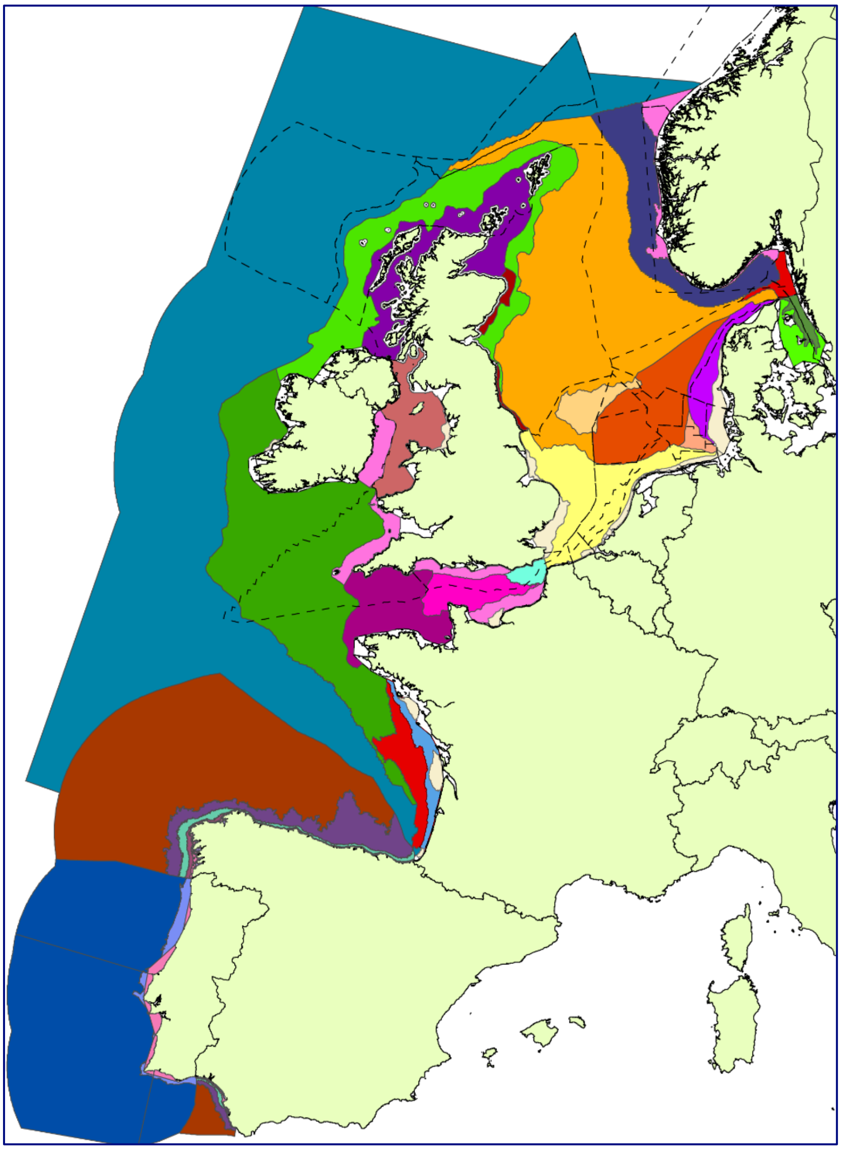
Deltares

# Spatial scales for OSPAR biodiversity assessments

NEA PANACEA project, task 2.3



NEA PANACEA
North East Atlantic project on biodiversity and eutrophication assessment integration and creation of effective measures

Co-funded by the European Maritime and Fisheries Fund

**Spatial scales for OSPAR biodiversity assessments**
NEA PANACEA project, task 2.3

**Author(s)**
Anouk Blauw

**Spatial scales for OSPAR biodiversity assessments**
NEA PANACEA project, task 2.3

| | |
|---|---|
| **Client** | Rijkswaterstaat Water, Verkeer en Leefomgeving |
| **Contact** | mevrouw L Enserink |
| **Reference** | Zaaknummer: 31167498 |
| **Keywords** | OSPAR, biodiversity, assessment, spatial scales |

| **Document control** | |
|---|---|
| **Version** | 1.0 |
| **Date** | 02-06-2023 |
| **Project nr.** | 11206303-002 |
| **Document ID** | 11206303-002-ZKS-0001 |
| **Pages** | 35 |
| **Classification** | |
| **Status** | final |

| **Author(s)** | | |
|---|---|---|
| | Anouk Blauw | |
| | | |

***The allowed use of this table is limited to check the correct order-performance by Deltares. Any other client-internal-use and any external distribution is not allowed.***

| **Doc. version** | **Author** | **Reviewer** | **Approver** |
|---|---|---|---|
| **1.0** | Anouk Blauw | Theo Prins | Myra van der Meulen |
| | | | |



Deltares

# Summary

This report describes the study of appropriate spatial scales for the assessment of the pelagic biodiversity indicator “Changes in Phytoplankton and Zooplankton Communities.” (PH1/FW5) of the biodiversity assessment in the upcoming OSPAR Quality Status Report 2023. We evaluated whether the assessment areas developed for the OSPAR eutrophication assessment are also appropriate for pelagic biodiversity indicators by analysing spatial gradients in lifeform abundance from Continuous Plankton Recorder (CPR) data with spatial gradients in stratification, salinity and chlorophyll-*a* concentrations. These were key variables used in the definition of the eutrophication assessment areas for OSPAR and the MSFD.

We analysed seven plankton lifeforms that were also used for the OSPAR biodiversity assessment of indicator PH1/FW5: diatoms, dinoflagellates, large copepods, small copepods, fish larvae, holoplankton and meroplankton. All these lifeforms showed strong changes in abundance between different stratification regimes: permanently mixed, seasonally stratified and permanently stratified. This leads us to conclude that the key environmental variable to define the eutrophication assessment areas is also key for determining lifeform distributions. We could not analyse the relevance of another key variable defining the assessment areas: salinity. This variable was used to define river plume areas. However, the CPR dataset did not have sufficient spatial resolution to analyse spatial gradients in the narrow river plume areas.

Interestingly, the gradients in chlorophyll-*a* concentrations did not show the same abrupt changes between areas with different stratification regimes as phytoplankton abundance. This can partly be explained by the large mesh size used in the CPR monitoring, so it only observes on the large plankton cells. It also illustrates the added value of in-situ phytoplankton abundance data for the analysis of ecosystem change.

We conclude that the assessment areas for eutrophication are also appropriate for the biodiversity assessment of indicator PH1/FW5. Further refinements of the assessment areas in oceanic regions could further improve the applicability of assessment areas for biodiversity assessments. These oceanic areas are not very relevant from the eutrophication viewpoint, but the biodiversity assessments are more focused on offshore waters. Our study showed distinct changes in plankton lifeform abundance in some oceanic areas around islands and shallow areas such as the Faroe Islands and Rockall plateau. These areas could be relevant to address separately in the biodiversity assessments due to their specific eco-hydrodynamical conditions.

# Contents

# 1 Introduction

## 1.1 Background

European countries work to protect and restore natural values of marine waters. This is implemented in the Marine Strategy Framework Directive, requesting member states to report on the ecological status of their waters every 6 years and planning measures when the ecological status is found to be insufficient. OSPAR contracting parties bordering the greater North Sea and northeast Atlantic Ocean collaborate in OSPAR on joint procedures for assessments of their marine waters. Joint procedures allow for coherent evaluation of ecological status at the scale of regional seas. In 2023 OSPAR delivers a quality status report (QSR), which will be used for the 2024 MSFD Article 8 reporting by EU member states that are also OSPAR contracting parties. The QSR includes the assessment of biodiversity and eutrophication, which are also descriptors for the Marine Strategy Framework Directive (MSFD): D1 and D5 respectively. In preparation for this report, several projects and initiatives have aimed to progress on joint assessment procedures to achieve more coherent ecosystem assessments.

From 2017 to 2019 the JMP-EUNOSAT project proposed a new coherent assessment method for marine eutrophication (Enserink et al., 2019). This included the use of joint assessment areas based on ecological functioning rather than country borders. Also, coherent threshold values were proposed for winter mean nutrient concentrations and growing season mean chlorophyll-*a* concentrations. These assessment levels were based on pre-eutrophic concentrations, estimated with a combination of a European-wide catchment model (E-HYPE), a nutrient transport model (DFLOW-FM) and a linear regression model between nutrients and chlorophyll-*a*. For evaluation of current chlorophyll-*a* concentrations against the threshold a joint satellite product was developed.

The OSPAR intersessional correspondence group for eutrophication (ICG-EUT) decided to implement this newly proposed joint assessment method for the 4th application of the OSPAR Common Procedure for the assessment of eutrophication (COMP4), which contributes to the upcoming QSR. To this end, the proposed assessment areas and threshold values were further refined, based on inputs from the contracting parties and a new initiative to estimate threshold values with an ensemble approach with a selection of marine biochemical models for the OSPAR area (OSPAR, 2022; van Leeuwen et al., 2023).

The current study is part of the NEA PANACEA project, funded by the EU DG-ENV as part of the research programme “DG ENV/MSFD 2020”: Marine Strategy Framework Directive: support to the preparation of the next 6-year cycle of implementation. The project aims to improve coherence on OSPAR biodiversity assessments. Chlorophyll-*a* is an indicator both for eutrophication and for biodiversity. To enhance the coherence between the assessment of phytoplankton for eutrophication and for biodiversity, the new QSR assessment for biodiversity prepared in the context of the NEA PANACEA project, applied the same assessment areas that are used for eutrophication also for pelagic biodiversity indicators:

- PH1/FW5: Plankton composition
- PH2: Biomass of phytoplankton and zooplankton
- PH3: Changes in plankton biodiversity
- FW2: Pelagic primary production

## 1.2 Objectives

This report describes the results of task 2.3 of the NEA PANACEA project: “Identification of ecologically relevant scales and areas for assessment of pelagic and benthic habitats”. It aims to evaluate to what extent the assessment areas developed for eutrophication are also applicable for other biodiversity assessments.

The eutrophication assessment areas for OSPAR QSR COMP4 were developed based on cluster analysis of satellite data of chlorophyll-*a* and primary production. So, they are also appropriate for the biodiversity indicators PH2: phytoplankton biomass, with indicator chlorophyll-*a* and FW2: primary production. The clusters that were identified in the satellite data have been linked to environmental variables during the JMP-EUNOSAT project (Blauw et al., 2019): salinity, water depth and duration of stratification. Additionally, assessment areas were separated by geographical areas that are commonly used by contracting parties to describe their waters, such as a separation between the Channel and the southern North Sea, or the German Bight or river plumes of specific large rivers.

To evaluate the applicability of the resulting assessment areas for other pelagic indicators we have explored similarities between spatial patterns in planktonic lifeforms and environmental variables that were used for the definition of the assessment areas for eutrophication:

- Salinity
- Stratification
- Water depth
- Chlorophyll-*a*

The benthic biodiversity assessments mostly focus on the evaluation of pressures on benthic habitats, which are not linked to the ecological functioning underlying the assessment area definitions for eutrophication. The only benthic indicator that evaluates the impact of nutrients on benthic habitats is BH2a: “Condition of benthic habitat communities: assessment of some coastal habitats in relation to nutrient and/or organic enrichment”. This indicator is only evaluated for WFD areas. These areas are excluded from the COMP4 assessment areas for eutrophication. Therefore, it was not feasible to evaluate the applicability of these assessment areas for benthic indicators.

## 1.3 Approach

In this initial exploration of similarities between spatial patterns we have only used visual inspection and interpretation of spatial patterns by plotting data of lifeform abundance together with relevant environmental variables: both in maps and along longitudinal transects.

The assessment of pelagic indicator PH1/FW5 on: ‘Changes in phytoplankton and zooplankton communities’ analyses temporal variability and trends in abundance of specific planktonic lifeforms in CPR data (Holland et al., 2023a). The data for this assessment were aggregated per COMP4 assessment area, per plankton lifeform and per season. The lifeforms were defined by McQuatters-Gollop et al. (2019). We focus our analysis on spatial variability at smaller scales than the assessment areas. We used the same dataset that was used for the PH1/FW5 assessment that was kindly shared with us for this analysis and used the same classification of seasons and lifeforms:

- Diatoms,
- Dinoflagellates
- Fish larvae
- Holoplankton
- Meroplankton
- Large copepods (lg_copepods)
- Small copepods (sm_copepods)

To account for differences in seasonal variability between these planktonic lifeforms data are aggregated per season:

- Spring: March-May
- Summer: June – August

In the current study we analyse to what extent the COMP4 assessment areas defined for eutrophication are also suitable for the assessment of planktonic lifeforms. To this end we compare spatial patterns of lifeforms in CPR data with spatial patterns in the variables that were used for the definition of eutrophication assessment areas: stratification, water depth and salinity. Data for these environmental variables were extracted from model runs with the DCSM-FM model for the greater North Sea and surrounding shelf and ocean waters by Deltares. These same model runs were also used for ensemble modelling (van Leeuwen et al., 2023) in the context of OSPAR ICG-EMO (Intersessional Correspondence Group for Ecological Modelling).

Additionally, the spatial patterns in lifeform abundance have been compared with satellite data for chlorophyll-a that were provided for the OSPAR QSR by RBINS. We used the same growing season mean data (March through October) over 2015 - 2020 that were also used for the OSPAR QSR COMP4 assessment of eutrophication.

The CPR data are collected from ships of opportunity at a spatial resolution of 10 nautical miles along the ship route (Richardson, 2006). The observations are made through filtering water approximately 3m$^3$ of water through silk with mesh size of 270 µm. The ship does not always follow exactly the same trajectory, so the observations are not made at fixed locations. For the calculation of statistics, such as season mean abundances, data that are close together need to be aggregated in space. We aggregated the CPR data on a grid of 0.33 x 0.33 degree latitude and longitude. We only used data in grid cells that had in total at least 10 observations per season to filter out locations with insufficient observations to calculate a representative mean. To enable the visual comparison of spatial scales between different variables on the same axis, we rescaled the lifeform abundance (cells/ml) by multiplication with a factor $f_{sc}$ to match the scale of stratification duration (as percentage of the year) between 0 and 100 (Table 1.1). For comparisons with chlorophyll growing season mean maps the rescaled life form abundance has been multiplied by 0.1 to match the scales of chlorophyll-a distribution.

*Table 1.1: Multiplication factors used per lifeform and season for rescaling abundance data to a range between 0 and 100, to be visualised along with percentage of the year stratification.*

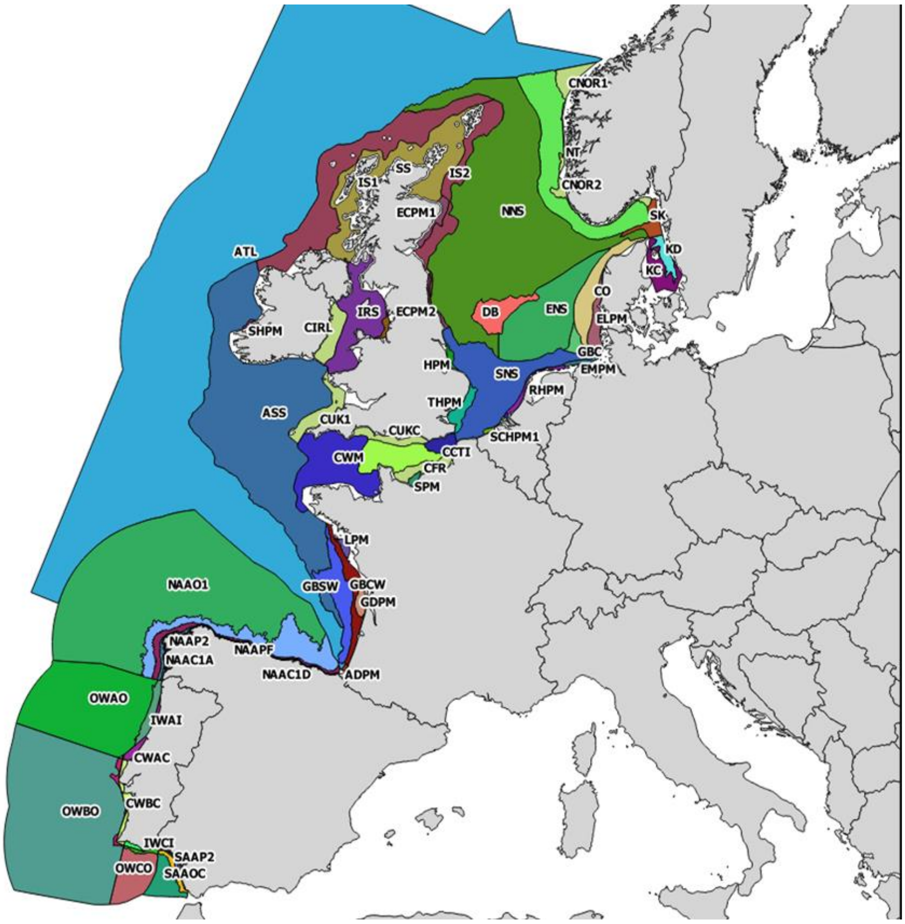
| Lifeform | Multiplication factor $f_{sc}$ spring | Multiplication factor $f_{sc}$ summer |
|---|---|---|
| **"diatom"** | 0.0004 | 0.0007 |
| **"dinoflagellate"** | 0.00027 | 0.0007 |
| **"fishlarvae"** | 50 | 80 |
| **"holoplankton"** | 0.0900 | 0.0450 |
| **"meroplankton"** | 0.07 | 0.05 |
| **"lg_copepods"** | 0.5 | 0.7 |
| **"sm_copepods"** | 0.3 | 0.1 |

In the definition of COMP4 assessment areas for eutrophication: the following cut-off values were used:

- Salinity: 32 ppt as boundary between river plumes and coastal waters
- Water depth: 35 m as boundary between southern North Sea and rest of North Sea and 250 m between shelf waters and deep waters of the Atlantic Ocean and Norwegian Trench.
- Stratification: waters were considered to be stratified when the density difference between surface and bottom exceeded 0.086 kg/m3 (following van Leeuwen et al., 2015). Waters were classified in 4 groups, depending on the duration of stratification per year, as shown in Table 1.2.

*Table 1.2: Definition of stratification regimes based on duration of stratification in the JMP-EUNOSAT project (in months per year) and in this study (in overall percentage of the year)*

| Group | Months per year stratified | Corresponding % of year |
|---|---|---|
| **Permanently stratified** | >8 | >67 |
| **Seasonally stratified** | ≤8 | ≤67 |
| **Intermittently stratified** | ≤2 | ≤17 |
| **Permanently mixed** | <1 | <8 |



# 2 Spatial variability in planktonic lifeforms

## 2.1 Results for whole domain

### 2.1.1 Diatoms

Comparing the map of duration of stratification (Figure 2.2) with the bathymetry map (Figure 2.1) it appears that the permanently mixed areas more or less coincide with the areas that are deeper than 250 m and the 35 depth contour in the southern North Sea coincides more or less with the boundary between permanently mixed and seasonally stratified waters. Therefore, we focus on the analysis of spatial patterns in stratification duration and to not separately analyse the spatial patterns in water depth. The extent of areas with intermittent stratification is relatively limited. Therefore, we focus on transitions between permanently mixed waters (<8%) and seasonally stratified waters (less than 67% and more than 8%) and between seasonally stratified and permanently stratified waters (>67%). The classification of stratification regimes is shown in Table 1.2.

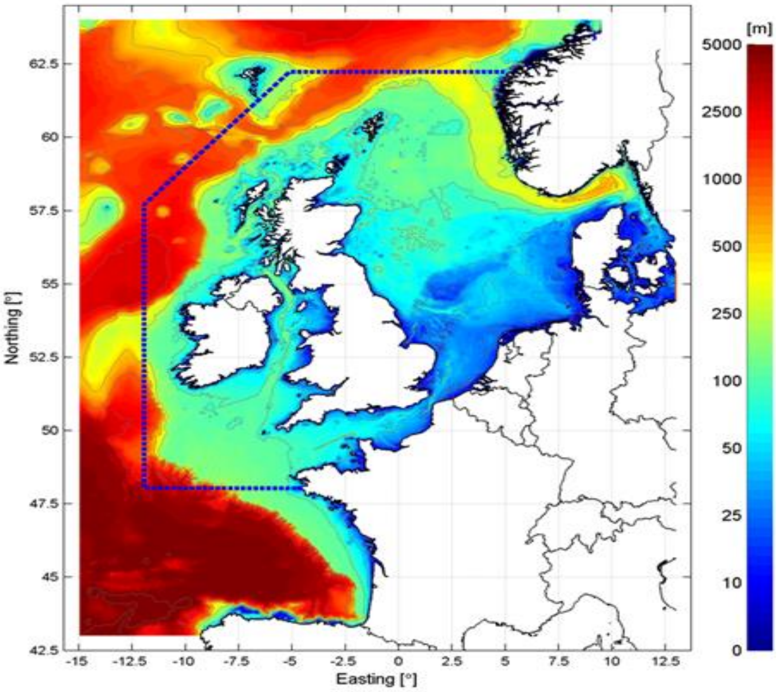



*Figure 2.1: Water depth in model domain.*


Deltares

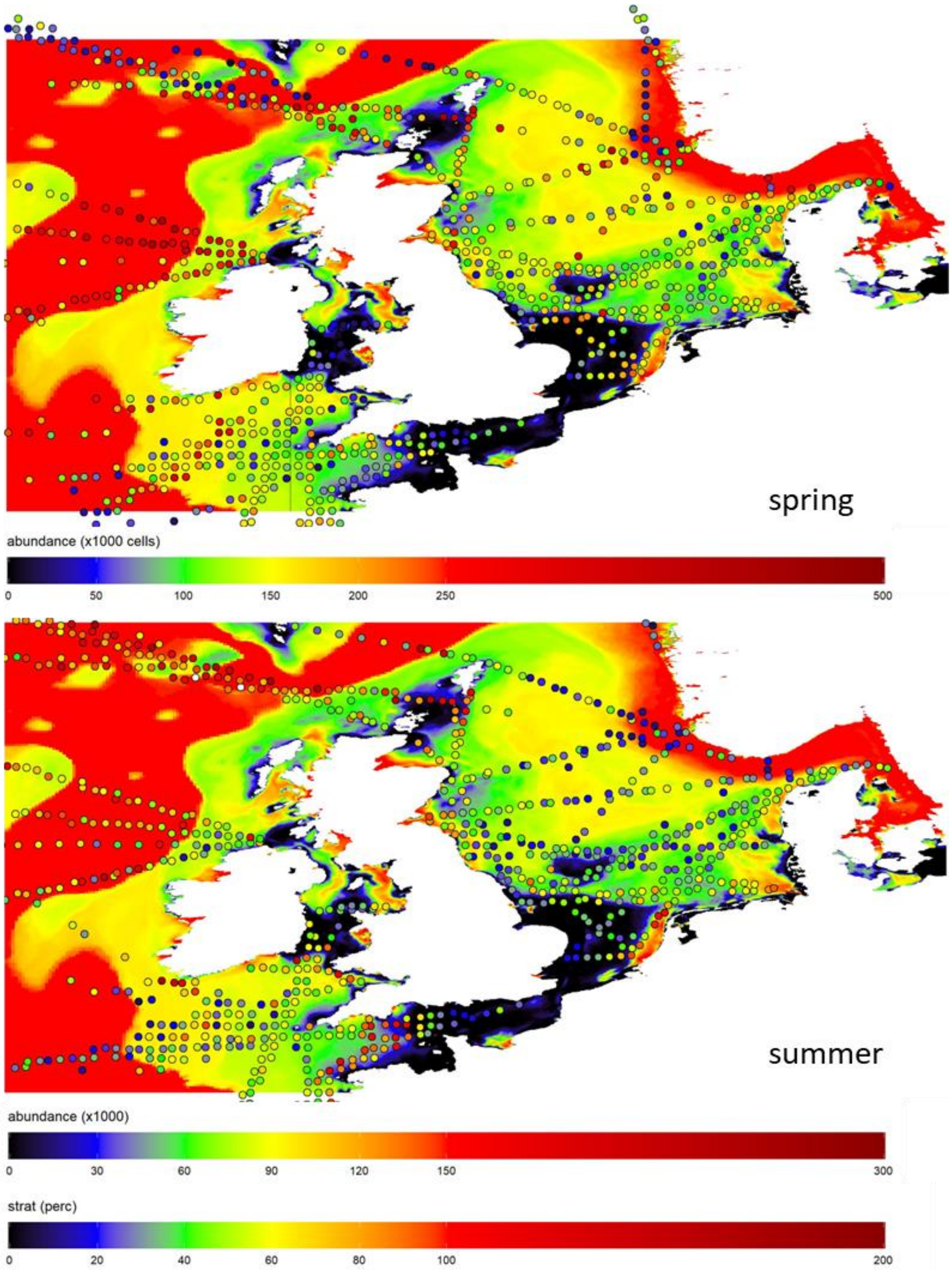



*Figure 2.2: Spatial patterns in season mean diatom abundance (circles) in spring in CPR data for 19060 - 2019 (upper panel) and summer (lower panel) overlayed with spatial patterns in percentage of year stratified in model data (background colour).*

Some of the transitions in stratification duration coincide with a strong gradient in diatom abundance. This can be seen for example in the transition between permanently mixed waters (dark blue) and seasonally stratified waters (green and yellow): 1) in the Channel, south of Plymouth, 2) in the Celtic Sea west of Liverpool, 3) between the Shetland and Orkney islands and 4) in the southern North Sea. Also, the transition between permanently stratified waters (red) and seasonally stratified waters in some cases is associated with a change in diatom abundance. This can be seen for example: 1) along the Norwegian Trench, 2) between the Orkney and Faroe Islands, 3) along the Atlantic margin north-west of Ireland and 4) south of Ireland. These sections are analysed in more detail in section 2.2 and are outlined in Figure 2.9.

Interestingly, spatial patterns in diatom abundance do not always align with those in growing season mean chlorophyll-*a* from satellite data (Figure 2.3). This can be seen for example between the Norwegian Trench and the Orkney islands in spring. In the satellite data chlorophyll is higher in the Norwegian Trench than in the adjacent seasonally stratified North Sea waters. Also, near the Thames estuary diatom abundance decreases towards the coast, whereas chlorophyll-*a* seems to increase. Partially these differences can be explained because the satellite data shows growing season means from March through October 2015 - 2020 and the diatom abundance shows separate means for spring (March through May) and summer (June through August) for 1960 through 2019. Another potential explanation could be that the CPR-data only count the larger diatoms at a specific water depth and the satellite data observe all chlorophyll pigments in phytoplankton in the upper euphotic water layer. Also, chlorophyll-*a* per phytoplankton cell may differ depending on environmental conditions. Under light limited conditions, such as turbid coastal waters in spring, chlorophyll-*a* concentrations for the same diatom abundance are likely to be higher than under conditions with excess light availability, such as clear water conditions in summer.

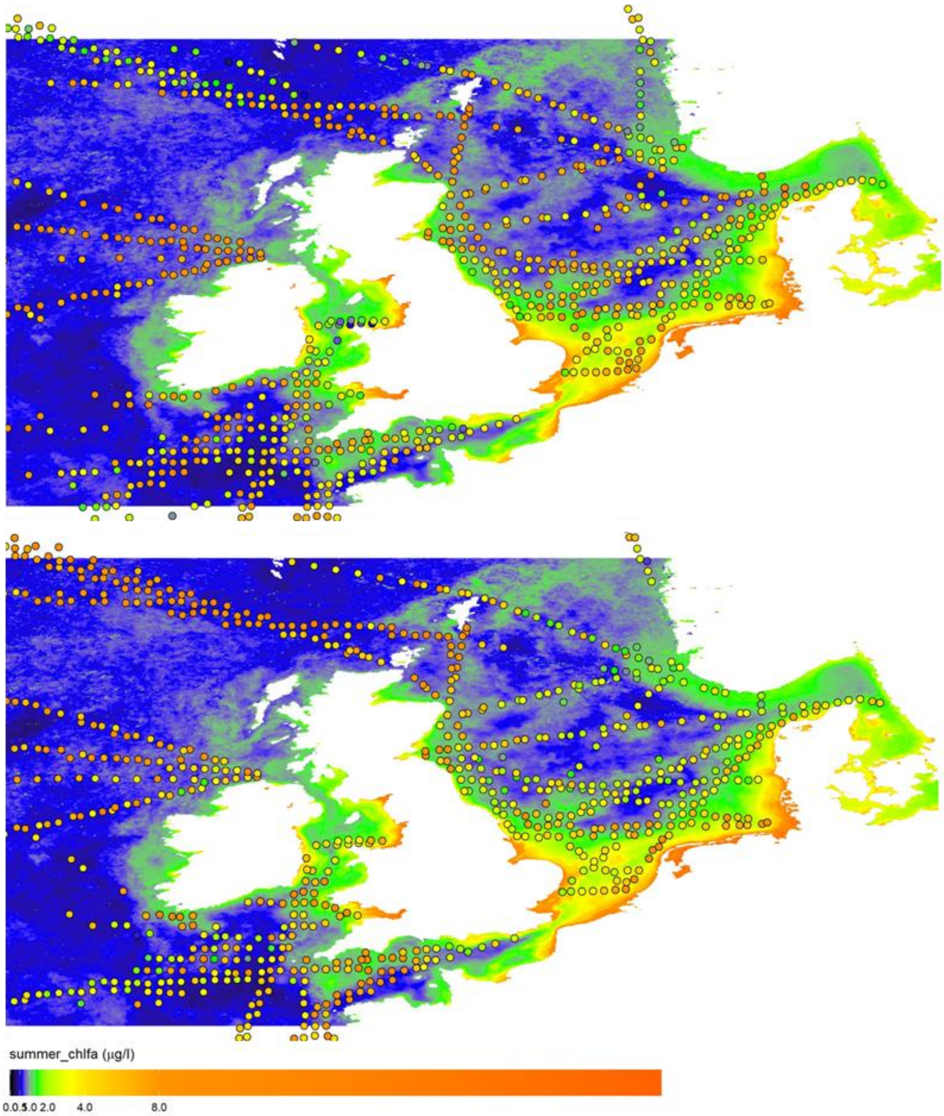



*Figure 2.3: Spatial patterns of rescaled season mean diatom abundance over 1960-2019 (circles) in spring (upper panel) and summer (lower panel) in comparison with spatial patterns of growing season mean chlorophyll-a concentrations for 2015 – 2020 based on satellite data by RBINS (background colour).*

The CPR data, with a spatial resolution of 10 nautical miles, aggregated to a 1/3 degree longitude and latitude resolution, do not allow for the evaluation of the suitability of a 32 psu threshold for the definition of assessment areas for lifeform abundance indicators. There are insufficient observation locations in waters with less than 32 psu, since the river plumes are generally relatively narrow strips along the coast. Figure 2.4 shows the spatial distribution of salinity, converted to freshwater percentage as: (35.5-salinity)/35.5*100%. The 32 psu boundary corresponds to 10% freshwater, which are shown as orange and red colours in the figure. These areas lack sufficient observations for analysis.

There is a striking resemblance in the areas with high and low spring diatom abundance and relatively low salinity in the northern North Sea, between the Norwegian Trench and the Faroe Islands. These areas coincide with the areas with permanent stratification and seasonal stratification in Figure 2.2.

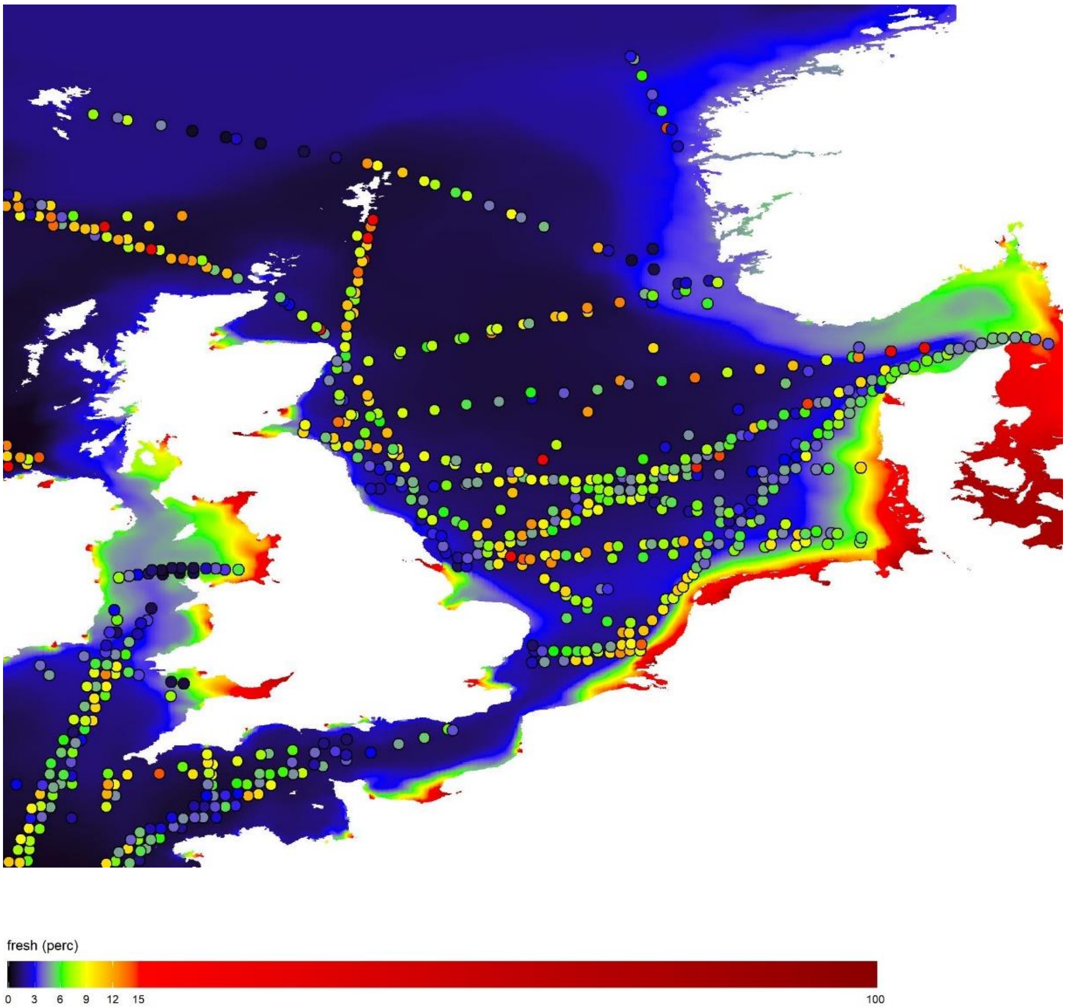



*Figure 2.4: Spatial distribution of rescaled spring mean diatom abundance in CPR data (circles) with the spatial distribution of freshwater percentage of water in model data: (35.5-salinity)/35.5 * 100% (background colour).*

### 2.1.2 Dinoflagellates

Dinoflagellates show similar gradients as diatoms in the Channel between permanently mixed and seasonally stratified water and in the Celtic Sea (Figure 2.5). Also, the spatial patterns in the northern part of the domain in spring show similar patterns as for diatoms. Along the Atlantic margin gradients seem to differ from those in diatoms. These gradients will be analysed in more detail in section 2.2.

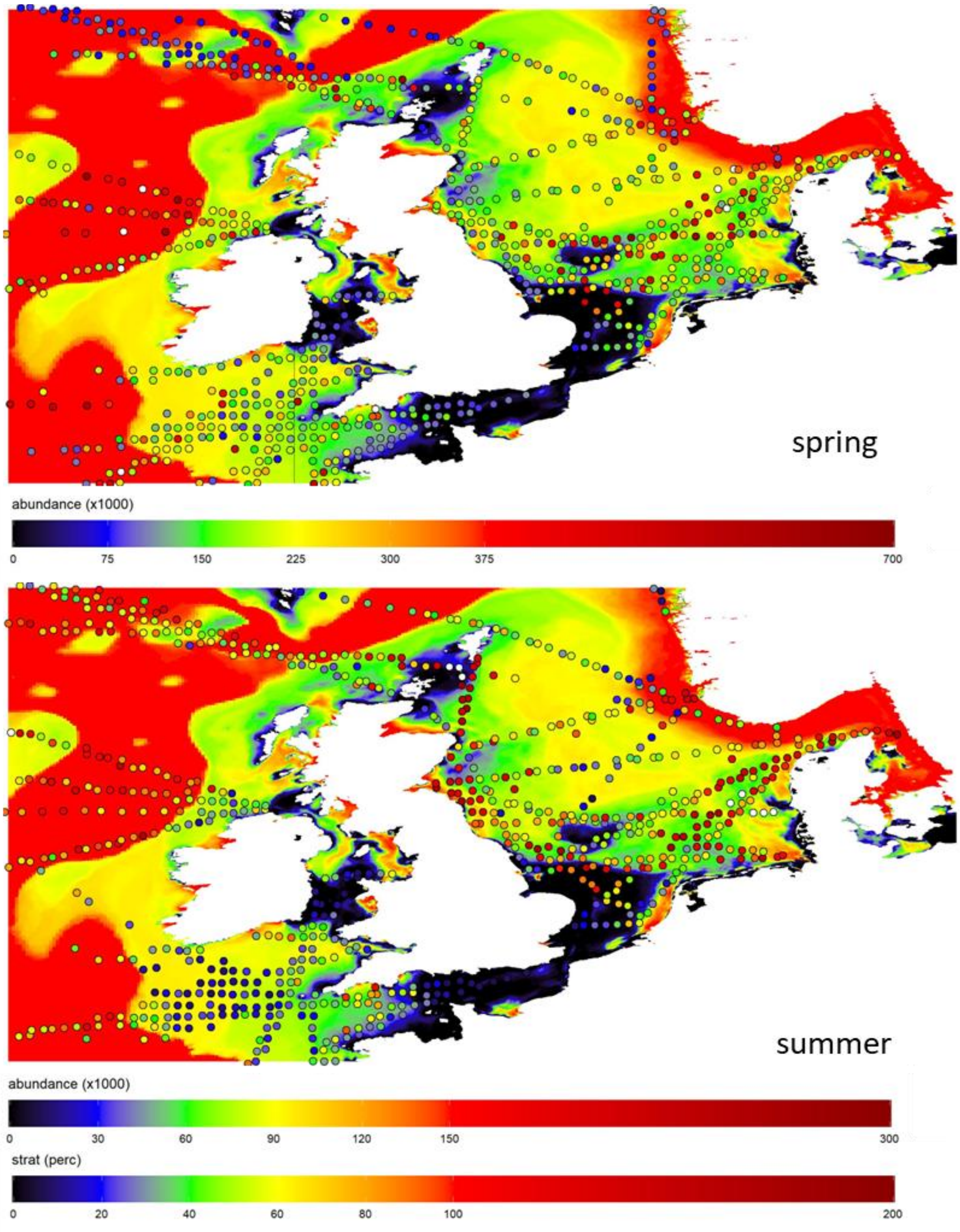



*Figure 2.5: Spatial patterns in season mean dinoflagellate abundance (circles) in CPR data in spring (upper panel) and summer (lower panel) with spatial patterns in percentage of year stratified in model data (background colour).*

### 2.1.3 Copepods

Figure 2.6 shows the spatial patterns of large copepods and small copepods in spring and summer. In some areas large copepods seem to show opposite preferences to stratification conditions from the small copepods. This can be seen for example south of Ireland, where large copepods have higher abundance in the seasonally stratified areas (yellow and green) than in the permanently stratified areas (red). For the small copepods the abundance is lower in the seasonally stratified areas than in the permanently stratified areas. Also, comparing seasonally stratified waters with permanently mixed water in the southern North Sea, large copepods seem to have a preference for seasonally stratified waters, whereas the small copepods show relatively large abundance in permanently mixed waters. Please note that abundances cannot be compared in absolute values between large and small copepods, since both abundances have been rescaled with different factors to optimise the visualisation of spatial trends on the scale from 0 to 100.

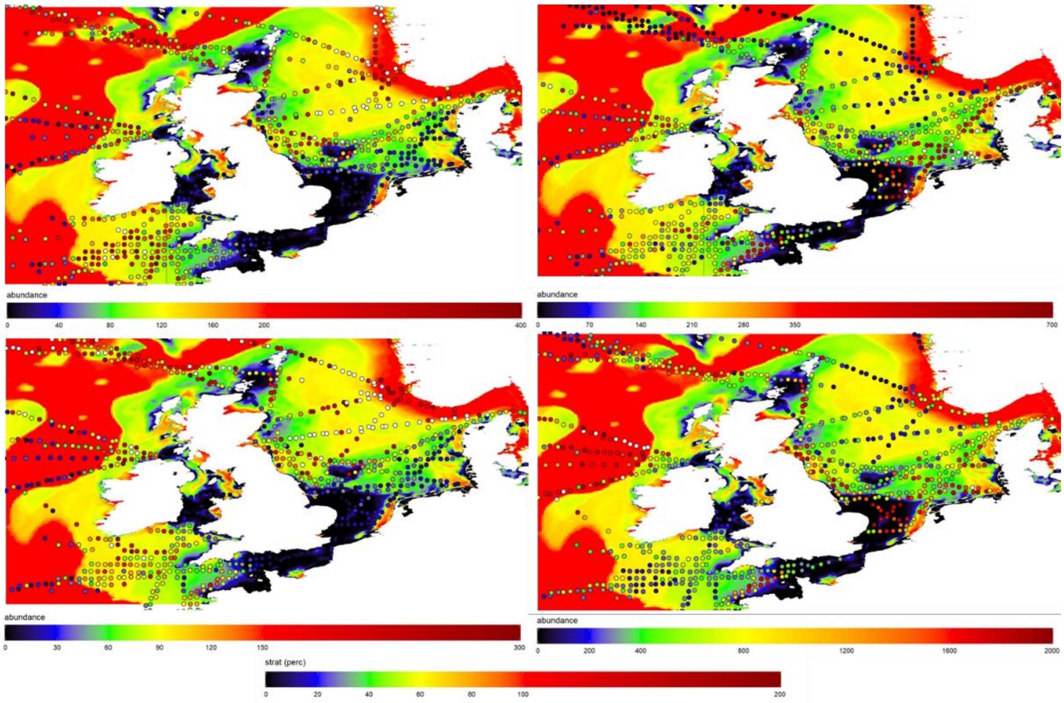



*Figure 2.6: Spatial patterns in season mean CPR-data (circles) for copepods in spring (upper panel) and summer (lower panel) for large copepods (left) and small copepods (right), with spatial patterns in percentage of time stratified in model data (background colour).*

### 2.1.4 Fish larvae

Contrary to the other lifeforms, the abundance of fish larvae does not show clear gradients associated to changes in stratification duration (Figure 2.7). Abundances are higher in the southern North Sea and south of England and Ireland than in the Atlantic waters. Yet the spatial patterns neither seem to align with spatial patterns of chlorophyll-*a*. Possibly the location of spawning grounds has a larger impact on the distribution of fish larvae than local environmental conditions. Additionally, lumping all larvae from a large range of fish species with different life strategies and habitat preferences may mask spatial gradients and habitat preferences of individual species. And in our analysis we have taken the mean over 1960 – 2019, which may obscure relations between fish larvae abundance and environmental conditions. Patterns may be more comparable when data from the same time period is considered.

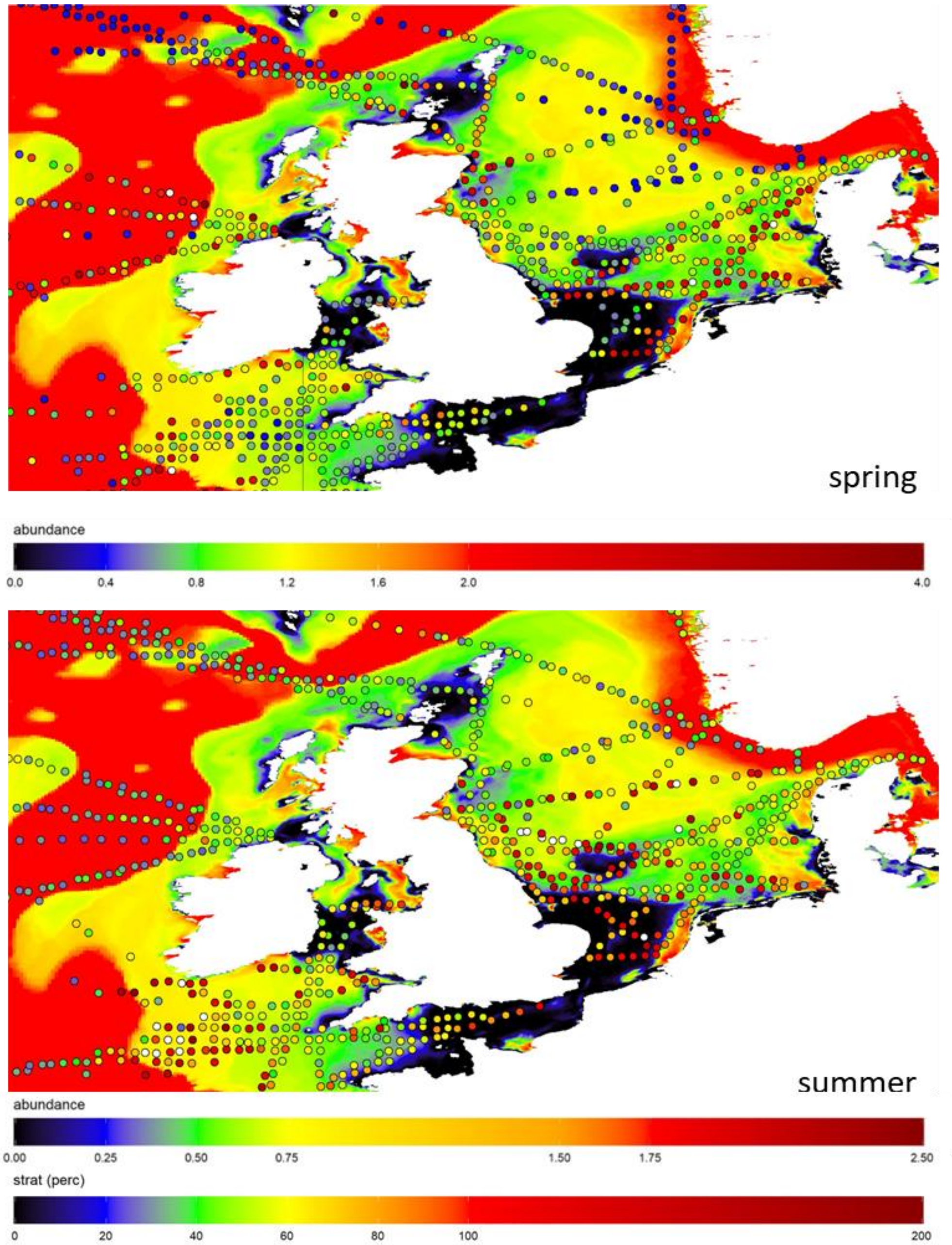



*Figure 2.7: Spatial patterns in season mean CPR-data (circles) for fish larvae in spring (upper panel) and summer (lower panel), with spatial patterns in percentage of time stratified in model data (background colour).*

### 2.1.5 Holoplankton and meroplankton

Holoplankton and meroplankton are zooplankton species that differ in their life cycle: holoplanktonic zooplankton lives in the water column its entire life, whereas meroplanktonic zooplankton spends its larval phase in the pelagic environment before recruiting to benthic habitat to live out its adult phase. Small copepods make up a large part of the holoplankton. The holoplankton shows abrupt changes in abundance across the Atlantic margin west and south of Ireland, with higher abundance in the seasonally stratified shelf waters. In the Channel abundances seem to be lower in the permanently mixed waters than in the seasonally stratified waters (Figure 2.8). For meroplankton the dominant spatial pattern shows relatively high abundance in the southeast North Sea and low abundance elsewhere. The resulting scaling obscures any transitions in abundance coinciding with changes in stratification regime. The longitudinal transect plots shown in section 2.2 are less affected by this scaling issue.

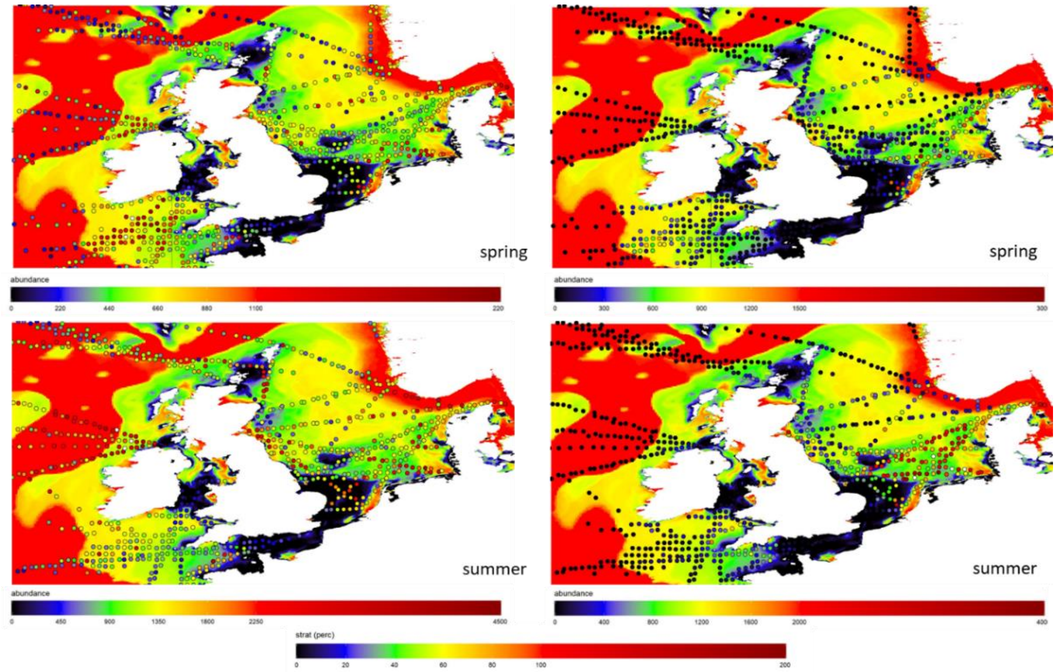



*Figure 2.8: Spatial patterns in season mean CPR-data (circles) for holoplankton (left) and meroplankton (right) in spring (upper panel) and summer (lower panel), with spatial patterns in percentage of time stratified in model data (background colour).*

## 2.2 Results for specific areas

The visibility of gradients in the previous section is affected by the chosen colour scale and with those type of plots the lifeform abundance can only be compared to one environmental variable at a time. Therefore, in this section we zoom in on several specific areas to compare spatial gradients in lifeform abundance, duration of stratification and chlorophyll-*a* in more detail. Rescaled lifeform abundance is plotted for spring and summer separately. In both cases these are compared with the same values of % of the year stratified from model data and growing season mean chlorophyll-a from satellite data. A red dashed line is added to indicate the location of changes in stratification regime. Figure 2.9 shows the areas where we plotted longitudinal gradients of lifeform abundance with relevant environmental variables.

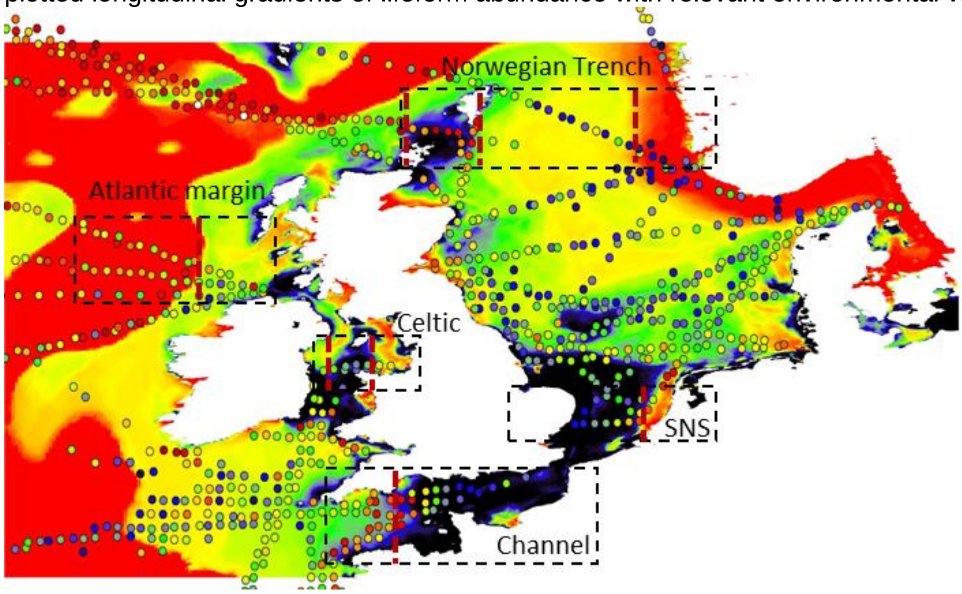



*Figure 2.9: Location of local areas to compare longitudinal gradients between lifeform abundance, duration of stratification and chlorophyll-a. The red dashed lines indicate the approximate locations of changes in stratification regime.*

### 2.2.1 Channel area

In the Channel there is a clear transition zone south of Plymouth, where diatom and dinoflagellate abundance is much lower in the permanently mixed waters to the east than in the seasonally stratified waters to the west. In summer, their abundance is even higher along the front than on either side of the front (Figure 2.10). The strong spatial gradient in diatoms abundance is not visible in satellite data of chlorophyll-*a* (2015 – 2020), although in the frontal region chlorophyll-*a* concentrations seem slightly increased.

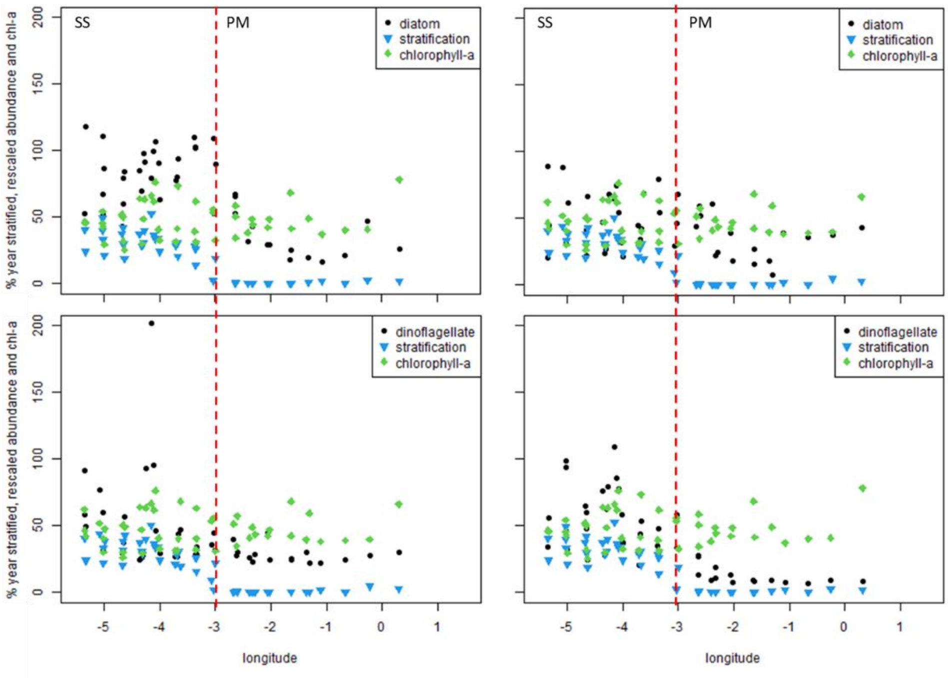



*Figure 2.10: Gradients in season mean phytoplankton abundance (left: spring, right: summer) for diatoms and dinoflagellates, with associated gradients in duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient in the Channel. The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

Other lifeforms also show a longitudinal gradient associated to the Ushant front (Figure 2.11). Particularly dinoflagellates, large copepods and holoplankton show higher abundance on the seasonally stratified areas west of the front than on the permanently mixed areas east of the front. Meroplankton only shows this pattern during summer. For small copepods this gradient is less strong and for fish larvae there is no clear difference in abundance on either side of the front.

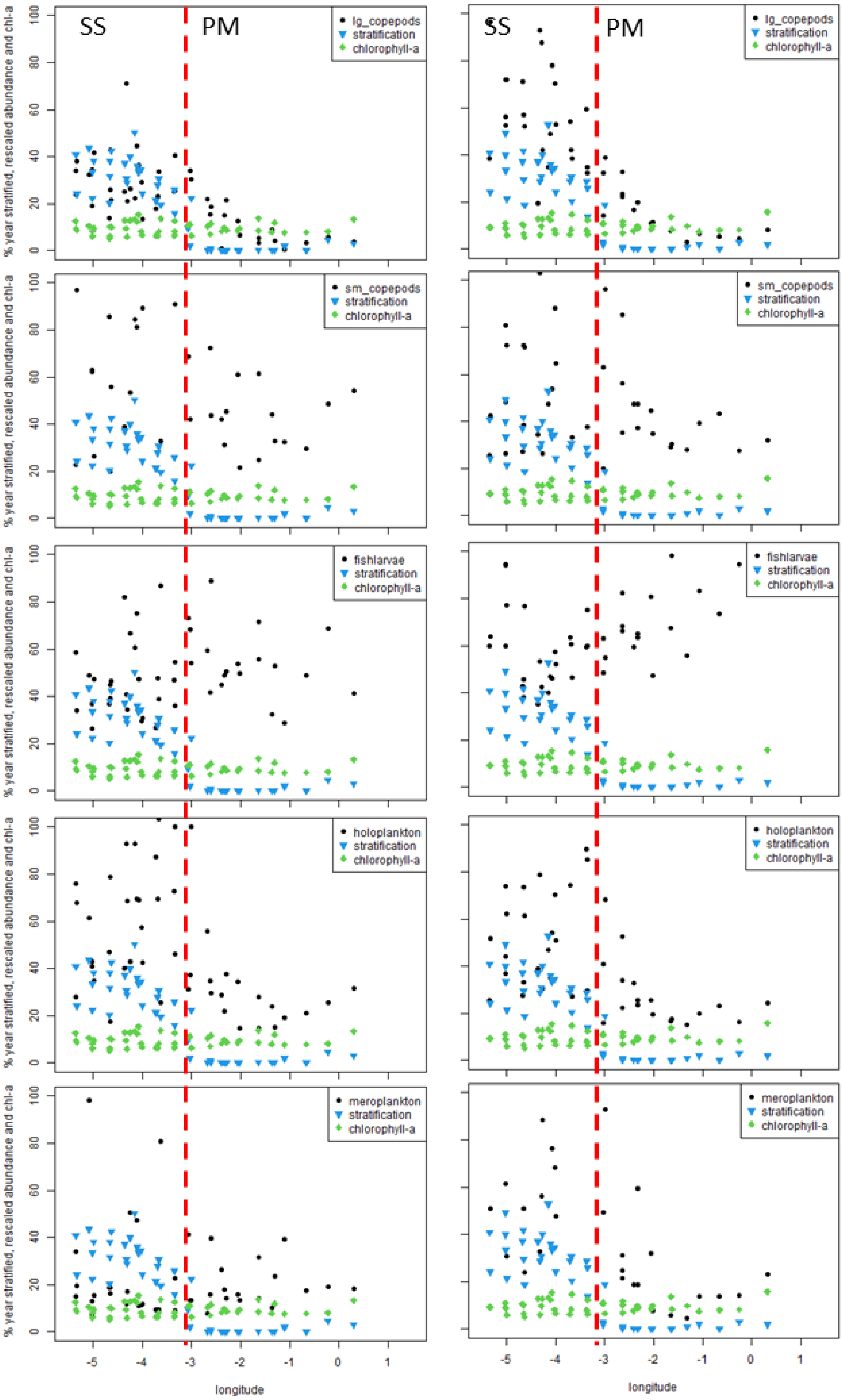



*Figure 2.11: Longitudinal gradients in plankton lifeforms in the Channel area, in comparison with gradients in stratification duration and rescaled chlorophyll-a (left: spring, right: summer). The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

### 2.2.2 Celtic Sea

The Celtic Sea shows a gradient from west to east with different levels of stratification. The majority of the transect is permanently mixed. Off the Irish coast there is a small region with intermittent stratification. Close to the English coast in Liverpool Bay waters are often stratified, presumably due to salinity stratification by high freshwater inputs (see salinity in Figure 2.4). Chlorophyll-*a* concentrations do not show clearly different concentrations in stratified waters compared to mixed waters. The chlorophyll-*a* concentrations close to the Irish Coast do show a clear increase compared to waters further offshore. The diatom abundance in summer is higher in the stratified waters of Liverpool Bay than in the permanently mixed waters further offshore. This may also be explained by higher nutrient concentrations in the waters with more freshwater inputs. (Figure 2.12). Dinoflagellates tend to show higher abundance in stratified waters than in permanently mixed waters, both in spring and in summer.

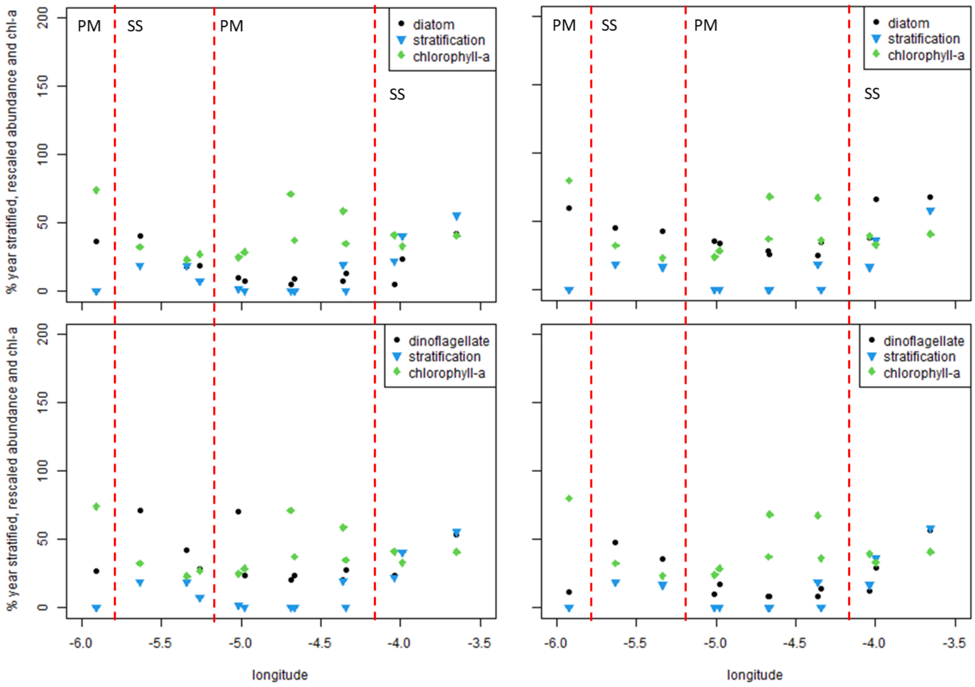



*Figure 2.12: Gradients in season mean diatom abundance (left: spring, right: summer) and dinoflagellate abundance (upper panels), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient in the Celtic Sea, between Liverpool and Ireland. The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

Large copepods do not show clear changes in abundance between stratified and non-stratified waters, but small copepods show higher abundance in the (haline) stratified waters: both in Liverpool Bay and off the Irish coast. Fish larvae show higher abundance in Liverpool Bay than offshore in spring, but in summer there is a gradual increase in abundance from the Irish to the English coast that does not show abrupt changes between stratified and non-stratified areas. Holoplankton also shows higher abundance in stratified waters and meroplankton shows only slightly elevated concentrations in stratified waters.

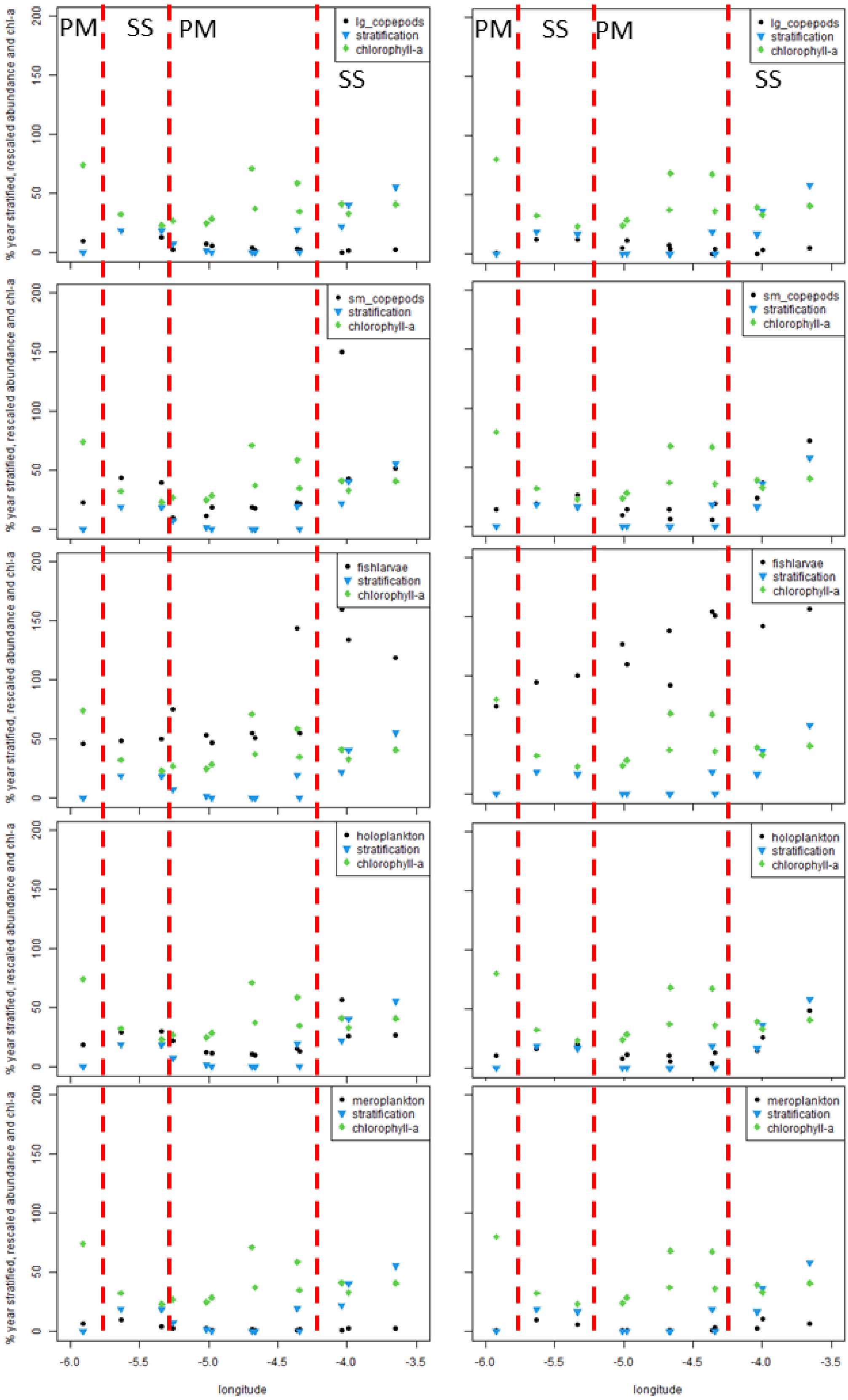



*Figure 2.13: Longitudinal gradients in zooplankton lifeforms in the Celtic Sea, in comparison with gradients in stratification duration and rescaled chlorophyll-a (left: spring, right: summer). The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

### 2.2.3 Southern North Sea (SNS)

In the southern North Sea diatom and dinoflagellate abundance does not show abrupt changes between the permanently stratified waters offshore and the stratified waters in the freshwater region of influence along the Dutch coast. Diatom abundance gradually increases towards the Dutch coast. Dinoflagellate concentrations in summer seem to be somewhat lower in the freshwater stratified waters near the coast, than further offshore. Chlorophyll-*a* concentrations do not show a clear gradient between the English and Dutch coast, but close to the English coast chlorophyll-*a* concentrations are strongly elevated. This increase is not visible in diatom or dinoflagellate abundance. Possibly, these locations are within the English plume with elevated turbidity. This would trigger phytoplankton to increase their chlorophyll-*a* content to compensate for reduced light availability.

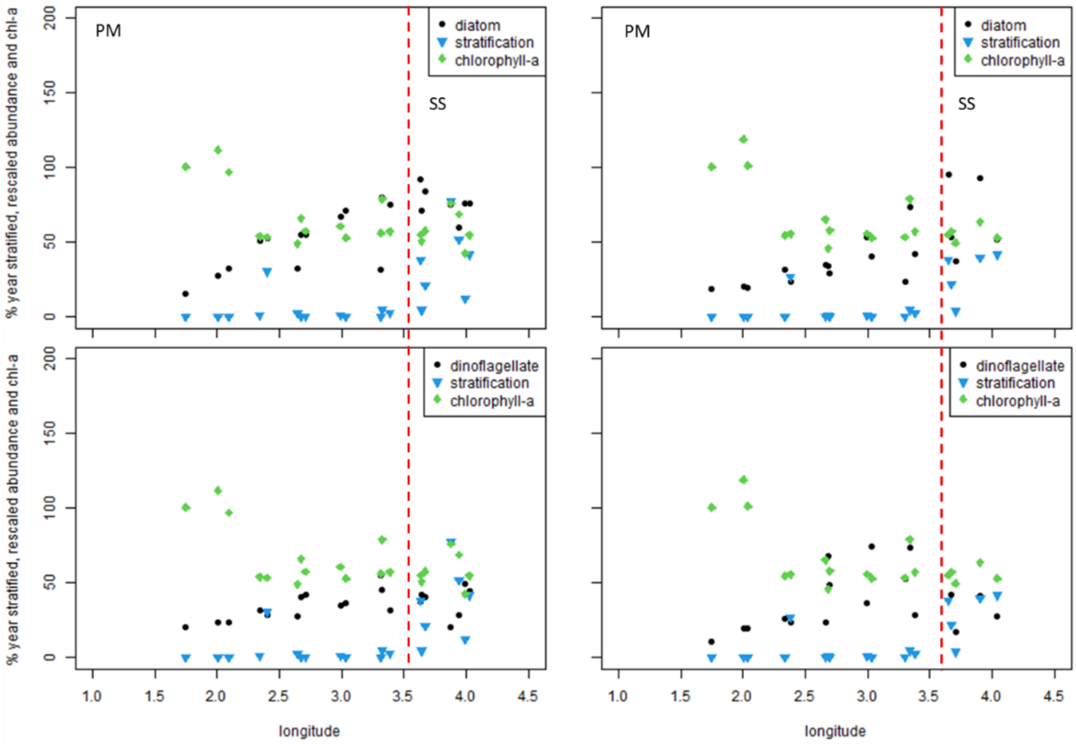



*Figure 2.14: Gradients in season mean diatom abundance (left: spring, right: summer) and dinoflagellate abundance (upper panels), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient in the Southern North Sea, between England and the Netherlands. The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

Large copepods show slightly elevated abundance in spring in the stratified ROFI, whereas small copepods show a decrease in summer in the ROFI. Small copepods, holoplankton and meroplankton in spring show a gradual increase from the English to Dutch coast, similar to the gradient in spring diatoms. Fish larvae do not show clear gradients.

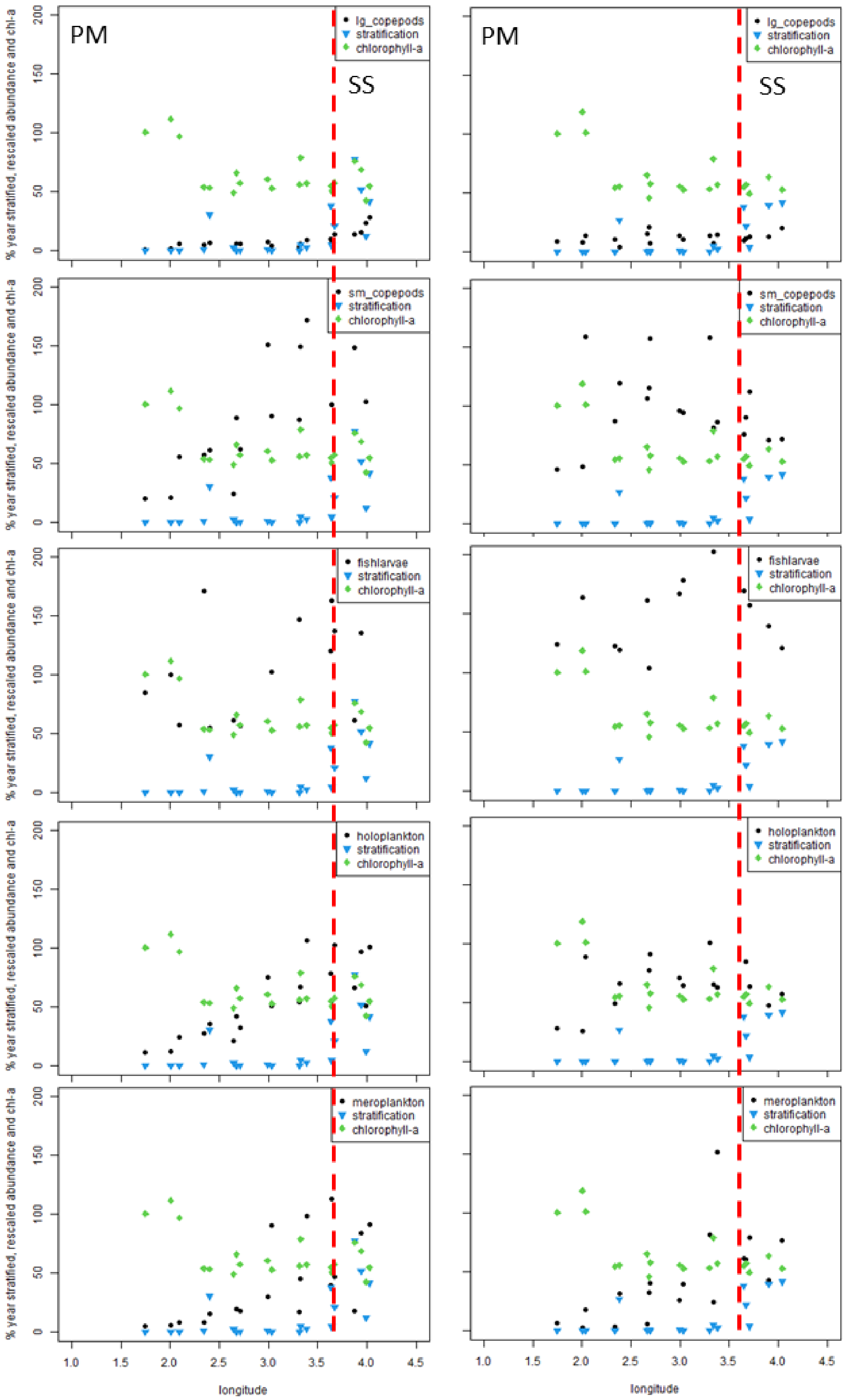



*Figure 2.15: Gradients in season mean abundance of zooplankton lifeforms (left: spring, right: summer), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient in the Southern North Sea, between England and the Netherlands. The red dashed line indicates the location of the change in stratification regime. PM = permanently mixed, SS = seasonally or salinity stratified.*

### 2.2.4 Atlantic margin

Across the Atlantic margin diatoms and dinoflagellates show higher abundance in the permanently stratified waters than in seasonally stratified waters, particularly dinoflagellates (Figure 2.16). This change is not visible in the chlorophyll-*a* observations. Small copepods in summer also show higher abundance in permanently stratified waters than in seasonally stratified waters. The opposite pattern is visible in large copepods in spring and holoplankton, with higher abundance in the seasonally stratified waters than in the permanently stratified waters off the shelf (Figure 2.17). Fish larvae do not show clear longitudinal gradients.

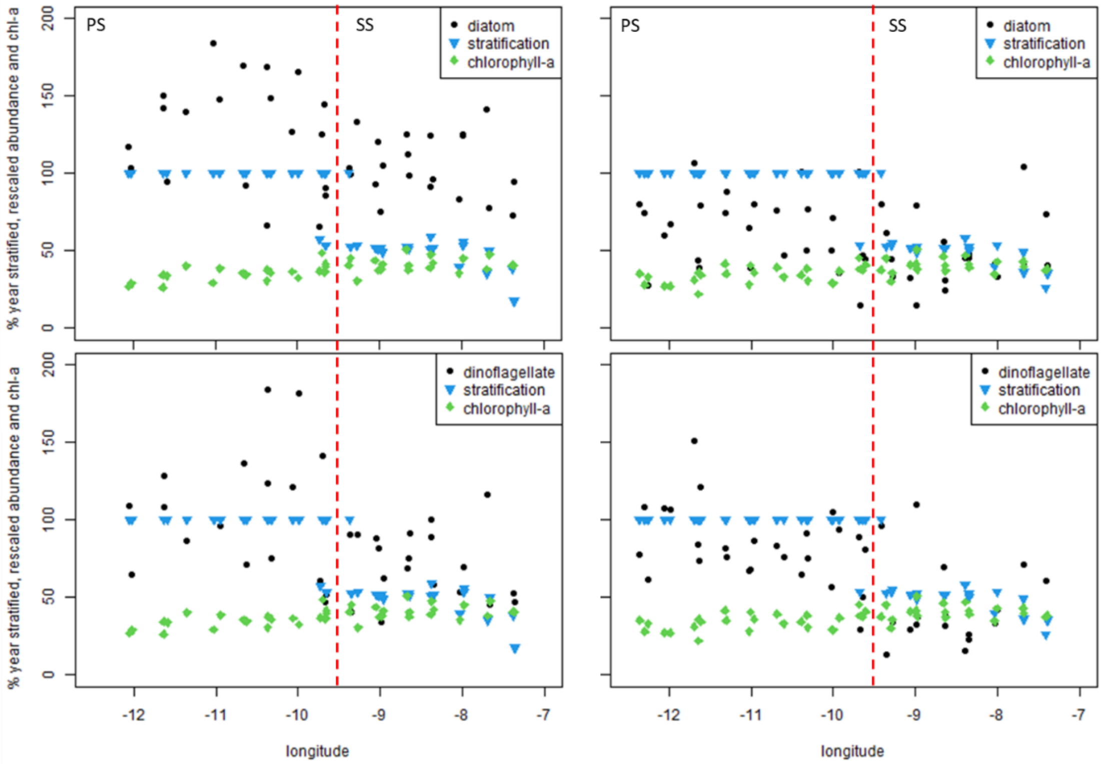



*Figure 2.16: Gradients in season mean diatom abundance (left: spring, right: summer) and dinoflagellate abundance (upper panels), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient across the Atlantic margin west of Ireland. The red dashed line indicates the location of the change in stratification regime. PS = permanently stratified, SS = seasonally or salinity stratified.*

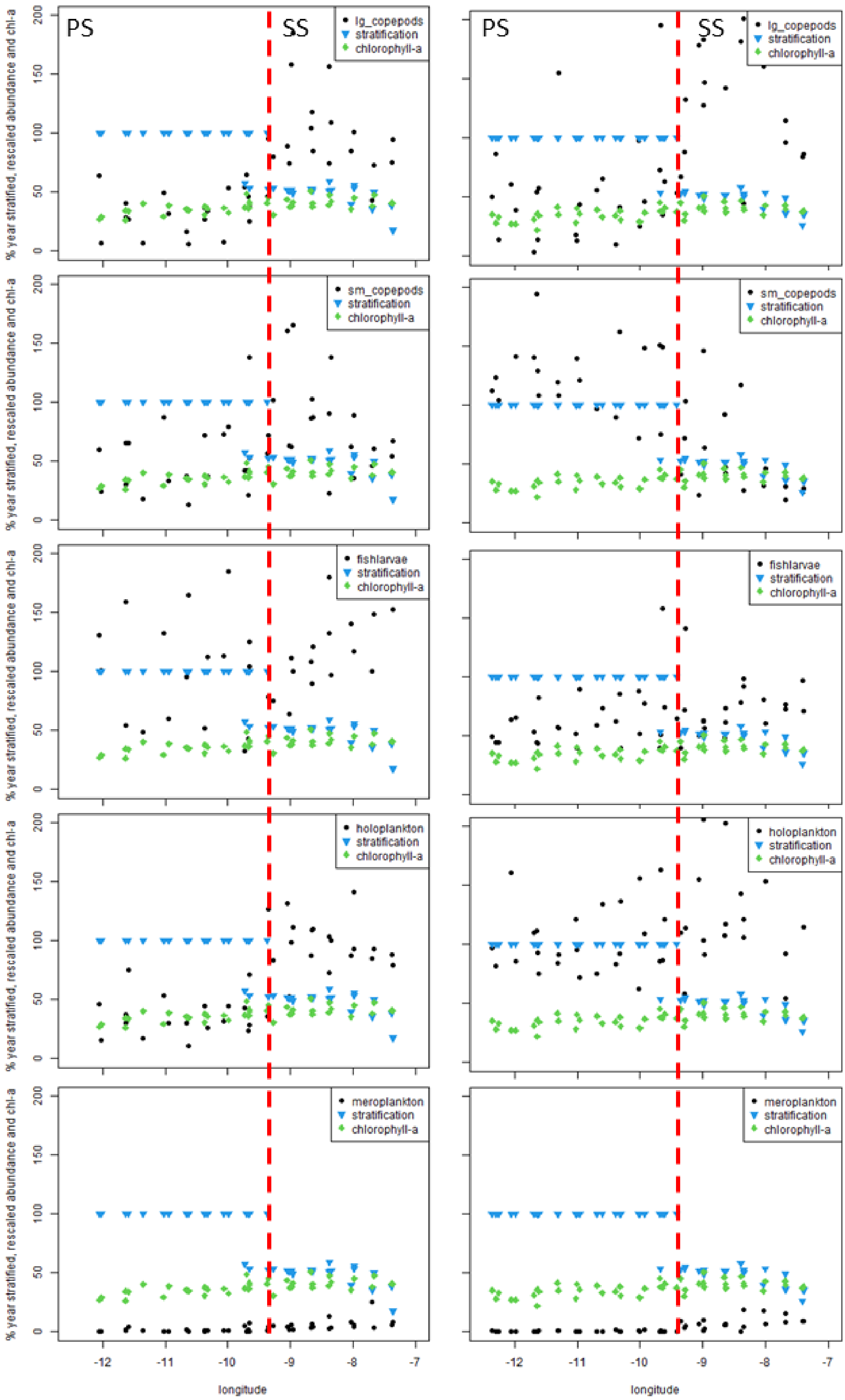



*Figure 2.17: Gradients in season mean abundance of zooplankton lifeforms (left: spring, right: summer), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient across the Atlantic margin, west of Ireland. The red dashed line indicates the location of the change in stratification regime. PS = permanently stratified, SS = seasonally or salinity stratified.*

### 2.2.5 Norwegian Trench

The transect from the Norwegian coast to the Orkney Islands crosses three different stratification regimes: from permanently stratified in the Norwegian Trench, through seasonally stratified waters in the northern North Sea to permanently mixed waters between the Orkney and Shetland Islands. Both transitions are visible in diatom abundance data: highest abundance is found in the permanently mixed waters in the west, intermediate abundance is found in the seasonally stratified waters and the lowest abundance is found in the permanently stratified waters in the Norwegian Trench. Chlorophyll-*a* concentrations do not show clearly different levels between the different stratification regimes. There is a slight increase at the front between permanently mixed and seasonally stratified waters. Dinoflagellates also have highest abundance in the permanently mixed waters, particularly in summer. There is no clear difference between the seasonally stratified waters in the North Sea and the Norwegian Trench. It is slightly lower in the permanently stratified Norwegian Trench. Large copepods show opposite spatial gradients from small copepods: large copepods are most abundant in the seasonally stratified waters whereas small copepods are most abundant in permanently stratified waters. There is no clear difference between the Norwegian Trench and the seasonally stratified North Sea. Fish larvae show strongly elevated abundance in the permanently stratified waters in spring, but not in summer. In summer fish larvae are most abundant in the seasonally stratified waters. Holoplankton and meroplankton do not show clear gradients in spring, but in summer their abundance is highest in the permanently mixed area between the Scottish islands.

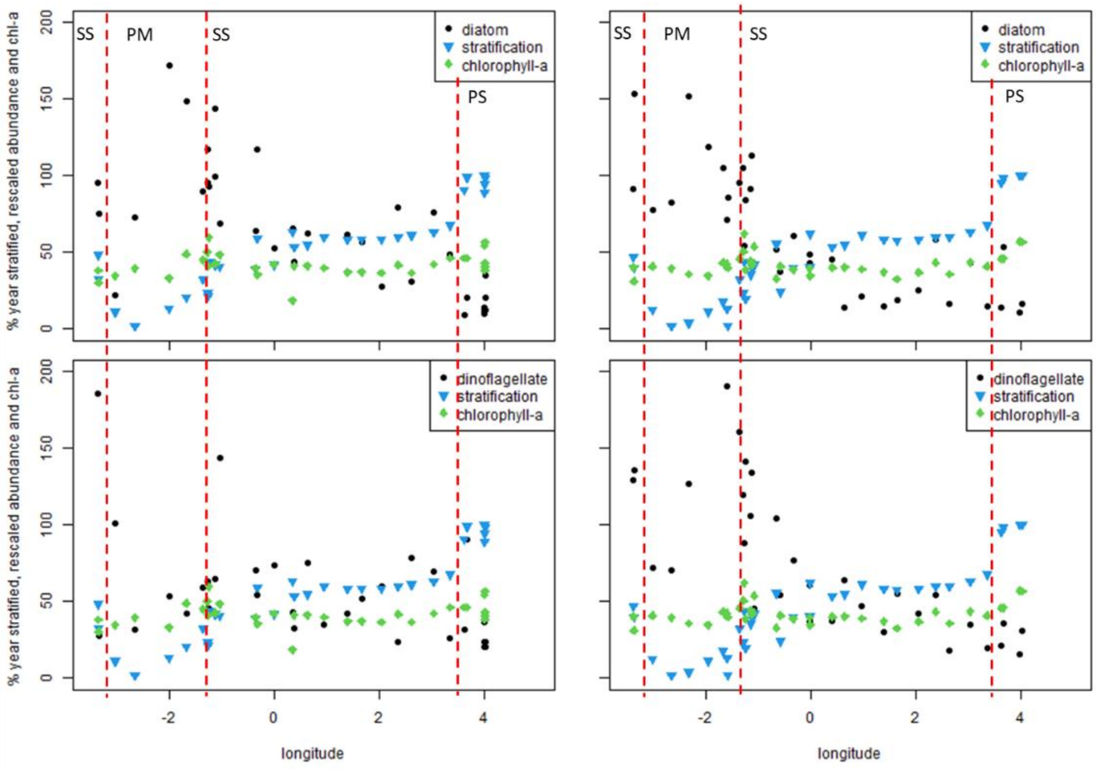



*Figure 2.18: Gradients in season mean diatom abundance (left: spring, right: summer) and dinoflagellate abundance (upper panels), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient across the Norwegian Trench and northern North Sea. The red dashed lines indicate the locations of the change in stratification regime. PM = permanently mixed, PS = permanently stratified, SS = seasonally or salinity stratified.*

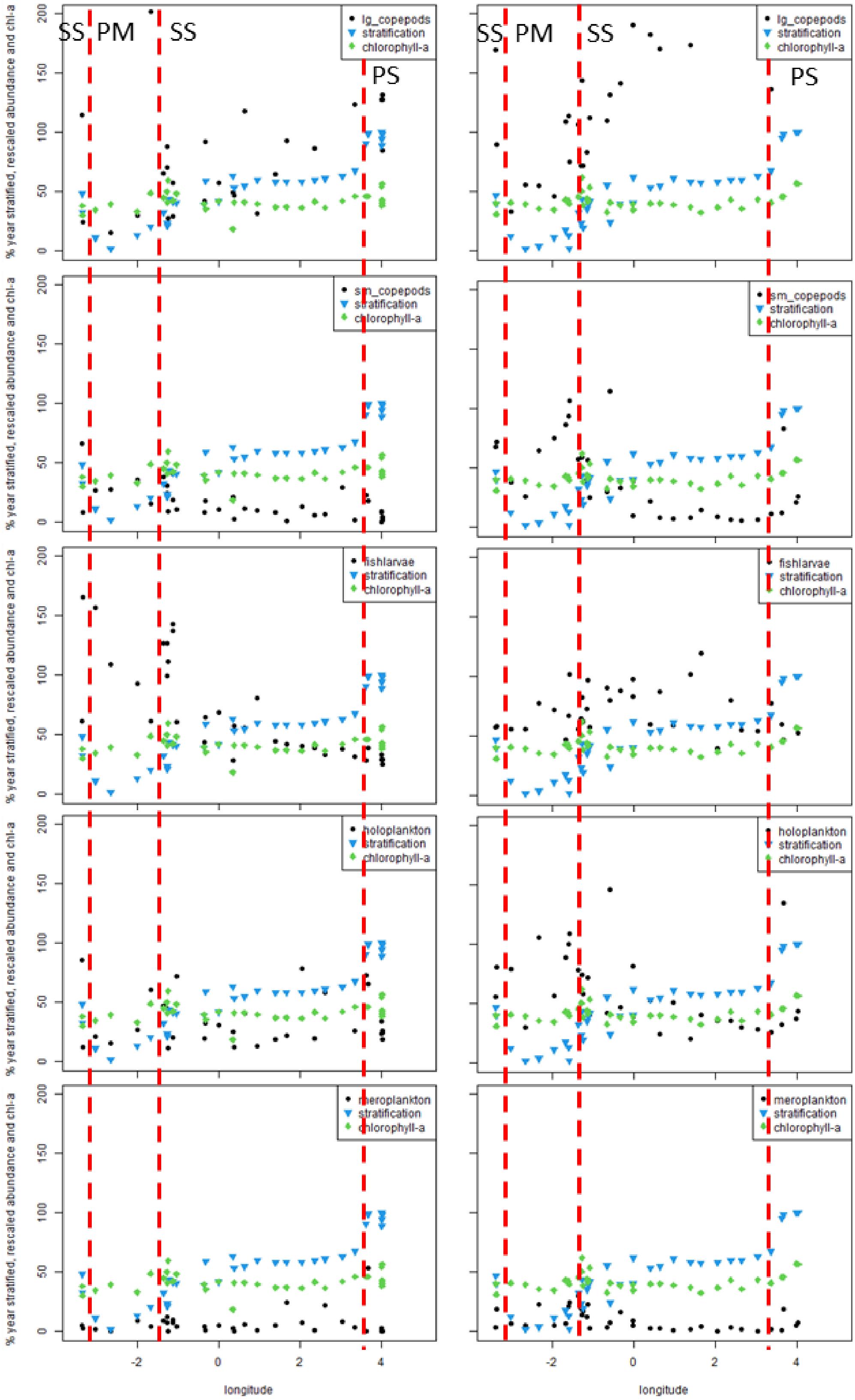



*Figure 2.19: Gradients in season mean abundance of zooplankton lifeforms (left: spring, right: summer), duration of stratification and rescaled growing season mean chlorophyll-a along the longitudinal gradient across the Norwegian Trench and northern North Sea. The red dashed lines indicate the locations of the change in stratification regime. PM = permanently mixed, PS = permanently stratified, SS = seasonally or salinity stratified.*

## 2.3 Summary

In summary, many plankton lifeforms in the CPR dataset show changes in abundance between different stratification regimes. But the patterns are not consistent between different areas. In the Channel and Celtic Sea, seasonally or salinity stratified areas tend to have higher plankton lifeform abundance than the permanently mixed areas. However, the permanently mixed waters between the Shetland and Orkney Islands show higher plankton abundance than nearby seasonally stratified waters. The transition between permanently stratified waters and seasonally stratified waters also does not show a consistent pattern. Along the Atlantic margin west of Ireland phytoplankton abundance is higher off the shelf than on shelf. For most zooplankton lifeforms the opposite pattern is shown across the Atlantic margin. Along the Norwegian Trench there is hardly any difference in plankton abundance between the permanently mixed waters of the Norwegian Trench and seasonally stratified waters further offshore. Only phytoplankton in spring shows lower abundance in the trench than beyond. Chlorophyll-*a* concentrations show hardly any changes between different stratification regimes, except for a slight increase at the transition front. It does show a strong increase close to the Irish and English coast on the west side of the Celtic Sea and southern North Sea respectively. This increase in chlorophyll-*a* is not associated to an increased abundance of phytoplankton lifeforms in the CPR dataset. Possibly, the chlorophyll-*a* content in the phytoplankton is increased in response to elevated turbidity in these areas.

*Table 2.1: Overview of elevated (red) and reduced (blue) abundance under different stratification regimes: permanently mixed (PM), seasonally or salinity stratified (SS) and permanently stratified (PS) for all categories of lifeforms.*

| Lifeform | Channel | Celtic | SNS | Atlantic | NorTrench |
|---|---|---|---|---|---|
| **diatoms** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **dinoflagellates** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **lg-copepods** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **sm-copepods** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **fish larvae** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **holoplankton** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **meroplankton** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |
| **chlorophyll-*a*** | PM SS | PM SS PM SS | PM SS | PS SS | SS PM SS PS |

# 3 Discussion

This study showed that plankton lifeform abundances are clearly affected by stratification regimes, which supports the use of the eutrophication assessment areas for the assessment of changes in plankton lifeform abundance (PH1/FW5) for the OSPAR QSR and MSFD reporting on biodiversity. This conclusion is further supported by Graves et al. (submitted), who found that trends in plankton index (PI) showed more consistent trends with the new COMP eutrophication assessment areas than in the previously used eco-hydrodynamic regions. We could not evaluate the suitability of the 32 psu salinity threshold for lifeform abundance, due to limited data resolution in the CPR dataset to detect gradients in such a narrow strip along the coast.

The spatial gradients in lifeform abundance, stratification, salinity and chlorophyll-*a* have now only been explored through visual inspection and interpretation of spatial patterns. The conclusions need further investigation, for example by adding a statistical test of the significance of differences across transitions in stratification regimes. Furthermore, the analysis of spatial gradients in primary production, mixed layer depth and turbidity would be valuable additions to this analysis and also the impact of the source of the stratification: temperature or salinity.

We did not yet consider possible effects of temporal trends in the CPR data. We used the data for the whole period of the dataset to have as many observations as possible and reduce noise due to undersampling. The PH1/FW5 QSR 2023 assessment showed that there are trends for several lifeforms in this dataset (Holland et al., 2023a, 2023b). It is still unclear to what extent this affects our analysis. The analysis could also be further refined by comparing lifeform abundance per season with chlorophyll-*a* and extent of stratification in the same season, rather than with growing season mean chlorophyll-*a* and percentage of the year stratified.

One would expect similar spatial patterns in separate phytoplankton lifeforms (diatoms and dinoflagellates) as in total phytoplankton biomass, approximated by chlorophyll-a. However, in our analysis changes in stratification did not show as gradients in growing season mean chlorophyll-*a* concentrations. Still, the current eutrophication assessment areas, along the lines of stratification duration, have been based on analysis of spatial patterns in chlorophyll-*a* data. This sounds contradictory. But the cluster analysis of the chlorophyll-*a* and primary production data was based on seasonal patterns rather than growing season mean concentration gradients. Abrupt changes in chlorophyll-*a* concentrations were not associated with transitions in stratification regime, but some abrupt changes suggested that other environmental variables, such as turbidity could be the cause. Chlorophyll-a to carbon ratios in phytoplankton are well-known to be affected by light climate, with increasing Chl-a/C ratios under reduced light availability (Geider, 1987; Cloern et al., 1995). Comparison with spatial gradients in turbidity could help to better understand these abrupt changes in chlorophyll-*a* concentrations that were not visible in phytoplankton abundance. Another explanation for the different gradients in chlorophyll-*a* and phytoplankton abundance in the CPR dataset could be that the CPR data collection misses the smallest phytoplankton cells that pass through the silk. These nanoflagellates often make up a large part of the phytoplankton, particularly offshore. This can also possibly partly explain the strong effects of stratification on plankton lifeform abundance. Vertical mixing and settling through a pycnocline is likely to affect the size distribution of plankton observed by the CPR.

The model results on stratification have been validated in some but not all areas analysed in this study. A more thorough validation of stratification duration could further improve the confidence in the outcomes of this study.

# 4 Conclusions

## 4.1 Applicability of eutrophication assessment areas for PH1/FW5 indicator

This study showed that the abundance of many plankton lifeforms in the CPR dataset is more strongly affected by stratification regimes than to chlorophyll-*a* concentrations. Since the level of stratification has been a key variable in the definition of the COMP4 assessment areas for eutrophication this suggests that these assessment areas are also appropriate for the assessment of changes in plankton lifeform abundances.

Interestingly, the strong changes in phytoplankton abundance at changes in stratification regime were not reflected in strong changes in chlorophyll-*a* concentrations in satellite data. These different spatial patterns between phytoplankton abundance suggest that phytoplankton abundance data provide an added value to chlorophyll-*a* data. Chlorophyll-*a* as proxy from phytoplankton lifeform abundance is affected not only by phytoplankton abundance but also by the chlorophyll-*a* content per cell, which is in turn affected by local environmental conditions. However, further investigation of the observed patterns and their significance is required before drawing firm conclusions on the limitations of chlorophyll-a as assessment indicator.

## 4.2 Options for optimisation of plankton biodiversity assessment areas

For the definition of assessment areas for eutrophication the focus has been on coastal waters that receive land-based inputs of nutrients through river inflows. Not much attention has been given to detailing different environments in the Atlantic Ocean. The biodiversity assessments are more focused on offshore and oceanic waters than the eutrophication assessments. For these assessments a more detailed subdivision of Atlantic waters can be considered. For example, differences between seasonally stratified areas and permanently mixed areas can be included around islands and relatively shallow areas such as the Faroe Islands and Rockall plateau. For eutrophication these areas are not very relevant, but for biodiversity these are distinctly different areas from the surrounding deep ocean.

# Acknowledgements

This study could not have been performed without the Continuous Plankton Recorder dataset of the Marine Biological Association. We thank Matthew Holland (University of Plymouth) for pre-processing these data and classification into plankton lifeforms and providing the aggregated data to us for this analysis. The hydrodynamic model has been developed and validated by my colleagues Firmijn Zijl, Julien Groenenboom and Stendert van der Laan. The data have been pre-processed for this analysis by Lauriane Vilmin. The satellite data for chlorophyll-a have been provided by RBINS through OSPAR for the QSR report.

We also thank Rijkswaterstaat and the NEA PANACEA project for providing the funding for this study. The NEA PANACEA project was funded under agreement No. 110661/2020/839628/SUB/ENV.C.2 by the European Commision DG-ENV as part of the research programme "DG ENV/MSFD 2020": Marine Strategy Framework Directive: support to the preparation of the next 6-year cycle of implementation.

*MSFD 2020 call*

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
ENVIRONMENT
Directorate C - Quality of Life
**ENV.C.2 – Marine Environment & Water Industry**

CALL FOR PROPOSALS "DG ENV/MSFD 2020"

*MARINE STRATEGY FRAMEWORK DIRECTIVE: SUPPORT TO THE PREPARATION OF THE NEXT 6-YEAR CYCLE OF IMPLEMENTATION*

Co-funded by the European Maritime and Fisheries Fund

# References


Blauw, A., Eleveld, M., Prins, T., Zijl, F., Groenenboom, J., Winter, G., Kramer, L., Troost, T., Bartosova, Alena Johansson, J., Capell, R., Eiola, K., Höglund, A., Tilstone, G., Land, P. E., Martinez-Vicente, V., Pardo, S. and van der Zande, D., 2019. Coherence in assessment framework of chlorophyll a and nutrients as part of the EUproject ‘Joint monitoring programme of the eutrophication of the North Sea with satellite data’ (Ref: ), DG ENV/MSFD Second Cycle/2016. Available at: https://www.informatiehuismarien.nl/uk/projects/algae-evaluated-from/information/results/.

Cloern, J. E., Grenz, C., & Vidergar-Lucas, L., 1995. An empirical model of the phytoplankton chlorophyll: carbon ratio-the conversion factor between productivity and growth rate. Limnology and Oceanography, 40(7), 1313-1321.

Enserink, L., Blauw, A., van der Zande, D. and Markager, S., 2019. Summary report of the EU project ‘Joint monitoring programme of the eutrophication of the North Sea with satellite data’ (Ref: DG ENV/MSFD Second Cycle/2016).

Geider, R. J.,1987. Light and temperature dependence of the carbon to chlorophyll a ratio in microalgae and cyanobacteria: implications for physiology and growth of phytoplankton. New Phytologist, 1-34.

Graves, C.A., Best, M., Atkinson, A., Bear, B., Bresnan, E., et al., submitted to DDIPA. At what scale should we assess the health of pelagic habitats? Trade-offs between small-scale manageable pressures and the need for regional upscaling.

Holland, M., McQuatters-Gollop, A., Louchart, A., Artigas, L. F, 2023a. Change in Phytoplankton and Zooplankton Communities. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London.

Holland, M., Louchart, A., Artigas, L.F., Ostle, C., Atkinson, A., … & Mcquatters-Gollop, A., 2023b. Major declines in NE Atlantic plankton contrast with more stable populations in the rapidly warming North Sea, submitted to Science of the Total Environment.

McQuatters-Gollop, A., Atkinson, A., Aubert, A., Bedford, J., Best, M., Bresnan, E., ... & Tett, P., 2019. Plankton lifeforms as a biodiversity indicator for regional-scale assessment of pelagic habitats for policy. *Ecological Indicators*, *101*, 913-925.

OSPAR, 2022. Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area. OSPAR Agreement 2022-07. https://www.ospar.org/documents?v=49366

Richardson, A. J., Walne, A. W., John, A. W. G., Jonas, T. D., Lindley, J. A., Sims, D. W., ... & Witt, M., 2006. Using continuous plankton recorder data. Progress in Oceanography, 68(1), 27-74.

van Leeuwen, S., Tett, P., Mills, D. and van der Molen, J., 2015. ‘Stratified and nonstratified areas in the North Sea: Long-term variability and biological and policy implications’, Journal of Geophysical Research: Oceans, 120, pp. 1–17. doi: 10.1002/ 2014JC010485.

Van Leeuwen, S. M., Lenhart, H. J., Prins, T. C., Blauw, A., Desmit, X., Fernand, L., ... & Vilmin, L., 2023. Deriving pre-eutrophic conditions from an ensemble model approach for the North-West European seas. Frontiers in Marine Science, 10.

Deltares is an independent institute for applied research in the field of water and subsurface. Throughout the world, we work on smart solutions for people, environment and society.

Deltares