Review of BG-2016-201

Dear Dr Zúñiga and co-authors,
I have read the updated version of your manuscript. It has improved considerably, although after some close reading of mine, my opinion remains that you need to make some more thorough changes to the manuscript before acceptance in Biogeosciences. First of all, in my previous assessment, I asked you to use your results to improve paleoceanographic reconstructions using diatoms. One of the reasons for asking this, is that approximately half of the introduction focusses on the use of diatoms for paleoceanographic reconstructions. Could paleosamples be included as 'additional' samples to the CCA (figure 8) to determine what past conditions were (given those included here in the analysis). What would roughly be the uncertainty related to such an approach and what could be done to further improve the applicability of diatoms as reconstruction tools? Second, and as stated earlier by one of the reviewers, the results presented here should be more directly be compared to the results of previous studies reporting (longterm) monitoring studies. Issues that need to be discussed include: are total fluxes comparable to those of other studies? What are the (dis)similarities between the relative abundances reported here and those of other studies? The CCA shows the correlation between some species and some environmental parameters: is this also reported in other studies? And if there are (large) discrepancies, what could have caused them? Are there environmental parameters that were not included in the analysis that are known from other studies to have a large influence on diatom distribution?

First of all, the authors would like to gratefully thank all comments and suggestions from the editor. They undoubtedly improve the quality of this manuscript.

In agreement with first editor´s comment, the authors consider that it would be very interesting to include paleosamples in the CCA. However, this is conceptually and methodologically not possible. CCA was carried out between the diatom assemblages from the sediment trap samples (dependent variables) and the environmental factors (independent variables) with the aim to evaluate how the environmental conditions were related with diatoms export from the surface productive layer. To do that they used interpolated water column environmental data for the time interval recovered by each trap sample (see section 3.5 for further details). It is obvious that such environmental data are not available for the paleosamples. Indeed, our sediment trap-environmental data calibration will bring the opportunity to infer paleoenvironmental conditions over geological timescales from using downcore fossil diatom assemblages. This is the goal of this work and why the authors consider it so relevant for the scientific community working in the NW Iberian margin, the most important coastal upwelling region of Europe.

On the other hand, answering the question raised by the editor with regards the comparison with other studies carried out in other coastal upwelling systems, the authors would like to underline that even though values were similar in terms of "orders of magnitude", they are not really comparable. Long-term diatom flux data in other coastal upwelling systems were recovered at locations further offshore and deeper, complicating a direct comparison with data presented here. For that reason, the authors would propose just to reference previous studies in the introduction section. However, whether editor considers such comparison absolutely necessary the authors would propose to initiate discussion section with a sentence like that:

Diatoms exported out from the photic zone (2.2 (±5.6) 106 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).

The authors would also like to state that to their knowledge there are no studies that made a CCA to correlate diatom fluxes and environmental variables. Such statistical analysis is frequently used on studies made over water column samples, but not over sediment trap samples. Indeed, this probe the value and worth of the data presented here, since it demonstrates for the first time how the relationship between water column diatoms assemblage and environment is also transferred to diatoms exported from the photic layer. In this regard, the authors would also like to highlight that they consider environmental variables dataset used in this study a fairly complete picture of factors affecting diatoms development and export in the marine environment. They want to remember that even only significant variables were presented in the CCA, a complete dataset of environmental parameters were considered (see section 3.5).

The authors encourage editor to read the new version of the manuscript where all suggestions pointed out by him/her were taken into account. They really consider that this new version really highlights the goal of this work. The abstract and both the introduction and discussion sections were modified in order to achieve this. In addition, main conclusions derived from this work were summarized in this new version.

Below, I have added some more, minor comments that may help to improve the manuscript.

Abstract
The first sentence of the abstract is a bit confusing: it is difficult to see how "diatom species could determine the primary production signal...". I think this reads better as something like: "...how the community composition of diatoms reflects sea surface conditions..." Or something similar. This would also make the second sentence of the abstract redundant.
The authors agree with editor´s comment. First sentence has been modified in the new version of the manuscript.

Line 17: remove "was used"
Done

Line 18 and throughout the text: "2.2 ± 5.6 106" is a bit confusing. "2.2 (±5.6) * 106" would be more clear.
Done

Line 19: remove "strong"
Done

Line 19-20: discrepancies usually refer to unexpected/ unusual differences between multiple items. I guess here the authors imply discrepancies between different sediment trap samples, although that may be better described as "variability". Or do the authors imply that there is a real discrepancy between the totality of the sediment trap samples and another dataset?

The authors would like to clarify that the term “discrepancies” is not referred to variations between sediment trap samples nor to the comparison with another dataset, but indicates unexpected results when comparing water column and sediment trap diatom´s abundances seasonally. In any case, this term has been modified by “contrasting results”.

Line 25-26: it is unclear what is supposed to correlate... Absolute numbers are not correlated to what exactly?
With this sentence the authors wanted to highlight that diatom fluxes registered by the sediment trap moored at the base of the photic zone did not reflect total diatoms abundance in the surface layer. In any case, sentence has been modified to make this statement clearer.

Lines 25-30: it should become clear that sediment trap-data were compared to diatoms retrieved from core-top material.
The authors totally agree with editor´s comment. Last paragraph of the abstract has been modified to remark this important aspect.

Line 32: the use of “Further” is inappropriate here.
This term has been eliminated in the new version of the manuscript

Line 33: please write “vs.” in full.
Done

Introduction
Line 5-8: the end of this paragraph suggests that this study will somehow deal with the global contribution of diatoms in exporting carbon and Si to the seafloor, which it doesn’t. These sentences should reflect the overall aim of this study and should connect to the main conclusions. It also doesn’t link to the first sentence of the second paragraph.
Attending to editor suggestion this paragraph has been modified. The authors consider new paragraph better reflects the overall aim of our study, and otherwise also connect to the main conclusions.

Line 9-15: it is not clear from the text why there should be a need for regional calibrations. Probably best to rephrase this paragraph: there are numerous long-term studies, which have shown that there are considerable differences between regions. Then, why is it particularly interesting/ necessary to study the Iberian Margin? Are regions with clear seasonal upwelling not covered in the listed long-term studies?
This paragraph has been modified attending to the issues raised.

Line 20-22: so, if other authors already showed that diatoms from core-top samples reflect those that are found in the overlying water column, what is the need of this particular study?
The need of this study is justified since studies based on core-top samples achieved their conclusions based on discrete water column data recovered during isolate cruises that directly were compared with surface sediment samples spatially distributed along the margin. So, from author´s perspective, they consider these studies “unfinished” because of the limitation of water column data to infer diatoms export out from the surface productive layer in seasonal terms. In that sense, their multi-year sediment trap dataset allowed the link between the seasonal successions of living diatoms community with the fossil

diatom assemblage registered on the seafloor sediments. With their data the authors not only show that *Chaetoceros* and *Leptocylindrus* spp. resting spores in the sediments marks upwelling favourable conditions but expose that each diatom genera reflect different environmental conditions in response to different phases of the upwelling regime. This is the goal of this work. The authors have modified abstract and discussion in order to clearly submit this message to the audience.

Material and methods
External forcing
Line 13-14: replace "accessed via" by "available through".
Done

Line 25: not all readers may be familiar with "Puertos del Estado". Please explain what this is. Water column
Web page has been included in the new version of the manuscript in order to provide the reader with additional information.

Line 27: replace "on board" by "by".
Done

Line 29: assuming that the Niskin bottles are made of PVC and have a volume of 10 liters, please put a space after the "L" in "10-LPVC".
Done

Line 7: from what depths were the samples taken for determining the diatom abundances? Were these depths sampled every single time? Were the samples combined before analysis of the diatom species assemblage? If not, did the authors find consistent differences between water depths?
As stated in methods section for diatoms counting and identification samples from **5 water depth** were used". This depth was sampled monthly during the experimental years, except during the period January-June 2010. The samples were never combined before the analysis. To determine diatom species assemblage each sample was treated separately as shown in figure 4.

Line 13-14: this sentence is redundant: it also appears at the end of section 3.3. Surface sediments
The authors agree with editor´s comment that the sentence is redundant. However, as suggested by one of the reviewers, they consider it a key aspect because all statistical analysis is based on these criteria.

Line 13-17: how was the sample taken? To what depth was the box core sampled? Do the authors have an idea about the sedimentation rate in this area and thereby, have an idea about the age that the diatoms may cover? Was there only one sample taken? If this is the case, could the authors make clear why there is no influence of spatial variability?
As explained in section 3.4. surface sediment sample was collected with a giant box corer in a station located near RAIA position at 111 m water depth.
In relation with the sedimentation rate for this study area the authors would like to pointed out that this was evaluated from Pb210 analyses carried out over a sediment core located close to our study site

(42.16664, -9.02669; 129 m). From this core, the authors estimated a linear sedimentation rate of 0.0784 cm/yr, meaning a temporal resolution of ca. 13 years in 1cm of sediment. However, they considered these data may be distorted by the strong resuspension processes occurring during autumn-winter downwelling periods. For that reason, they decided not to use these data in the manuscript and just consider the surface sediment sample as representative of the "present".

The authors would also like to clarify that this is not the unique sample recovered along the NW Iberian margin. Indeed, in the first version of the manuscript the authors presented two core top samples across margin. However, as suggested by reviewer 1, only the sample located close to the mooring line should be used.
Response to reviewer 1 (first version of the manuscript): Higher diatom abundances in the surface sediment at GeoB 11002-1 onshore station responded to primary production signal in the photic layer. Even not presented here the authors have evaluated Chl a contents through a transect perpendicular to the coast during almost the entire sampling period. They observed how seasonal Chl a at the surface productive layer is intensified close to the coast, in agreement with diatom´s abundance in surface sediment samples. This confirms the use of valves/g as a good indicator of diatom´s production in the photic zone. In that sense, since onshore surface sediment sample is closest to the RAIA station the authors consider it better to reflect the conditions at this site and will be the only one used in the new version of the manuscript.

Statistical data analysis
Line 19: please remove the second "between".
Done

Results
Environmental conditions
Line 8-22: please add a description of the variability between years. I.e. are the observed trends consistent between years?
After a careful reading of the manuscript the authors consider inter-annual description as not necessary. This aspect is not discussed at any time neither in the other result sections nor in the discussion.

Line 15-16: what exactly is the uncertainty here? Is this the standard deviation? If this is the case, the variability between samples must be very high and there should be a report here of minimum and maximum values in addition to the average values.
Done

Line 16-17: what do "exceptionally" and "relevant" mean here?
The term "exceptionally" has been modified to "sporadically" to avoid confusion. Also, the term "relevant" has been replaced by "highly abundant".

Line 18: should be "lead" instead of "leaded" Sinking particulate material
Corrected

Line 24-5: the description does not mention (variability in) absolute numbers as found in the samples, only the relative numbers. A brief description of the trends in absolute numbers should also be included.

Additional information has been included in the new version of the manuscript.

Line 25: should be "followed".
Corrected

Relationships between sediment trap main diatom groups
Line 11-22: why are the samples from the water column not added to the CCA?
The authors have only used sediment trap data for the CCA since they consider strength of this work is to show the link between the environmental and the sink of diatoms as a potential source of microfossils to the seafloor sediments. Indeed, the relationship between the water column diatom community and the environmental variables in this coastal upwelling system has been described in previous works as shown in the discussion.

Nogueira, E., Figueiras, F.G.: The microplankton succession in the Ría de Vigo revisited: species assemblages and the role of weather-induced, hydrodynamic variability. J. Mar. Sys. 54, 139-155, 2005.

Figueiras, F.G., Rios, A.F.: Phytoplankton succession, red tides and the hydrographic regime in the Rias Bajas of Galicia. In: Toxic Phytoplankton Blooms in the Sea. T.J., Smayda and Y. Shimizu, Ed. Elsevier Science Publishers B.V., 239-244, 1993.

Casas, B, Varela, M., Bode, A.: Seasonal succession of phytoplakton species on the coast of A Coruña (Galicia, Northwest Spain). Boletín del Instituto Español de Oceanografía, 15, 413-429, 1999.

Discussion
Sediment trap diatom assemblage
Line 19: "One additional evidence" is not correct English. Please rephrase.
Sentence has been rewritten.

Line 9-28: this section lacks a thorough comparison to previous (long-term) monitoring studies on diatom assemblages, which needs to be included in the discussion.
As explained immediately above long-term diatom flux data in other coastal upwelling systems were recovered at locations further offshore and deeper, complicating a direct comparison with data presented here. For that reason and even values were similar in terms of "orders of magnitude", they would propose not to include these studies in the discussion section, only reference them in the introduction.
However, whether editor considers such comparison absolutely necessary the authors would propose to initiate discussion section with a sentence like that:

Diatoms exported out from the photic zone (2.2 (±5.6) 106 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).

Seasonal succession of diatom species As stated before, this section (or an entire new one) needs to make clear what this dataset can add to the use of diatom assem-blages as reconstruction tools. With the

statistical analysis presented in this section, the authors should be able to propose a (quantitative) use of such assemblages to reconstruct upwelling/ downwelling conditions.
A new section at the end of the manuscript has been added trying to summarize main conclusions of the study. Differences between upwelling/donwelling conditions in relation with diatoms assemblages have been described.

Figures The lighter two colors are difficult to distinguish in figure 4.
Figure has been modified

Figure 8 can be improved too by enhancing the contrast in the symbols used.
Figure has been modified. Maximum contrast has been applied to the symbols. The authors wonder whether it is a colour screen problem.

The captions of figures 3-7 should explicitly state whether the figure displays CTD- or sediment trap samples.
New information has been included in the new version of the manuscript

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 ~~as to~~with regards how water column ~~diatoms species determine primary production signal in exported and buried particles. We evaluated how the~~ diatom's abundance and assemblage composition is seasonally transferred from the photic zone to seafloor sediments. To address this, we used a data~~combined analysis~~set ~~of~~ derived from water column, sediment trap and surface sediment samples recovered in the NW Iberian coastal upwelling system~~ was used~~.

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 ~~strong~~ seasonal variability. ~~Discrepancies~~ 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~~ registered during low productive downwelling periods~~. They were principally related to surface sediment remobilization and intense Minho and Douro riverine discharges that constitute an additional source of particulate ~~material~~ matter to the inner continental shelf. In fact, ~~C~~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. ~~Nevertheless, during highly productive upwelling periods~~

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~~no water column-sediment trap direct correlations were found in terms of absolute numbers. However, diatom species sinking out from the photic zone (principally represented by *Chaetoceros* and *Leptocylindrus* spp. resting spores) agreed with those species dominating the water column. This demonstrates that the prevalence of these highly resistant resting spores in the sediments reflect the dominance of both diatom taxa in the surface photic layer when primary production is seasonally intensified. Moreover, our data shows that *Chaetoceros* spp. resting spores dominated the sediment trap assemblage under persistent upwelling winds, high irradiance levels and cold and nutrient-rich waters, while *Leptocylindrus* spp. spore fluxes were favoured when northerly winds relaxed, and surface water warming promoted water column stratification. Further, this finding will enable the use of relative abundance of both groups in the sediment records as a proxy of persistent vs. intermittent upwelling conditions, which is of particular relevance to infer climatic and oceanographic conditions in the past.~~

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

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Con formato: Color de fuente: Automático 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.

~~The ocean plays a critical role in the global carbon cycle as a vast reservoir that takes up a substantial portion of the anthropogenically-released carbon from the atmosphere (LeQuéré et al., 2009). A key aspect to understand the ocean carbon cycle includes the role of diatoms as sinkers of primary-produced organic carbon and biogenic silica from the surface productive layer to the sediment record (Sancetta, 1989; Smetacek, 1999; Boyd and Trull, 2007; Romero and Armand, 2010; Tréguer and De La Rocha, 2013). This point underpins the importance and effectiveness of diatom species as productivity indicator in Earth´s climate system studies.~~

~~Despite the significant advances in this topic, primary production paleoreconstructions via diatom species still require regional calibrations to better understand their response to particular environmental conditions, and to analyse which species transfer the primary production signal via exported and buried particles. Coastal upwelling systems, as sites of major primary production with a marked seasonality are thus ideal for these types of studies (Walsh, 1991; Falkowski et al., 1998; Capone and Hutchins, 2013). The importance and the effectiveness of diatoms as productivity indicators at longer time scales in highly productive coastal regions have been shown by many long-term continuous datasets (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 where seasonal upwelling favouring winds generate high primary production rates through modulation of the microplankton community structure (Figueiras and Pazos, 1991; Nogueira and Figueiras, 2005; Espinoza-González et al., 2012), several works have assessed the diatom species ecology – in terms of its environmental conditions by comparing the recent sediment record to the hydrographic conditions (Abrantes, 1988; Bao et al., 1997; Abrantes and Moita, 1999; Gil et al., 2007; Bernárdez et al., 2008; Abrantes et al., 2011). Those authors concluded that the spatial distribution of the sedimentary diatom abundance and assemblages´ composition reflects the hydrographic upwelling patterns and primary production trends, with *Chaetoceros* resting spores appearing as a good tracer of the upwelling regime.~~

~~The aim of this study is to understand the seasonal mechanisms regulating diatom production and export from the photic zone into the seafloor sediments in the NW Iberian coastal upwelling system, through the combined analysis of diatom abundances and assemblages composition in the water column, sediment trap and surface sediment samples.~~

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 nutrients rich subsurface Eastern North Atlantic Central Water (ENACW) ~~on the shelf and into~~

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~~the Rías~~, resulting in ~~a~~high primary production ~~increase in the area~~ (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 ~~hydrodynamic~~ 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 ~~accessed~~ available through ~~via t~~the MeteoGalicia website (www2.meteogalicia.es).

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

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

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 ~~W~~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).

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3.2 Water column

RAIA station (75 m water depth) was visited monthly ~~on board~~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 (~~with~~ 10-L PVC Niskin bottles). Aliquots of these samples were used for ~~for i~~inorganic nutrients, ~~and~~ chlorophyll *a* (Chl *a*)~~analysis,~~ and diatoms counting/~~and~~ species identification analysis.~~.~~

Water column stability (0-35 m) was analysed by using Brunt Väisälä frequency parameter, $N^2 = [g / z] \ln$ (ρ~~p~~$_z$/ρ~~p~~$_0$) where g is the local acceleration of gravity, z is the water depth and, ρ_z~~p_z~~ and ρ_0~~p_0~~ the bottom and surface density, respectively.

Inorganic ~~N~~nutrient~~s~~ concentrations w~~as~~ere 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 ~~from 5 water depth~~ was used~~, taking into account that for the whole sampling period maximum variability of Chl *a* content occurred at the surface (Zúñiga et al., 2016)~~. The samples were preserved with Lugol´s iodine until micrococscopic observation. Depending on the water column Chl *a* concentration volumes ~~varied~~ between 10 to 50 mL ~~and~~ 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 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., 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 ~~I~~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, (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~~opal~~ 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~~ing~~ ~~with~~ $HgCl_2$ by repeated settling in distilled water. Subsequently, organic matter and carbonates were removed by the addition of H_2O_2 (30 %) and HCl (10 %), 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 ~~between~~ 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~~-Q_x~~ values (Fig. 2a and 2b). During these periods the region was strongly affected by strong SW storms promoting wave heights ~~frequently~~ 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 ~~were low~~ ranged from 5 to 135 cel mL^{-1}~~(34 ± 49 cel mL^{-1})~~ with small centric diatoms accounting for the largest shares (52 ± 25 %) (Fig. 3c, 4b and Table 3). Only ~~exceptionally~~sporadically, *Navicula* spp. and *Paralia sulcata* ~~become relevant~~were highly abundant (Fig. 4) ~~(Fig. 3c, 4 and Table 3)~~. 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~~ed~~ to the development of Chl *a* maxima (Fig. 2a, 2b and 3). During the~~o~~se highly productive upwelling periods, diatom abundances ~~achieved maximum levels~~were high (up to 7629 cel mL^{-1}~~-~~) (Figure 3c). T~~and t~~he predominant ~~genera~~ 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).

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4.2 Sinking particulate material time series

The biogenic silica flux time series~~,~~ ~~as registered by the trap,~~ that ranged between 7 - 1001 mg m^{-2} d, contributed from 2% to 10% of the total material, and was~~is~~ 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~~2~~ x 10~~^{4}~~^{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) s~~s~~tepwise 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 ~~temperature~~ 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 ~~and IPC periods~~periods.

5 Discussion

~~The~~ Diatoms exported out from the photic zone (2.2 (±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). ~~siliceous microorganism fluxes determined from the sediment trap, mostly represented by diatoms, showed significant discrepancies with water column diatom abundances (Fig. 3c, 5c and 5e)~~In fact, ~~. Such discrepancies were determined by the NW Iberian inner continental margin hydrodynamics, as explained in detail by Zúñiga et al. (2016). These authors described how maximum particle fluxes occurring during downwelling periods were associated with allochthonous sources, explaining~~ 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, ~~these authors~~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. ~~The implications of these aspects over the use of diatoms as a proxy of paleoproductivity are discussed hereafter.~~

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 ~~M~~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) ~~run parallel with higher wave heights during highly hydrodynamic downwelling periods (Fig. 2c and 6a). 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) confirms~~ may only be explained if~~that~~ 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 ~~had a significant effect over~~ impacted the water column thermohaline structure (Fig. 2c and 2d). The ~~significant~~ increase in freshwater diatoms associated to river runoff ~~also confirms~~reinforce that those continental inputs are~~s~~ 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 ~~- As pointed out by previously published sediment trap data from the adjacent Ría de Vigo,~~ 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~~, in fact,~~ 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 ~~living~~ water column diatom community was ~~strongly linked to seasonality revealed by~~ modulated by the seasonality of environmental variables, with the highest abundances always recorded during upwelling ~~favourable~~ periods, when irradiance and water column characteristics promote favourable conditions for diatom growth (Fig. 2 and 3). In this regard,

~~A~~a detailed analysis of the marine diatom assemblage as a whole ~~during upwelling productive seasons~~ 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 ~~(e.g. *Nitzschia* spp., *Pseudo-nitzschia* spp. and small centric)~~ in both the sediment trap and the surface sediment samples (Table 3). This confirms that~~. This observation points to~~ selective dissolution processes act~~ed~~ed~~ing~~ on thin-walled, less silicified diatoms and thus, only ~~. As a result, the~~ 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 ~~frustules, not only have a ballast effect that promotes a faster arrival to the sediments, but they also have a higher preservation potential in seafloor sediments (Alexander, 1990; Raven and Waite, 2004). Indeed, diatoms assemblages in both sediment trap and surface sediment samples were mainly composed of highly dissolution resistant *Chaetoceros* and *Leptocylindrus* spp. resting spores (Table 3). This fact confirms that these diatom genera are a good sedimentary indicator of highly productive upwelling conditions. Indeed, the sink of *Chaetoceros* and *Leptocylindrus* spp. resting spores, occurring in close correlation with the dominance of both diatom groups in the water column assemblage during the upwelling periods~~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

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sedimentary indicator of high primary production in the NW Iberian margin. This bring~~s~~s new ~~important~~ relevant information to previous works carried out along ~~the Iberian~~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).

~~Canonical analysis performed for the sediment trap data confirms the relationship between the relative abundances of both *Chaetoceros* and *Leptocylindrus* spp. resting spores with upwelling favourable conditions (positively positioned in CCA1) (Fig. 8)~~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 ~~. However,~~ (Fig. 4, 7 and 8). Indeed, our sediment trap dataset reflected how~~they occurred at different times as previously described by other works based on water column data (Figueiras and Rios, 1993; Escaravage et al., 1999; Casas et al., 1999; Nogueira and Figueiras, 2005).~~ 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). ~~The sink of *Chaetoceros* spp. resting spores into the sediment trap was 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. 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.~~In this regard, our finding linking environmentally controlled diatom blooms and resting spores vertical export, ~~8).~~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

E~~In summary, e~~ven though the remobilization of bottom sediments by resuspension processes ~~at the inner NW Iberian continental shelf~~may ~~does not allow for~~distort diatoms accumulation/preservation rates in the NW Iberian margin, our results ~~a quantitative evaluation of the water column/sediment record preservation efficiencies, our results~~ bring ~~to~~ light in relation with the use of fossil diatoms in marine sediment records for determining~~the important role of Chaetoceros and Leptocylindrus spp. resting spores formation/preservation in determining the~~ allochtonous sources and primary production paleosignals in this margin ~~at this margin~~. Our main observations may be summarize as follows: i) high diatom fluxes during

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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.~~Moreover, the *Chaetoceros* and *Leptocylindrus* spp. spores contribution to the total marine diatom assemblage in sediment records should allow for the identification of persistent vs intermittent upwelling favourable winds in the past, which has important implications for paleoceanographic and paleoclimatic studies.~~

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~~A~~ 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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The authors gratefully thank the crew of “R/V *Mytilus*” for their valuable help during the cruises. The authors also want to specially recognize specific lab work made from different members of both the Oceanography group from the Instituto de Investigaciones Marinas de Vigo (CSIC) and the Divisão de Geologia e Georecursos Marinhos from Instituto Português do Mar e da Atmosfera (IPMA). Special thanks to M. Zúñiga for his help in the writing process. This study was sponsored by CAIBEX (CTM2007-66408-C02-01/MAR) and REIMAGE (CTM2011–30155–C03–03) projects funded by the Spanish Government, EXCAPA project (10MDS402013PR) supported by Xunta de Galicia, the EU FEDER funded projects RAIA (INTERREG 2009/2011-0313/RAIA/E) and RAIA.co (INTERREG 2011/2013-052/RAIA.co/1E) and the CALIBERIA project (PTDC/MAR/102045/2008) financed by Fundação para a Ciência e a Tecnologia (FCT-Portugal). D.Z. and E.S. were funded by a postdoctoral fellowship (Plan I2C) from Xunta de Galicia (Spain) and (SFRH/BPD/111433/2015) from FCT, respectively. C.S. was funded by a doctoral grant from FCT (Portugal) (SFRH/BD/88439/2012).

References

Abrantes, F.: Diatoms assemblages as upwelling indicators in surface sediments in Portugal. Mar. Geol. 85, 15-39, 1988.

Abrantes, F., Moita, M.T.: Water column and recent sediment data on diatoms and coccolithophorids, off Portugal, confirm sediment record of upwelling events. Oceanol. Acta, 22(1), 67-84, 1999.

Abrantes, F., Meggers, H., Nave, S., Bollman, J., Palma, S., Sprengel, C., Henderiks, J., Spies, A., Salgueiro, E., Moita, T., Neuer, S.: Fluxes of micro-organisms along a productivity gradient in the Canary Islands region (29ºN): implications for paleoreconstructions. Deep Sea Res. II, 49, 3599-3629, 2002.

Abrantes, F., Gil, I., Lopes, C., Castro, M.: Quantitative diatom analyses: a faster cleaning procedure. Deep Sea Res. II 52, 189-198, 2005.

Abrantes, F., Rodrigues, T., Montanari, B., Santos, C., Witt, L., Lopes, C., Voelker, A.H.L.: Climate of the last millennium at the southern pole of the North Atlantic Oscillation: an inner-shelf sediment record of flooding and upwelling. Clim. Res. 48, 261-280, 2011.

Alexander, RMcN.: Size, speed and buoyancy adaptation in aquatic animals. Am. Zool. 30, 189-196, 1990.

Álvarez-Salgado, X.A., Figueiras, F.G., Pérez, F.F., Groom, S., Nogueira, E., Borges, A.V., Chou, L., Castro, C.G., Moncoiffé, G., Ríos, A.F., Miller, A.E.J., Frankignoulle, M., Savidge, G., Wollast, R.: The Portugal coastal counter current off NW Spain: new insights on its biogeochemical variability. Prog. Oceanogr. 56, 281-321, 2003.

Bakun, A.: Coastal upwelling Indices, West Coast of North America, 1946-71. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 1973.

Bao, R., Varela, M., Prego, R.: Mesoscale distribution patterns of diatoms in surface sediments as tracers of coastal upwelling of the Galician shelf (NW Iberian Peninsula). Mar. Geol. 144, 117-130, 1997.

Battarbee, R. W.: A new method for estimating absolute microfossil numbers with special reference to diatoms. Limnol. Oceanogr. 18, 647-653, 1973.

Bernárdez, P., Prego, R., Varela, M., Francés, G.: Diatom thanatocoenosis in a middle Galician Ría: Spatial patterns and their relationship to the seasonal diatom cycle in the water column and hydrographic conditions. Cont. Shelf Res. 28, 2496-2508, 2008.

Bernárdez, P., Varela, M., Pazos, Y., Prego, R., Francés, G.: Biocenosis and thanatocoenosis of diatoms in a western Galician ría. J. Plank. Res. 32 (6), 857-883, 2010.

Boyd, P.W., and Trull, T.W.: Understanding the export of biogenic particles in oceanic waters: Is there consensus?. Progr. Oceanogr. 72, 276-312, 2007.

Capone, D.G., Hutchins, D.A.: Microbial biogeochemistry of coastal upwelling regimes in a changing ocean. Nature, 6, 711-717, 2013.

Castro, C.G., Álvarez-Salgado, X.A., Figueiras, F.G., Pérez, F.F., Fraga, F., 1997. Transient hydrographic and chemical conditions affecting microplankton populations in the coastal transitions zone of the Iberian upwelling system (NW Spain) in September 1986. J. Mar. Res. 55, 321-352.

Casas, B, Varela, M., Bode, A.: Seasonal succession of phytoplakton species on the coast of A Coruña (Galicia, Northwest Spain). Boletín del Instituto Español de Oceanografía, 15, 413-429, 1999.

Castro, C.G., Nieto-Cid, M., Álvarez-Salgado, X.A., Pérez, F.F.: Local remineralization patterns in the mesopelagic zone of the Eastern North Atlantic, off the NW Iberian Peninsula. Deep Sea Res. I, 53, 1925-1940, 2006.

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Dias, J.M.A., González, R., García, C., Díaz-del-Río, V.: Sediment distribution patterns on the Galicia–Minho continental shelf. Prog. Oceanogr. 52 (2–4), 215–231, 2002.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Marquéz, J.R., Gruber, B., Lafourcade, B., Leitao, P.J., Munkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D., Lautenbach, S.: Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography, 36: 27-46, 2013.

Escaravage, V., Prins, T.C., Nijdam, C., Smaal, A.C., Peeters, J.C.H.: Response of phytoplankton communities to nitrogen input reduction in mesocosm experiments. Mar. Ecol. Prog. Series 179, 187-199, 1999.

Espinoza-González, O., Figueiras, F.G., Crespo, B., Teixeira, I.G., Castro, C.G.: Autotrophic and heterotrophic microbial plankton biomass in the NW Iberian upwelling: seasonal assessment of metabolic balance. Aquat. Microb. Ecol. 67, 77-89, 2012.

Falkowski, P.G., Barber, R.T., Smetacek, V.: Biogeochemical controls and feedbacks on ocean primary production. Science, 281, 200, 1998.

Fatela, F., Taborda, R.: Confidence limits of species proportions in microfossil assemblages. Mar. Micropaleontol. 45, 169-174, 2002.

Figueiras, F.G., Pazos, Y.: Microplankton assemblages in three Rías Baixas (Vigo, Arosa and Muros, Spain) with a subsurface chlorophyll maximum: their relationships to hydrography. Mar. Ecol. Prog. Ser. 76, 219-233, 1991.

Figueiras, F.G., Rios, A.F.: Phytoplankton succession, red tides and the hydrographic regime in the Rias Bajas of Galicia. In: Toxic Phytoplankton Blooms in the Sea. T.J., Smayda and Y. Shimizu, Ed. Elsevier Science Publishers B.V., 239-244, 1993.

Figueiras, F.G., Labarta, U., Fernández Reiriz, M.J.: Coastal upwelling, primary production and mussel growth in the Rías Baixas of Galicia. Hydrobiologia, 484, 121-131, 2002.

Fiuza, A.F.G.: Hidrologia e dinâmica das águas costeiras de Portugal. Ph.D. Thesis, Facultade de Ciencias, Univ. Lisboa, Portugal, 1984.

Fraga, F.: Upwelling off the Galician coast, nothwest of Spain. In: Richards, F. (Ed.), Coastal Upwelling. American Geophysical Union, Washington, 176-182, 1981.

Gil, I., Abrantes, F., Hebbeln, D.: Diatoms as upwelling and river discharge indicators along the Portuguese margin: instrumental data linked to proxy information. The Holocene, 17 (8), 1245-1252, 2007.

Hansen, H.P. and Grasshoff, K.: Automated chemical analysis. In: Grasshoff, K., Ehrhadt, M., and Kremling, K. (Eds). Methods of seawater analysis. Verlag Chemie, Weinheim, 347-395, 1983.

Haynes, R., Barton, E.D.: A poleward flow along the Atlantic coast of the Iberian Peninsula. J. Geophys. Res. 95, 11425-11442, 1990.

Jouanneau, J.M., Weber, O., Drago, T., Rodrigues, A., Oliveira, A., Dias, J.M.A., Garcia, S., Schmidt, S., Reyss, J.L.: Recent sedimentation and sedimentary budgets on the wester Iberian shelf. Prog. Ocenogr. 52, 261-275, 2002.

Lange, C.B., Romero, O.E., Wefer, G., Gabric, A.J.: Offshore influence of coastal upwelling off Mauritania, NW Africa, as recorded by diatoms in sediment traps at 2195 m water depth. Deep Sea Res. I, 45, 985-1013, 1998.

~~LeQuéré, C., Raupach, M., Canadell, J.G., Marland, G. et al.: Trends in the sources and sinks of carbon dioxide. Nature Geoscience, doi: 10.1038/ngeo689, 2009.~~

Moita, T.: Spatial variability of phytoplankton communities in the upwelling region off Portugal, Proceedings of the International Council for the Exploration of the Sea, L64, 1-20, 1993.

Mortlock, R.A., Froelich, P.N.: A simple method for the rapid determinations of biogenic opal in pelagic marine sediments. Deep Sea Res. 36 (9), 1415–1426, 1989.

Nogueira, E., Figueiras, F.G.: The microplankton succession in the Ría de Vigo revisited: species assemblages and the role of weather-induced, hydrodynamic variability. J. Mar. Sys. 54, 139-155, 2005.

Oberle, F.K.L., Storlazzi, C.D., Hanebuth, T.J.J.: Wave-driven sediment mobilization on a storm-controlled margin. J. Mar. Sys. 139, 362-372, 2014.

Oksanen J., Blanchet F. G., Kindt R., Legendre P., Minchin P. R., O'Hara R. B., et al.: Vegan: Community ecology. Avaliable online at: http://CRAN.R-project.org/package=vegan, 2015.

Onodera, J., Takahashi, K., Honda, M.C.: Pelagic and coastal diatom fluxes and the environmental changes in the northwestern North Pacific during December 1997-May 2000. Deep Sea Res. II, 52, 2218-2239, 2005.

Otero, P., Ruiz-Villarreal, M., Peliz,A., Cabanas, J.M.: Climatology and reconstruction of runoff time series in northwest Iberia: influence in the shelf buoyancy budget off Ría de Vigo. Sci. Mar. 74 (2), 247-266, 2010.

Raven, J.A., Waite, A.M.: The evolution of silicification in diatoms: inescapable sinking and sinking as escape? New Phytol. 162, 45-61, 2004.

Relvas, P., Barton, E.D., Dubert, J., Oliveira, P.B., Peliz, A., da Silva, J.C.B., Santos, A.M.P.: Physical oceanography of the western Iberia ecosystem: Latest views and challenges. Prog. Oceanogr. 47, 149-173, 2007.

Romero, O.E., Lange, C.B., Wefer, G.: Interannual variability (1988-1991) of siliceous phytoplankton fluxes off northwest Africa. J. Plankton Res. 24 (10), 1035-1046, 2002.

Romero, O.E., Armand, L.K.: Marine diatoms as indicators of mordern changes in oceanographic conditions. In: The Diatoms: Applications for the Environmental and Earth Sciences, 2nd Edition, eds. John P. Smol and Eugene F. Stoermer. Published by Cambridge University Press. Cambridge University Press, 373-400, 2010.

Sancetta, C.: Processes controlling the accumulation of diatoms in sediments: a model derived from the british columbian fjords. Paleoceanography, 4 (3), 235-251, 1989.

Sancetta, C.: Diatoms in the Gulf of California: seasonal flux patterns and the sediment record for the last 15 000 years. Paleoceanography, 10(1), 67-84, 1995.

Schrader, H. J., and Gersonde, R.: Diatoms and silicoflagellates. Utrecht Micropaleontol. Bull., 17:129-176, 1978.

Smetacek, V.: Diatoms and the Ocean Carbon Cycle. Protist, 150, 25-32, 1999.

Tenore, K. R., Alonso-Noval, M., Álvarez -Ossorio, M., Atkinson, L.P., Cabanas, J. M., et al.: Fisheries and oceanography off Galicia, NW Spain: Mesoscale spatial and temporal changes in physical processes and resultant patterns of biological productivity. J. Geophys. Res. 100(C6), 10943-10966, 1995.

ter Braak, C. J. F.: Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology, 67, 1167-1179, 1986.

Tréguer, P.J., De La Rocha, C.L.: The world Ocean Silica Cycle. Annu. Rev. Marine Sci. 5, 477-501, 2013.

Utermöhl, H.: Neue Wege in der quantitativen Erfassung des Planktons (mit besonderer Berücksichtigung des Ultraplanktons). Verh. int. Ver. theor. angew. Limnol. 5: 567-596, 1931.

Utermöhl, H.: Zur Vervollkomnung der quantitativen Phytoplankton-Methodik. Mitt. int. Ver. ther. angew. Limnol. 9: 1-38, 1958.

Venrick, E.L., Reid, F.M., Lange, C.B.: Siliceous phytoplankton in the Santa Barbara Channel: a seven-year comparison of species in a near-bottom sediment trap and in water samples from the euphotic layer. CalCOFI Rep., Vol. 44, 2003.

Vitorino, J., Oliveira, A., Jouanneau, J.M., Drago, T.: Winter dynamics on the northern Portuguese shelf. Part 2: bottom boundary layers and sediment dispersal. Progr. Oceanogr. 52 (2–4), 155–170, 2002.

Walsh, J.J.: Importance of continental margins in the marine biogeochemical cycling of carbon and nitrogen. Nature, 350, 53-55, 1991.

Zúñiga, D., Alonso-Perez, F., Castro, C.G., Arbones, B., Figueiras, F.: Seasonal contribution of living phytoplankton carbon to vertical fluxes in a coastal upwellig system (Ría de Vigo, NW Spain). Cont. Shelf Res. 31, 414-424, 2011.

Zúñiga, D., Villacieros-Robineau, N., Salgueiro, E., Alonso-Pérez, F., Rosón, G., Abrantes, F., Castro, C.G.: Particle fluxes in the NW Iberian coastal upwelling system: hydrodynamical and biological control. Cont. Shelf Res. 123, 89-98, 2016.

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.

~~Small centric group in water column samples includes centric diatoms cells which diameter did not allow for species identification and *Thalassiosira* spp. small. Small centric in both sediment trap and surface sediment samples includes: *Coscinodiscus marginatus, Coscinodiscus radiatus, Thalassiosira eccentrica*; Chaeto. and Lepto. spp: *Chaetoceros* and *Leptocylindrus* spp. cells and resting spore valves counted in the water column and both sediment trap and surface sediment samples, respectively; Aster. glac: *Asterionellopsis glacialis*; Deton. pum: *Detonula pumila,* Guin. del: *Guinardia delicatula,* Skelet. cost: *Skeletonema costatum.* Most relevant species are highlighted in bold.~~

	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

Tabla con formato

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 irrradiance 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~~-Q_x~~), (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 ~~at~~ 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 ~~has been classified~~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 ~~diatom and~~ valves and resting spores~~s valves~~) fluxes ~~registered at RAIA station~~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~~registered 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~~registered 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

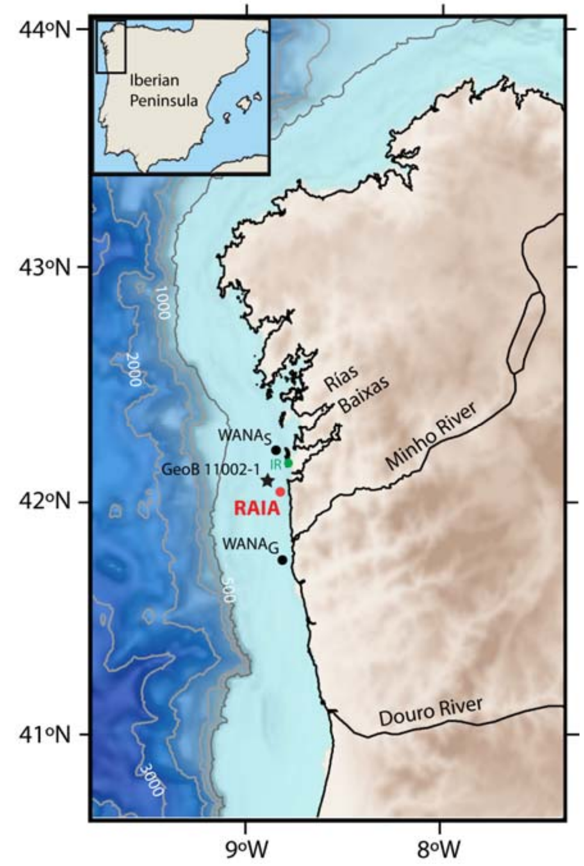
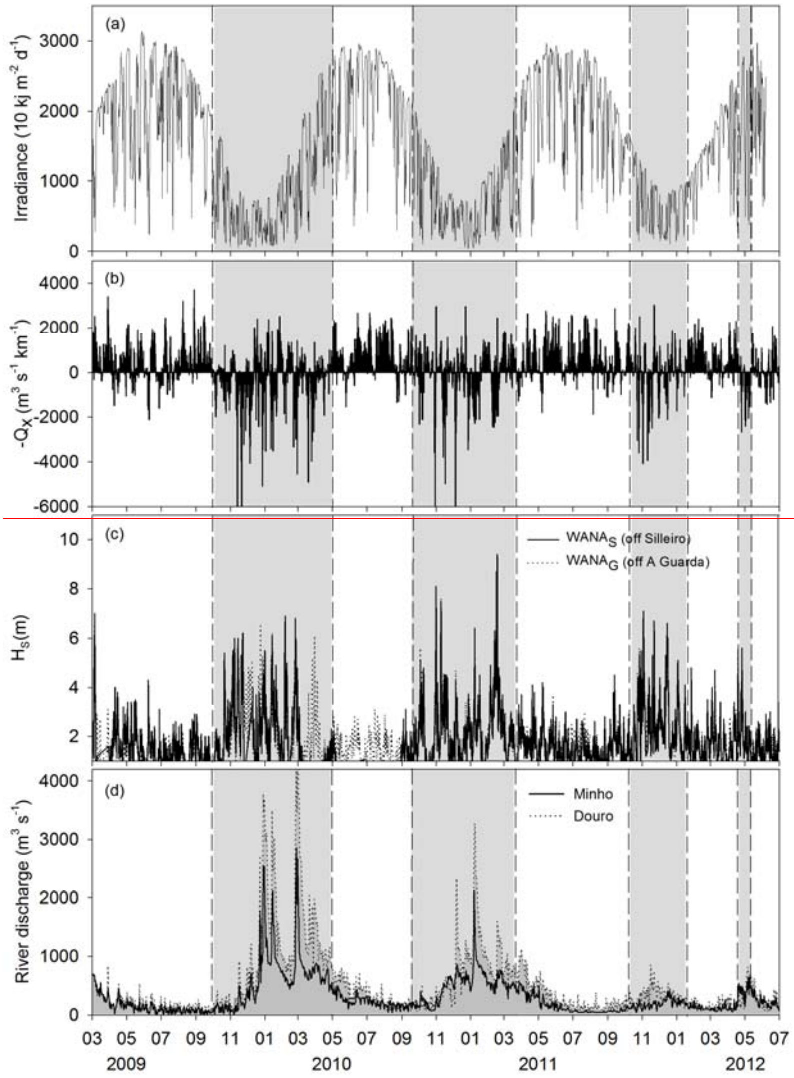
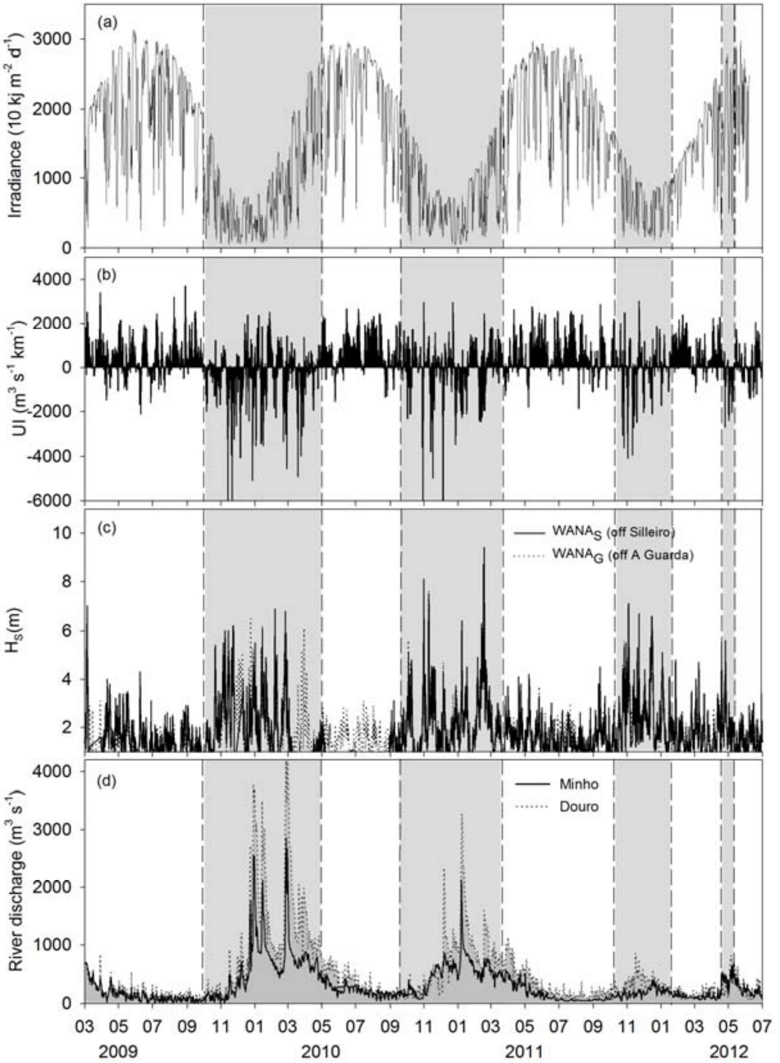

44°N
43°N
42°N
41°N
9°W
8°W
Iberian Peninsula
1000
2000
3000
500
Rías Baixas
Minho River
Douro River
WANA$_S$
IR
GeoB 11002-1
RAIA
WANA$_G$

Figure 2


(a)
Irradiance (10 kj m^{-2} d^{-1})
3000
2000
1000
0
(b)
-Q_X (m^3 s^{-1} km^{-1})
4000
2000
0
-2000
-4000
-6000
(c)
H_S(m)
10
8
6
4
2
WANA$_S$ (off Silleiro)
WANA$_G$ (off A Guarda)
(d)
River discharge (m^3 s^{-1})
4000
3000
2000
1000
0
Minho
Douro
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012



(a)
Irradiance (10 kj m^{-2} d^{-1})
0
1000
2000
3000
(b)
UI (m^3 s^{-1} km^{-1})
-6000
-4000
-2000
0
2000
4000
(c)
H_S(m)
2
4
6
8
10
WANA$_S$ (off Silleiro)
WANA$_G$ (off A Guarda)
(d)
River discharge (m^3 s^{-1})
0
1000
2000
3000
4000
Minho
Douro
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

Figure 3

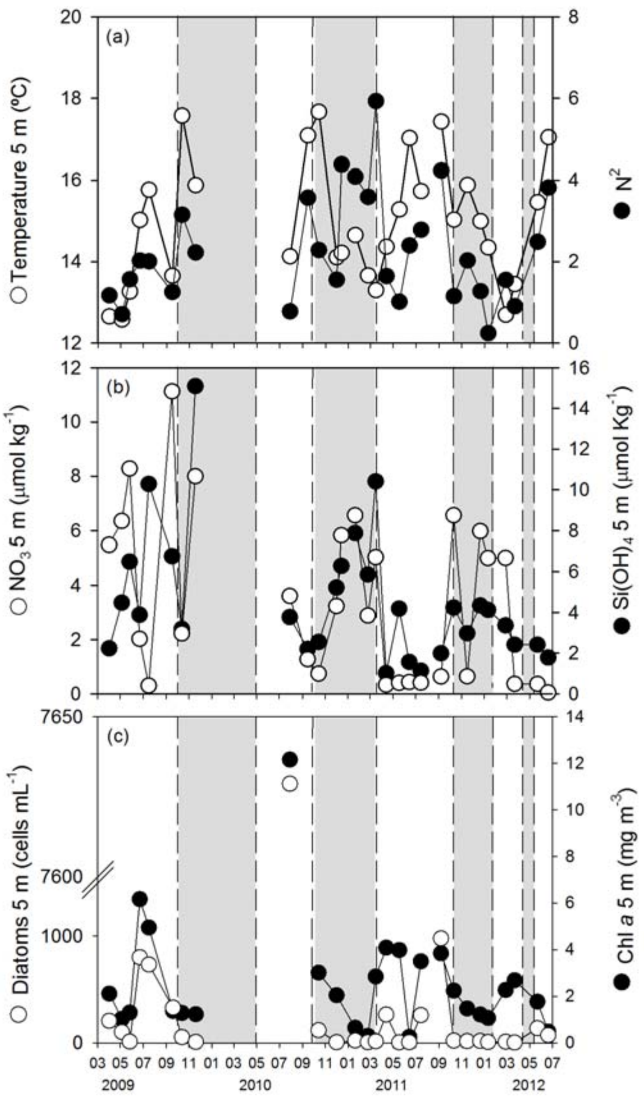
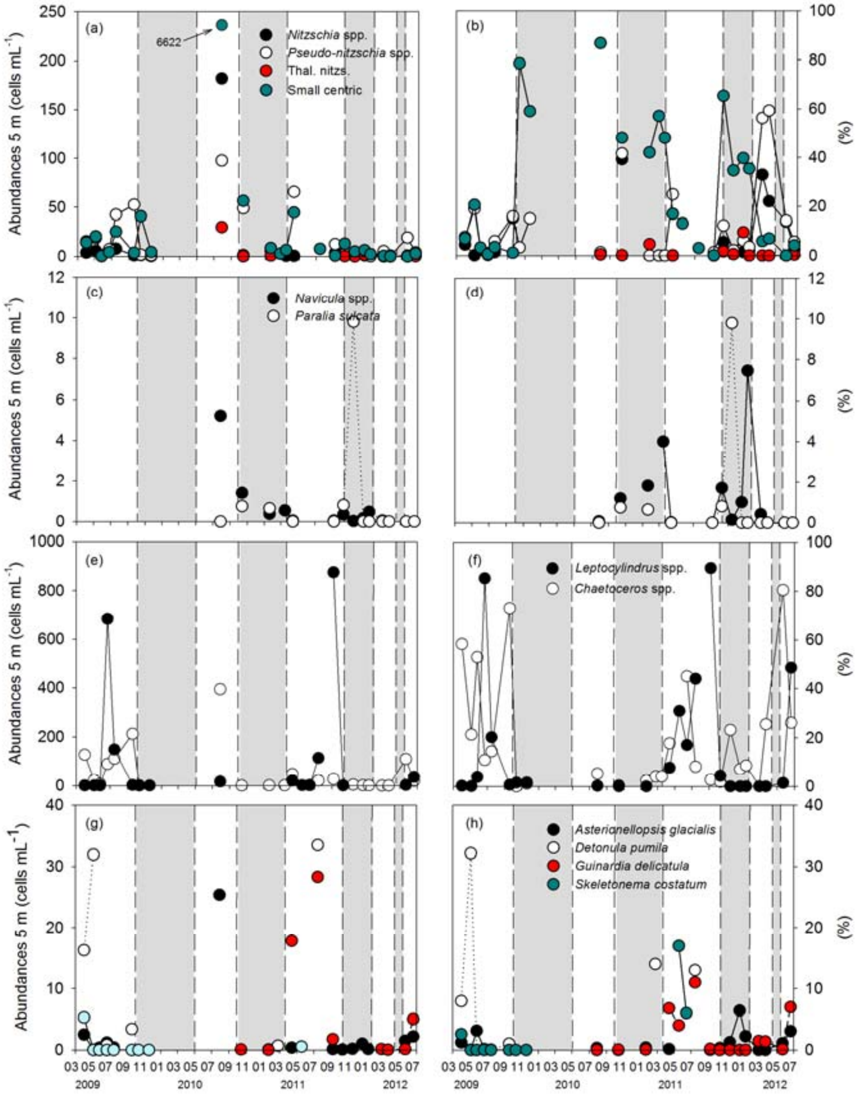

(a)
(b)
(c)
Temperature 5 m (ºC)
N^2
NO$_3$ 5 m (µmol kg^{-1})
Si(OH)$_4$ 5 m (µmol Kg^{-1})
Diatoms 5 m (cells mL^{-1})
Chl *a* 5 m (mg m^{-3})
20
18
16
14
12
8
6
4
2
0
12
10
8
6
4
2
0
16
14
12
10
8
6
4
2
0
7650
7600
1000
0
14
12
10
8
6
4
2
0
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

Figure 4


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
6622
Nitzschia spp.
Pseudo-nitzschia spp.
Thal. nitzs.
Small centric
Navicula spp.
Paralia sulcata
Leptocylindrus spp.
Chaetoceros spp.
Asterionellopsis glacialis
Detonula pumila
Guinardia delicatula
Skeletonema costatum
Abundances 5 m (cells mL^{-1})
(%)
250
200
150
100
50
0
12
10
8
6
4
2
1000
800
600
400
200
100
80
60
40
20
40
30
20
10
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

~~Figure 4~~

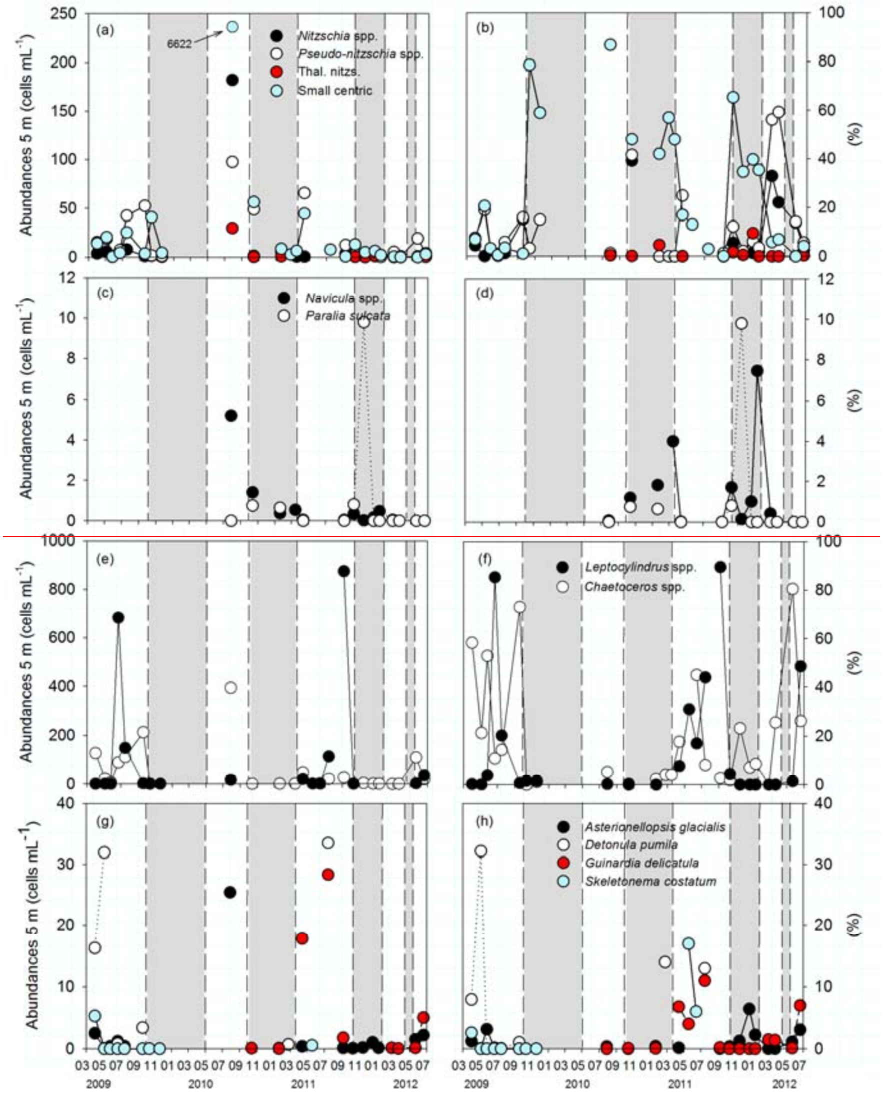
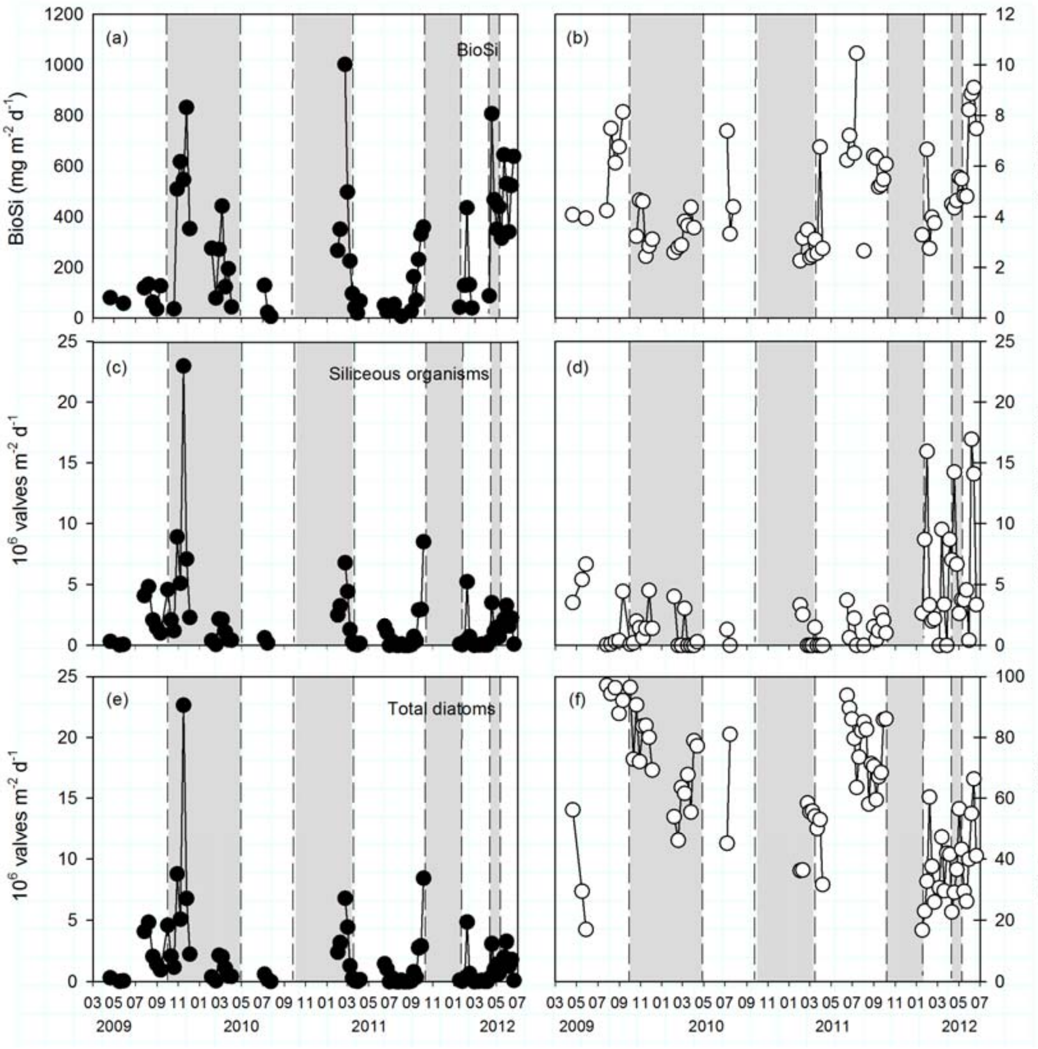

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
6622
Nitzschia spp.
Pseudo-nitzschia spp.
Thal. nitzs.
Small centric
Navicula spp.
Paralia sulcata
Leptocylindrus spp.
Chaetoceros spp.
Asterionellopsis glacialis
Detonula pumila
Guinardia delicatula
Skeletonema costatum
Abundances 5 m (cells mL^{-1})
(%)
0
50
100
150
200
250
0
2
4
6
8
10
12
0
200
400
600
800
1000
0
10
20
30
40
0
20
40
60
80
100
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

Figure 5



(a)
BioSi
BioSi (mg m-2 d-1)
0
200
400
600
800
1000
1200
(b)
BioSi (%)
0
2
4
6
8
10
12
(c)
Siliceous organisms
10^6 valves m-2 d-1
0
5
10
15
20
25
(d)
Silicoflagellates (%)
0
5
10
15
20
25
(e)
Total diatoms
10^6 valves m-2 d-1
0
5
10
15
20
25
(f)
Total spores (%)
0
20
40
60
80
100
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

Figure 6

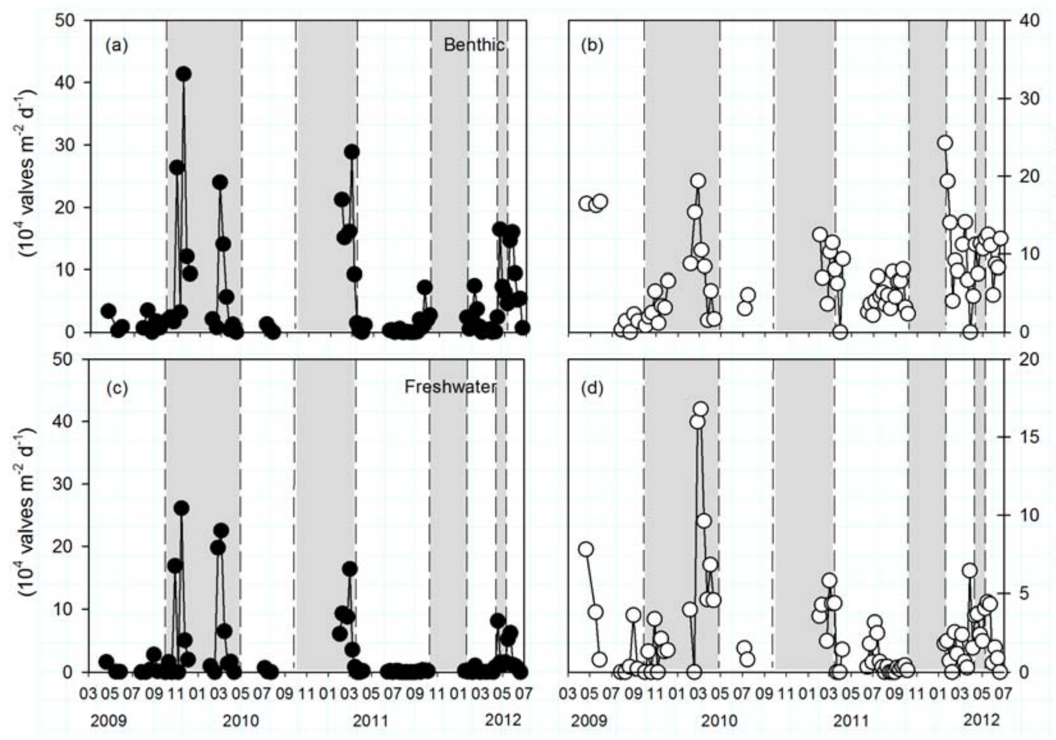
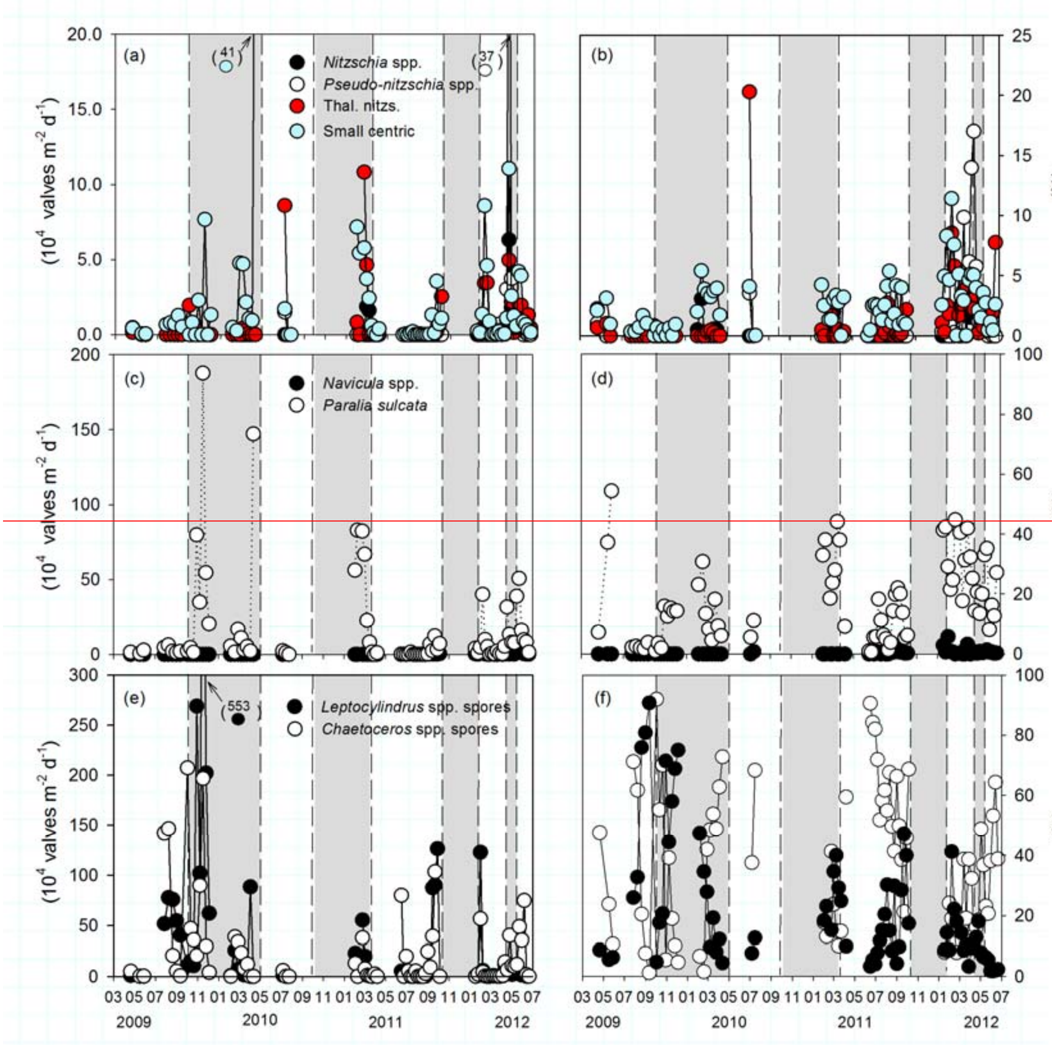
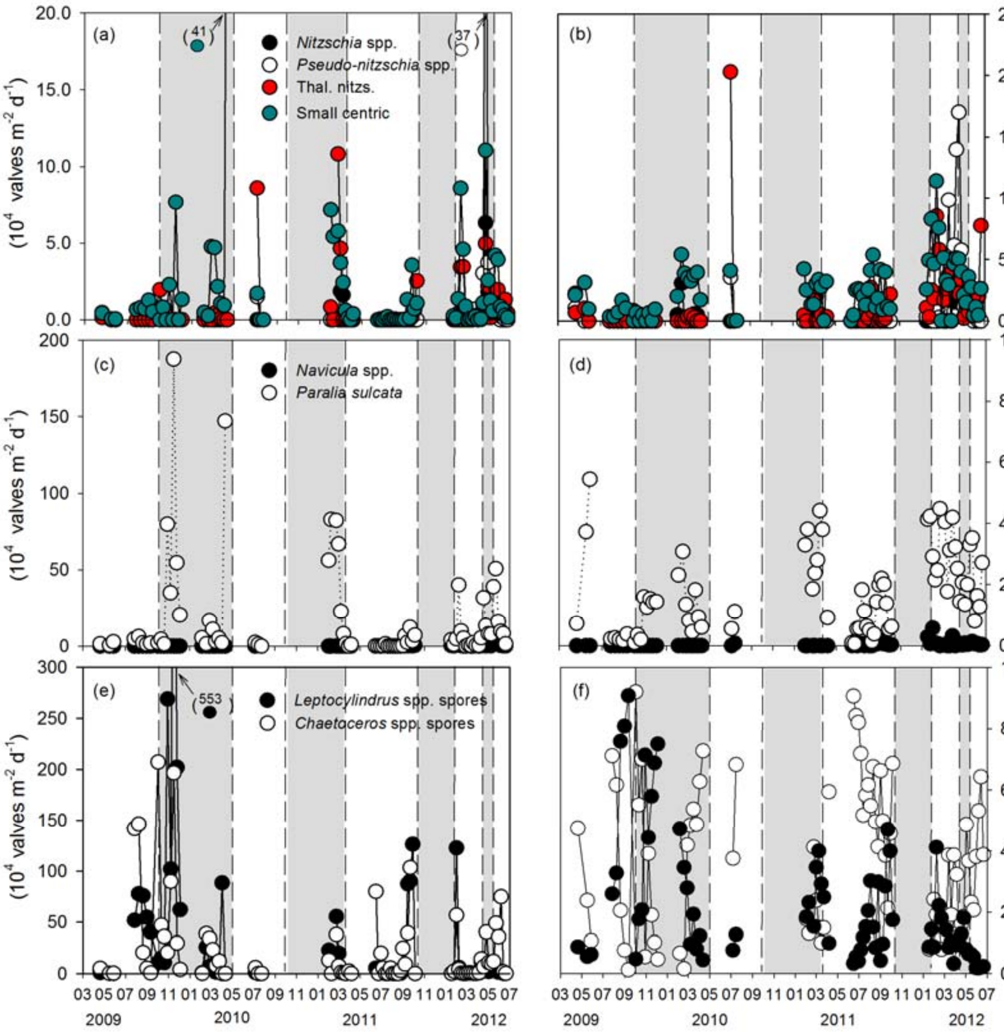

(a)
Benthic
(b)
(c)
Freshwater
(d)
(10^4 valves m^{-2} d^{-1})
(10^4 valves m^{-2} d^{-1})
Benthic (%)
Freshwater (%)
0
10
20
30
40
50
0
10
20
30
40
0
5
10
15
20
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

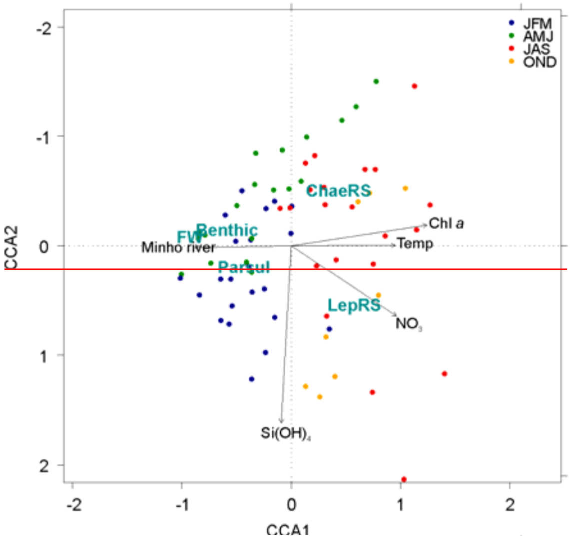
Figure 7

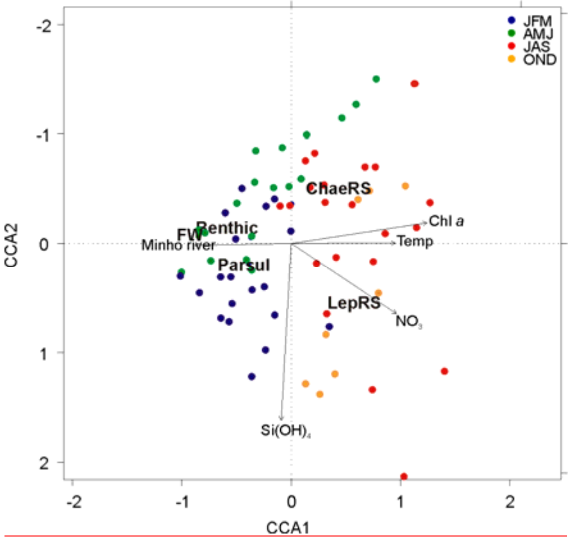

(a)
(b)
(c)
(d)
(e)
(f)
(41)
(37)
(553)
Nitzschia spp.
Pseudo-nitzschia spp.
Thal. nitzs.
Small centric
Navicula spp.
Paralia sulcata
Leptocylindrus spp. spores
Chaetoceros spp. spores
(10^4 valves m^{-2} d^{-1})
(%)
20.0
15.0
10.0
5.0
0.0
25
20
15
10
5
0
200
150
100
50
0
100
80
60
40
20
0
300
250
200
150
100
50
0
100
80
60
40
20
0
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012


(a)
(b)
(c)
(d)
(e)
(f)
Nitzschia spp.
Pseudo-nitzschia spp.
Thal. nitzs.
Small centric
Navicula spp.
Paralia sulcata
Leptocylindrus spp. spores
Chaetoceros spp. spores
(41)
(37)
(553)
(10^4 valves m^{-2} d^{-1})
(%)
0.0
5.0
10.0
15.0
20.0
0
5
10
15
20
25
0
50
100
150
200
0
20
40
60
80
100
0
50
100
150
200
250
300
03 05 07 09 11 01 03 05 07 09 11 01 03 05 07 09 11 01 03 05 07
2009
2010
2011
2012

5

Figure 8


JFM
AMJ
JAS
OND
ChaeRS
Benthic
FW
Minho river
Parsul
LepRS
Chl *a*
Temp
NO_3
$Si(OH)_4$
CCA2
CCA1
-2
-1
0
1
2


JFM
AMJ
JAS
OND
ChaeRS
Benthic
FW
Minho river
Parsul
LepRS
Chl *a*
Temp
NO_3
$Si(OH)_4$
CCA2
CCA1
-2
-1
0
1
2

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	
5	*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	
10	*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	
15	*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	
20	*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	
25	***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	
30	*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
35	*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	
40	*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 suborbicularis (W.Gregory) Cleve	B-M	X	
45	*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	
50	*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	
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	
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	
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	
Hantzschia sp.	B-M-MB	X	
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
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	
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	
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	
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
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
*Petroneis humeros*a (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	
Pleurosigma sp.	P	X	
*Pleurosira laev*is (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	
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 amphicero*s (Ehrenberg) Ehrenberg	B-M	X	
Rhabdonema arcuatum (Lyngbye) Kützing	B-M	X	
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	
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	
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	
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	
*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
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	
Tryblionella navicularis (Brébisson) Ralfs	B-BR	X	