Changing *Pseudo-nitzschia* and *Dinophysis* distribution in the NE-Atlantic and their suitability as proxies for diatom and dinoflagellate abundance – interim report

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Executive summary

As an extension of the NC34 Pelagic Project (PEL-CAP) of Defra’s Marine Natural Capital and Ecosystem Assessment (mNCEA) programme, the UK Pelagic Habitats Expert Group (PHEG) has committed to quantifiying changes in the distribution and abundance of the diatom genus, *Pseudo-nitzschia,* and the dinoflagellate genus, *Dinophysis,* and their suitability as proxies to identify changes occurring in pelagic habitats biodiversity indicators. This study investigates the potential of using monitoring data of the toxic phytoplankton genera *Pseudo-nitzschia* and *Dinophysis* as proxies for broader diatom and dinoflagellate communities, respectively, for statutory biodiversity assessments. While these genera are routinely monitored in shellfish growing waters due to their production of toxins and associated risks to human health, it is unclear whether the data generated is useful for statutory biodiversity assessments to support OSPAR and UK Marine Strategy. Using long-term data (1958-2021) from three sources – Plymouth Marine Laboratory’s L4 station, the Scottish Government’s Stonehaven station, and the Continuous Plankton Recorder (CPR) survey – we examined temporal and spatial distribution patterns in the abundance of these genera. We assessed their proxy power by comparing their abundance to that of other diatoms and dinoflagellates, analysing seasonal correlations, mean annual cycles, and timing of the annual abundance peaks. Additionally, we compared station data with adjacent CPR data to evaluate their comparability. Finally, we analysed long-term abundance trends at the two stations and examined long-term changes in the seasonality and spatial distribution of *Pseudo-nitzschia* and *Dinophysis*

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using CPR data. Our results reveal limited correlation between *Pseudo-nitzschia*/*Dinophysis* and other diatoms/dinoflagellates, suggesting their limited utility as proxies of their genera. Furthermore, station and CPR data showed poor agreement. Spatially, *Pseudo-nitzschia* exhibited dynamic seasonal distribution patterns, with notable increases in the North Sea since 2000. *Dinophysis* distribution was less variable, with decreased coastal abundance in recent decades. These findings highlight the challenges of using limited species data for broader biodiversity assessments and emphasise the need for comprehensive phytoplankton monitoring.

Key messages

These findings highlight the challenges of using limited species data for broader biodiversity assessments and emphasise the need for comprehensive phytoplankton monitoring. Our key recommendations to arise from this study are:

1. **Limited proxy potential:** *Pseudo-nitzschia* and *Dinophysis* are not reliable proxies for broader diatom and dinoflagellate abundance, respectively. While some seasonal and localised correlations exist, they are inconsistent and weak overall. This invalidates the assumption that monitoring these two genera alone (e.g., through Food Standards Agency monitoring) is sufficient for assessing wider phytoplankton biodiversity.
2. **Species-specific dynamics:** The study highlights the distinct dynamics of individual species within *Pseudo-nitzschia* (e.g., *P. delicatissima, P. seriata*), emphasising the need for species-level identification in monitoring programs. Changes in the distribution of one species may not reflect changes in others.
3. **Spatial and temporal variability:** Both *Pseudo-nitzschia* and *Dinophysis* distributions exhibit significant spatial and temporal variability, highlighting the need for comprehensive and long-term monitoring across regions and seasons.
4. **North Sea changes:** A notable increase in springtime *Pseudo-nitzschia* abundance has been observed in the southern North Sea since 2000, suggesting potential changes in environmental conditions and warranting further investigation.
5. **Coastal *Dinophysis* decline:** Declines in *Dinophysis* abundance around Orkney and Shetland in spring and off the northeast coast of England in summer have been observed in recent decades, the causes of which are unknown and warrant further research.
6. **Data source discrepancies:** Significant discrepancies exist between station-based and CPR data for both genera, likely due to differences in sampling methods and gear. This highlights the importance of considering these biases when interpreting data from different sources.

Introduction

Pseudo-nitzschia and *Dinophysis* are both common phytoplankton and are two of the most likely culprits in European waters for causing detrimental impacts on human health and environment due to the toxins they naturally produce. *Pseudo-nitzschia* is routinely detected in the waters around the British Isles. Species within this genus are potent producers of the neurotoxin Domoic Acid (DA). Similarly, the dinoflagellate genus, *Dinophysis*, occupies the same waters and can cause diarrhetic shellfish poisoning (DSP) in humans due to its production of okadaic acid (OA), dinophysistoxins (DTXs), pectenotoxins (PTXs).

In recent decades there has been evidence that distributions of these two genera are shifting due to climate change, and it is important to understand these changes so we can better understand the relative risks associated with shellfish consumption in waters where they are present. The risk to humans posed by the toxins they produce is the reason why these taxa are both monitored frequently in areas where shellfish aquaculture is prevalent. These groups are monitored in order to detect when they exceed important thresholds so we can enact harvest closures to protect human health and prevent incidents.

Monitoring for *Pseudo-nitzschia* and *Dinophysis* has generated decades-long time-series of their abundance in shellfish waters, creating a potentially useful dataset to repurpose for understanding changes in pelagic habitats biodiversity. In many areas where this *Pseudo-nitzschia* and *Dinophysis* monitoring occurs, long term phytoplankton time-series needed for statutory assessment of the marine environment are scarce or unavailable. However, it is possible that *Pseudo-nitzschia* and *Dinophysis* could serve as proxies for the wider diatom and dinoflagellate communities, respectively, making this monitoring data useful for statutory biodiversity assessments.

Using *Pseudo-nitzschia* and *Dinophysis* as proxies for diatoms and dinoflagellates, respectively, was already trialled for the OSPAR QSR2023 (OSPAR, 2023). The Portuguese Institute for Sea and Atmosphere (IPMA) only monitors for these two genera and does not monitor for any other phytoplankton groups, however, this application was never validated for how abundances of these genera covary with the wider plankton lifeforms they were expected to represent.

In light of this, our aims were to determine how *Pseudo-nitzschia* and *Dinophysis* distribution have changed through time, and whether their monitoring data can be used as representative proxies for diatoms and dinoflagellates, respectively, to facilitate statutory biodiversity assessment of the marine environment.

Methods

Monitoring data

Phytoplankton abundance data were obtained from three sources (**Figure 1**):

1. Plymouth Marine Laboratory (PML) phytoplankton monitoring data for the L4 station in the English Channel (1992-2021)
2. Marine Directorate of the Scottish Government (SCobs) phytoplankton monitoring data for the Stonehaven monitoring station on the east coast of Scotland (2000-2021)
3. Marine Biological Association (MBA) Continuous Plankton Recorder (CPR) data for the North-east Atlantic (1958-2021) (Bounding box: W=-18°, S=32°, E=14°, N=66°)

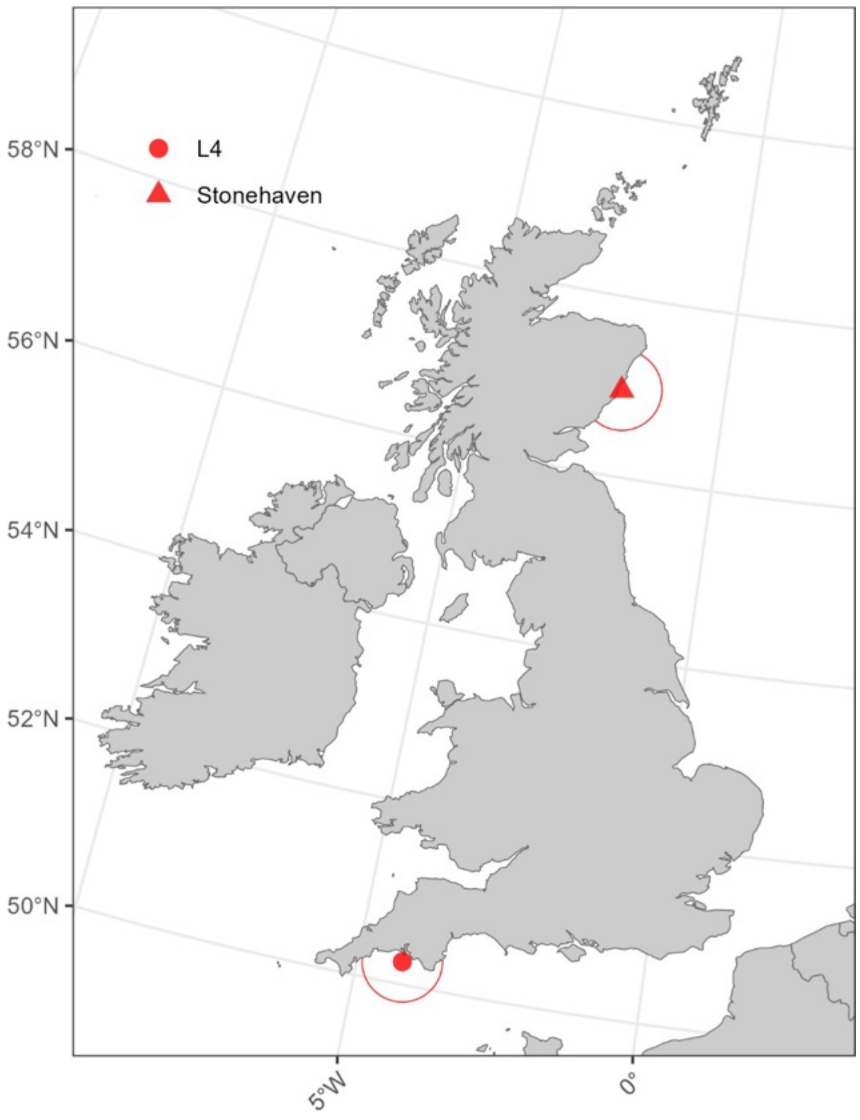

Figure 1. Locations for the L4 and Stonehaven monitoring stations. The buffer around each station represents the 50 km radius which was used to extract intersecting data from the CPR for comparison with station data.

These datasets consisted of two main types, fixed-point station data (L4 and Stonehaven) and spatially distributed transect data (CPR). Fixed-point data for the L4 and Stonehaven monitoring stations are collected with high temporal frequency (i.e. weekly or bi-weekly) via discrete water bottle (L4) or 10m integrated tube sampling (Stonehaven) (Bresnan et al., 2016). Transect data were obtained from the Continuous Plankton Recorder (CPR) Survey, a spatially extensive open water survey which represents the longest running, most geographically extensive marine ecological dataset in the world (Richardson et al., 2006). CPR data are collected in transect at a broad spatial scale using ships-of-opportunity at a mean depth of 10m. CPR data are collected offshore and in the open ocean and are best analysed at a monthly time scale (Richardson et al., 2006).

These two data types are complementary, each revealing different aspects of variability across the plankton community. Transect data can be particularly useful for examining the direction and magnitude of changes occurring across large offshore pelagic habitats, revealing spatial patterns of change (Bedford et al., 2020). Additionally, fixed-point, full depth time-series stations provide complementary information at a higher sampling frequency on a larger fraction of the plankton size spectrum and in the more nearshore habitats that are particularly valuable for studying anthropogenic pressures such as eutrophication (McQuatters-Gollop et al., 2019) and pollution (Serranito et al., 2016).

Spatial and temporal scale for aggregation

To use datasets from multiple sources effectively, procedures were implemented to ensure the comparability of results. Datasets were not combined due to differences in sampling, analysis, and enumeration methods. Instead, all datasets were analysed separately, using an identical set of methods. To ensure datasets were comparable, CPR abundance values were transformed to units of cells litre^{-1} by dividing abundance by 3000, since an average CPR sample filters 3 m^{3} of seawater (Richardson et al., 2006).

All data analysis for this study was conducted using R-programming language (R Core Team, 2020). To calculate total *Pseudo-nitzschia* abundance for each plankton sample from the PML L4 station data, we summed the abundances of the three counted groups belonging to the genus, *P. delicatissima*, *P. pungens* and *P. seriata* (

Table 1). For Stonehaven data, *Pseudo-nitzschia* cells were counted as a single category without speciation, so no summing was necessary. For the CPR data, we summed the abundance of *P. delicatissima* and *P. seriata* only. The CPR group, *Nitzschia*/*Pseudo-nitzschia* spp. (unidentified), was excluded from the analysis, due to uncertainty in the genus classification for this group.

Table 1. List of species counted as *Pseudo-nitzschia* and *Dinophysis* for each of the three plankton monitoring programmes used in this analysis.

***Pseudo-nitzschia* categories counted**					
L4		**Stonehaven**		**CPR**	
Aphia ID	**Taxon**	**Aphia ID**	**Taxon**	**Aphia ID**	**Taxon**
149153	*Pseudo-nitzschia delicatissima*	149151	*Pseudo-nitzschia*	149153	*Pseudo-nitzschia delicatissima*
160528	*Pseudo-nitzschia pungens*			149152	Pseudo-nitzschia seriata
149152	*Pseudo-nitzschia seriata*				

***Dinophysis* categories counted**					
L4		**Stonehaven**		**CPR**	
Aphia ID	**Taxon**	**Aphia ID**	**Taxon**	**Aphia ID**	**Taxon**
109462	*Dinophysis*	109462	*Dinophysis*	109462	*Dinophysis*
109603	*Dinophysis acuminata*	109603	*Dinophysis acuminata*		
109604	*Dinophysis acuta*	109604	*Dinophysis acuta*		
232496	*Dinophysis nasuta*	232155	*Dinophysis borealis*		
232261	*Dinophysis sacculus*	109612	*Dinophysis caudata*		
109662	*Dinophysis tripos*	109616	*Dinophysis dens*		
		109624	*Dinophysis fortii*		
		109627	*Dinophysis hastata*		
		232496	*Dinophysis nasuta*		
		109637	*Dinophysis norvegica*		
		109638	*Dinophysis odiosa*		
		646201	*Dinophysis ovum*		
		109649	*Dinophysis pulchella*		
		109651	*Dinophysis punctata*		
		162793	*Dinophysis rotundata*		
		232261	*Dinophysis sacculus*		
		109659	*Dinophysis skagii*		

	109662 *Dinophysis tripos*	

To calculate total *Dinophysis* abundance for each plankton sample from the PML L4 station data, we summed the abundances of five counted species, as well as unspeciated *Dinophysis* (**Table 1**), while for Stonehaven data *Dinophysis* abundance was summed from 17 taxa and unspeciated *Dinophysis*. For the CPR data, *Dinophysis* cells were only counted as a single category without speciation, so no summing was necessary.

To support the analysis of *Pseudo-nitzschia* and *Dinophysis'* performance as proxies to represent variation across the wider diatom and dinoflagellate communities, respectively, we also calculated per sample total diatom and dinoflagellate abundance, using the Pelagic Habitats Expert Group Masterlist of plankton trait information (available from https://www.dassh.ac.uk/lifeforms/; Ostle et al., 2021), to identify matching records by WoRMS Aphia ID. Per sample total *Pseudo-nitzschia* and *Dinophysis* abundance were then subtracted from total diatom and total dinoflagellate abundance, respectively, in order to ensure these groups remained independent.

To support the comparison of station data with CPR data, station and CPR sample coordinates were projected to the ETRS89-extended / LAEA Europe planar coordinate system and a 50 km radius buffer was generated around each of the two stations. The two buffers were intersected with CPR sample coordinates to extract all CPR samples falling within each radius (**Figure 1**).

Station data and CPR samples intersecting each buffer were then aggregated by month to generate monthly time-series for *Pseudo-nitzschia* and *Dinophysis,* for station and adjacent CPR data to generate four data subsets (i.e. Station data: PML data at L4, SCObs data at Stonehaven; CPR data: CPR data around L4, CPR data around Stonehaven).

Proxy power to represent the wider phytoplankton community

To assess the proxy power of *Pseudo-nitzschia* and *Dinophysis* to represent changes occurring across the whole diatom and dinoflagellate communities, and to assess how this proxy power varies regionally and seasonally, we divided the L4 and Stonehaven station data into four seasons (Spring: March to May, Summer: June to August, Autumn: September to November and Winter: December to February) and conducted Pearson correlation tests on the relationship between "total *Pseudo-nitzschia"* and "other diatoms" abundance and between "total *Dinophysis*" and "other dinoflagellate" abundance for each subset. The same four seasonal grouping of months was applied for all seasonal analysis described in this study.

We subsequently assessed the full monthly abundance time-series for each group and calculated the mean annual abundance cycle for the four data subsets across a shared time period (1992-2021). Finally, we used linear regression to assess synchronisation in the seasonality of peak abundance by comparing the month (1-12) when peak abundance occurred for each year to assess how well annual cycles in *Pseudo-nitzschia* and *Dinophysis* abundance reflect annual cycles of the overall diatom and dinoflagellate communities.

Comparison of station and CPR data

To assess to what degree station monitoring data were comparable with CPR data from adjacent waters, we conducted a similar comparison to what was used to assess the proxy power of these groups in the previous example. Seasonal subsets of *Pseudo-nitzschia* and *Dinophysis* abundance were extracted for the same four seasons we used to assess proxy power, and Pearson correlation tests were conducted on each subset to assess the degree of correlation in abundance between station and CPR data at the two locations. We also examined differences in the mean annual abundance cycle for these two groups at the two stations.

Trend analysis of station time-series

To examine and compare long-term abundance trends in *Pseudo-nitzschia* and *Dinophysis* with those of the other diatoms and dinoflagellates, we applied the Kendall trend test separately for each station time-series. Prior to calculating trends, annual mean abundance values were calculated to smooth out the seasonal variation typical of plankton time-series. The Kendall trend test generates a statistic which is derived by comparing each value in a time-series with preceding values. If a latter value is greater than a previous value, the pairwise comparison is assigned 1. If it is lower, it is assigned -1, with 0 when values are identical. Kendall's S-statistic is the sum of the pairwise comparisons for the time-series is. The variance in the S-statistic is used to derive a Z-score with an approximately normal distribution; thus, confidence in this statistic can be assessed with an associated p-value. The sign of the test statistic reveals the direction of the trend and the magnitude is proportional to the consistency in the trend, ranging between -1 and 1. A benefit of this nonparametric test is that it yields identical results irrespective of the data transformation method and is not sensitive to either gaps in data or to non-linear or irregular trends.

Examining changes in distribution

To calculate changes in the distribution of *Pseudo-nitzschia* and *Dinophysis* through time, we used CPR data exclusively due to its broad offshore distribution. For *Pseudo-nitzschia*, CPR samples were aggregated by summing the abundance of *P. delicatissima* and *P. seriata* to derive total *Pseudo-nitzschia* abundance. Separate distribution maps were also generated for *P. delicatissima* and *P. seriata* in order to understand how variation in the distribution of the genus is influenced by variation in these two species.

For *Dinophysis,* the aggregation to genus level step was unnecessary since *Dinophysis* is only counted at genus level in the CPR dataset. Similarly, it was not possible to study how *Dinophysis* species contributed to the overall distribution of the genus. Samples were intersected with a 1° × 1° square grid to calculate monthly mean abundance values for each grid cell and regularise the data across the grid. Abundance values were then $\log_{10}(x + 1)$ transformed and interpolated across the grid using inverse distance weighted interpolation, following methods described in Edwards et al. (2021), with a maximum search radius of 250 km, and a minimum number of neighbours of 3. Finally, to fill additional gaps in the time-series all gaps of 3 months or less were filled via linear interpolation independently for each grid cell (Bedford et al., 2020; Holland et al., 2024; Holland et al., 2023).

To assess the performance and reliability of the interpolation results, we plotted interpolated values against regularised values and conducted linear regression to assess how the comparison varied from the expected 1:1 relationship.

From the interpolated gridded abundance data, maps displaying mean patterns of *Pseudo-nitzschia* and *Dinophysis* distribution were generated for spring, summer, autumn and winter so that changes in distribution could be studied through time.

Results

Proxy power to represent the wider phytoplankton community

Correlation analysis revealed that total *Pseudo-nitzschia* abundance is not a very informative indicator of the variation in abundance occurring across the rest of the diatom community (**Figure 2**). The proxy power for the ability of *Pseudo-nitzschia* to represent the rest of the diatom community for a particular region appeared to vary by season, with strongest correlation occurring in spring and autumn, with less correlation in summer and much lower in winter. Similarly, a low degree of correlation was observed between *Dinophysis* cell abundance, with that of the rest of the dinoflagellate community. For both L4 and Stonehaven, correlation was particularly low in winter, largely influenced by zero-counts for *Dinophysis* while low numbers of other dinoflagellate cells were present. Significant positive correlation was only observed in spring and autumn at L4, and in spring and summer at Stonehaven.

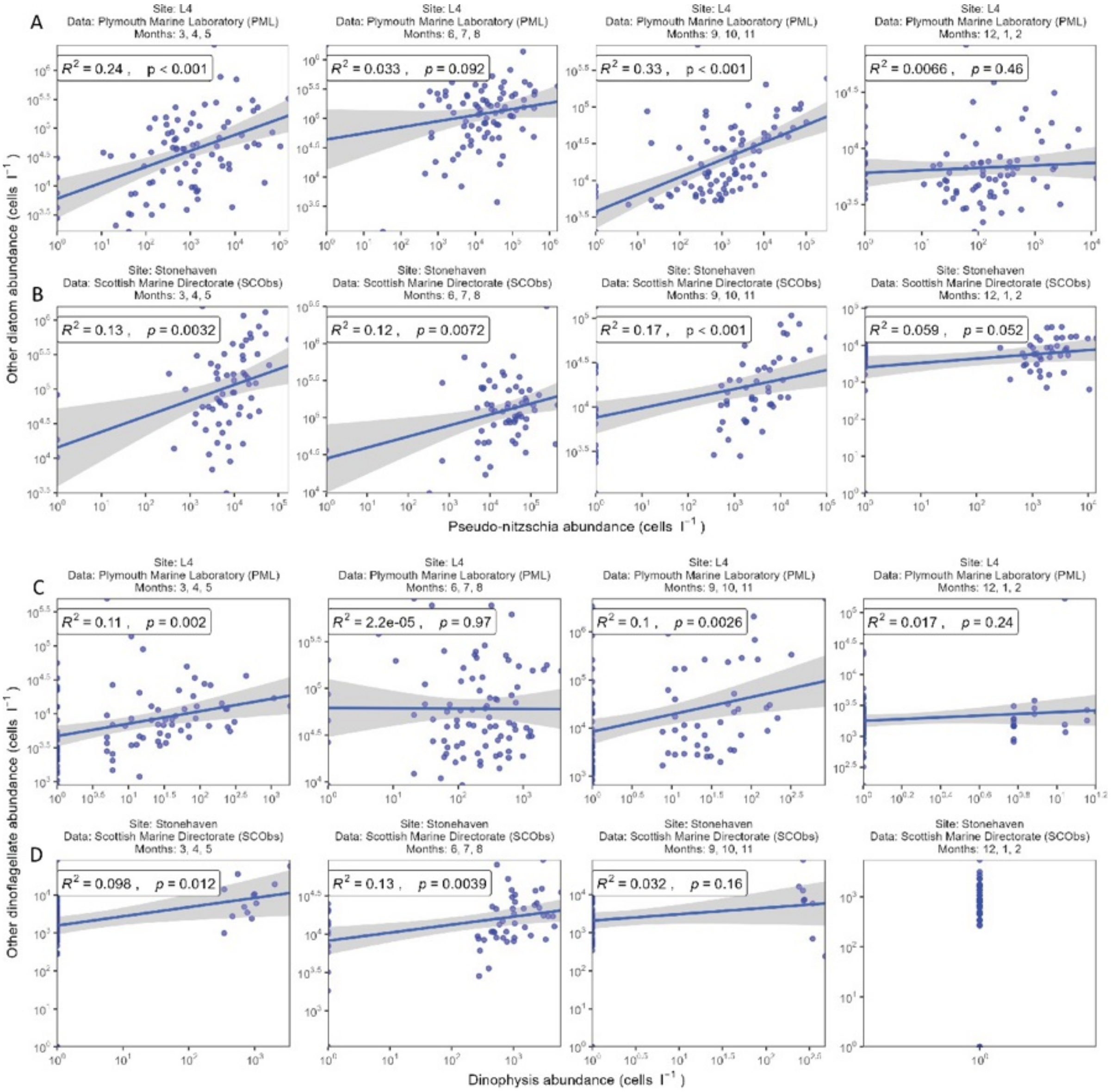

Figure 2. Seasonal correlation analysis of total *Pseudo-nitzschia* abundance with the abundance of all other diatom cells at sites L4 (A) and Stonehaven (B), and for total *Dinophysis* abundance with the abundance of all other dinoflagellate cells at sites L4 (C) and Stonehaven (D). Each subplot displays the R^2 and p-values for the data subset, indicating how closely the abundance of the proxy represents the abundance of the broader taxonomic group.

A comparison of the mean annual abundance cycle for *Pseudo-nitzschia* and other diatoms demonstrated a high degree of similarity in the timing of the annual peak (**Figure 3A, B**). At both stations, mean abundance of *Pseudo-nitzschia* and other diatoms peaked in June. The period of high abundance for other diatoms spanned roughly from March to October, whereas the main peak in *Pseudo-nitzschia* abundance lasted for a shorter period, from May to September. At both sites the annual abundance cycle for *Pseudo-nitzschia* demonstrated two peaks per year, with the first peak occurring between April and June and the second peak between June and September. Both *Dinophysis* and other dinoflagellates demonstrated only one peak in their mean annual cycles (**Figure 3C, D**). *Dinophysis* and other dinoflagellates showed differences in the timing of peak abundance within the mean annual cycle. At site L4, *Dinophysis* peaked in July, while other dinoflagellates peaked in September. At Stonehaven, *Dinophysis* peaked in June, while other dinoflagellates peaked in July.

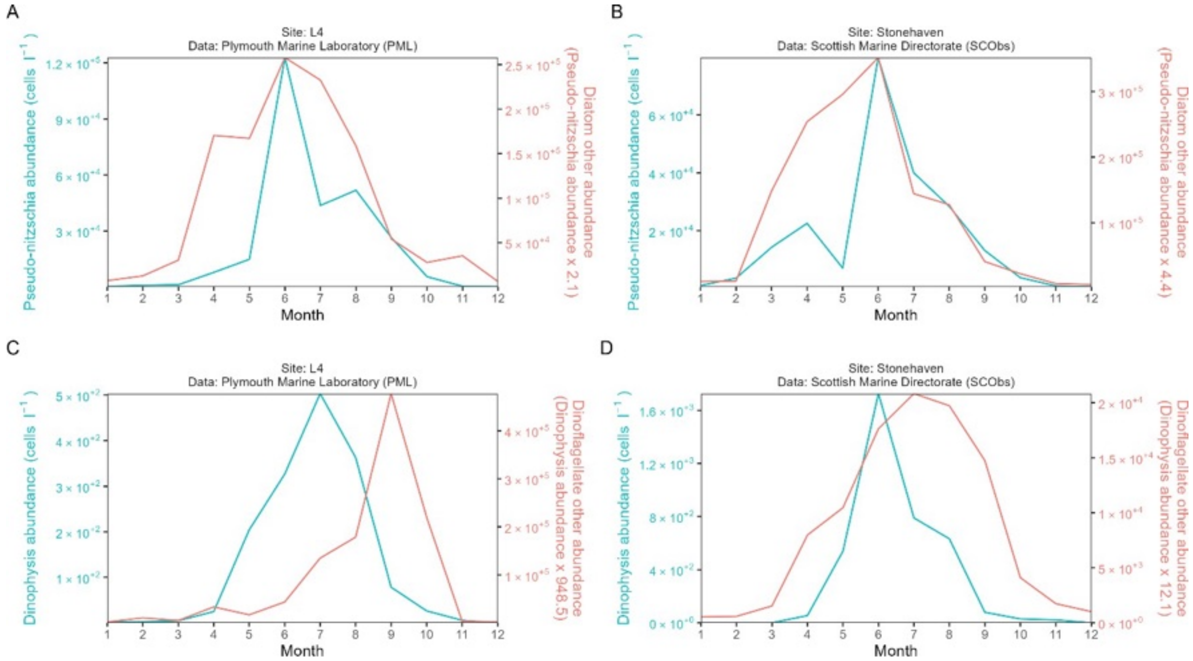

Figure 3. The mean annual cycle of *Pseudo-nitzschia* (green) and other diatom (red) abundance for station L4 (A) and Stonehaven (B), as well as the mean annual cycle of *Dinophysis* (green) and other dinoflagellate (red) abundance for station L4 (C) and Stonehaven (D). Note that the second y-axis on all plots has been transformed to allow for both time-series to be resolved on the same plots.

The regression analysis comparing the timing of annual peaks in *Pseudo-nitzschia* and other diatoms abundance indicated some similarity in timing, although the comparison was only statistically significant for station data at Stonehaven and CPR data at L4 (**Figure 4**). For *Dinophysis* and other dinoflagellates, there were no statistically significant pairings, indicating high variability in the timing of annual peaks in abundance. In all cases, regression coefficients were below 1, indicating tendency for *Pseudo-nitzschia* and *Dinophysis* to peak in abundance earlier than diatoms and dinoflagellates, respectively.

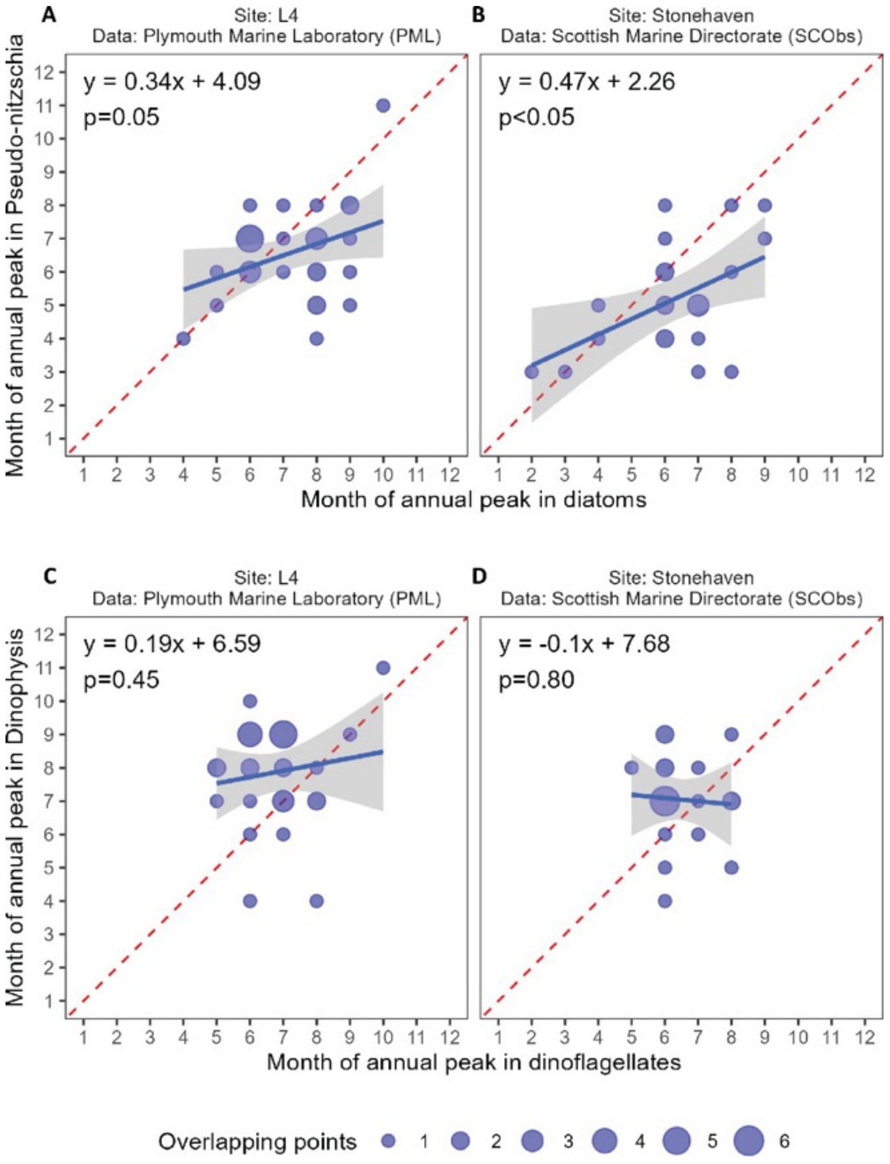

Figure 4. Comparison of the month of the year when the annual peak in abundance occurred for *Pseudo-nitzschia* and other diatom cells at sites L4 (A) and Stonehaven (B), and for *Dinophysis* and other dinoflagellate cells at sites L4 (C) and Stonehaven (D). The 1:1 trendline (dashed red line) represents a hypothetical example of perfect correlation between the two groups. R^2 and p-value for each data subset indicate Pearson correlation test results. For each data subset, a linear trendline (blue line) is indicated, along with its standard error (grey band). The size of each point is proportional to the number of overlapping points.

The proportion of total diatom abundance contributed by *Pseudo-nitzschia* varied throughout the annual cycle (**Figure 5**). At L4, *Pseudo-nitzschia*'s abundance, relative to the rest of the diatom community, was 12% on average and peaked throughout the summer, between June and September, during which time it comprised on average 22% of all diatoms present in samples. At Stonehaven the relative abundance of *Pseudo-nitzschia* was on average 16% and peaked in February at 24% with a second peak in July at 26% of total diatom abundance. *Dinophysis* made up a much smaller proportion of the dinoflagellate community, on average 0.4% at L4 and 2.5% at Stonehaven. At L4, the proportion of dinoflagellates belonging to *Dinophysis* peaked at 1.5% in May, while at Stonehaven they peaked in June at 9.5%.

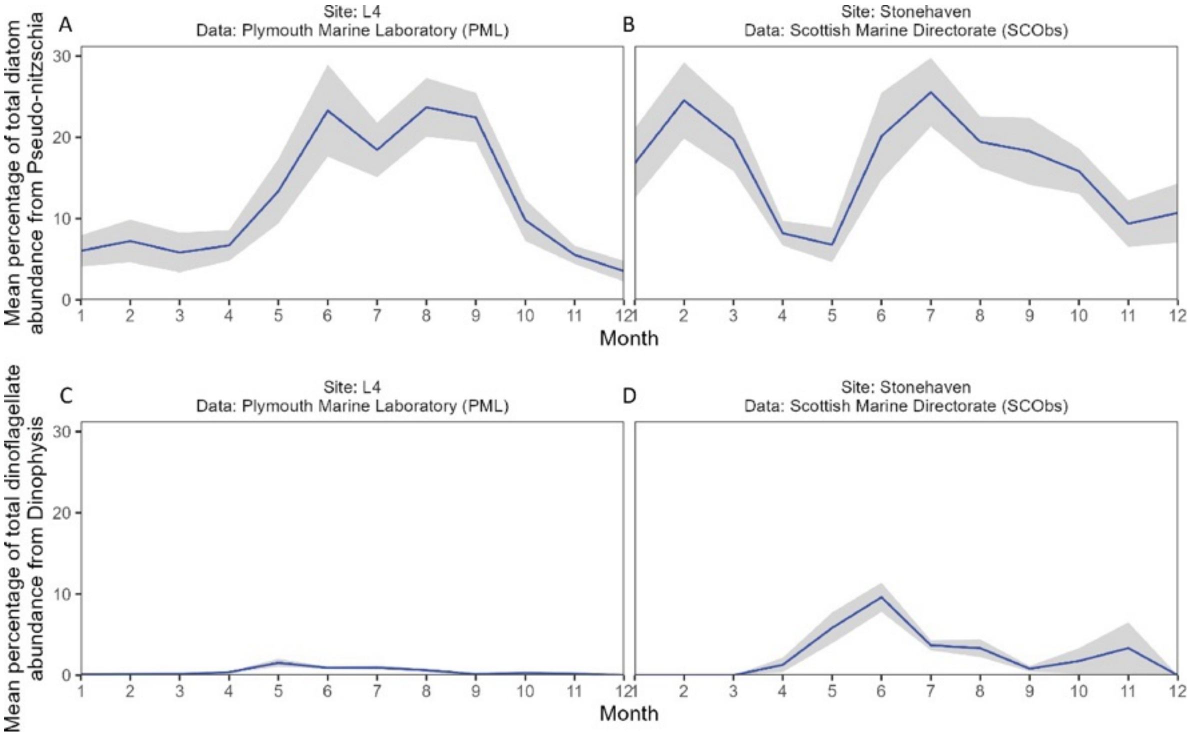

Figure 5. The mean annual percentage of total diatom community abundance contributed by *Pseudo-nitzschia* for sites L4 (A) and Stonehaven (B), and the mean annual percentage the total dinoflagellate community abundance contributed by *Dinophysis* at sites L4 (C) and Stonehaven (D). The grey band indicates the standard error of the mean.

Comparison of station and CPR data

The correlation analysis of station data with CPR data from adjacent waters revealed little similarity in *Pseudo-nitzschia* or other diatom abundance between the two data types (**Figure 6**). The R^2 of the comparisons were typically highest in autumn, ranging from 0.12 to 0.25, but were low throughout the rest of the year. There was a tendency for the CPR to observe zero abundance counts of *Pseudo-nitzschia* throughout the time-series, and particularly in winter. Corresponding zero counts were less commonly observed from the station data. For *Dinophysis* there was even lower correlation observed between station and CPR data, with the best correlation being 0.11 at Stonehaven in autumn. There was a greater tendency to observe zero counts of *Dinophysis* in CPR samples, particularly in winter and spring.

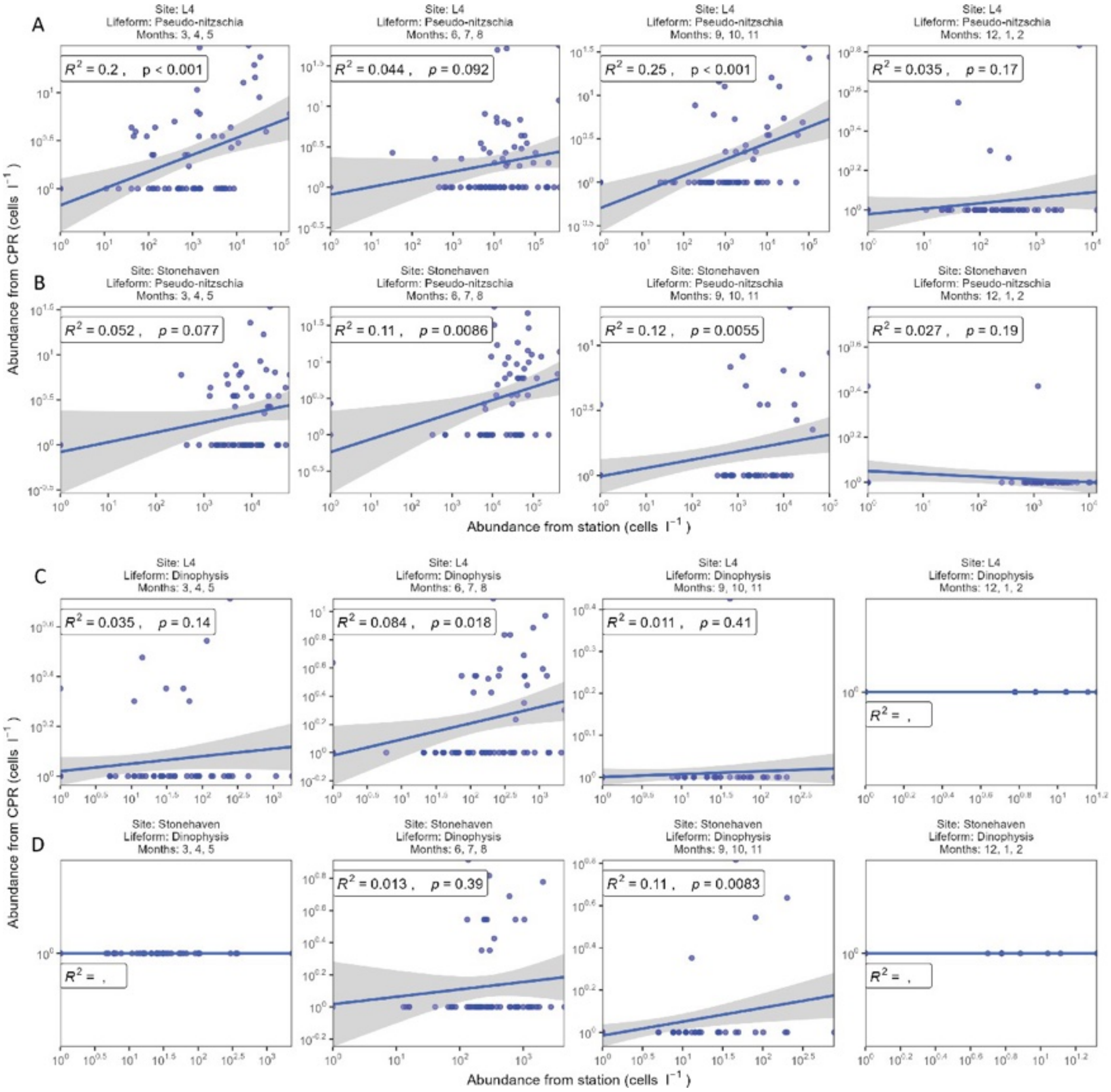

Figure 6. Correlation of total *Pseudo-nitzschia* abundance and other diatom abundance from station monitoring data with their abundance as counted from adjacent CPR samples for sites L4 (A) and Stonehaven (B), as well as correlations of total *Dinophysis* abundance and other dinoflagellate abundance from sites L4 (C) and Stonehaven (D).

Trend analysis of station time-series

Long-term abundance trends in *Pseudo-nitzschia* and other diatoms were most similar at L4, with a near-identical negative Kendall trend test result (**Figure 7**). For both L4 and Stonehaven, in no cases was the long-term trend in either *Pseudo-nitzschia* or other diatom abundance statistically significant, indicating that there was no evidence of long-term change observed within the surveyed period at the two sites. For *Dinophysis*, long-term abundance trends demonstrated a similarly low level of similarity. However, while only one trend was statistically significant (negative trend in other dinoflagellate abundance at L4), the test statistics for *Dinophyis* and other dinoflagellate abundance were all negative. There was also a degree of synchronisation in the timing of peaks and troughs in their annual abundance, particularly at Stonehaven.

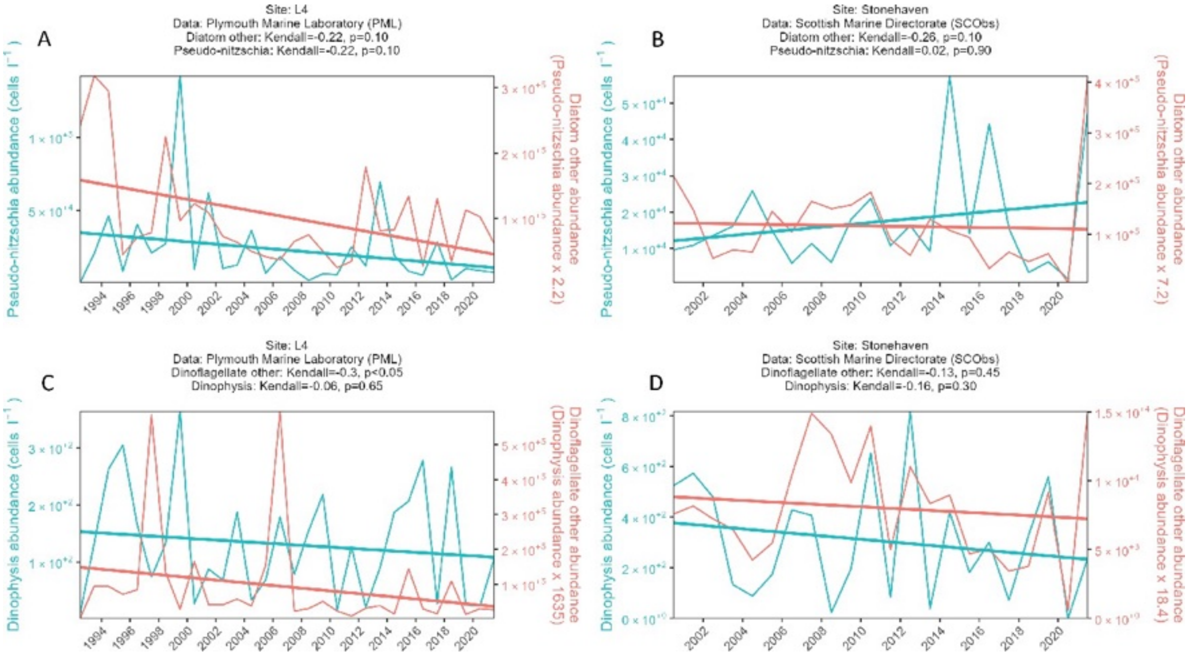

Figure 7. Long-term (annual mean) abundance time-series for *Pseudo-nitzschia* (green) and other diatom (red) abundance for sites L4 (A) and Stonehaven (B) and for *Dinophysis* (green) and other dinoflagellate (red) abundance at station L4 (C) and Stonehaven (D). Linear regression trendlines are displayed for each time-series. The results of the Kendall trend test and p-value are printed above each plot. Note that for all plots the second y-axis has been transformed to allow for both time-series to be resolved on the same plots.

Examining changes in spatial distribution

Spatially interpolated abundances of *Pseudo-nitzschia* from CPR data (**Figure 8**) revealed a reasonable degree of correlation between the grid-regularised and interpolated values, with R^2 of 0.62. It was much more common to observe zero abundance counts in the grid-regularised data than in the interpolated data, which contributed to the smaller linear coefficient of 0.55. Despite the small coefficient, The R^2 of 0.62 was still reasonable, indicating that while reported abundance values in the interpolated plots are likely underestimated, the general spatial patterns were likely to be a realistic representation of *Pseudo-nitzschia* distribution across the time period examined.

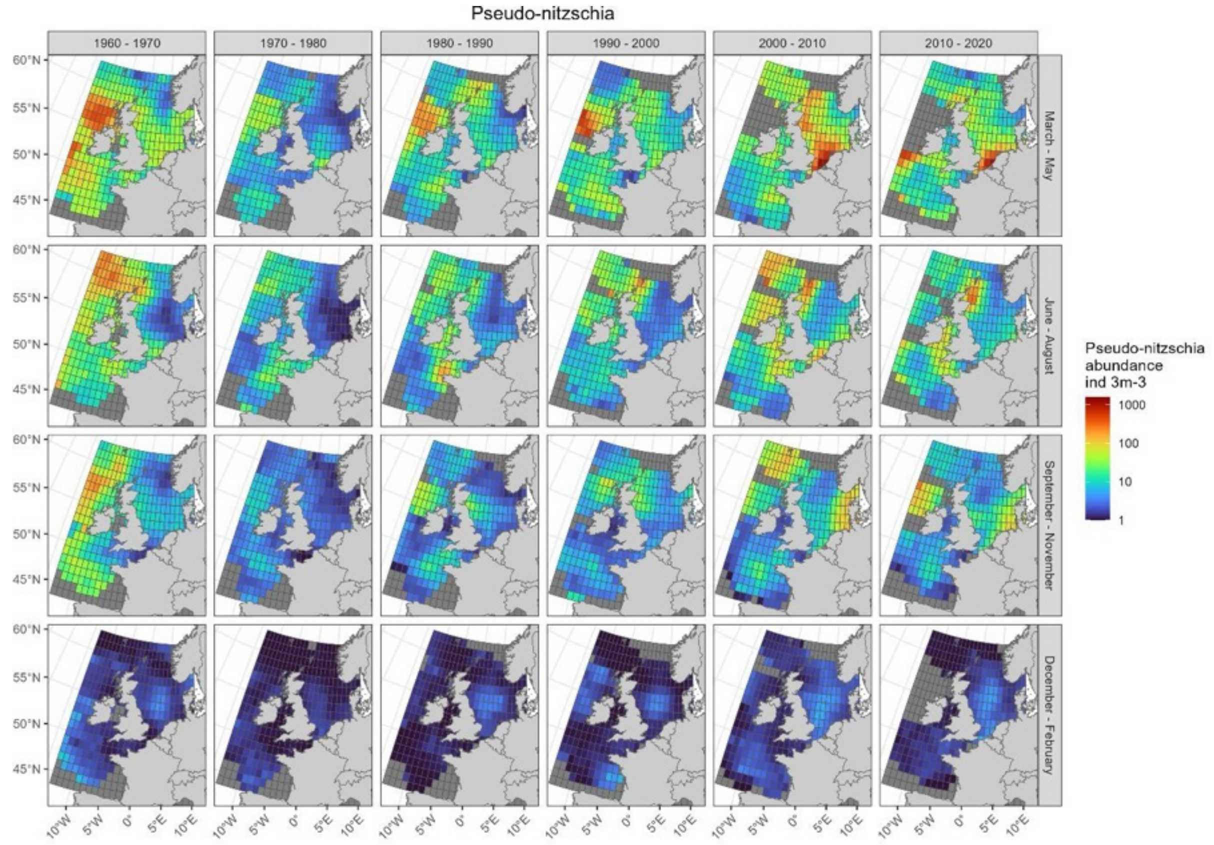

Figure 8. Mean spatial distribution of total *Pseudo-nitzschia* across the North-West European shelf for March to May (top row), June to August (second row), for September to November (third row) and for December to February (bottom row) separately for each decade, from 1960 to 2020. All maps use the same logarithmic colour scale to represent abundance.

Seasonal distribution patterns of *Pseudo-nitzschia* abundance have been highly dynamic over the past 60 years, with some important changes occurring in the North Sea. While springtime areas of high abundance were largely restricted to the north of Ireland and west of Scotland, they were relatively low in the North Sea until 2000. Between 2000 and 2020 there has been a large increase in springtime *Pseudo-nitzschia* abundance along the Flemish coast and extending to the eastern Channel and southeast England. In summer these blooms appear to die down, while an area of high abundance forms off the northeast of Scotland, extending as far as Shetland. Autumn distributions between 2000 and 2020 also indicate an increase along the eastern North Sea extending into the Kattegat.

Spatially interpolated abundances of *Dinophysis* (**Figure 9**) from CPR data revealed a reasonable degree of correlation between the grid-regularised and interpolated values, with R^2 of 0.61. Similar to the *Pseudo-nitzschia* example, zero abundance counts were more commonly observed in the grid-regularised data than in the interpolated data, contributing to the smaller linear coefficient of 0.53.

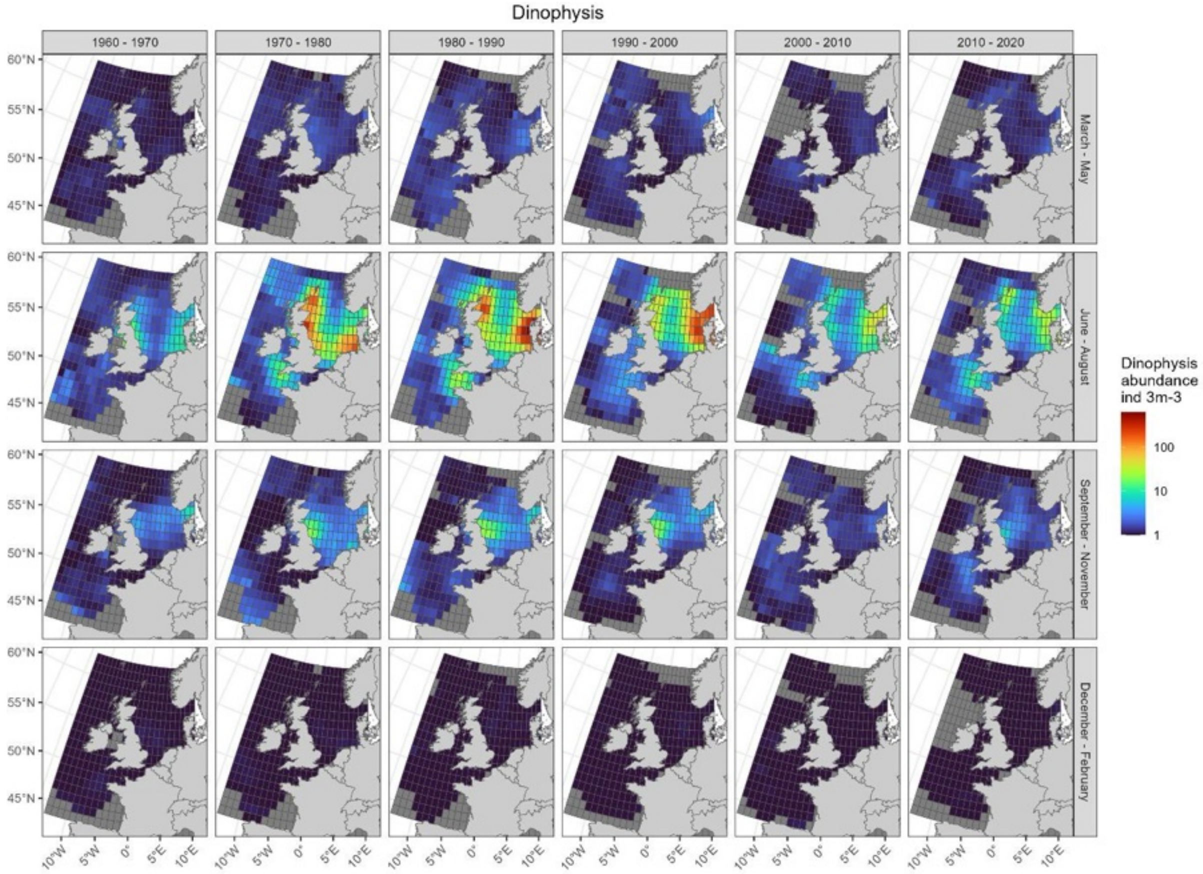

Figure 9. Mean spatial distribution of total *Dinophysis* across the North-West European shelf for March to May (top row), June to August (second row), for September to November (third row) and for December to February (bottom row) separately for each decade, from 1960 to 2020. All maps use the same logarithmic colour scale to represent abundance

Seasonal distribution patterns of *Dinophysis* abundance have been less variable than those for *Pseudo-nitzschia* over the past 60 years. *Dinophysis* were only abundant in summer months, and in the 2010s summertime abundance declined in coastal areas relative to what was observed between the 1970s and 1990s. *Dinophysis* were consistently abundant through the decades between the Shetland and Orkney islands off northern Scotland, as well as in the eastern North Sea. Between the 1970s and 1990s, high abundance was observed along the north-east coast of England in autumn, however, this has not been observed over the past two decades.

Preliminary discussion

Relationships between phytoplankton lifeforms and potential proxies

Across all seasons at both the L4 and Stonehaven stations, there was limited evidence that either *Pseudo-nitzschia* nor *Dinophysis* could be considered reliable proxies to represent diatom or dinoflagellate abundance, respectively. While *Pseudo-nitzschia* abundance showed low correlation with the abundance of other diatoms, its mean seasonal cycle largely followed that of other diatoms, peaking in the same month. When the timing of peak abundance was assessed on an annual basis there was evidence that *Pseudo-nitzschia* peaks earlier on average than the bulk of the diatom community. The proportion of the diatom community made up by *Pseudo-nitzschia* also varies throughout the seasonal cycle.

The relationship between *Dinophysis* and other dinoflagellate abundance was even more tenuous, with lower correlation coefficients at the seasonal level. The mean seasonal cycle for *Dinophysis* indicated that it peaks one to two months before the rest of the dinoflagellate community, and their abundance remains high for a shorter duration in the middle of summer.

Comparability of station and CPR data

There was limited agreement between either *Pseudo-nitzschia* or *Dinophysis* abundance from station time-series with those from concurrent CPR samples from the same period and rough geographic location. This suggests that there were differences in capture or preservation between station and CPR methods, or that there was very high variability within the 50 km radius and within each month.

The CPR Survey instrument is biased in terms of what can be captured in its 270 µm silk mesh, which is generally quite large for phytoplankton sampling. It tends to capture more of the larger cells, while allowing most small cells to pass through. Preserved CPR samples are also biased in terms of which cells are well preserved. The CPR uses formalin, which can dissolve some cells which are less well-armoured, particularly athecate dinoflagellates, while station time-series tend to use Lugol’s iodine, which is less detrimental. While these are important fundamental differences between station and CPR data, only CPR data have the broad spatial extent and high temporal resolution required to assess changes in the distribution of organisms through time.

Changes in distribution of *Pseudo-nitzschia* and *Dinophysis* through time

The spatial distribution of *Pseudo-nitzschia* derived from CPR data reveals dynamic shifts over the past six decades, particularly within the North Sea. A substantial increase in springtime *Pseudo-nitzschia* abundance has emerged in the southern North Sea in the period since 2000, extending from the Flemish coast to the eastern English Channel. This contrasts with earlier periods where high abundance was primarily confined to areas north of Ireland and west of Scotland, although this area has been poorly sampled over the past two decades. These changes indicate potential changes in environmental conditions, warranting further investigation into how their abundance is affected by factors such as nutrient availability, light penetration (potentially related to changes in water clarity), and temperature. The observed expansion in autumn distributions within the eastern North Sea and Kattegat further emphasises the dynamic nature of *Pseudo-nitzschia* blooms and their potential to impact coastal pelagic habitats.

In contrast to *Pseudo-nitzschia*, the spatial distribution of *Dinophysis* exhibits less interannual variability. *Dinophysis* abundance was primarily concentrated during the summer months, which is a characteristic typical of dinoflagellate seasonality. However, there was also an apparent decline in *Dinophysis* summertime abundance within coastal areas during the past two decades compared to previous decades. The reasons behind this coastal decline are unclear and require further investigation. While *Dinophysis* remains consistently abundant between the Shetland and Orkney islands and in the eastern North Sea, the disappearance of previously observed high autumn abundance along the northeast coast of England is another important change. These shifts in *Dinophysis* distribution patterns, despite their lower variability compared to *Pseudo-nitzschia*, highlight the need for ongoing monitoring to understand the underlying drivers and potential ecological consequences, especially given the importance of *Dinophysis* in causing diarrhetic shellfish poisoning.

Next steps

At this stage we have completed the analysis and produced all the figures necessary to build this into a paper draft to submit for peer-review. To progress this work, we now need to work to improve the Introduction and Discussion sections, and in particular ensuring that these sections are better integrated with our findings and with the state of current research. We intend to initially explore submission to Ocean and Coastal Management (Impact factor: 4.8, CiteScore: 8.5) in early 2025.

Conclusion

While there is still work to be done to turn these findings into a peer-reviewed published academic paper, our results can still be interpreted to provide a set of useful recommendations to policyholders, namely:

1. **Limited proxy potential:** *Pseudo-nitzschia* and *Dinophysis* are not reliable proxies for broader diatom and dinoflagellate abundance, respectively. While some seasonal and localised correlations exist, they are inconsistent and weak overall. This invalidates the assumption that monitoring these two genera alone (e.g., through Food Standards Agency monitoring) is sufficient for assessing wider phytoplankton biodiversity.
2. **Species-specific dynamics:** The study highlights the distinct dynamics of individual species within *Pseudo-nitzschia* (e.g., *P. delicatissima, P. seriata*), emphasising the need for species-level identification in monitoring programs. Changes in the distribution of one species may not reflect changes in others.
3. **Spatial and temporal variability:** Both *Pseudo-nitzschia* and *Dinophysis* distributions exhibit significant spatial and temporal variability, highlighting the need for comprehensive and long-term monitoring across regions and seasons.
4. **North Sea changes:** A notable increase in springtime *Pseudo-nitzschia* abundance has been observed in the southern North Sea since 2000, suggesting potential changes in environmental conditions and warranting further investigation.
5. **Coastal *Dinophysis* decline:** Declines in *Dinophysis* abundance around Orkney and Shetland in spring and off the northeast coast of England in summer have been observed in recent decades, the causes of which are unknown and warrant further research.
6. **Data source discrepancies:** Significant discrepancies exist between station-based and CPR data for both genera, likely due to differences in sampling methods and gear. This highlights the importance of considering these biases when interpreting data from different sources.

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