Diatoms as a paleoproductivity proxy in the NW Iberian coastal upwelling system (NE Atlantic)

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Abstract. The objective of the current work is to improve our understanding with regards how water column diatom's abundance and assemblage composition is seasonally transferred from the photic zone to seafloor sediments. To address this, we used a dataset derived from water column, sediment trap and surface sediment samples recovered in the NW Iberian coastal upwelling system.

Diatom fluxes (2.2 (±5.6) 10^6 valves m^{-2} d^{-1}) represented the majority of the siliceous microorganisms sinking out from the photic zone during all studied years and showed seasonal variability. Contrasting results between water column and sediment trap diatom abundances were found during downwelling periods, as shown by the unexpectedly high diatom export signals when diatom-derived primary production achieved their minimum levels. They were principally related to surface sediment remobilization and intense Minho and Douro riverine discharges that constitute an additional source of particulate matter to the inner continental shelf. In fact, contributions of allochthonous particles to the sinking material were confirmed by the significant increase of both benthic and freshwater diatoms in the sediment trap assemblage.

On the other hand, we found that most of the living diatom species blooming during highly productive upwelling periods were dissolved during sinking, and only the resistant to dissolution and the *Chaetoceros* and *Leptocylindrus* spp. resting spores were susceptible to be exported and buried. Furthermore, *Chaetoceros* spp. dominate during spring-early summer, when persistent northerly winds lead to the upwelling of nutrient-rich waters on the shelf, while *Leptocylindrus* spp. appears associated to late summer /upwelling relaxation, characterized by water column stratification and nutrient depletion. These findings evidence that the contributions of these diatom genera to the sediment's total marine diatom assemblage should allow for the reconstruction of different past upwelling regimes.

Keywords: diatoms; coastal upwelling; organic carbon; biogenic silica; sediment trap; NW Iberian;

1 Introduction

Diatoms are the most important primary producers in the ocean and play a key role in biogeochemical cycles through transferring organic carbon and biogenic silica from the surface layer to the seafloor sediments (Sancetta, 1989; Romero and Armand, 2010; Tréguer and De La Rocha, 2013). The preservation of their siliceous valves in marine sediment records has promoted their use as paleoproductivity indicators. However, reconstruction of primary production still suffer from diverse uncertainties, indicating that more studies are needed to accurately discern how particular environmental conditions regulate the diatom response, and how diatom´s ecological traits transfer primary production signal from the water column to the sediments through exported and buried particles. In this regard, the analysis of data provided by sediment traps have contributed significantly to improve our knowledge of this topic, because the deployment of traps still is the best approach for monitoring downward diatom fluxes, as response to oceanographic and biological processes occurring in surface waters on long-term basis.

Coastal upwelling systems are sites with major diatom-derived primary production where seasonality is often a noticeable feature (Walsh, 1991; Falkowski et al., 1998; Capone and Hutchins, 2013). Consequently, many studies focused on how primary production signal is exported through the water column in these highly productive coastal regions were conducted through the analysis of downward diatom flux time series (Sancetta, 1995; Lange et al., 1998; Romero et al., 2002; Abrantes et al., 2002; Venrick et al., 2003; Onodera et al., 2005). In the NW Iberian margin, despite being the most productive upwelling region in Europe (Figueiras and Pazos, 1991; Nogueira and Figueiras, 2005; Espinoza-González et al., 2012), the use of diatoms as a productivity tracer to date was based on a direct comparison of the hydrographic conditions with surface sediment (Abrantes, 1988; Bao et al., 1997; Abrantes and Moita, 1999). From these studies it was concluded that *Chaetoceros* resting spores could be used as a good tracer of upwelling patterns, in particular the position of the upwelling front. Nevertheless, none of these studies provided information on the processes regulating seasonal diatom production and export from the photic zone to the seafloor sediments. In this context, the aim of this work is to go further in this topic by presenting the first analysis of the diatom community that combines water column, sediment trap and surface sediment samples recorded in this margin. Our results will provide relevant information regarding the use of fossil diatom assemblages as a primary production paleotracer in the highly productive NW Iberian coastal upwelling system.

2 Regional setting

Our study site (RAIA station) is located in the NW Iberian continental shelf off Cape Silleiro (42º 05´ N; 8º 56´ W at 75 m water depth, Fig. 1). During spring – summer, the NW Iberian coast is characterized by prevailing northerly winds, that favour upwelling of cold and nutrient rich subsurface Eastern North Atlantic Central Water (ENACW), resulting in high primary production (Fraga, 1981; Fiuza, 1984; Tenore et al., 1995: Figueiras et al., 2002). In contrast, south-westerly winds favour coastal downwelling during autumn-winter. Hydrographically, from October to January the region is generally

affected by the northward advection of warm, saline and nutrient-poor waters by the Iberian Poleward Current (IPC) (Haynes and Barton, 1990, Castro et al., 1997; Relvas et al., 2007). Later on, usually between February–March, a decrease of temperature associated with winter cooling leads to a well homogenized mixed layer of cold and nutrient rich waters (Álvarez–Salgado et al., 2003; Castro et al., 2006). In addition, during downwelling seasons, the occurrence of south-westerly winds can generate moderate to extreme storms with wave heights > 6 m, which have been simulated to produce high sediment remobilization (Vitorino et al., 2002; Jouanneau et a., 2002; Oberle et al., 2014). During these highly energetic periods, this region is also strongly influenced by the Minho and Douro Rivers discharges (annual averages of 550 m^3 s^{-1} and 310 m^3 s^{-1}, respectively), which are important sources of terrestrial sediments to the inner shelf. This mainly occurs during the winter months, when river inflows can reach 3850 m^3 s^{-1} for the Douro River and 1800 m^3 s^{-1} for the Minho River (Dias et al., 2002; Otero et al., 2010).

3 Material and methods

3.1 External forcing

Irradiance data was obtained from Cies Islands meteorological station (IR; 42° 13′ N, 8° 54′ W, 25 m height) (Fig. 1) and available through the MeteoGalicia website (www2.meteogalicia.es).

Upwelling index (UI), an estimate of the volume of upwelled water per kilometre of coast was calculated according to Bakun´s (1973) method:

$$UI = - ((\rho_a \, C_D \, |V|) / (f \, \rho_{sw})) \, V_y$$

where ρ_a is the density of the air (1.22 kg m^{-3}) at 15 ºC, C_D is an empirical dimensionless drag coefficient (1.4 10^{-3}), f is the Coriolis parameter (9.76 10^{-5}) at 42 ºN, ρ_{sw} is the seawater density (1025 kg m^{-3}) and |V| and V_y are the average daily module and northerly component of the geostrophic winds centred at 42º N, 10º W, respectively. Positive values show the predominance of northerly winds that induces upwelling on the shelf and negative values indicate the presence of downwelling. Minho and Douro River discharges were obtained from https://github.com/PabloOtero/uptodate_rivers (Otero et al., 2010). Significant wave height data were based on WANA hindcast reanalysis of 3027034 ($WANA_S$: off Silleiro: 42º 15'N; 9º W) and 1044067 ($WANA_G$: off A Guardia: 41º 45′N; 9º W) (Fig. 1) points, and supplied by Puertos del Estado (www.puertos.es).

3.2 Water column

RAIA station (75 m water depth) was visited monthly by R/V *Mytilus* from March 2009 to June 2012 except during the period December 2009-June 2010. Characterization of the water column was conducted by i) CTD-SBE25 profiling and ii) collection of discrete water column samples at 5 m water depth using a rosette sampler (10-L PVC Niskin bottles). Aliquots

of these samples were used for inorganic nutrients, chlorophyll *a* (Chl *a*) and diatoms counting/species identification analysis.

Water column stability (0-35 m) was analysed by using Brunt Väisälä frequency parameter, $N^2 = [g / z] \ln (\rho_z/\rho_0)$ where g is the local acceleration of gravity, z is the water depth and, ρ_z and ρ_0 the bottom and surface density, respectively.

5 Inorganic nutrient concentrations were determined by segmented flow analysis with Alpkem autoanalysers (Hansen and Grasshoff, 1983). The analytical errors were ± 0.05 μmol kg^{-1} for nitrate and silicate, and ± 0.01 μmol kg^{-1} for phosphate. Final Chl *a* concentrations were determined by pigment extract fluorescence using a Turner Designs fluorometer calibrated with pure Chl *a* (Sigma) (see details in Zúñiga et al., 2016).

For diatoms counting and identification a volume of 100 ml sample was used. The samples were preserved with Lugol´s
10 iodine until microcoscopic observation. Depending on the water column Chl *a* concentration volumes between 10 to 50 mL were deposited in composite sedimentation chambers for observation through an inverted microscope. The microorganisms were counted and identified to the species level, whenever possible, using the Utermöhl sedimentation method (Utermöhl, 1931, 1958). Centric diatom cells whose diameter did not allow for species identification were grouped as small centric diatoms. Only diatom species that appeared in more than one sample with a percentage higher than 2 % of the total
15 abundance were considered for further analysis.

3.3 Sediment trap

At RAIA station an automated cylindric-conical Technicap PPS 4/3 sediment trap (height/diameter ratio of 1.7 and a collecting area of 0.05 m^2) was deployed at 35 m water depth from March 2009 to June 2012. Sampling intervals ranged from 4 to 12 days. Unfortunately some data were lost due to technical problems and bad weather conditions (Zúñiga et al.,
20 2016). Examination of CTD pressure data mounted 2 m below the trap showed that the mooring line tilting was less than 5º during 70 % of the time it was deployed. Only in exceptional hydrodynamic events that lead to velocities higher than 25 cm s^{-1} the mooring tilted 15-20º. Therefore, we assume the sediment trap was not affected by hydrodynamic biases. Sampling strategy and sample processing details are explained at length in Zúñiga et al. (2016).

Total mass flux was gravimetrically determined. Biogenic silica content was analysed following Mortlock and Froelich,
25 (1989). The samples were treated with 2M Na_2CO_3 for 5 h at 85 ºC to extract the silica and then measure as dissolved silica by colorimetric reaction. Biogenic silica was converted from Si concentration after multiplying it by a factor of 2.4.

Sample preparation for diatom abundance and assemblage assessment was adapted from Abrantes et al. (2005). Depending on the recovered material 1/5 or 2/5 splits of the original samples were used, after rinse $HgCl_2$ by repeated settling in distilled water. Subsequently, organic matter and carbonates were removed by the addition of H_2O_2 (30 %) and HCl (10 %),
30 respectively. Permanent slides were prepared using the evaporation-tray method of Battarbee, (1973) and Norland optical adhesive (NOA61) as the mounting medium. Diatoms counting and species identification was performed at 1000 X (10 x eyepieces and 100 x objectives), using a Nikon Eclipse E100 microscope equipped with Differential Interference Contrast

(DIC). 100 randomly selected fields of view were counted in 3 replicate slides (Abrantes et al., 2005). The diatom flux was calculated as follows:

$$F = ((N)(A/a)\,(V)(S)(X))/D$$

where the flux F is expressed as number of valves $m^{-2}\,d^{-1}$, N is the number of valves counted in 100 randomly selected fields of view, (a) represents the counted fraction of the total tray area (A), V is the dilution volume, S is the split fraction, X is the conversion factor from the collecting area to $1\,m^2$, and D is the sampling interval in days for each sample.

Relative abundance of diatom taxa was determined following the counting procedures from Schrader and Gersonde, (1978) and Abrantes, (1988). For each sample, ca. 300 individuals were identified to the lowest taxonomic possible level, and raw counts were converted to percentage abundance. In samples containing low diatom abundances, the number of individuals identified was 100 – 200 (Fatela and Taborda, 2002). For this study only diatom species that appeared in more than one sample with a percentage higher than 2% of the total abundance were considered for further analysis.

3.4 Surface sediments

To evaluate the sedimentary record, we used one core-top sediment (0 - 1 cm) from box-core GeoB 11002-1 (42º 10´N, 8º 58´ W; 111 m) recovered near the RAIA position (Fig. 1). The sample was collected in August 2006, using a giant box corer during the GALIOMAR expedition (P342) on board of the R/V *Poseidon*. Sample cleaning and slides preparation was carried out following the methodology of Abrantes et al. (2005). Counting and identification procedures were the same as for sediment traps samples.

3.5 Statistical data analysis

Relationships between environmental variables and sediment trap diatom species relative abundances were evaluated with Pearson correlation coefficients and presented in Table 1 and 2, respectively.

In addition, the relationship between the relative abundance of the main groups of diatoms (freshwater diatoms, benthic diatoms, *Chaetoceros* resting spores, *Leptocylindrus* resting spores and *Paralia sulcata*) and the environmental variables were analysed using the ordination technique Canonical Correspondence Analysis (CCA) (vegan package, R-project (ter Braak, 1986; Oksanen et al., 2015). The water column environmental data was at first monthly interpolated and later averaged for the time interval recovered by each trap sample. Resulting data were subsequently integrated to 35 m where the sediment trap was moored. The multicollinearity of environmental variables was previously tested by Pearson correlations (Dormann et al., 2013) and checked after modelling using variance inflation factors (VIFs) applied to the CCA. Nine environmental variables were thus initially included in the ordination: irradiance, temperature, Brunt Väisälä frequency parameter (N^2), Chl a, NO_3, $Si(OH)_4$, upwelling index (UI), Minho River flow, A Guarda wave height (Hs). Significant environmental variables were identified via a stepwise procedure, using permutation tests (999 permutations). After the

selection of the significant variables, the model was tested a second time through a Monte Carlo global permutation test (999 permutations) to assess the significance of ordination axes.

The results of CCA were presented as ordination bi-plot diagram containing the explanatory variables plotted as arrows along with points for samples (dates) and species (main groups of diatoms). Using these diagrams, we were able to identify the relationships between species, between samples, and relationships of samples and species to environmental variables.

4 Results

4.1 Environmental conditions and water column characteristics

From October to April-May, the NW Iberian margin was characterized by the prevalence of low irradiance levels and south-westerly winds as shown by the negative UI values (Fig. 2a and 2b). During these periods the region was strongly affected by strong SW storms promoting wave heights higher than 4 m, and intense Minho and Douro River discharges (Fig. 2c and 2d). As explained in detail in Zúñiga et al. (2016), hydrographically, we can distinguish in a first phase the presence of the IPC (October-January), characterized by anomalously warm water (15-17 ºC) with relatively low nutrient concentrations and Chl a (< 4 mg m^{-3}) (Fig. 3). Later on, we differentiate the mixing period (from February to April-May), with temperatures of around 14 ºC (due to winter cooling), and higher nutrient levels associated with intense river discharges (Fig. 2d, 3a, 3b and Table 1). During downwelling periods, diatom abundances ranged from 5 to 135 cel mL^{-1} with small centric diatoms accounting for the largest shares (52 ± 25 %) (Fig. 3c, 4b and Table 3). Only sporadically, *Navicula* spp. and *Paralia sulcata* were highly abundant (Fig. 4). On the other hand, from April- May to October, the margin was characterized by high irradiance levels and the upwelling of cold (< 14ºC) and nutrient rich ENACW on the continental shelf, that lead to the development of Chl *a* maxima (Fig. 2a, 2b and 3). During these highly productive upwelling periods, diatom abundances were high (up to 7629 cel mL^{-1}) (Figure 3c). The predominant diatoms in the water column alternated between *Chaetoceros* spp. at the onset of the upwelling season and *Leptocylindrus* spp. during the relaxation of the upwelling event when the water column became stratified (Fig. 4e and 4f). Other species frequently associated with upwelling favourable conditions (e.g. *Asterionellopsis glacialis*, *Detonula pumila* or *Guinardia delicatula*), appeared sporadically and with lower abundances (Fig. 4g, 4h and Table 3).

4.2 Sinking particulate material time series

The biogenic silica flux time series that ranged between 7 - 1001 mg m^{-2} d, contributed from 2% to 10% of the total material, and was closely follow by the siliceous organism fluxes calculated from microscopic counting (Fig. 5a, 5b and 5c). The contribution of diatoms to total siliceous microorganisms dominated throughout the entire period (Fig. 5c and 5e). Only

during the 2012 upwelling season did silicoflagellates become relevant, achieving a relative abundance > 7 % (Fig. 5d). Maximum total diatom fluxes were registered under downwelling conditions (Fig. 5e). During these periods benthic and freshwater diatoms became relevant, contributing to the total diatom fluxes up of 24 % and 17 %, respectively (Fig. 6). On the contrary, during upwelling phases total diatom fluxes were relatively low, ranging around a mean seasonal value of 6 ± 10 10^5 valves m^{-2} d^{-1} (Fig. 5e and Table 3). During these periods, the diatom assemblage found in the trap samples were mainly composed of *Chaetoceros* spp. and *Leptocylindrus* spp. resting spores, with mean contributions to total marine diatom fluxes of 46 % and 20 %, respectively (Fig. 7 and Table 3).

4.3. Surface sediment samples

Diatom abundances in GeoB 11002-1 top sediment sample was 14 x 10^5 valves g^{-1}. Marine diatom assemblage was dominated by resting spores of both *Chaetoceros* (33%) and *Leptocylindrus* (37%) spp., and *Paralia sulcata* (17%) (Table 3). Benthic and freshwater diatoms had contributions < 4 %.

4.4 Relationships between sediment trap main diatom groups and environmental variables

Canonical correspondence analysis (CCA) stepwise procedure identified five significant variables for the abundance of the main diatom groups (p-value < 0.05), Minho River flow (Minho River), temperature (Temp), Chlorophyll *a* (Chl *a*), NO$_3$ and Si(OH)$_4$ (Fig. 8). The first two canonical axes explained 48.7 % and 40.4 %, i.e. 89 % of the modelled inertia and consequently only those two axes were considered. The CCA model with the five variables explained 46% of the total inertia. The first canonical axis showed a positive gradient with Temp and Chl *a*, opposite to Minho River discharge. Freshwater (FW) diatoms, benthic diatoms and *Paralia sulcata* (Parsul) were negatively positioned in the first canonical axis, indicating thus a positive relationship with the Minho River, and a negative relationship with Temp and Chl *a*. The second canonical axis showed a negative gradient with NO$_3$ and Si(OH)$_4$ and a negative relationship between these variables and *Chaetoceros* resting spores (ChaeRS). Conversely, *Leptocylindrus* resting spores (LepRS) were positively related with NO$_3$ and Si(OH)$_4$. The temporal distribution of the sediment trap samples confirmed that FW diatoms, benthic diatoms and Parsul occurred mainly during downwelling months while ChaeRS and LepRS were associated to upwelling periods (Fig. 8). In addition, this figure also identifies LepRS with late summer periods.

5 Discussion

Diatoms exported out from the photic zone (2.2 ($\pm$5.6) 10^6 valves m^{-2} d^{-1}), similar to those registered in other coastal upwelling systems (Sancetta, 1995; Lange et al., 1998; Romero et al., 2002; Abrantes et al., 2002; Venrick et al., 2003;

Onodera et al., 2005) showed contrasting results compared to diatom abundances on the surface waters (Fig. 3c, 5c and 5e). In fact, the a priori contradictory observation of maximum diatom fluxes during autumn-winter when irradiance conditions were unfavourable for phytoplankton growth and Chl *a* showed minimum levels (Fig. 2, 3c and 5e) can be explained by the input of allochtonous sources associated to the inner continental margin hydrodynamics (Zúñiga et al., 2016). Furthermore, Zúñiga et al. (2016) have also showed how seasonal intensification of primary production promoted biogenic settling particles during spring-summer seasons, clarifying why diatom assemblages´ dominant species recorded in the trap material were the same as in the water column (Fig. 4 and 7). With this in mind, our results confirm the major influence of both hydrodynamic and biogenic processes over the diatoms abundance, assemblage composition and export in this coastal upwelling system.

5.1. Sediment trap diatom assemblage as a tracer for allocthonous sources in sinking material

During highly hydrodynamic downwelling periods, higher wave heights as indicative of strong storms, co-occurred with maximum fluxes of benthic diatoms (Fig. 2c and 6a), whose natural habitat is the sediment interface. This finding along with the fact that during these high-energy episodes lithogenic particle fluxes achieved their maximum levels (as shown in Zúñiga et al., 2016) may only be explained if strong storms resuspended surface sediments covering the Iberian continental shelf (Dias et al., 2002; Vitorino et al., 2002. Jounneau et al., 2002, Oberle et al., 2014). Furthermore, stormy conditions were accompanied by intense Minho and Douro River discharges which impacted the water column thermohaline structure (Fig. 2c and 2d). The increase in freshwater diatoms associated to river runoff reinforce that those continental inputs are an additional source of terrestrial material to the inner continental shelf (Fig. 2d and 6c). Indeed, canonical analysis of sediment trap samples revealed a high correlation between benthic and freshwater diatoms, corroborating the co-ocurrence of both resuspension processes and river discharges during downwelling periods (Fig. 8 and Table 2).

One additional evidence of resuspension resulted from the analysis of the marine diatom assemblage collected in the sediment trap. *Paralia sulcata* was sporadically found in the water column diatom assemblage during the 2009-2012 studied years (Fig. 4c and Table 3). This meroplanktonic and shadow species, was by contrast common in sediments, and contributed significantly to the trap diatom fluxes during downwelling phases (Fig. 7c and Table 3). All this points out to this resistant to dissolution species can be easily resuspended from the sediments under highly hydrodynamic conditions (Bernárdez et al., 2010; Zúñiga et al., 2011). This is also supported by the positive relationship found between *Paralia sulcata* and benthic diatoms in the trap samples (Fig. 8 and Table 2).

Also of interest is the positive correlation between freshwater and benthic diatoms to *Thalassiosira eccentrica* (Table 2), a species which is known to occur in areas where nutrient input is continuous throughout the year, such as in areas influenced by river discharge (Moita, 1993, Abrantes and Moita, 1999).

5.2 Seasonal succession of diatom species during upwelling seasons: the imprint of the fossil diatom assemblage

During the studied period, the water column diatom community was modulated by the seasonality of environmental variables, with the highest abundances always recorded during upwelling periods, when irradiance and water column characteristics promote favourable conditions for diatom growth (Fig. 2 and 3). In this regard, a detailed analysis of the marine diatom assemblage as a whole revealed that most living diatom species linked to upwelling favourable conditions were either not present (e.g. *Asterionellopsis glaciallis*, *Detonula pumila*, *Guinardia delicatula* and *Skeletonema costatum*) or appeared with a significantly lower contribution (e.g. *Nitzschia* spp., *Pseudo-nitzschia* spp. and small centric) in the diatom assemblages in both the sediment trap and the surface sediment samples (Table 3). This confirms that selective dissolution processes acted on thin-walled, less silicified diatoms and thus, only the robust and heavily silicified frustules and resting spores will be available to be exported and buried. Although this may lead to underestimate primary production from fossil diatoms, analysis made over the sediment trap data demonstrate that the vertical sinking of the highly resistant *Chaetoceros* and *Leptocylindrus* spp. resting spores (positively positioned in CCA1) (Fig. 8) occurred in agreement with their dominance in the upper water column, and therefore both diatom genera are a good sedimentary indicator of high primary production in the NW Iberian margin. This brings new relevant information to previous works carried out along this margin, which have only considered *Chaetoceros* spp. resting spores group as a tracer of the coastal upwelling regime (Abrantes, 1988; Bao et al., 1997; Abrantes and Moita, 1999).

Furthermore, during the highly productive upwelling periods, we found how the environmentally controlled succession between *Chaetoceros* and *Leptocylindrus* spp. blooms (Figueiras and Rios, 1993; Escaravage et al., 1999; Casas et al., 1999; Nogueira and Figueiras, 2005), is clearly reflected in the export of their corresponding resting spores (Fig. 4, 7 and 8). Indeed, our sediment trap dataset reflected how the sinking fluxes of *Chaetoceros* spp. resting spores were mostly associated to the onset of the upwelling period, when irradiance conditions are favourable and persistent northerly winds lead to the upwelling of nutrient-rich subsurface ENACW waters on the shelf (Fig. 3, 4, 7 and 8). On the contrary, *Leptocylindrus* spp. resting spores fluxes were significantly associated to late-summer autumn when more frequent relaxation of winds promoted water column stratification and nutrient depletion (Fig. 3, 4, 7 and 8). In this regard, our finding linking environmentally controlled diatom blooms and resting spores vertical export, give us the opportunity to reinterpret previous studies published on this margin with regards upwelling-related paleosignals , where it is shown, despite not discussed, a downcore alternation between the resting spores accumulation rates of these two genera (Bernárdez et al., 2008; Abrantes et al., 2011).

6 Conclusions

Even though the remobilization of bottom sediments by resuspension processes may distort diatoms accumulation/preservation rates in the NW Iberian margin, our results bring light in relation with the use of fossil diatoms in marine sediment records for determining allochtonous sources and primary production paleosignals in this margin. Our main

observations may be summarize as follows: i) high diatom fluxes during downwelling periods did not represent water column primary production signal, but reflected highly energetic episodes that provoked that resuspended sediment and river inputs were the main sources of diatoms to the sinking fluxes. This fact is also evidenced in the significant increase of both benthic and freshwater diatoms in the sediment trap assemblage; ii) during highly productive upwelling periods, diatom´s export signal, mainly represented by the highly resistant to dissolution *Chaetoceros* and *Leptocylindrus* spp. resting spores, mirrored diatoms community structure in the upper water column, and thus both diatom genera may be considered as good sedimentary imprint of highly productive upwelling conditions; iii) the seasonal succession as a response to particular environmental conditions in both the bloom and export of *Chaetoceros* and *Leptocylindrus* spp. postulates that contributions of these diatom genera to the total marine diatom assemblage in the sediment records should allow the identification of paleoceanographic conditions attributed to different patterns (onset versus relaxation) of the upwelling regime.

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Table 1. Environmental variables matrix Pearson correlations. Irrad: irradiance; Temp: temperature; Sal: salinity; N^2: Brunt Väisälä frequency parameter; Chl a: Chlorophyll a; SPM: suspended particulate matter; POC: particulate organic carbon; UI: upwelling index; Minho: Minho River discharge; Waves: Significant wave height in off A Guarda (WANA$_G$) station.

	Irrad	Temp	Sal	N^2	Chl a	SPM	POC	NO$_3$	PO$_4$	Si(OH)$_4$	Oxygen	UI	Minho	Waves
Irrad	1.00	-0.394	0.487	-0.0827	0.528	-0.555	0.376	0.0167	0.0764	-0.642	0.148	0.487	-0.236	-0.357
Temp		1.00	-0.263	0.616	-0.196	0.332	0.184	-0.284	-0.195	0.351	-0.346	-0.456	0.0961	0.0557
Sal			1.00	-0.0509	0.228	-0.645	0.348	0.0839	0.263	-0.841	-0.137	0.518	-0.689	-0.27
N^2				1.00	-0.284	0.249	0.124	-0.266	0.0559	0.0825	-0.38	-0.266	-0.101	-0.0122
Chl a					1.00	-0.476	0.355	0.0608	-0.0003	-0.321	0.124	0.205	0.0433	-0.272
SPM						1.00	-0.104	0.153	0.0953	0.79	-0.223	-0.409	0.334	0.257
POC							1.00	0.24	0.341	-0.201	-0.39	0.0841	-0.246	-0.242
NO$_3$								1.00	0.871	0.287	-0.677	0.182	-0.106	-0.252
PO$_4$									1.00	0.137	-0.823	0.233	-0.274	-0.185
Si(OH)$_4$										1.00	-0.297	-0.466	0.523	0.240
Oxygen											1.00	0.0592	0.213	0.204
UI												1.00	-.0394	-0.116
Minho													1.00	0.139
Waves														1.00

Table 2 Pearson correlation matrix for the sediment trap diatom species relative abundances (%). FW: freshwater diatoms; ChaetoRS: *Chaetoceros* spp. resting spores; Cos.mar: *Coscinodiscus marginatus*; Cos.rad: *Coscinodiscus radiatus*; LeptoRS: *Leptocylindrus* spp. resting spores; Nav: *Navicula* ; Nitzs.mar: *Nitzschi*a *marina*; Par.sulc: *Paralia sulcata*; Pse.Pun: *Pseudo-nitzschia pungens*; Thal.ecc: *Thalassiosira eccentrica*; Thal.nitzs: *Thalassionema nitzschioides*.

	FW	Benthic	ChaetoRS	Cos.mar	Cos.rad	LeptoRS	Nav.spp	Nitzs.mar	Par.sulc	Pse.pun	Thal.ecc	Thal.nitzs
FW	1.00	0.482	-0.0085	-0.312	0.161	0.226	-0.126	0.176	0.293	0.0318	0.382	-0.0879
Benthic		1.00	-0.38	0.267	0.51	-0.377	0.2	0.0623	0.671	0.159	0.428	0.0777
ChaetoRS			1.00	-0.315	-0.388	-0.0163	-0.147	-0.389	-0.493	-0.318	-0.337	-0.214
Cos.mar				1.00	0.416	-0.137	0.517	-0.138	0.201	0.15	0.182	0.253
Cos.rad					1.00	0.283	0.267	0.0427	0.487	0.0773	0.261	0.202
LeptoRS						1.00	-0.224	-0.107	-0.495	-0.185	-0.0972	-0.173
Nav.spp							1.00	-0.0424	0.196	0.18	0.074	0.174
Nitzs.mar								1.00	0.173	0.547	0.338	0.079
Par.sulc									1.00	0.113	0.288	0.0748
Pse.pun										1.00	0.412	0.561
Thal.ecc											1.00	0.451
Thal.nitzs.												1.00

Table 3. Total abundance and relative contributions of the marine diatom assemblage preserved in the water column, sediment trap and core top sediment sample. SD: Standard deviation. Nitzs: *Nitzschia*; Pseudo-nitzs: *Pseudo-nitzschia*; Thal. nitzs: *Thalassionema nitzschioides*; Nav: *Navicula*; Chaeto. and Lepto. spp: *Chaetoceros* and *Leptocylindrus* spp.; Aster. glac: *Asterionellopsis glacialis*; Deton. pum: *Detonula pumila,* Guin. del: *Guinardia delicatula,* Skelet. cost: *Skeletonema costatum.* Water column diatom species were grouped in order to easily compare them with fossil diatom assemblage from both the sediment trap and surface sediment samples. *Nitzschia* spp: *Nitzschia longissima*; *Pseudo-nitzschia* spp: *Pseudo-nitzschia* cf. *delicatissima* and *Pseudo nitzschia* cf. *seriata*; Thal. nitzs: *Thalassionema nitzschioides*; Small centric: includes centric diatom cells which diameter did not allow for species identification and *Thalassiosira* spp. small; *Navicula* spp: *Navicula transitans* var. *derasa*; *Chaetoceros* (Chaeto.) spp: Ch. *curvisetus*, Ch. *socialis*, Ch. *didymus*, Ch. *laciniosus*, Ch. *decipiens* and small *Chaetoceros*; *Leptocylindrus* (Lepto) spp: *Leptocylindrus danicus*. Fossil diatom species from both the sediment trap and surface sediment samples were classified in three groups in order to compare them with water column diatom assemblage. *Nitzschia* spp: *Nitzschia marina*; *Pseudo-nitzschia* spp: *Pseudo-nitzschia pungens*; Thal. Nitzs: *Thalassionema nitzschioides*. Small centric: includes *Coscinodiscus marginatus*, *Coscinodiscus radiatus* and *Thalassiosira eccentrica*. Chaeto. and Lepto. spp: *Chaetoceros* and *Leptocylindrus* spp. resting spores.

	Total	Nitzs. spp.	Pseudo-nitzs. spp.	Thal. nitzs.	Small centric	Nav. spp.	*Paralia sulcata*	Chaeto. spp	Lepto. spp	Aster. glac.	Deton. pum.	Guin. del.	Skelet. cost.
WATER column													
Upwelling													
cel mL^{-1} (± SD)	717 (1869)	17 (50)	25 (30)	10 (17)	486 (1766)	1 (2)	0 (0)	72 (108)	126 (271)	3 (8)	17 (15)	11 (12)	1 (2)
% (± SD)		3(4)	16 (24)	0.1 (0.4)	20 (31)	0.1 (0.4)	0 (0)	27 (28)	26 (33)	1 (1)	3 (9)	2 (4)	2 (9)
Downwelling													
cel mL^{-1} (± SD)	34 (49)	2 (2)	12 (21)	1 (1)	10 (18)	0 (0)	1 (1)	1 (1)	1 (1)	1 (1)	1 (0)	0 (0)	0 (0)
% (± SD)		12 (12)	18 (28)	2 (4)	52 (25)	2 (4)	2 (4)	7 (10)	1 (3)	2 (3)	2 (7)	0 (0)	0 (0)
TRAP													
Upwelling													
10^4 valves m^{-2} d^{-1} (± SD)	59 (97)	0.2 (0.1)	1.1 (5.8)	0.7 (1.6)	0.5 (0.7)	0.1 (0.3)	5.3 (13)	40.3 (87.2)	23.0 (49.9)	0 (0)	0 (0)	0 (0)	0 (0)
% (± SD)		2 (1)	6 (6)	2 (4)	2 (2)	1 (1)	14 (13)	46 (25)	20 (22)	0 (0)	0 (0)	0 (0)	0 (0)
Downwelling													
10^4 valves m^{-2} d^{-1} (± SD)	216 (462)	0.1 (0.2)	0.1 (0.2)	0.9 (2.1)	1.3 (2.1)	0.3 (0.5)	31.2 (43.6)	25.6 (40.6)	43.9 (111)	0 (0)	0 (0)	0 (0)	0 (0)
% (± SD)		1 (1)	1 (1)	2 (2)	3 (2)	1 (1)	23 (12)	28 (19)	24 (19)	0 (0)	0 (0)	0 (0)	0 (0)
SEDIMENT													
GeoB 11002-1													
10^4 valves g^{-1}	142	0	0	2	3	0	24	47	52	0	0	0	0
%		0.2	0	2	2	0	17	33	37	0	0	0	0

Figure captions

Fig. 1. Map of the NW Iberian Peninsula continental margin showing the position of the mooring line (RAIA) site. WANA hindcast reanalysis points 3027034 (WANA$_S$ off Cape Silleiro) and 1044067 (WANA$_G$ off A Guarda) from which wave data were obtained, location of the irradiance Cíes station (IR) and position of the core-top sediment sample GeoB11002-1 are also shown.

Fig. 2. Temporal series of (a) total irradiance at Cies Islands station (IR), (b) upwelling index (UI), (c) significant wave heights (Hs) obtained from the off Silleiro and off A Guarda WANA points and, (d) Minho and Douro River discharges. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016).

Fig. 3. Temporal series of (a) temperature and water column integrated Brunt-Väisälä frequency (N^2), (b) nitrates (NO$_3$) and silicates (Si(OH)$_4$) content and, (c) diatoms abundance and Chl a concentration, measured on samples recovered at 5 m water depth. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016).

Fig. 4. Time series of water column diatom abundances (a, c, e and g) and assemblages (b, d, f, h) from water column samples recovered at 5 m water depth. Water column diatom species were grouped in order to easily compare them with fossil diatom assemblage from the sediment trap samples. *Nitzschia* spp: *Nitzschia longissima*; *Pseudo-nitzschia* spp: *Pseudo-nitzschia* cf. *delicatissima* and *Pseudo nitzschia* cf. *seriata*; Thal. nitzs: *Thalassionema nitzschioides*; Small centric: includes centric diatom cells which diameter did not allow for species identification and *Thalassiosira* spp. small; *Navicula* spp: *Navicula transitans* var. *derasa*; *Chaetoceros* (Ch.) spp: Ch. *curvisetus*, Ch. *socialis*, Ch. *didymus*, Ch. *laciniosus*, Ch. *decipiens* and small *Chaetoceros*; *Leptocylindrus* spp: *Leptocylindrus danicus*. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016). The number and the corresponding arrow in figure 4a is referred to small centric cells abundance in July 2010.

Fig. 5. Time series of (a) biogenic silica (BioSi), (c) total siliceous organisms and (e) total diatom (including valves and resting spores) fluxes recorded with a PPS 4/3 sediment trap at RAIA station. Relative contribution of (b) biogenic silica to total mass flux, (d) silicoflagellates respect to total siliceous organisms and (f) resting spores to total diatoms flux are also presented. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016).

Fig. 6. Time series of (a) benthic and (c) freshwater diatom fluxes (and relative contributions respect to total diatoms (b, d)) recorded with a PPS 4/3 sediment trap at RAIA station. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016).

Fig. 7. Time series of marine diatoms fluxes (a, c, e) and assemblages (relative contributions to total marine diatoms (b, d, f)) recorded with a PPS 4/3 sediment trap at RAIA station. Fossil diatom species has been classified in three groups in order to compare them with water column diatom assemblage. *Nitzschia* spp: *Nitzschia marina*; *Pseudo-nitzschia* spp: *Pseudo-nitzschia pungens*; Thal. Nitzs: *Thalassionema nitzschioides*. Small centric: includes *Coscinodiscus marginatus*,

Coscinodiscus radiatus and *Thalassiosira eccentrica*. Upwelling and downwelling periods are highlighted with white and grey bars, respectively, based on upwelling index and biogeochemical data presented in Zúñiga et al. (2016).

Fig. 8. RDA biplot results of the canonical ordination (only significant variables shown) for main fossil sediment trap diatom groups (freshwater (FW) diatoms, benthic diatoms, *Paralia sulcata* (Parsul), *Chaetoceros* spp. spores (ChaeRS) and *Leptocylindrus* spp. spores (LepRS), and forward selected environmental variables (Chlorophyll *a* (Chl *a*), Temperature (Temp), nitrates (NO_3), silicates ($Si(OH)_4$) and Minho River flow). JFM: January-February-March, AMJ: April-May-June, JAS: July-August-September, OND: October-November-December.

Figure 1

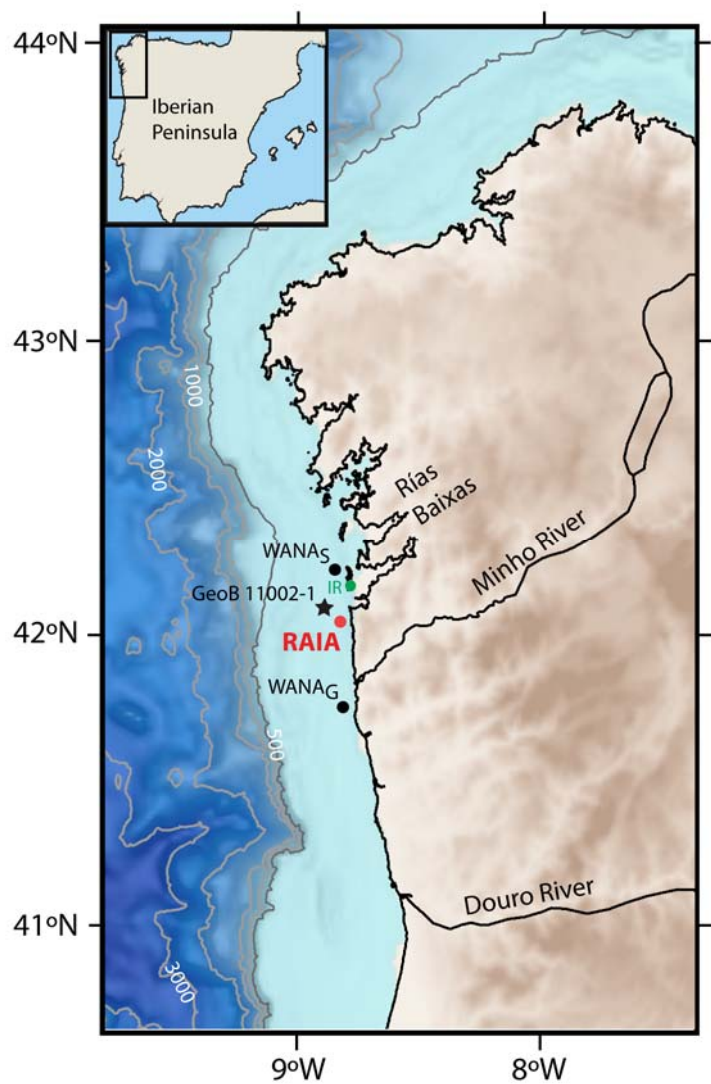
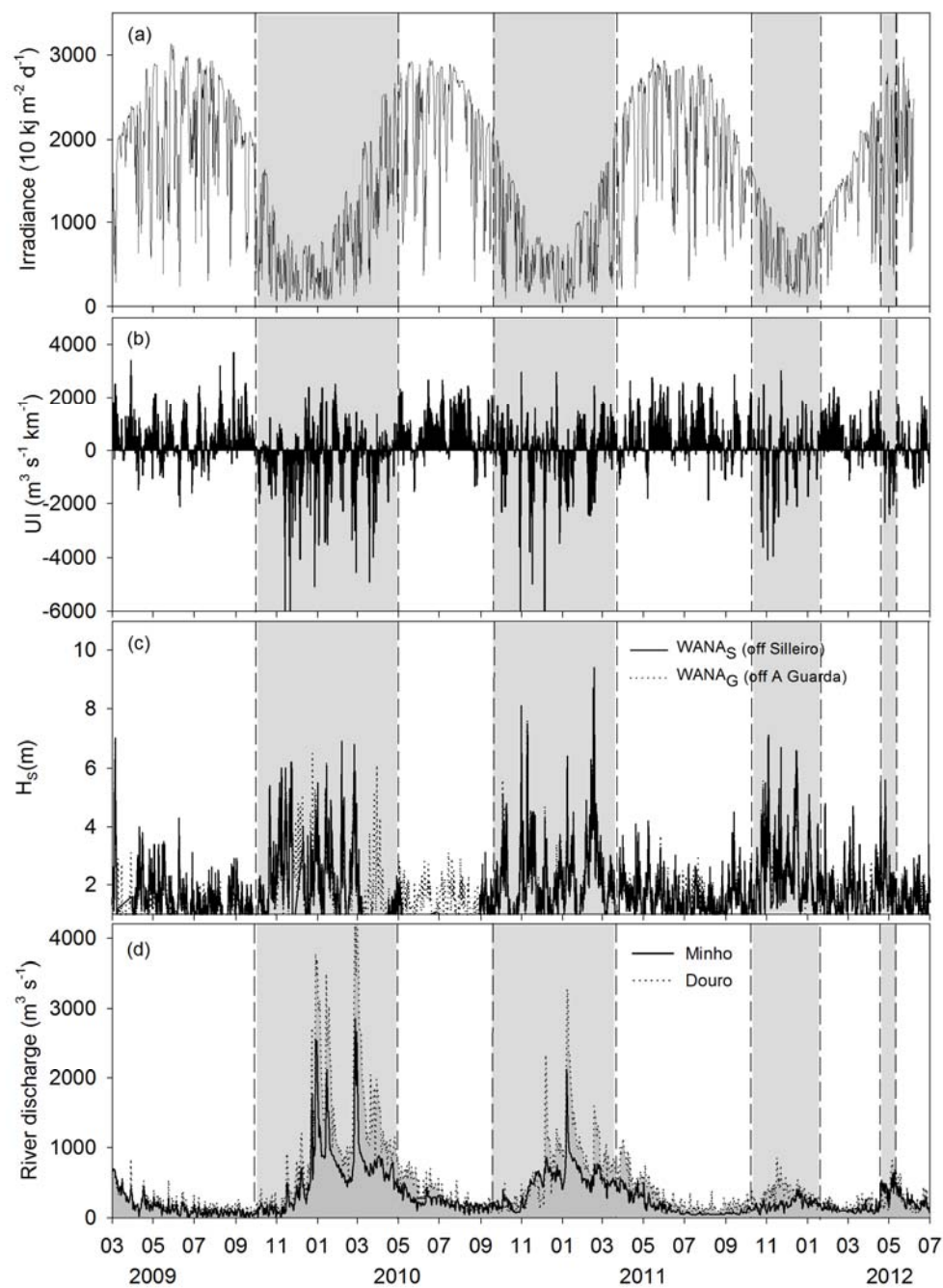
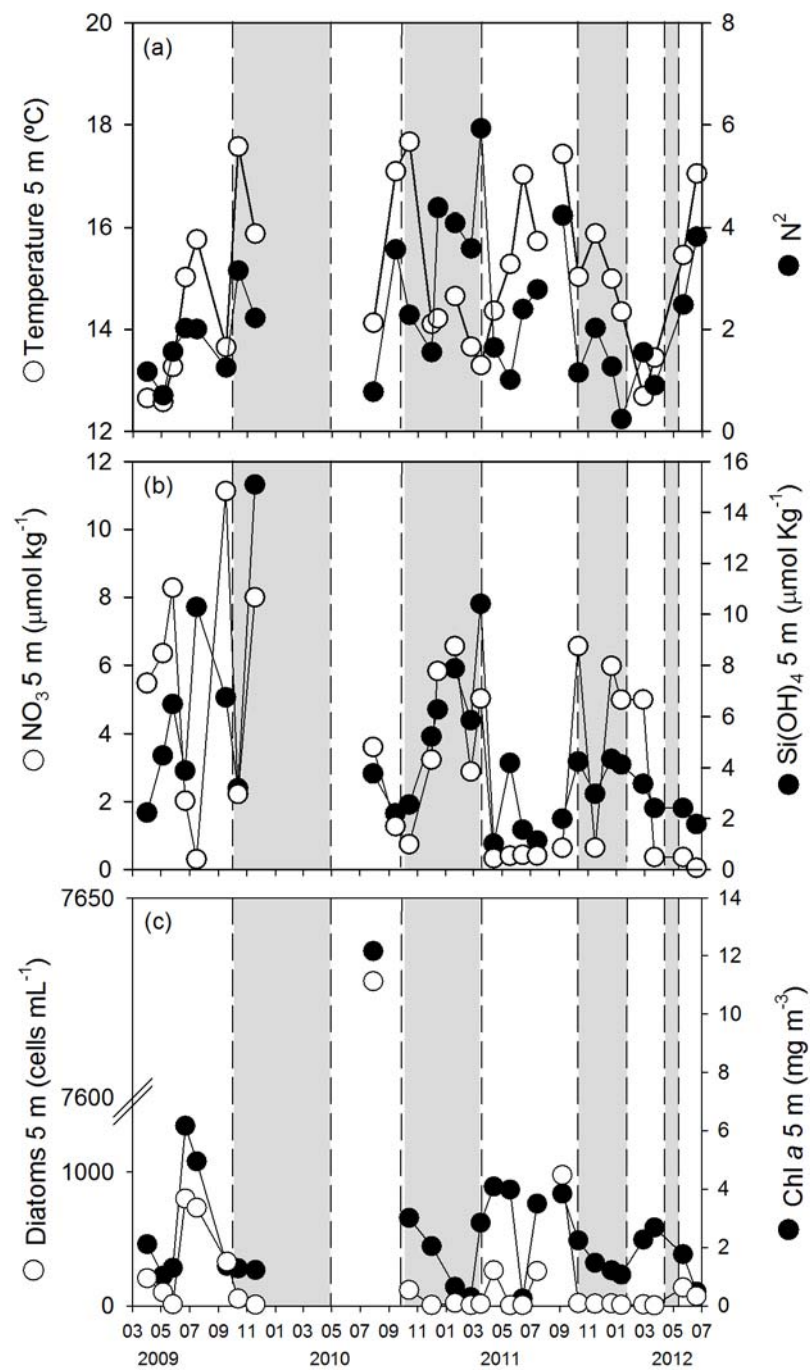
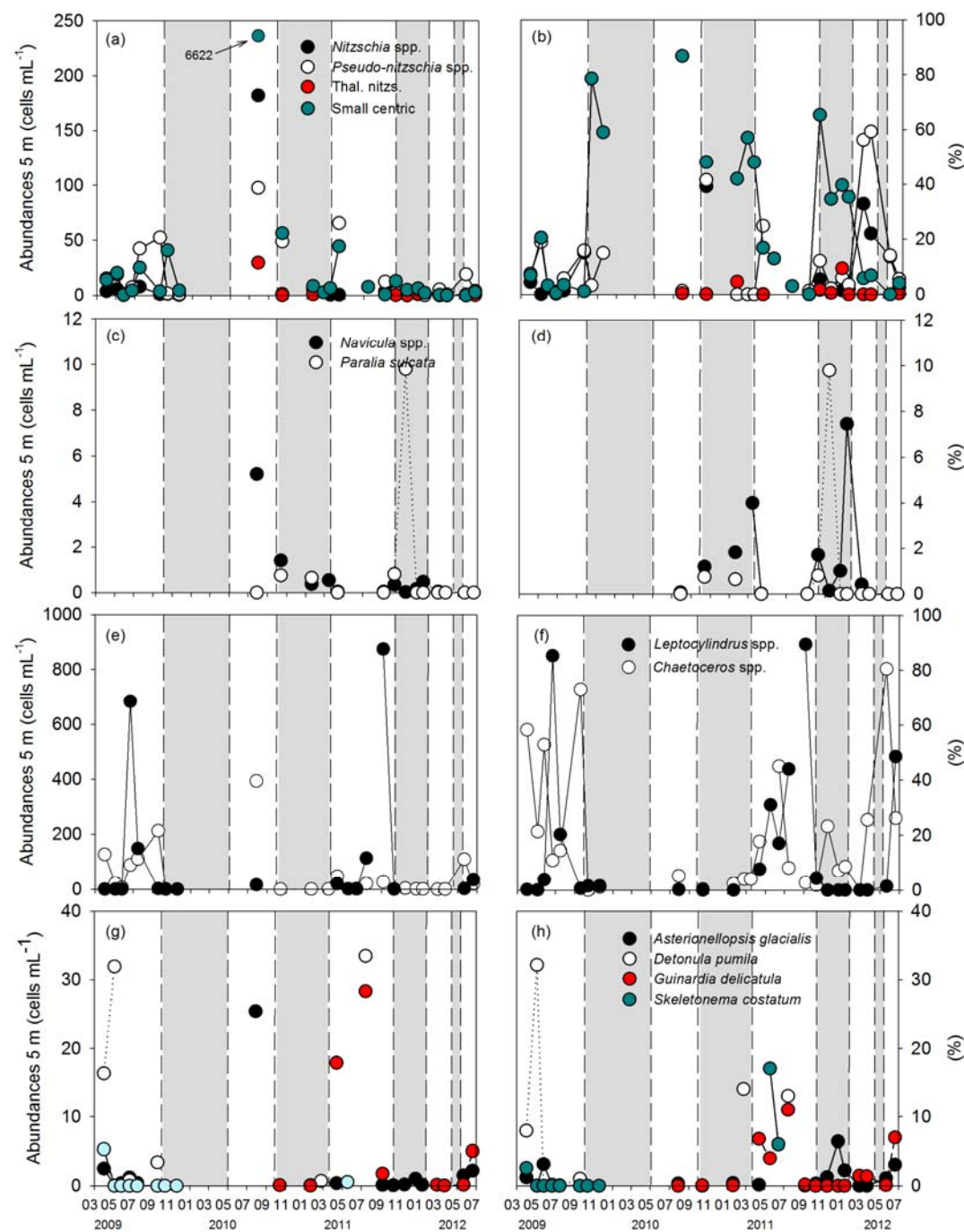



Figure 2

Figure 3

Figure 4

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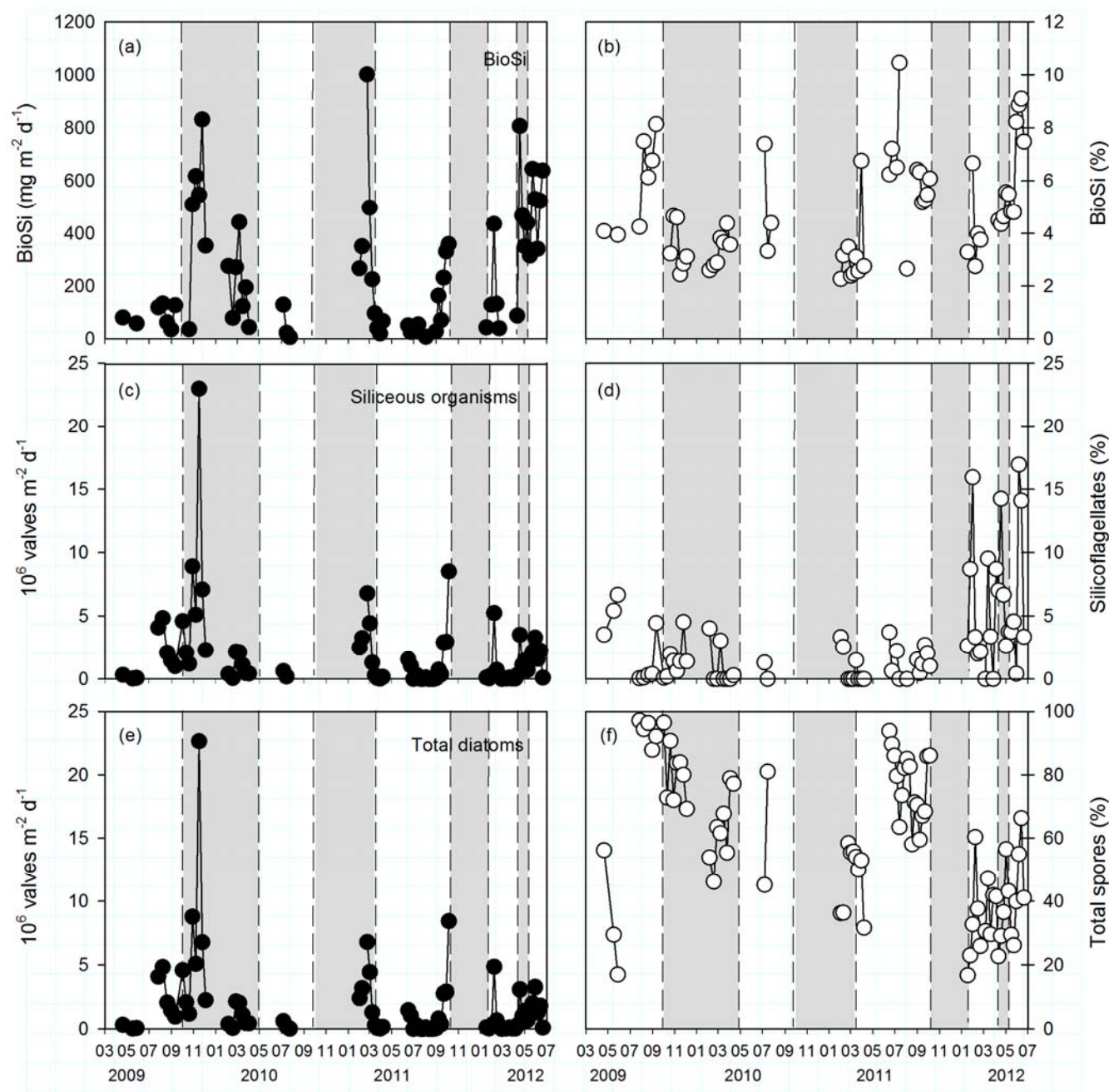
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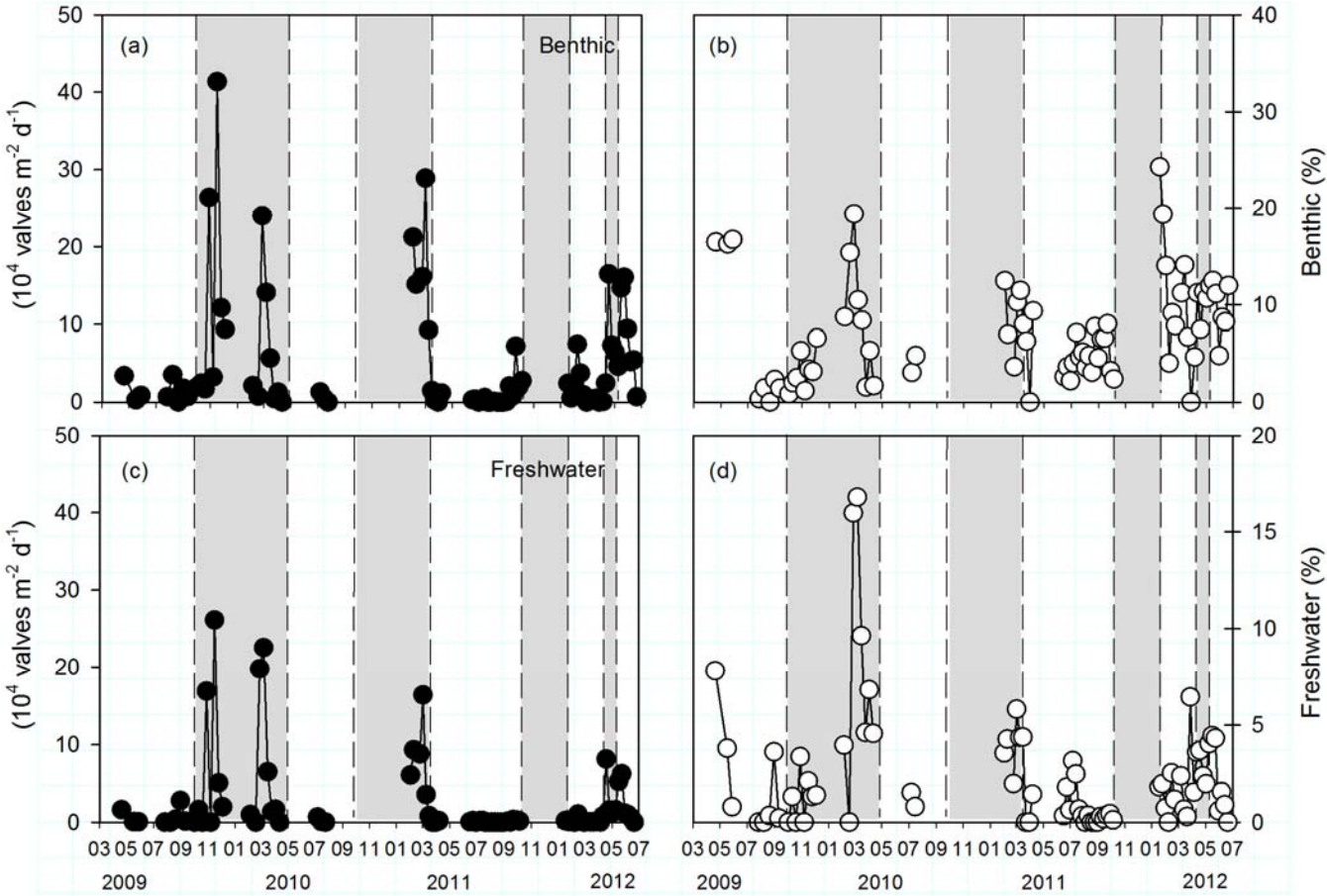
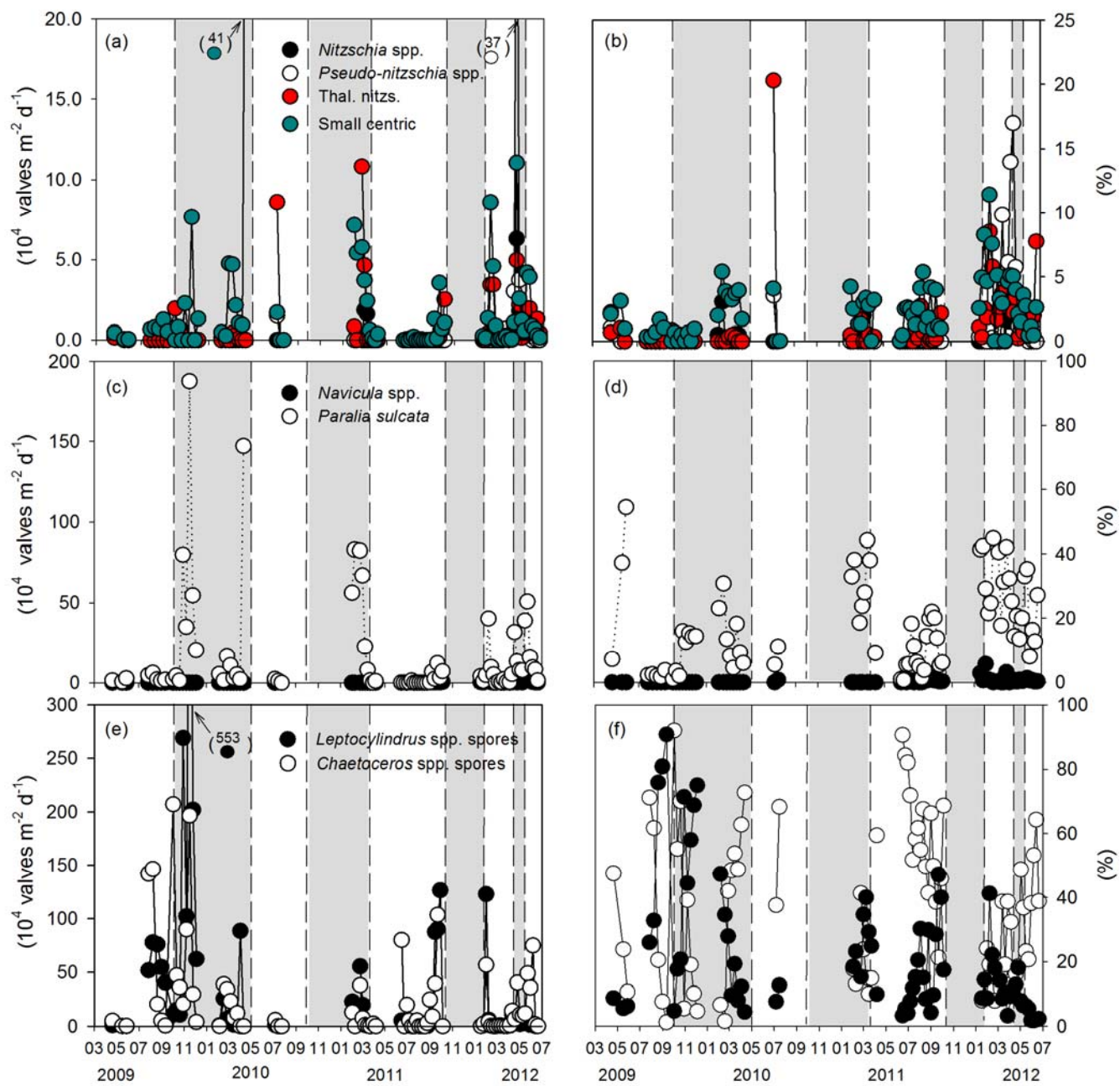
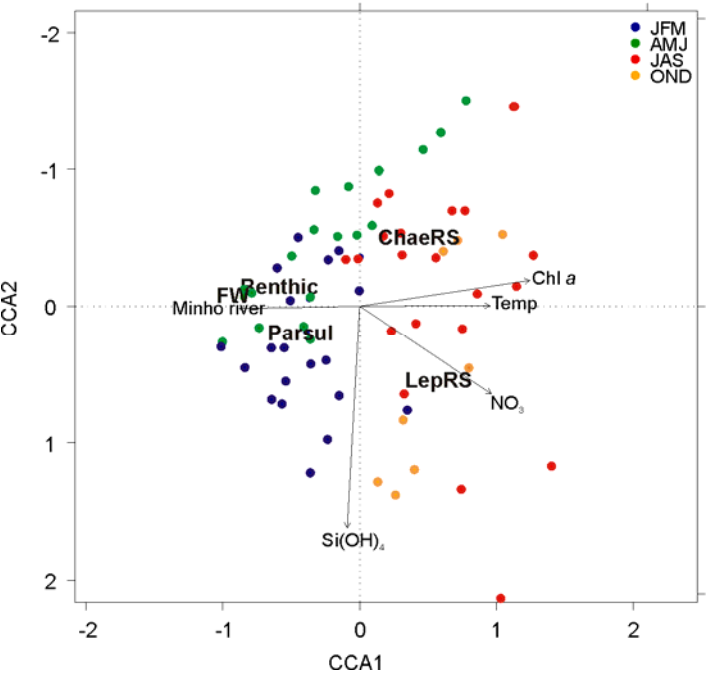


Figure 7

Figure 8

Appendix A. List of diatom species found in both the RAIA sediment trap and surficial sediment sample (Geo B 11002). Species that appeared in more than one sediment trap sample with a percentage higher than 2% of the total abundance are highlighted in bold. Ecology preferences: B: benthic; MP: meroplanktonic; P: planktonic; CO: coastal; O: open ocean; C: cosmopolitan; M: marine; MB: marine to brackish; BF: brackish to freshwater; BR: brackish; FW: freshwater.

Diatom species	Ecology	Sediment trap	Sediments
Achnanthes brevipes C. Agardh	B-MB	X	X
Achnanthes sp. (cf. FW)	B-FW	X	
Actinocyclus curvatulus Janisch	P-M-C	X	X
Actinocyclus octonarius Ehrenberg	P-M-C	X	
Actinoptychus senarius (Ehrenberg) Ehrenberg	MP-C	X	X
Actinocyclus sp.	P	X	X
Amphora gracilis Ehrenberg	B-FW	X	
Amphora marina T.V. Desikachary & P. Prema	B-MB	X	
Amphora sp.	B	X	
Anorthoneis excentrica (Donkin) Grunow	B-M	X	
Asteromphalus flabellatus (Brébisson) Greville	P-M	X	
Asteromphalus sp.	P-M-O	X	
Aulacoseira cf. *granulata* (Ehrenberg) Simonsen	P-FW	X	X
Aulacoseira sp.	P-FW	X	X
Azpeitia neocrenulata (S.L.VanLandingham)	P-M	X	
Azpeitia nodulifera (A.Schmidt) G.A.Fryxell & P.A.Sims	P-M	X	
Bacillaria paxillifera (O.F. Müller) T.Marsson	B-P-M	X	
Bacteriastrum hyalinum Lauder	P-M	X	
Caloneis sp.	B-MB	X	
Campylodiscus incertus A.W.F. Schmidt	P-M	X	
Campyloneis grevillei (W.Smith) Grunow & Eulenstein	B-M	X	
Campylosira cymbelliformis Grunow ex Van Heurck	B-MB-CO	X	
Catacombas gaillonii (Bory) D.M.Williams & Round	B-M	X	
Cerataulus smithii Ralfs ex Pritchard	B-MB	X	
Chaetoceros lorenzianus Grunow	P-M-CO	X	
Chaetoceros sp.	P-M-CO	X	
Chaetoceros sp. (resting spores)	M-CO	X	X
Cocconeis disculoides (Hustedt) Stefano & Marino	B-M	X	
Cocconeis guttata Husted & Aleem	B-M	X	
Cocconeis hoffmannii Simonsen	B-M	X	
Cocconeis neodiminuta Krammer	B-FW	X	
Cocconeis placentula Ehrenberg	B-FW	X	X
Cocconeis pseudomarginata Gregory	B-M	X	
Cocconeis scutellum Ehrenberg	B-M	X	X
Cocconeis speciosa Gregory	B-M	X	
Cocconeis stauroneiformis (W.Smith) H. Okuno	B-M	X	

	Cocconeis sp.	B	X	
	Coscinodiscus gigas Ehrenberg	P-M	X	
	Coscinodiscus marginatus Ehrenberg	P-M-OC	X	X
	Coscinodiscus cf. *oculus-iridis* (Ehrenberg) Ehrenberg	P-M-OC	X	
5	**Coscinodiscus radiatus** Ehrenberg	P-M-OC	X	X
	Coscinodiscus sp.	P-M	X	
	*Ctenophora pulchell*a (Ralfs ex Kützing)	P-BF	X	
	Cyclotella meneghiniana Kützing	P-CO-BF	X	X
	Cyclotella plitvicensis Husted	P-FW	X	
10	*Cyclotella stelligera* Cleve & Grunow in Van Heurck	P-FW	X	
	Cyclotella radiosa (Grunow) Lemmermann	P-FW	X	
	Cyclotella sp.	P-(FW)	X	
	Cyclostephanos sp.	P	X	
	Cymbella affinis Kützing	B-FW	X	X
15	*Cymbela* sp.	B	X	
	Delphineis minutissima (Husted) Simonsen	P-M-CO	X	X
	Delphineis surirella (Ehrenberg) G.W. Andrews	P-M-CO	X	
	Detonula pumila (Castracane) Gran	P-M-CO	X	
	Dimeregramma minor (Gregory) Ralfs ex Pritchard	B-M	X	
20	*Diploneis* cf. *bombus* (Ehrenberg) Ehrenberg	B-MB	X	X
	Diploneis didymus (Ehrenberg) Ehrenberg	B-MB-BFW	X	
	Diploneis smithii (Brébisson) Cleve	B-MB-BFW	X	
	Diploneis cf. *stroemii* Husted	B-M	X	
	*Diploneis suborbiculari*s (W.Gregory) Cleve	B-M	X	
25	*Diploneis weissflogii* (A.W.F.Schmidt) Cleve	B-M	X	
	Diploneis sp.	B	X	
	Dytilum sp	P-M-CO	X	
	Encyonema sp.	B-FW	X	
	Epithemia sp.	B-BFW	X	
30	*Eunotia* cf. *pectinalis* (Kützing) Rabenhorst	B-FW	X	
	Eunotia praerupta (Grunow)	B-FW	X	
	Eunotia sp.	B-FW	X	
	Fragilariforma constricta (Ehrenberg) D.M.Williams & Round	B-FW	X	
	Fragilaria crotonensis (Kitton) Cleve & Möller	B-BFW	X	
35	*Fragilaria inflata* (Heiden) Hustedt	B-FW	X	
	Fragilaria investiens (W. Smith) Clever-Euler	B-M	X	
	Fragilaria schulzii Brockmann	B-M	X	
	Fragilaria sp.	B-C	X	
	Fragilariforma virescens (Ralfs) D.M.Williams & Round	B-P-FW	X	
40	*Gomphonema* sp.	B	X	X
	Gomphonema cf. *acuminatum* (Ehrenberg)	B-BFW	X	
	Gomphonema cf. *constrictum* (Ehrenberg)	B-FW	X	
	Gomphonema parvulum (Kützing) Kützing	B-FW	X	
	Grammatophora angulosa (Ehrenberg)	B-M	X	
45	**Grammatophora marina** (Lyngbye) Kützing	B-M	X	X
	Grammatophora oceanica (Ehrenberg) Cleve	B-M	X	
	Grammatophora sp.	B-M	X	
	Grammatophora serpentina (Ehrenberg) Hartley	B-M	X	
	Haslea sp.	B-P-M-MB	X	
50	*Hantzschia* sp.	B-M-MB	X	

	Species	Ecology		
	Hemidiscus cuneiformis Wallich	P-M-O	X	
	Hemiaulus sp.	P-M-CO	X	
	Hyalodiscus scoticus (Kützing) Grunow	P-M-CO	X	
	Leptocylindrus sp. (resting spores)	M-CO	X	X
5	*Licmophora abbreviata* (C.Agardh)	B-M	X	
	Licmophora sp.	B-M	X	
	Luticola mutica (Kützing) D.G.Mann	B-FW	X	
	Martyana martyi (Héribaud-Joseph) Round	B-BR-FW	X	
	Melosira moniliformis (O.F.Müller) C.Agardh	B-M	X	
10	*Melosira varians* C.Agardh	P-FW	X	
	Melosira westii W. Smith	P-M-CO	X	X
	Melosira sp.	B-P-M-BR-FW	X	X
	Navicula bacillum Ehrenberg	B-(P)-M-CO	X	
	Navicula cf. *cancellata* Donkin	B-(P)-M-CO	X	
15	*Navicula cincta* (Ehrenberg) Ralfs	B-FW	X	
	Navicula mutica Kützing	B-FW	X	
	Navicula cf. *pennata* A.Schmidt	B-(P)-M-CO	X	
	***Navicula* sp**.	B-(P)	X	
	Nitzschia angularis W. Smith	P-M-CO	X	
20	*Nitzschia longissima* (Brébisson) Ralfs	P-M	X	
	Nitzschia macilenta W. Gregory	M-CO	X	
	Nitzschia marina Grunow	P-M	X	X
	Nitzschia umbonata (Ehrenberg) H. Lange-Bertalot	M-FW	X	
	Nitzschia sp.	P-M-O	X	X
25	**Odontella aurita** (Lyngbye) C.Agardh	P-M-CO	X	
	Odontella longicruris (Greville) M.A.Hoban	P-M-CO	X	
	Odontella sp.	P-M	X	
	Opephora marina (W. Gregory) Petit	B-M	X	
	Paralia sulcata (Ehrenberg) Cleve	MP-CO	X	X
30	*Petroneis humerosa* (Brébisson ex W.Smith) Stickle & D.G.Mann	B-M	X	
	Pinnularia borealis Ehrenberg	B-FW	X	
	Pinnularia sp.	B	X	
	Pleurosigma elongatum W. Smith	P-BR	X	
	Pleurosigma normanii Ralfs in Pritchard	P-M	X	
35	*Pleurosigma* sp.	P	X	
	Pleurosira laevis (Ehrenberg) Compère	P-BR	X	
	Porosira glacialis (Grunow) Jørgensen	P-BR	X	
	Podosira stelliger (Bailey) Mann	P-M	X	X
	Proboscia alata (Brightwell) Sundström)	P-M	X	
40	*Psammodiscus nitidus* (Gregory) Round & Mann	MP-M-CO	X	
	Pseudo-nitzschia pungens (Grunow ex Cleve) G.R.Hasle	P-M-C	X	
	Pseudo-nitzschia seriata (Cleve) H.Peragallo	P-M	X	
	Rhaphoneis amphiceros (Ehrenberg) Ehrenberg	B-M	X	
	Rhabdonema arcuatum (Lyngbye) Kützing	B-M	X	
45	*Rhabdonema minutum* Kützing	B-M	X	
	Rhabdonema sp.	B-M	X	
	Rhizosolenia bergonii Peragallo	P-M-O	X	
	Rhizosolenia hebetata (Bailey) Gran	P-M-O	X	
	Rhizosolenia sp.	P-M-O	X	
50	*Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot	B-BR-FW	X	

	Rhoicosphenia marina (Kützing) M.Schmidt	B-M-CO	X	
	Roperia tesselata (Roper) Grunow ex Pelletan	P-M-O	X	X
	Staurosirella pinnata (Ehrenberg) D.M.Williams & Round	MP-FW	X	
	Staurosirella sp.		X	
5	*Stellarima stellaris* (Roper) G.R.Hasle & P.A.Sims	P-M	X	
	Stephanodiscus astrea (Ehrenberg) Grunow	P-C	X	
	Stephanodiscus sp.	P-C	X	X
	Stephanopyxis turris (Greville) Ralfs in Pritchard	P-M	X	
	Surirella sp.	B-M-BR	X	
10	*Synedra* sp.		X	
	Ulnaria ulna (Nitzsch) Compère	B-FW	X	X
	Tabellaria fenestrata (Lyngbye) Kützing	B-FW	X	
	*Tabellaria flocculos*a (Roth) Kützing	B-FW	X	
	Tabellaria sp.		X	
15	*Tetracyclus glan*s (Ehrenberg) F.W.Mills	B-FW	X	
	Thalassiosira eccentrica (Ehrenberg) Cleve	P-M-O	X	X
	Thalassiosira cf. leptopus (Grunow) Hasle & G.Fryxell	P-M-O	X	X
	Thalassiosira lineata Jousé	P-M-O	X	
	*Thalassiosir*a sp.	P	X	X
20	**Thalassionema nitzschioides** (Grunow) Mereschkowsky	P-M	X	X
	Toxarium undulatum Bailey	P-M	X	
	Trachyneis aspera (Ehrenberg) Cleve 1894	B-M-BR	X	X
	Triceratium favus Ehrenberg	P-M	X	
	Tryblionella angustata W.Smith	P-M	X	
25	*Tryblionella navicularis* (Brébisson) Ralfs	B-BR	X	