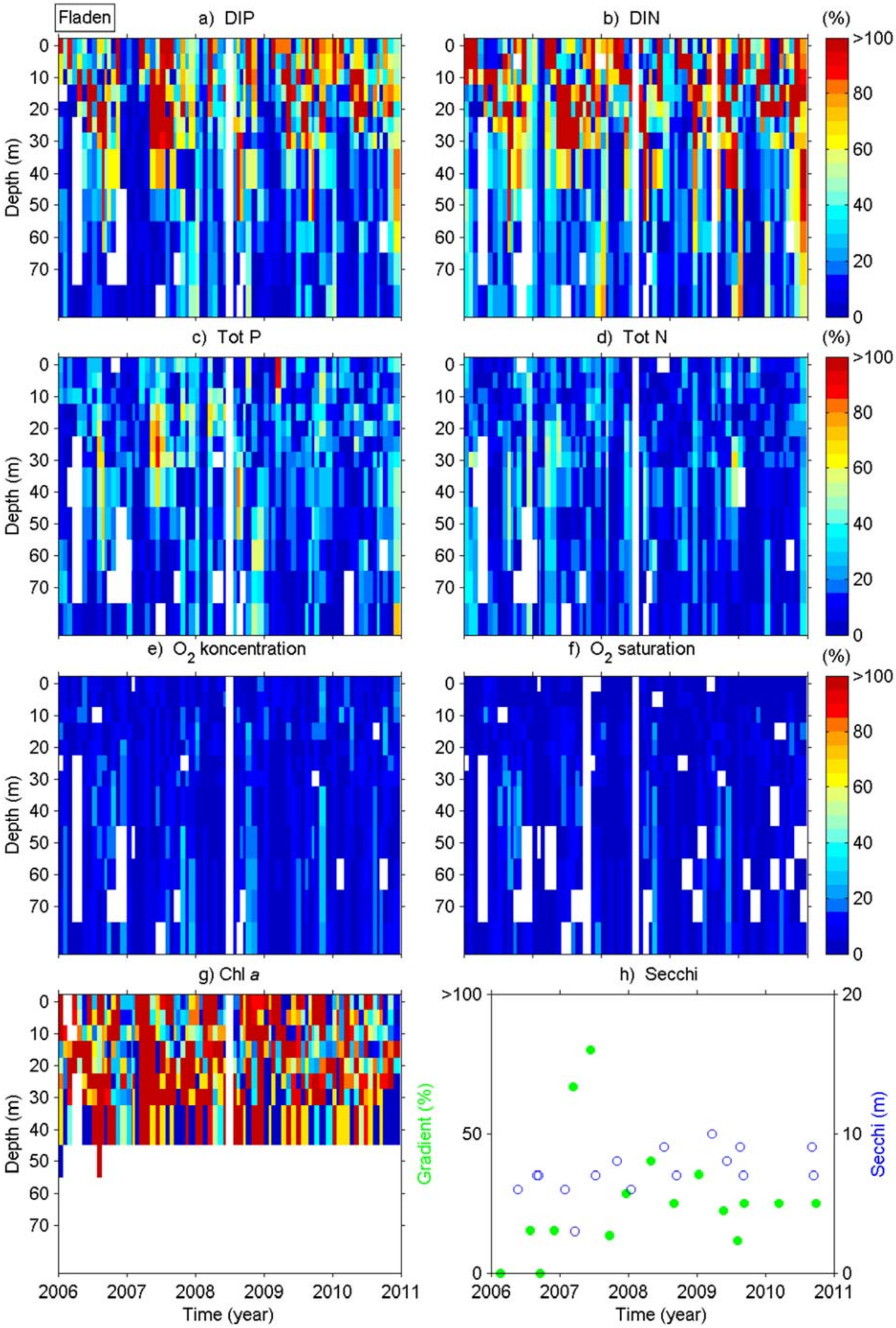
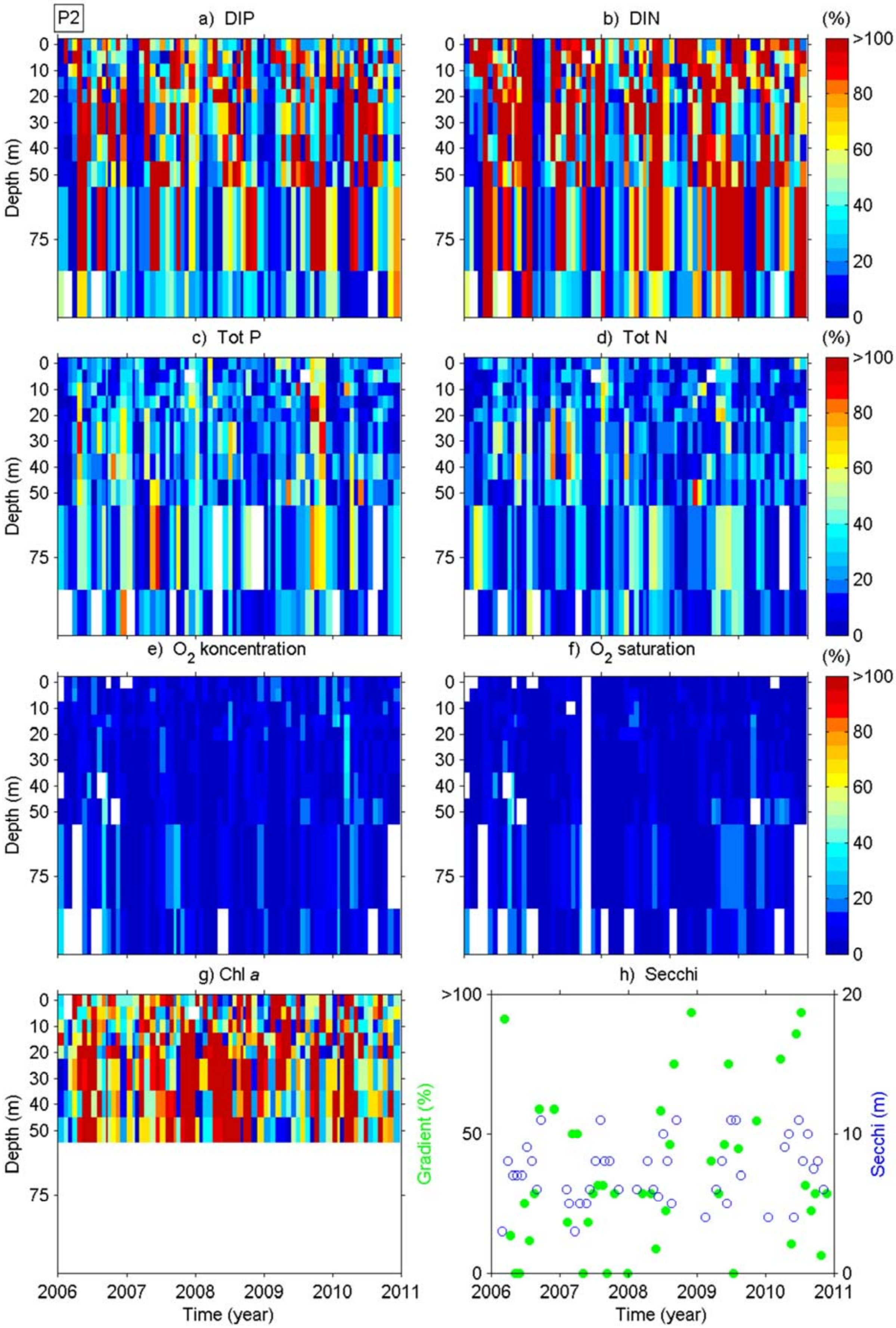
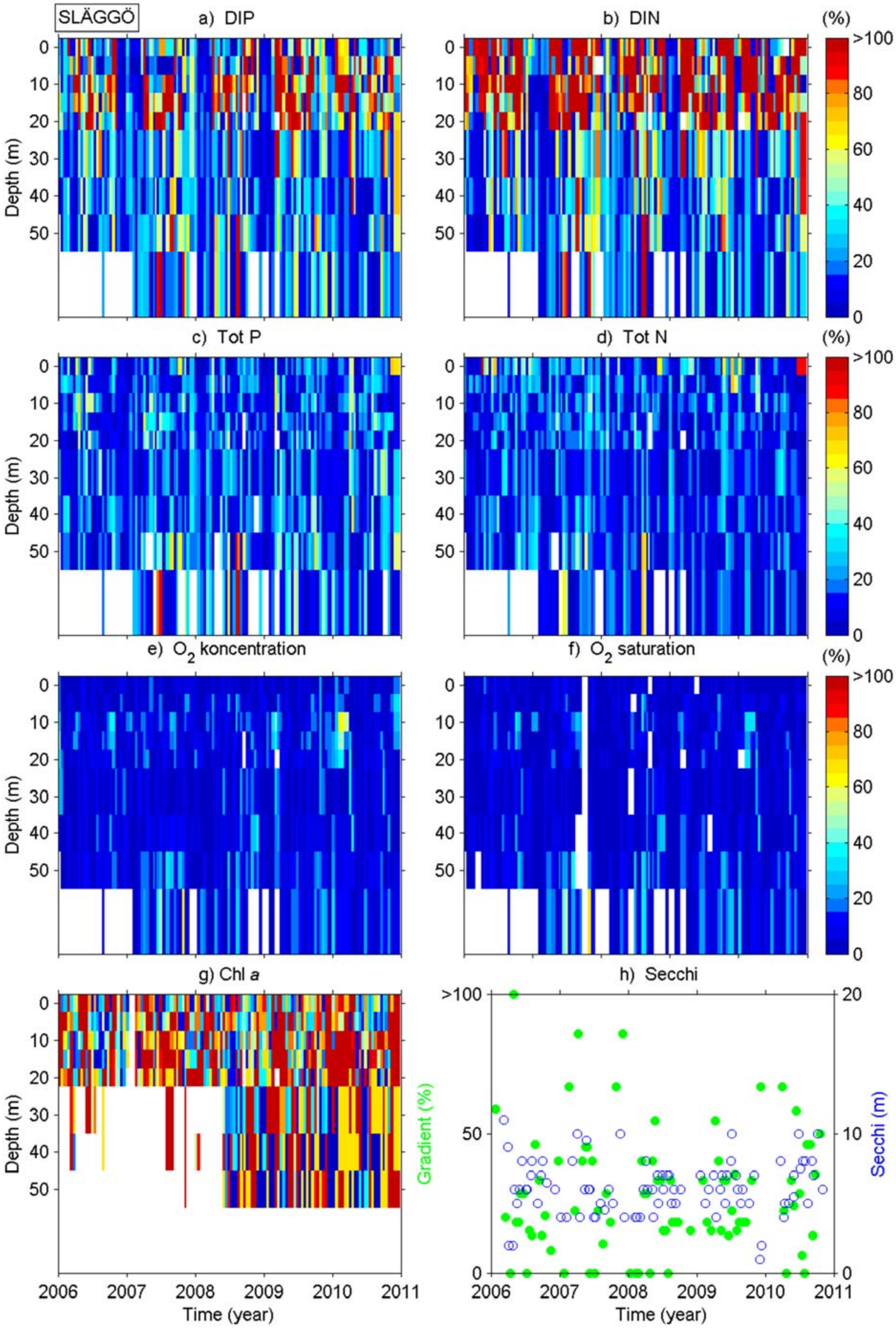

Fladen
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O_2 koncentration
f) O_2 saturation
g) Chl *a*
h) Secchi
(%)
>100
Depth (m)
Time (year)
Gradient (%)
Secchi (m)

Figure 25 Temporal gradients in concentration at Fladen. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



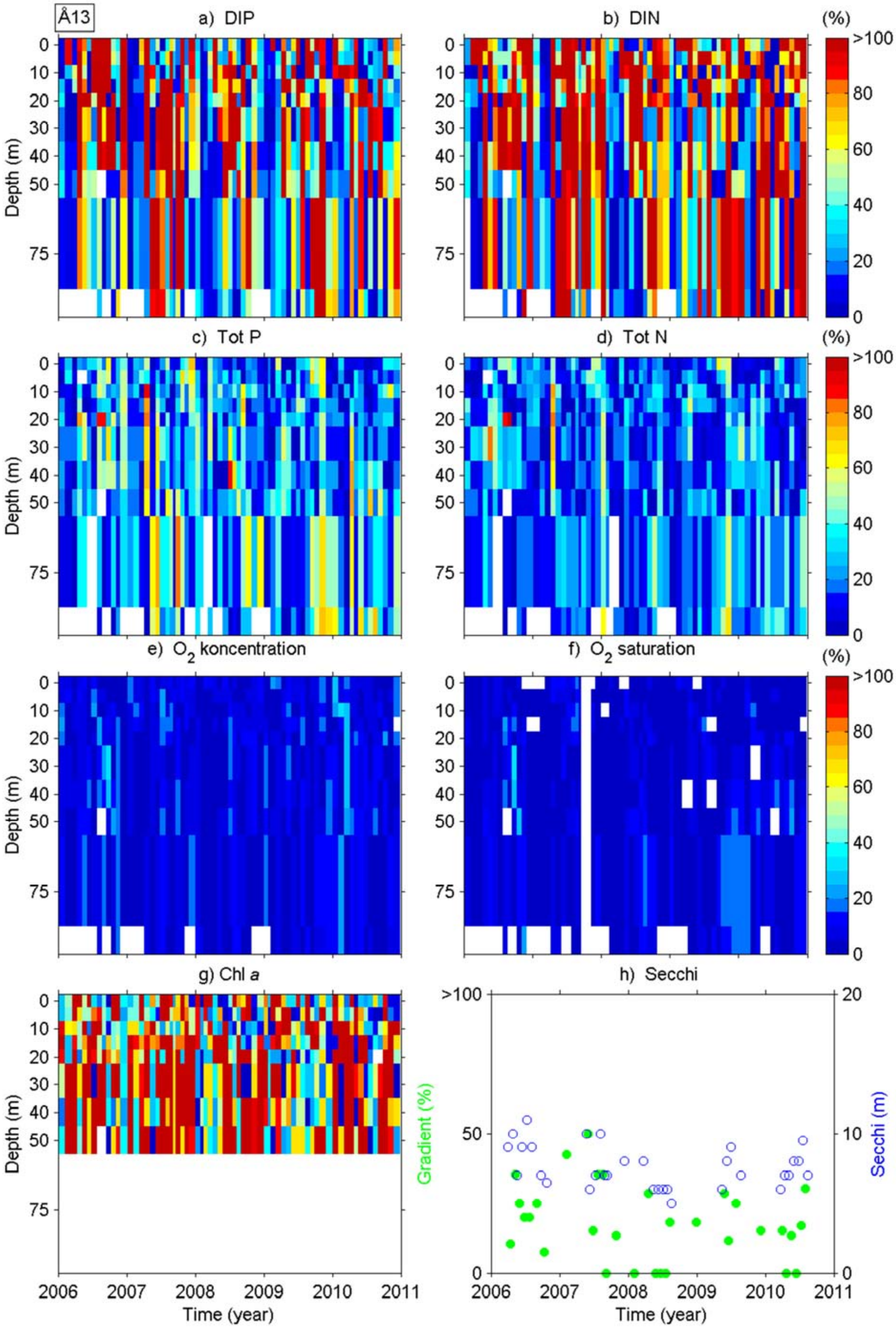
P2
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O2 koncentration
f) O2 saturation
g) Chl a
h) Secchi
(%)
>100
80
60
40
20
0
Depth (m)
0
10
20
30
40
50
75
Gradient (%)
Secchi (m)
Time (year)
2006
2007
2008
2009
2010
2011

Figure 26 Temporal gradients in concentration at P2. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



SLÄGGÖ
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O_2 koncentration
f) O_2 saturation
g) Chl *a*
h) Secchi
Depth (m)
(%)
>100
Gradient (%)
Secchi (m)
Time (year)
2006
2007
2008
2009
2010
2011

Figure 27 Temporal gradients in concentration at Släggö. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



Å13
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O2 koncentration
f) O2 saturation
g) Chl a
h) Secchi
Depth (m)
Gradient (%)
Secchi (m)
Time (year)
(%)

Figure 28 Temporal gradients in concentration at Å13. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.

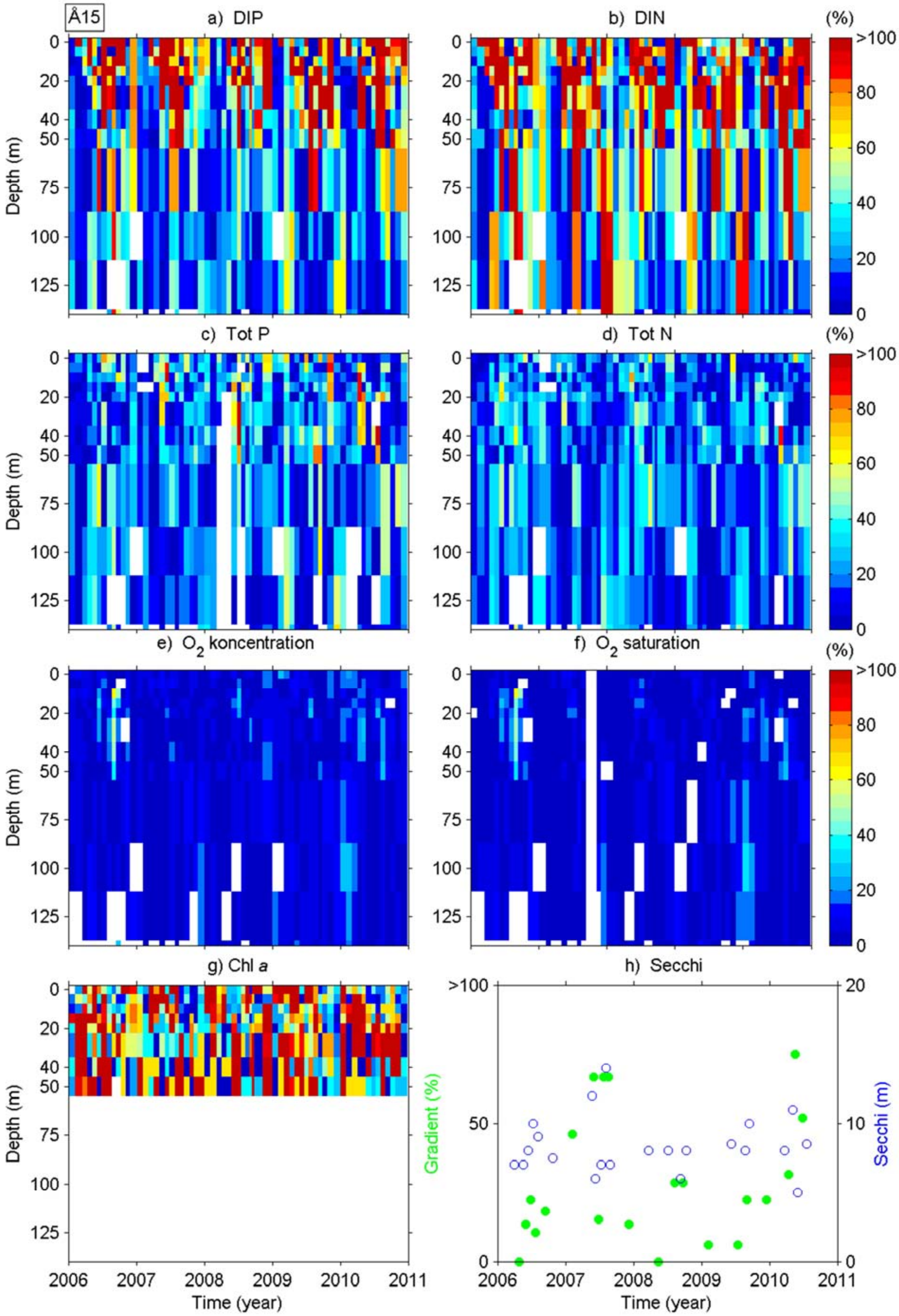
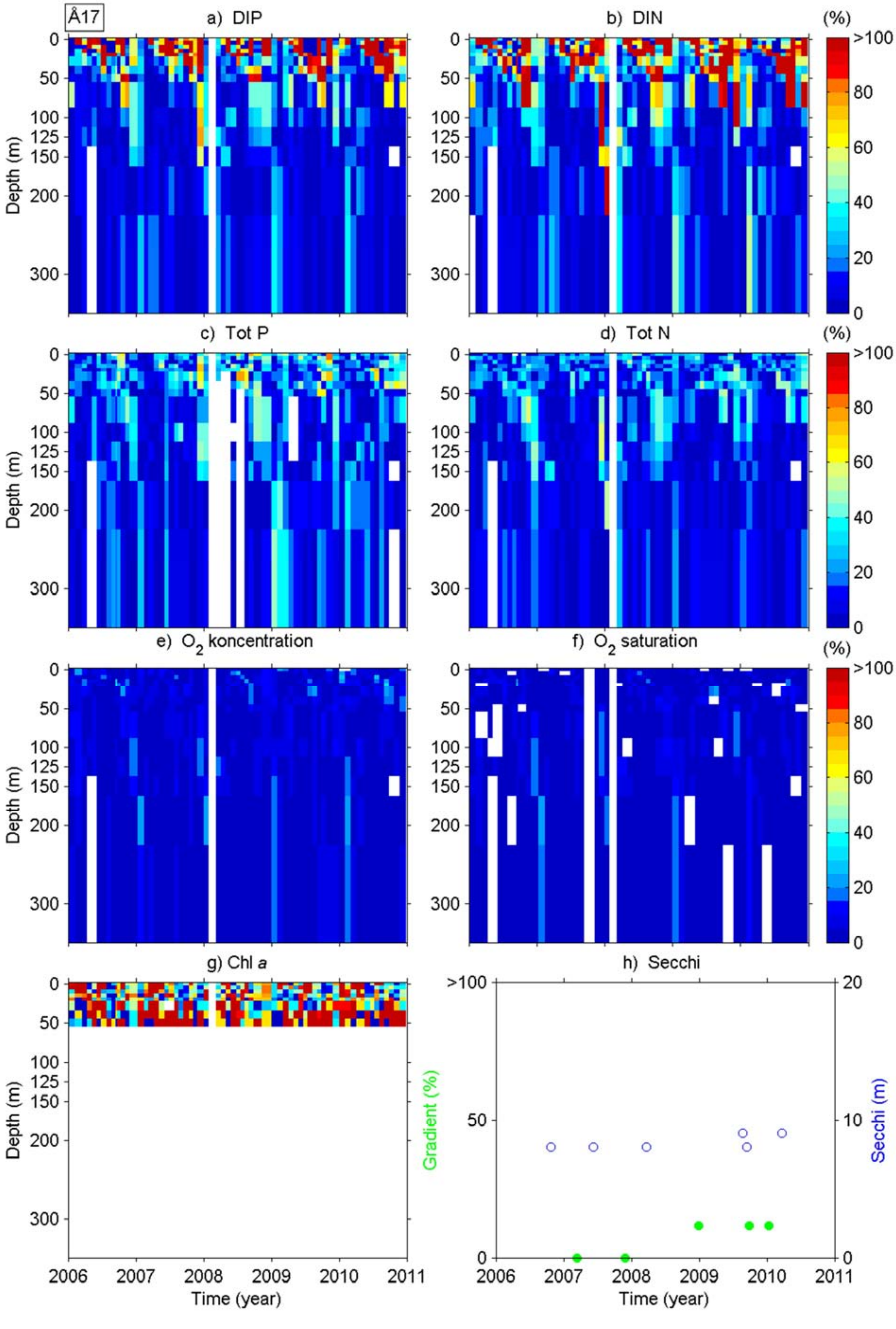

Å15
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O2 koncentration
f) O2 saturation
g) Chl a
h) Secchi
(%)
Depth (m)
Gradient (%)
Secchi (m)
Time (year)

Figure 29 Temporal gradients in concentration at Å15. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.



Å17
a) DIP
b) DIN
c) Tot P
d) Tot N
e) O2 koncentration
f) O2 saturation
g) Chl a
h) Secchi
Depth (m)
(%)
Gradient (%)
Secchi (m)
Time (year)

Figure 30 Temporal gradients in concentration at Å17. h) Filled green circles show the variation between successive Secchi depth observations; open blue circles show the Secchi depth.

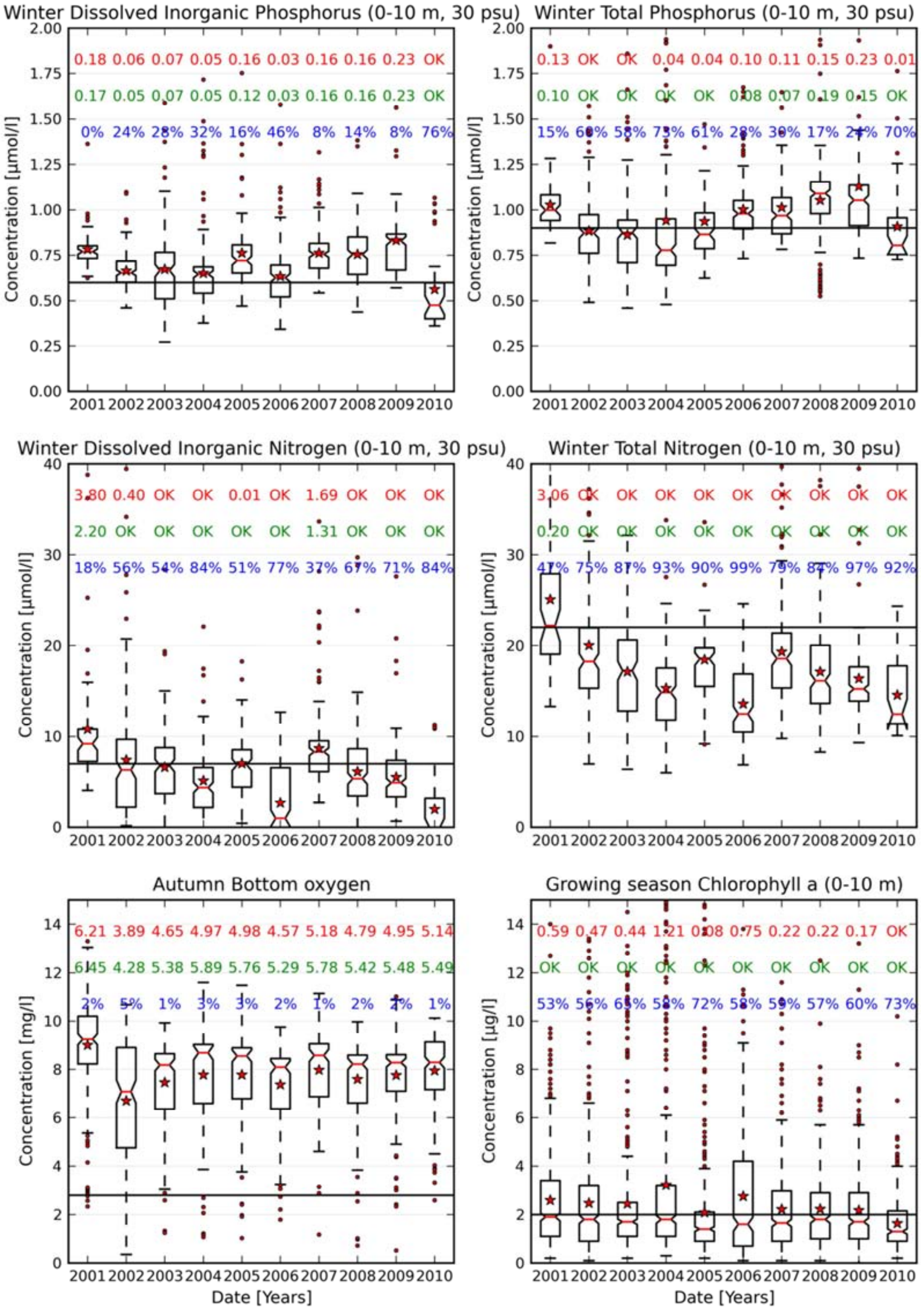


Figure 31 Indicator concentration in the inshore Kattegat. Nutrients corrected to 30 psu. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

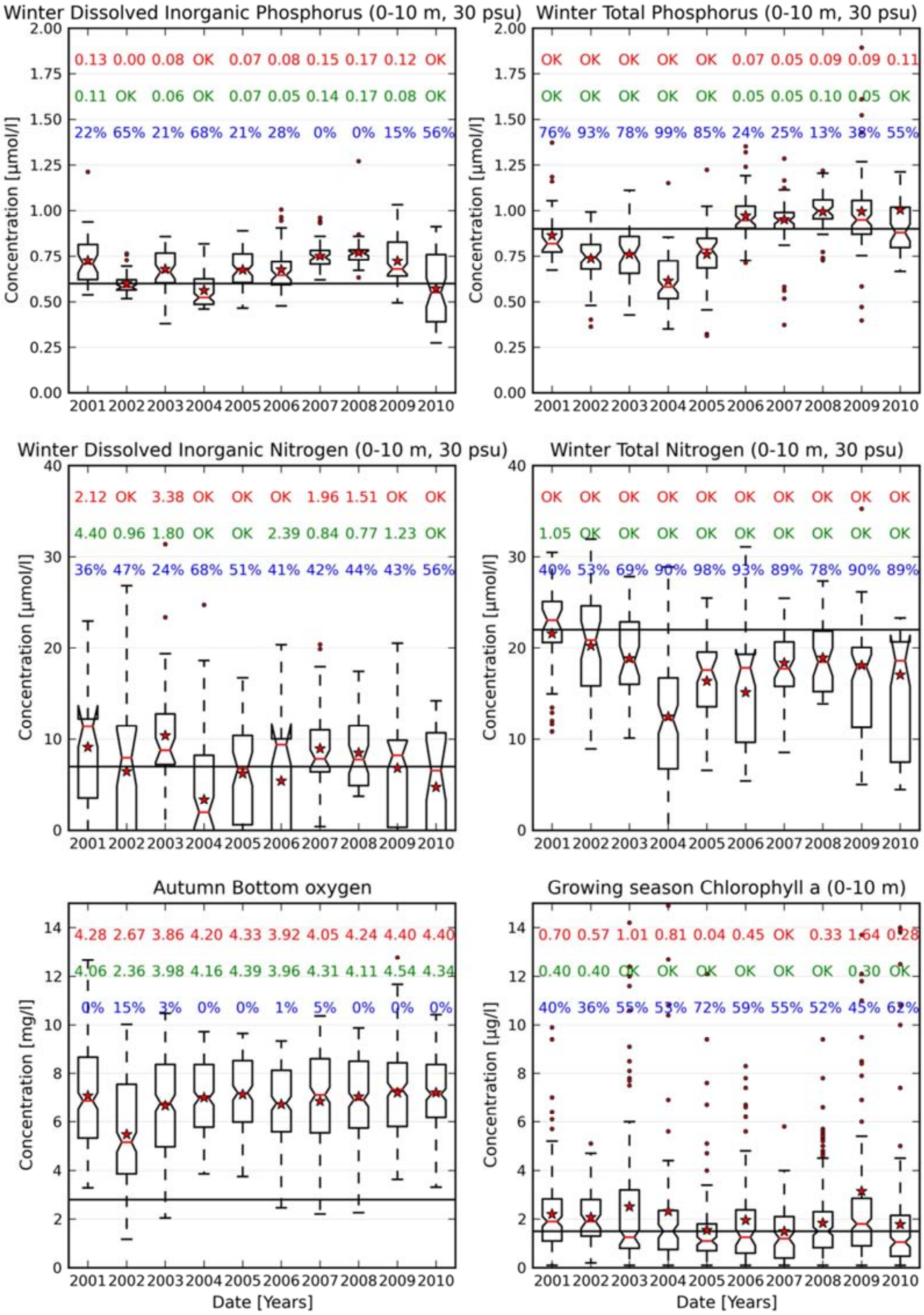


Figure 32 Indicator concentration in the offshore Kattegat. Nutrients corrected to 30 psu. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

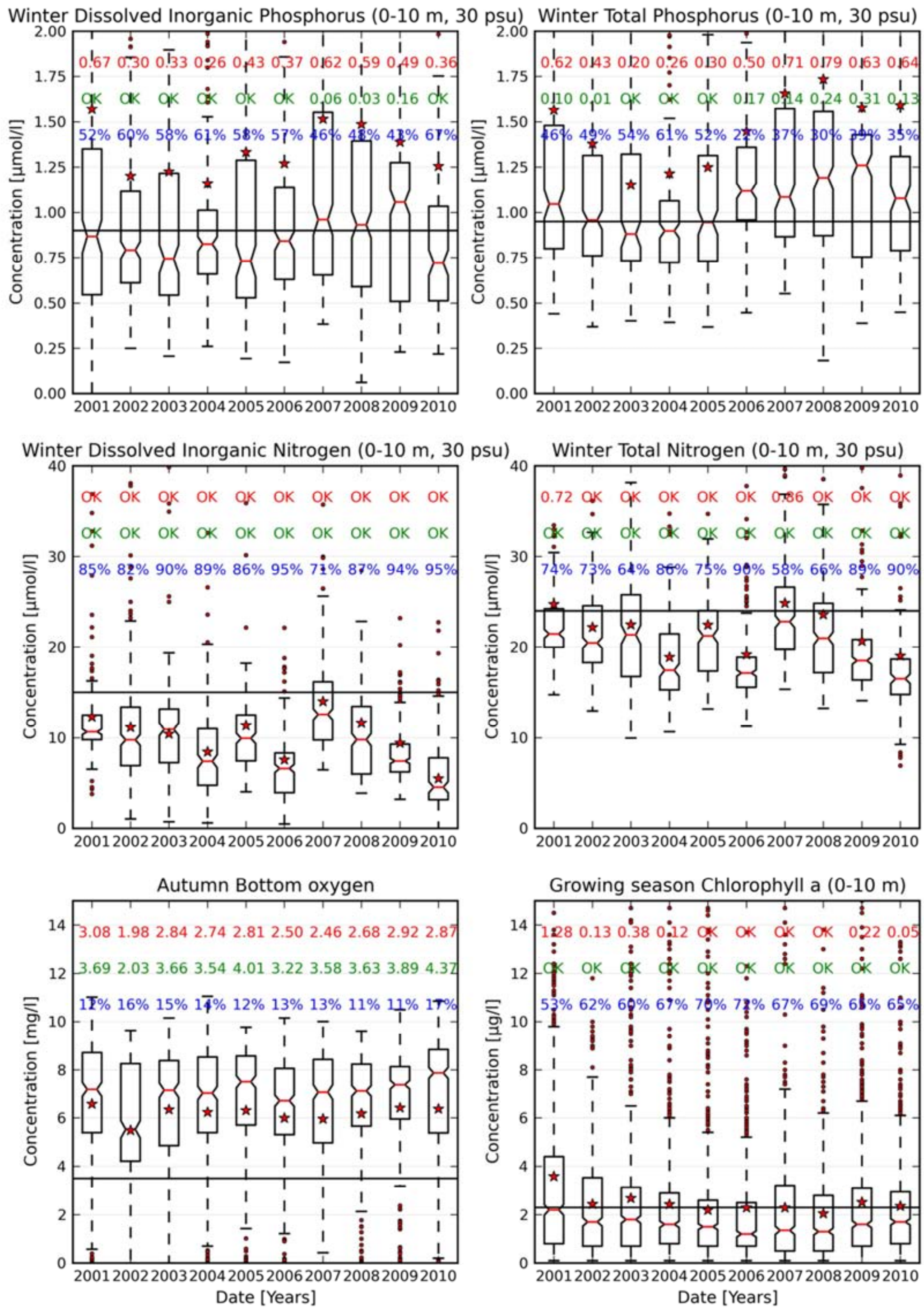


Figure 33 Indicator concentration in the inshore Skagerrak. Nutrients corrected to 30 psu. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

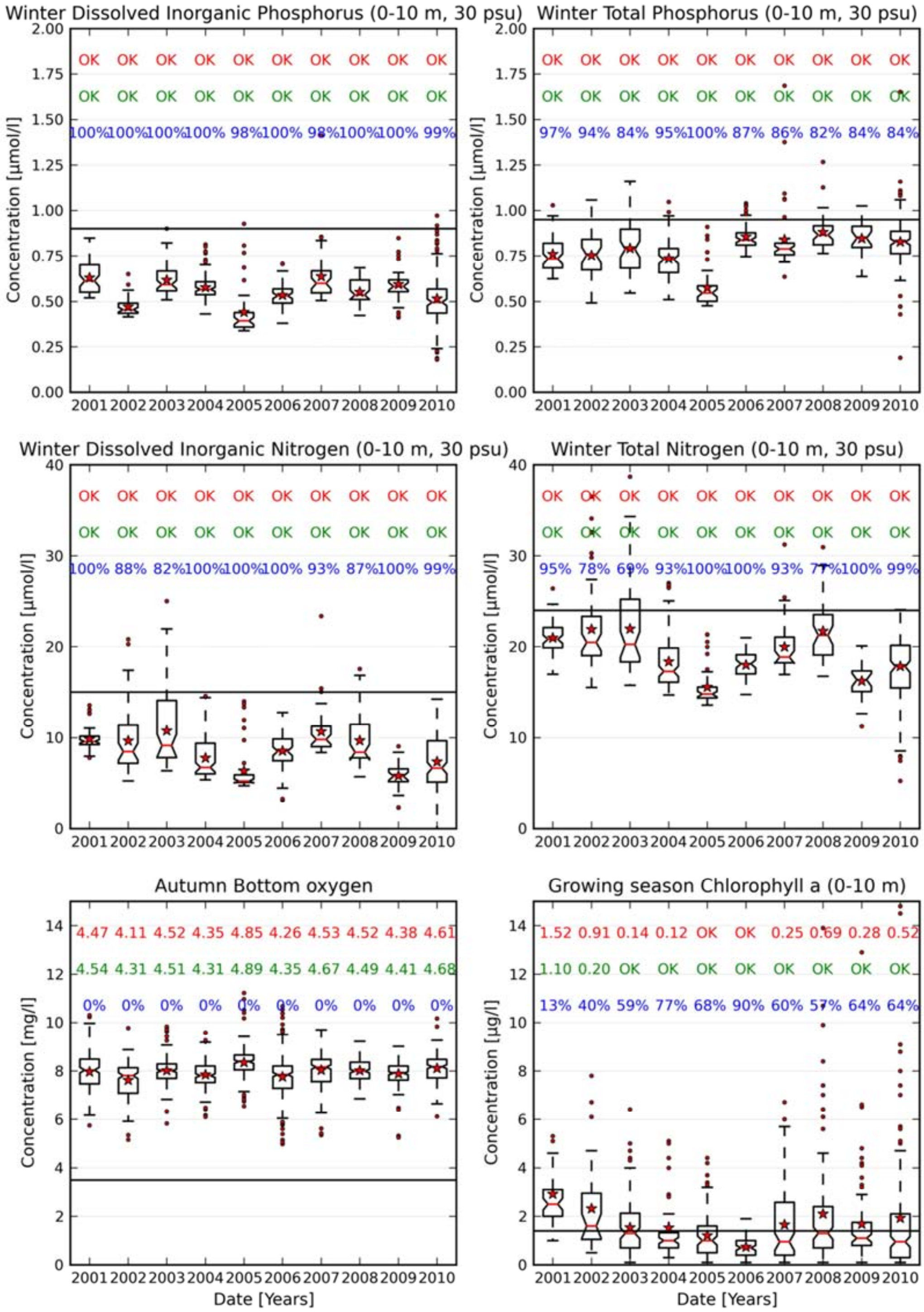


Figure 34 Indicator concentration in the offshore Skagerrak. Nutrients corrected to 30 psu. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

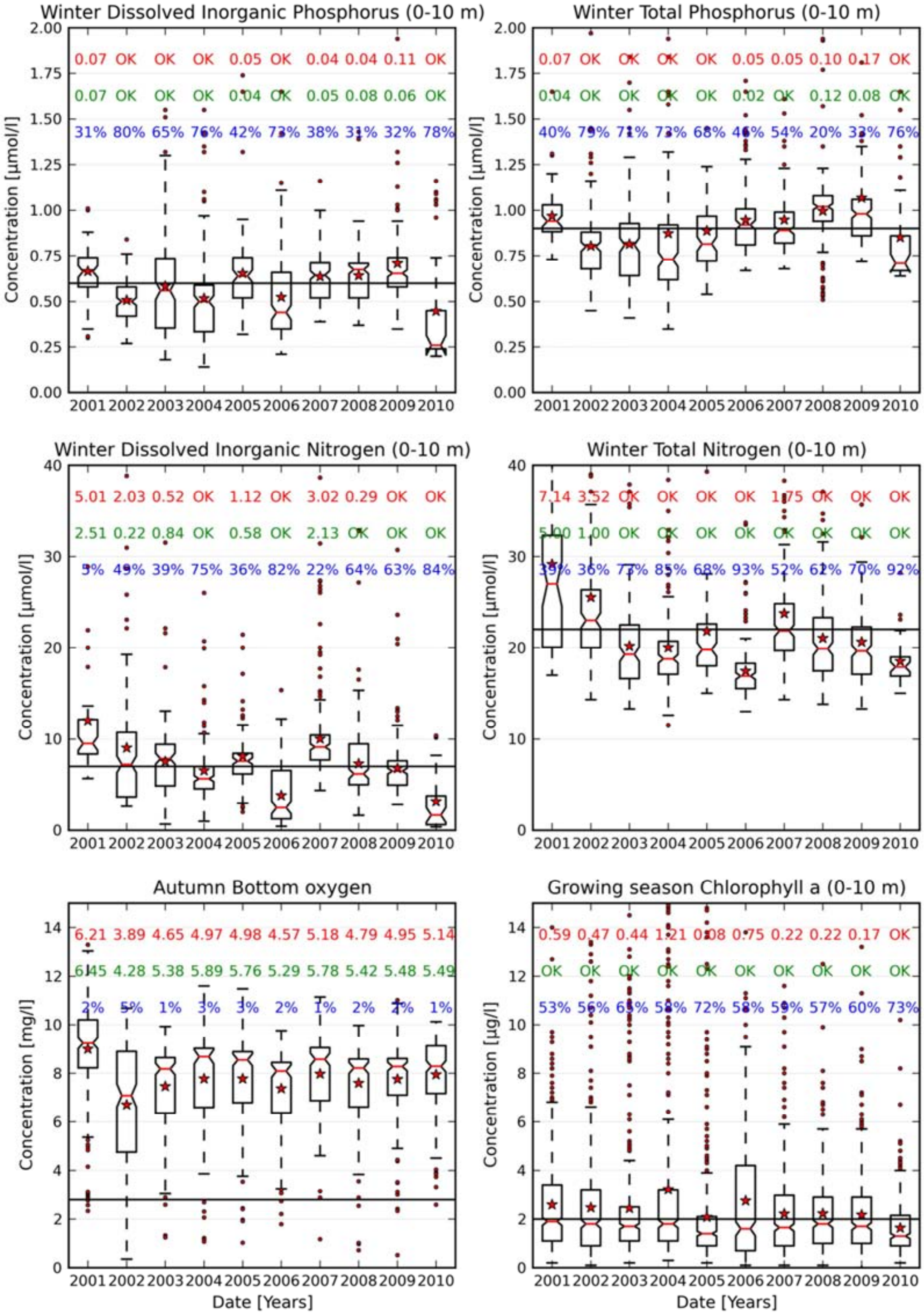


Figure 35 Indicator concentration in the inshore Kattegat. No salinity correction. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

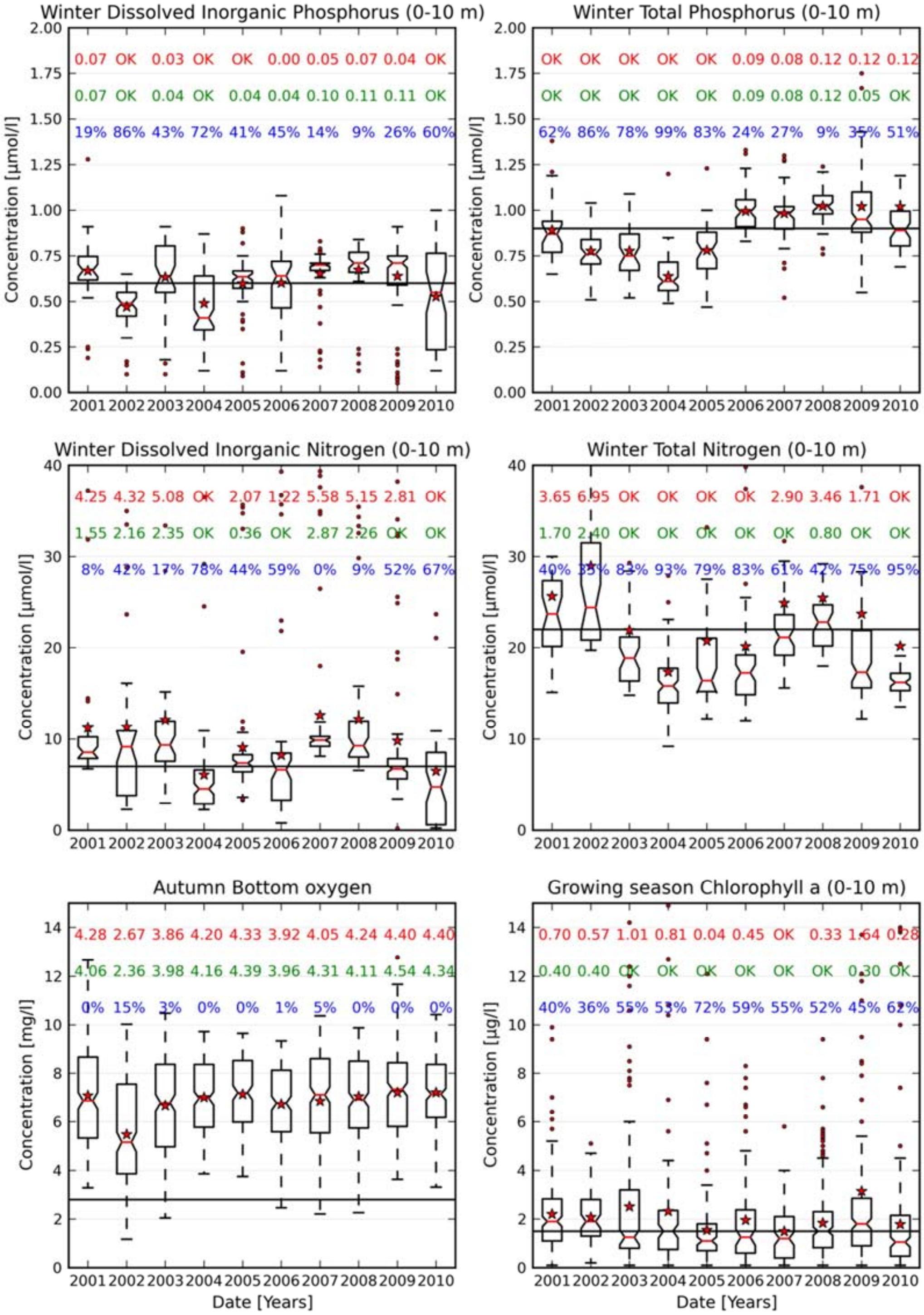


Figure 36 Indicator concentration in the offshore Kattegat. No salinity correction. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

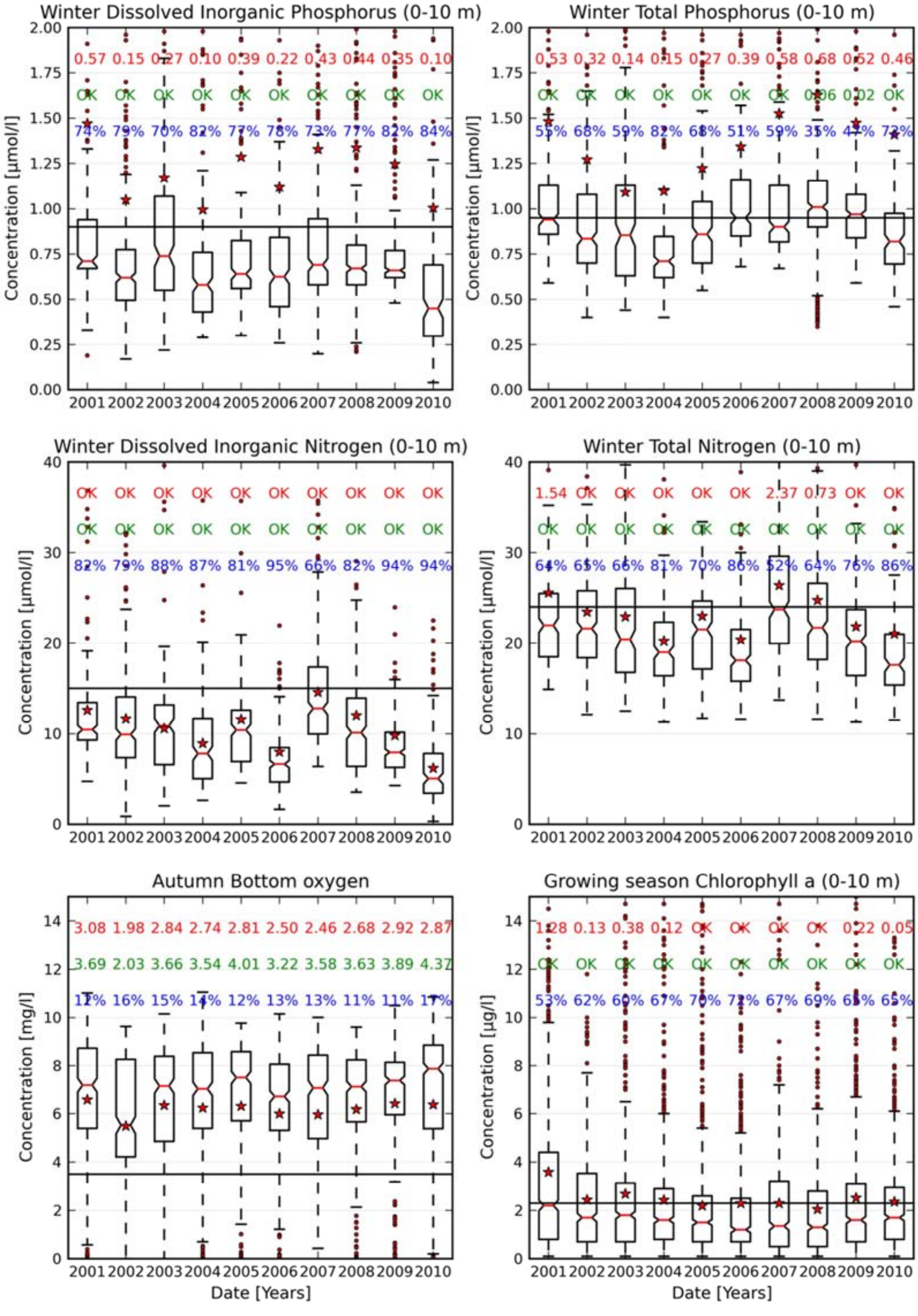


Figure 37 Indicator concentration in the inshore Skagerrak. No salinity correction. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

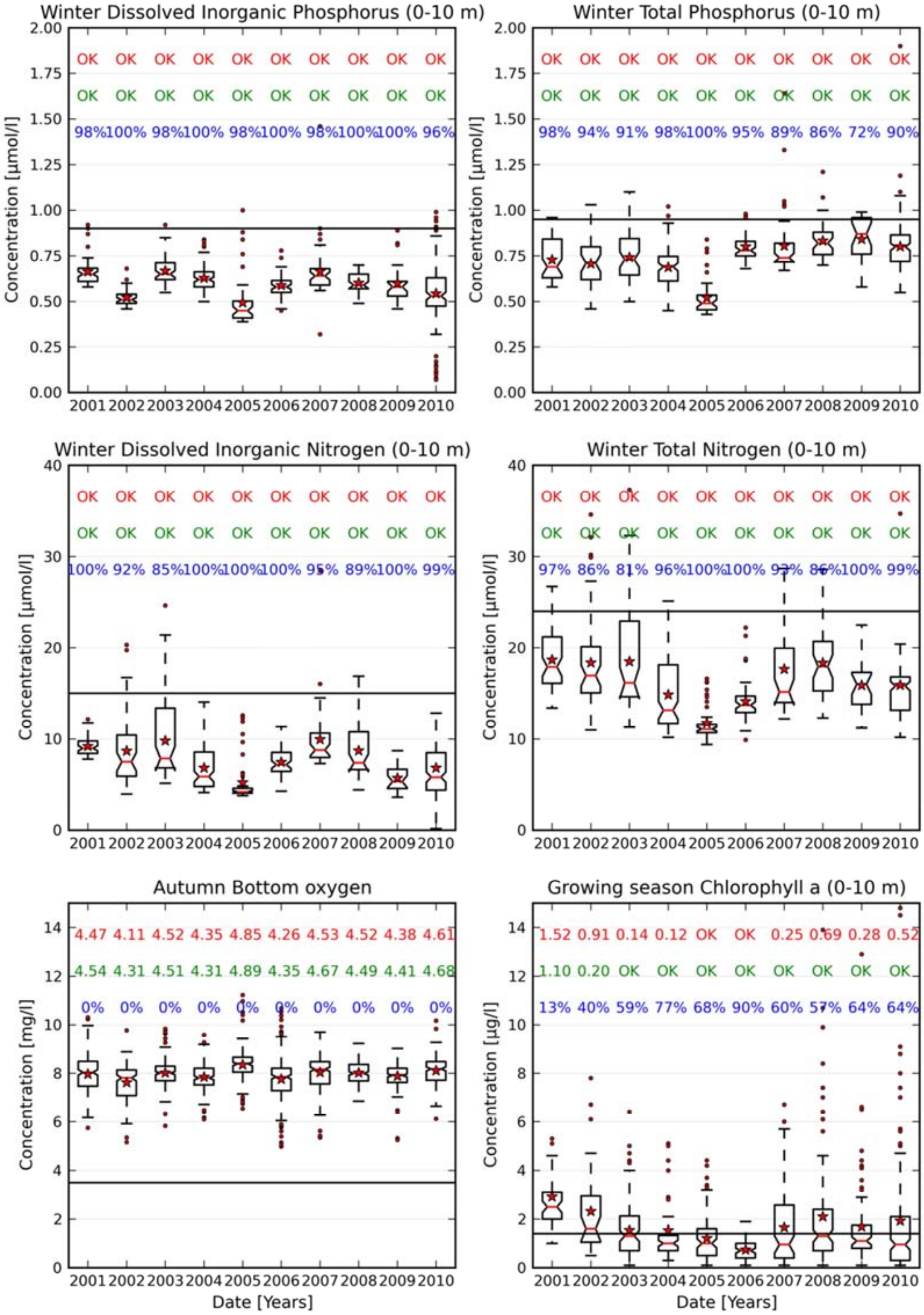


Figure 38 Indicator concentration in the offshore Skagerrak. No salinity correction. Red and green text indicates distance from mean and median to assessment level; blue the proportion of observations under assessment level

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