A spring poleward current and its influence on microplankton assemblages and harmful dinoflagellates on the western Iberian coast

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Abstract

Along-shore currents can propagate Harmful Algal Blooms (HABs) over long distances in many coastal areas of the ocean. Harmful dinoflagellate blooms on the west coast of Iberia frequently occur when the Iberian Poleward Current (IPC) establishes on the continental slope. This has led to the suggestion that HABs could be transported northward by the IPC. To examine this possibility, the microplankton composition along the west coast of Iberia was studied in May 1993 coinciding with the presence of the IPC. The microplankton of the IPC was almost exclusively composed of small flagellates, with the notable absence of the harmful species usually associated with coastal waters. The primary influence of the IPC was to confine coastal microplankton populations to the shelf, where a downwelling convergence prevented their export from the coastal environment. Microplankton assemblages on the shelf revealed a north-south gradient related to different stages of succession. Earlier stages of succession in which diatoms were prominent were found on the northern shelf, whereas dinoflagellates were more abundant in the south. The toxic species Gymnodinium catenatum, which was only present in the southern shelf, did not show a northward transport associated with the IPC. It is suggested that the northward spreading of HABs along the west coast of Iberia must be related to the interaction between the IPC, which accumulates coastal populations on the shelf, and the latitudinal progress of microplankton succession that determines species composition. Thus, during the course of the season, HABs are likely to be observed in the south prior to their development in the north.

Keywords: microplankton distribution, spring poleward flow, harmful algal blooms, Gymnodinium catenatum, accumulation, Iberian upwelling.
1. Introduction

Harmful Algal Blooms (HABs) impact many coastal areas of the world ocean (GEOHAB, 2001) where they may have severe economic and ecological consequences (Smayda, 1990; Anderson et al., 2002) and often induce human illness. For these reasons, there is constant research focused on understanding which factors trigger, maintain and propagate these blooms along the coastlines. Although this research has revealed that HABs result from a complex interaction among physical, chemical and biological factors that operate at different rates and several spatial and temporal scales, it is evident now that along-shore and across-shelf currents play a key role in HAB dynamics in many coastal areas. Thus, blooms generated in offshore waters may be advected to the coast by onshore currents (Tester and Steidinger, 1997; Raine and McMahon, 1998; Anderson et al., 2005), while alongshore flows can transport HABs hundreds of kilometres along the coast (Tester et al., 1991; Franks and Anderson, 1992). Frequently, these two currents combine to first concentrate and/or advect blooms towards the coast and next disseminate them (Tester et al., 1991; Anderson et al., 2005). This kind of combination has been reported as especially important in coastal upwelling systems (Pitcher and Boyd, 1996; Pitcher et al., 1998; Trainer et al., 2002), where across-shelf and along-shore currents are prominent physical features. In addition to the transport of HABs, it has also been suggested that alongshore and onshore currents may interact to create suitable environmental conditions for the in situ development of HABs (Figueiras et al., 1998; Ryan et al., 2005). To establish the extent to which the transport of populations versus the modification of environmental conditions influence HAB dynamics within a specific region is important in developing accurate models of blooms and in managing HABs.
The general circulation in the western Iberian margin, a region where HABs of dinoflagellates are recurrent (e.g. Margalef, 1956; Fraga et al., 1988; Figueiras et al., 1994; Moita et al., 1998), is greatly influenced by seasonal upwelling-downwelling (Wooster et al., 1976). In summer, dominant northeasterly winds cause upwelling on the shelf and a surface southward flow near the shelf break (Ambar and Fiúza, 1994). The predominance of southwesterly winds during winter strengthens the general circulation of the region, which is characterised by the presence of a surface poleward current on the slope (Frouin et al., 1990; Haynes and Barton, 1990; Álvarez-Salgado et al., 2003; Peliz et al., 2005; Torres and Barton, 2006) that forces an associated shoreward flow at the surface and induces coastal downwelling (Castro et al., 1997; Álvarez-Salgado et al., 2003). This Iberian Poleward Current (IPC) originates at approximately 39-40ºN from an intrusion of subtropical oceanic water that flows along western and northern Iberia to reach the Armorican Shelf off SW France (Pingree and Le Cann, 1990) and even the Goban Spur region near 50ºN (Pingree et al., 1999). HABs of dinoflagellates on the western Iberian coast often succeed the development of the IPC (e.g. Fraga et al., 1988, 1993; Estrada, 1995). Furthermore, toxic episodes in the north frequently occur a few days after they are detected in the south. Although these observations have led to suggest that HABs on the northern coast result from their transport from the south (Sordo et al., 2001), direct evidence remains to be established.

Here we report on how the IPC affects the microplankton distribution in the western Iberian margin in spring. We thereby assess the role that the IPC has in the northward transport of HABs or in the modification of the environment to create suitable conditions for the development of HABs.
2. Material and methods

2.1. Study area and sampling

The western Iberian margin was extensively sampled at 92 stations in the spring of
1993 (12-26 May) on board of the RV “Cornide de Saavedra”. The stations, located
along 13 sections perpendicular to the shoreline between 9° and 11°W and from 40° to
43°N (Fig. 1a), were initially surveyed using a conductivity-temperature-depth (CTD)
equipped with a fluorometer and a rosette with PVC Niskin bottles. Sampling began at
the northernmost section 1 and ended at section 13 in the south. Nitrate and chlorophyll
a concentrations and microplankton abundance were determined at several depths from
surface to the bottom in shelf waters and from surface to 100-150m deep in the open
ocean stations. Water samples were collected from the CTD upcasts.

2.2. Ekman transport components

The magnitude and direction of the wind in front of Cape Finisterre (43° N, 11° W)
deduced from surface pressure charts were used to calculate cross-shelf (Qx) and along-
shore (Qy) Ekman transport components (m³ s⁻¹ km⁻¹) according to Wooster et al.
(1976):

\[ Q_{x,y} = \frac{\rho_{\text{air}} C_D |V| V_{y,x}}{\rho_{\text{sw}} f} \]

where \( \rho_{\text{air}} \) is the air density (1.22 kg m⁻³), \( C_D \) is the empirical drag coefficient (1.3 x
\( 10^{-3} \), dimensionless) according to Hidy (1972), \( |V| \) is the wind speed at the sea surface
with components \( V_{y,x} \), \( \rho_{\text{sw}} \) is the seawater density (∼1025 kg m⁻³) and \( f \) is the
Coriolis parameter at 43° N (9.946 x 10⁻⁵ s⁻¹). Since SW winds force northward and
onshore (downwelling) transport and NE winds cause southward and offshore (upwelling) transport, the sign of Qx was changed to facilitate comparisons between both transport components. Therefore, positive and negative values (Fig. 1b) indicate southward-upwelling and northward-downwelling transport, respectively.

2. 3. Nitrate, chlorophyll a and microplankton

Nitrate concentrations (µmol kg\(^{-1}\)) were determined using a segmented flow analysis system, Technicon AAII, by the reduction method to nitrite (Hansen and Grassoff, 1983) with some modifications (Mouriño and Fraga, 1985).

Chlorophyll a (chl \(a\); mg m\(^{-3}\)) was determined by fluorometry using a Turner Designs fluorometer calibrated with pure chlorophyll a (Sigma Chemical Co.). Seawater samples of 100 ml were filtered under low vacuum pressure through 25 mm Whatman GF/F filters, which were immediately frozen at -20ºC. Pigments were extracted in 90 % acetone over 24 h in the dark at 4ºC.

Microplankton samples of 100 ml were preserved in Lugol’s iodine and sedimented in composite sedimentation chambers. The organisms were counted and identified to species level, when possible, using an inverted microscope. The small species (<20 µm) were counted from two transects at x400 and x250 magnifications and the large species, typically less abundant, were counted from the whole slide at x100 magnification. Inverted microscope counts do not include the picoplankton fraction (<2 µm) and the preservation procedure may cause losses in the nanoplankton fraction (2-20 µm), which is mainly composed of flagellates.

Principal component analysis (PCA) was used to reduce and simplify the information included in the list of species abundance, to resolve changes in species composition and to identify assemblages within the microplankton community. The analysis was carried
out with the correlation matrix of species abundances transformed to \( \log (X + 1) \), where 

\( X \) is the number of cells per 100 ml. Since double zero values in the correlation matrix 
can distort the results, these were reduced by including in the analysis only those 
species present in at least 20% of the samples. This provided an initial matrix of 41 
species and 449 samples.

3. Results

3.1. Wind pattern and hydrographic field

Sampling, which took place under downwelling conditions (Fig. 1b), was preceded 
by an upwelling event that relaxed at the beginning of the sampling period (12-15 May). 
Then, intense and highly variable southwesterly winds caused a strong downwelling (-
\( Q_x = -922 \pm 952 \, \text{m}^3\text{s}^{-1}\text{km}^{-1}; Q_y = -457 \pm 399 \, \text{m}^3\text{s}^{-1}\text{km}^{-1} \)) that persisted until after the 
cruise.

Although poorly defined by surface temperature (Fig. 2a), the IPC was clearly visible 
from surface salinity (Fig. 2b), where it can be traced by salinities > 35.9. The IPC, 
which developed a strong salinity gradient over the shelf where the less saline coastal 
waters were confined, was characterised by a wide tongue of salty water (S > 35.9) south 
of 42ºN that became narrower to the north (Fig. 2b). The vertical sections of salinity 
(Figs. 3f-j) show that the core of the IPC was deeper (~150m) and saltier (S = 36.0) in 
the south than in the north, where the core of the IPC surfaced near the coast. The 
vertical sections also indicate that the main intrusion of the saline water from the ocean 
occurred as a surface layer of ~150 m at about 41-42 ºN (section 6, Fig. 3h). The 
downward orientation of the isotherms and isoalines towards the coast (Figs. 3a-j) 
indicates that the IPC induced downwelling at the shelf break, due to its confluence with
surface coastal waters with higher continental influence. The counterpart to this
downwelling was a divergence at the ocean side (Figs. 3a-j).

3. 2. Nitrate and chlorophyll

While surface waters in the IPC and shelf domain showed nitrate depletion (< 0.05
µmol kg\(^{-1}\)), low nitrate concentrations (0.1-0.8 µmol kg\(^{-1}\)) were detected at the oceanic
stations in the NW corner of the sampling area (Fig. 2c). This was caused by the
divergent front on the oceanic side of the IPC, which induced a shallowing of the
nitracline (Fig. 4b). The depth of the nitracline, modulated by the convergence at the
shelf break and the divergence on the oceanic side of the IPC (Figs. 4a-e), was therefore
shallower in the north than in the south, consistent with the surfacing of the IPC in the
north (Figs. 3f-j) and weaker downwelling at the start of sampling when the northern
sections were visited.

Chl \(a\) concentrations in the surface waters were generally low (Fig. 2d), with a
subsurface chlorophyll maximum (Figs. 4f-j) associated with the nitracline (Figs. 4a-e).
Consequently, the chlorophyll maximum surfaced (Figs. 2d, 4f-g) where the nitracline
was shallower (Figs. 2c, 4b). Thus, the highest chl \(a\) values in the surface layer were
recorded in the NW corner, where the highest surface nitrate concentrations were also
measured (Fig. 2c). Coastal surface waters in the NE, off the Rías Baixas, had the
lowest chl \(a\) concentrations (~0.2 mg chl \(a\) m\(^{-3}\)) owing to downwelling on the shelf
induced by the IPC (Figs. 3f-g) that impeded surfacing of the chlorophyll maximum
(Figs. 4f-g). In contrast, the subsurface chlorophyll maximum showed a slight surfacing
in the SE (Figs. 4h-j) and, therefore, shelf surface waters south of the Rías Baixas had
chl \(a\) values somewhat higher than those of the surface waters of the IPC (Fig. 2d).
3. 3. Microplankton abundance and distribution

Small flagellates dominated the microplankton community accounting for 75% of the total cell abundance. Dinoflagellates and diatoms represented 18% and 5%, respectively, while ciliates accounted for the remaining 2%. In general, cell abundance was lower in the IPC than in the surrounding waters (Fig. 5a).

Diatoms, which were absent from the IPC waters, were mainly confined to the coast (Figs. 5b, 6a-e), although they were also present in the surface waters of the oceanic stations in the NW corner, outside of the IPC domain (Figs. 5b, 6a-b). Coastal surface waters showed higher diatom abundance in the north, outside of the Rías Baixas, than in the south (Fig. 5b). In the south, diatoms were mostly found in subsurface waters (Figs. 6d, e). The most abundant species in shelf waters were small centric diatoms, Phaeodactylum tricornutum and small centric diatoms, Leptocylindrus spp., Pseudo-nitschia cf. seriata and Chaetoceros curvisetus.

The dinoflagellate community was dominated by small species such as Prorocentrum minimum, small Gymnodinium spp., Heterocapsa niei, and Amphidinium flagellans, which accounted for 81% of the total dinoflagellate abundance. The contribution of small species to the dinoflagellate community was even higher in the IPC (92%) and in the chlorophyll maximum located in the NW corner (94%) (Figs. 5c, 6f). Small dinoflagellates were somewhat less important (77%) in the other dinoflagellate maximum located in the SE (Figs. 5c, 6j). At this location, where Heterocapsa niei accounted for 42% of the total dinoflagellate abundance, the large
The dinoflagellate *Gymnodinium catenatum* attained a significant proportion, representing 15% of total dinoflagellates and 74% of the total abundance of larger dinoflagellates. Small flagellates, though ubiquitous (Fig. 5d), showed two zones of maximum abundance. One was in the surface waters of the IPC in the north (Figs. 5d, 6l), where abundances >500 cells ml\(^{-1}\) contributed to the surface chlorophyll maximum found in this area (Figs. 2d, 4g). The other maximum (>400 cells ml\(^{-1}\)) was in the subsurface waters (~35m) corresponding to the main entry of oceanic waters to form the IPC (section 6, Fig. 6m). In both cases small flagellates accounted for >90% of the total microplankton abundance. Small flagellates were the most important components of the microplankton community in the IPC (75%), in which small dinoflagellates accounted for 19%, and diatoms, large dinoflagellates and ciliates represented 2% each.

3.4. Microplankton assemblages

PCA analysis extracted three principal components that explained 35% of the total variance in the original data set of microplankton abundance. The first principal component (PC1) explained 18%, the second (PC2) explained 10% and the third (PC3) explained 7%. The dinoflagellate *Cystodinium steini* was the only species that showed a small negative load with PC1 (Table 1). The load arrangement of the species with this component, with almost all species having positive loads, and the positive correlation (r = 0.68) between the logarithm of total cell abundance and the PC1 scores (not shown) indicate that PC1 explained the variance due to variations in cell abundance (Fig. 5a).

The large dinoflagellates *Gyrodinium spirale* and *Gymnodinium catenatum*, the diatom *Proboscia alata* and the flagellate *Solenica setigera* showed the highest positive loads (>0.4) with PC2 (Table 1). Cryptophyceae spp., small flagellates, 3 ciliates (*Strombidium turbo*, *Strombidium strobilum* and *Strombidium conicum*), and several
small Gymnodinium species had the highest negative loads (<-0.4). The distributions of
the PC2 scores showed positive values in the SE, with the rest of the sampling area to
be occupied by negative scores (Figs. 7a, 8d-e). The highest negative values were
located in the main body of the IPC and in the NW corner (Figs. 7a, 8a-c).

PC3 differentiated between an assemblage composed of diatoms (Leptocylindrus
danicus, small centric diatoms, Pseudo-nitzschia cf. seriata) and ciliates (Strobilidium
spiralis and Mesodinium rubrum) with positive loads >0.4, and another assemblage of
large dinoflagellates (dominated by Lingulodinium polyedrum and Ceratium furca) with
negative loads <-0.4 (Table 1). The surface distribution of the PC3 scores (Fig. 7b)
showed positive values on the shelf, except in the south where the highest negative
scores were found. Also the IPC and the ocean stations in the NW had negative scores.

Figure 8 shows that the negative scores were mainly found in the southern sections
(sections 6 to 12; Figs. 8h-j). Lower negative scores in the northern part were restricted
to the surface layer of the most oceanic stations and to the entire water column in the
middle of the sections (sections 1 and 3; Figs. 8f, g). Southern shelf waters had positive
scores of PC3 in the bottom layers (Fig. 8j).

3. 5. The distribution of Gymnodinium catenatum

The presence in the region of the toxic dinoflagellate Gymnodinium catenatum,
which often causes severe HABs in the Rías Baixas on the northern coast (Fraga et al.
examine its distribution. This species was restricted to shelf waters in the SE (Fig. 9a),
outside of the IPC, with the highest abundances at about 50 m (Figs. 9b, c). There were
no records of G. catenatum northward of 41°N.
4. Discussion

The IPC reported here follows the scheme proposed by Peliz et al. (2005) in their review of the IPC regime, according to which the poleward flow in the western Iberian margin originates as an eastward advection of relatively warm salty water at about 39-40 ºN that shifts northward near the continental shelf to generate the IPC. Its formation, which is related to the large scale meridional density gradients in the NE Atlantic (Frouin et al., 1990; Pingree et al., 1999; Peliz et al., 2005), is also greatly favoured by southerly winds (Frouin et al., 1990; Haynes and Barton, 1990; Álvarez-Salgado et al., 2003; Torres and Barton, 2006). Thus, the IPC that typically occurs during autumn and winter (Frouin et al., 1990; Haynes and Barton, 1990; Peliz et al., 2005) when meridional density gradients are the strongest and southerly winds dominate in the region (Wooster et al., 1976; Figueiras et al., 2002; Álvarez-Salgado et al., 2003), can also be observed in spring during periods of strong southerly winds (Mazé et al., 1997; Fiúza et al., 1998; Álvarez-Salgado et al., 2003).

In May 1993, intense southwesterly winds (Fig. 1b), although preceded by upwelling favourable northerly winds, promoted the formation of the IPC which was well defined by salty waters (S > 35.9, Fig. 2b). The observed weak thermal signal of this spring IPC (Fig. 2a) was due to the previous cooling and strong mixing that regularly take place in winter and that leaves the IPC with an upper mixed layer of ~150m and temperatures of ~14 ºC (Álvarez-Salgado et al., 2003). In early spring, the incipient solar heating was sufficient to develop weakly stratified conditions (Figs. 3a-e) but not strong enough to allow the differentiation between IPC and coastal waters. The clearest thermal signature of the IPC, with surface temperatures of ~20 ºC, occurs in autumn (Álvarez-Salgado et al., 2003), when stratification is stronger and cool upwelled waters still remain on the shelf.
Corresponding geopotential anomaly computations (Figueiras et al., 1998; Álvarez-Salgado et al., 2003) indicated the existence of opposed flows north and south of 42ºN (Fig. 2b), where the main entry of oceanic waters to form the IPC occurred (Fig. 3h). While the IPC demonstrated poleward flow in the north, flow in the south was predominantly equatorward, indicating that the oceanic intrusion diverged once it reached the continental slope. There was also a weak southward flow in the northwest corner, outside of the IPC, where salinity was < 35.9 (Fig. 2b). This flow, which appears to be a permanent feature of the circulation in the Iberian Basin even when the IPC is present (Ambar and Fiúza, 1994; Peliz et al., 2005), transports colder and fresher water from the north and confines the IPC to the slope in the northern area (Peliz et al., 2005). This confinement of the IPC promotes the development of downwelling at the shelf break. The existence of convergent and divergent fronts associated with the IPC is a well known feature (Fernández et al., 1991; Castro et al., 1997; Álvarez-Salgado et al., 2003). The convergent front near the shelf break prevents the oceanward extension of shelf waters, whereas the more diffuse divergence front on the ocean side separates the subtropical waters of the IPC from the less saline oceanic waters transported from the north (Fig. 2b).

Although winter mixing injects nitrate (1.5-2.0 µmol kg$^{-1}$) into the surface layer (Álvarez-Salgado et al., 2003), the low nitrate and chl $a$ concentrations recorded in the surface waters of the IPC in May 1993 suggest that the spring bloom had already occurred. This view is also supported by the existence of a nutricline and its associated chl $a$ maximum, as well as by the dominance of a microplankton assemblage (negative values of PC2) in which heterotrophic ciliates (Strombidium turbo, Strombidium strobilum and Strombidium conicum) were important components (Figs. 7a, 8a-c). The presence of ciliates tends to suggest the existence of regenerative processes.
The dominance of small flagellates, the absence of diatoms and a low contribution of small dinoflagellates constituted an assemblage that has been reported previously for other IPCs in autumn (Castro et al., 1997) and spring (Bode et al., 1990; Fernández et al., 1991). In general, the IPC is characterised by the almost exclusive dominance of pico-nanoplankton communities with a minor contribution of microplankton (Tilstone et al., 2003; Calvo-Díaz et al., 2004; Lorenzo et al., 2005). This dominance of small phytoplankton forms, but specifically the absence of diatoms, corroborates the oceanic origin of the poleward waters (Malone et al., 1983).

The microplankton distributions (Figs. 5, 6) also serve to confirm that the primary effect of the IPC is to prevent across-shelf exchange and, therefore, the oceanic export of coastal microplankton (Castro et al., 1997; Álvarez-Salgado et al., 2003). The distributions of diatoms were especially informative to this respect (Figs. 5b, 6c-e), as they were confined to the coast. The distributions of diatoms and dinoflagellates in the north (Figs. 5bc, 6af) also demonstrate that the IPC, while progressing to the north, broke the across-shelf microplankton distribution typical of the previous upwelling event, characterised by the dominance of diatoms in coastal waters and a higher importance of dinoflagellates towards the open ocean (Tilstone et al., 1994). Episodes of similar intrusions, leaving different microplankton populations on and off the shelf, have also been described for northern Iberia in spring (Bode et al., 1990; Fernández et al., 1991).

The distributions of the PC2 and PC3 scores (Figs. 7, 8) showed a spatial segregation of microplankton assemblages on the shelf that must be related to different stages of succession (Margalef, 1958). The microplankton assemblage in the SE, with dominance of large heterotrophic and autotrophic dinoflagellates (Gyrodinium spirale and Gymnodinium catenatum, positive loads with PC2), is typical of a later stage of the
succession than the diatom assemblage (positive loads with PC3) dominating further north (Figueiras and Niell, 1987; Figueiras and Ríos, 1993). The more advanced stage of the succession in the south is also confirmed by the presence of the toxic dinoflagellate *G. catenatum*, which usually appears in the north, in front of the Rías Baixas, during summer and autumn (e.g. Fraga et al., 1988; Figueiras et al., 1994; Fermín et al., 1996). The higher negative scores of PC3 (*Lingulodinium polyedrum* and *Ceratium furca*) in the south than in the north (Figs. 7b, 8f-j) also support this view, since both dinoflagellates are recurrent components of the summer-autumn assemblages in the north (Figueiras and Ríos, 1993; Castro et al., 1997).

Despite the reduced importance of diatoms on the southern shelf, the location of the diatom assemblage (positive values of PC3) at a deeper level than the large dinoflagellate assemblage (positive values of PC2) (Figs. 8d,e,i,j) indicates that the IPC intrusion caused a vertical segregation of microplankton. This might be forced by the onshore flow and near-shore sinking associated with the IPC, which could transpose the horizontal surface distribution of microplankton associated with the previous upwelling to the vertical dimension near the coast. Surface microplankton distribution during upwelling is characterised by diatom dominance in coastal waters (positive values of PC3) and a higher importance of large dinoflagellates at the oceanic side (positive values of PC2) (Margalef, 1978; Tilstone et al., 1994). After this transposition and under suitable downwelling conditions, the vertical swimming capability of large dinoflagellates (Eppley and Harrison, 1975; Cullen, 1985; Fraga et al., 1992), in opposition to the passive behaviour of diatoms, would allow them to counteract the downward velocities and, hence, to remain in the surface layers for the initiation of a bloom (Fraga et al., 1988; Figueiras et al, 1994; Fermín et al., 1996).] Thus, it appears that the IPC, through the action of downwelling, selects for the local microplankton
populations instead of transporting them to the north. This view is also supported by the
distribution of *Gymnodinium catenatum*, which does not point to its northward
transport.

5. Conclusion

The spring IPC instead of transporting HABs creates the suitable environmental
conditions to trigger them. This action occurs through the downwelling and the
associated onshore-downward currents generated by the IPC on the shelf, which remove
diatoms from the water column and allow the selection of dinoflagellates. Although
more research is needed to corroborate this single observation, we suggest that the
northward spreading of HABs on the west coast of Iberia is related to the interaction of
the IPC and the latitudinal progression of microplankton succession on the shelf, rather
than the northward transport of harmful species by the IPC. This explanation is
consistent with the more frequent occurrence of HABs in the north, specifically in the
Rias Baixas region, during late summer-early autumn, since this is the time when the
local microplankton community is likely to contain potentially harmful dinoflagellates
and corresponds to the onset of the IPC.

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Table 1. Correlation coefficients (loads) of the species and taxa selected for Principal Component Analysis (PCA) with the first 3 principal components. Species and taxa are ordered according to PC1. The highest positive and negative loads for PC2 and PC3 are in bold. The groups are (Diat) diatoms, (Dinof) dinoflagellates, (Flag) flagellates other than dinoflagellates and (Cil) ciliates

<table>
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<tr>
<th>Group</th>
<th>Taxon</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
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<tr>
<td>Dinof</td>
<td>Heterocapsa niei</td>
<td>0.722</td>
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<tr>
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<td>Protoperidinium divergens</td>
<td>0.560</td>
<td>0.134</td>
<td>-0.272</td>
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<td>Diat</td>
<td>Pseudo-nitzschia cf. seriata</td>
<td>0.547</td>
<td>0.283</td>
<td>0.420</td>
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<tr>
<td>Dinof</td>
<td>Prorocentrum minimum</td>
<td>0.532</td>
<td>-0.076</td>
<td>0.129</td>
</tr>
<tr>
<td>Dinof</td>
<td>Gymnodinium catenatum</td>
<td>0.518</td>
<td>0.467</td>
<td>-0.250</td>
</tr>
<tr>
<td>Flag</td>
<td>Unidentified small flagellates</td>
<td>0.517</td>
<td>-0.508</td>
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<tr>
<td>Dinof</td>
<td>Ceratium horridum</td>
<td>0.512</td>
<td>0.396</td>
<td>-0.230</td>
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<tr>
<td>Dinof</td>
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<td>0.501</td>
<td>0.065</td>
<td>-0.131</td>
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<td>-0.403</td>
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<td>0.427</td>
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<tr>
<td>Diat</td>
<td>Leptocylindrus danicus</td>
<td>0.423</td>
<td>0.219</td>
<td>0.482</td>
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<td>Torodinium robustum</td>
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<td>-0.147</td>
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<tr>
<td>Dinof</td>
<td>Small Gymnodinium spp.</td>
<td>0.416</td>
<td>-0.406</td>
<td>0.181</td>
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<td>Mesoporos perforatus</td>
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<tr>
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**Figure captions**

Fig. 1. (a) Map of the sampling region in the western Iberian margin; the sections selected for vertical representations in figures 3, 4, 6 8 and 9 are indicated. (b) Ekman transport components, -Qx (cross-shore transport) and Qy (along-shore transport), during May 1993 calculated at 43°N 11°W. Dashed area denotes the sampling period.

Fig. 2. Surface distributions of (a) temperature, (b) salinity, (c) nitrate concentration and (d) chlorophyll concentration in the sampled region off western Iberian Peninsula. Dashed line in (c) and (d) corresponds to the isohaline of 35.9 in (b) and represents the Iberian Poleward Current (IPC) domain. Black arrows in (b) represent the main geostrophic flow pattern in the sampled region. More details are given in the discussion.

Fig. 3. Vertical distributions at the five selected sections (see Fig. 1a) of (a-e) temperature and (f-j) salinity with shaded areas indicating the IPC domain.

Fig. 4. Vertical distributions at the five selected sections (see Fig. 1a) of (a-e) nitrate and (f-j) chlorophyll concentrations.

Fig. 5. Surface distributions of abundance of (a) total microplankton, (b) diatoms, (c) dinoflagellates and (d) flagellates other than dinoflagellates. Dashed line represents the IPC domain defined by the 35.9 isohaline (see Fig. 2b).

Fig. 6. Vertical distributions at the five selected sections (see Fig. 1a) of abundance of (a-e) diatoms, (f-j) dinoflagellates and (k-o) flagellates other than dinoflagellates.
Fig. 7. Surface distributions of (a) PC 2 and (b) PC 3 scores extracted by the principal component analysis of microplankton species abundance. Dashed line represents the IPC domain defined by the 35.9 isohaline (see Fig. 2b).

Fig. 8. Vertical distributions at the five selected sections (see Fig. 1a) of (a-e) PC 2 and (f-j) PC 3 scores extracted by principal components analysis of microplankton species abundance.

Fig. 9. Distributions of the abundance of *Gymnodinium catenatum* at (a) the sea surface and (b, c) the southernmost sections where it was present. Dashed line in (a) represents the IPC domain defined by the 35.9 isohaline (see Fig. 2b).
Fig. 1
Crespo & Figueiras
Fig. 2
Crespo & Figueiras
Fig. 3
Crespo & Figueiras
Fig. 4
Crespo & Figueiras
Fig. 5
Crespo & Figueiras
Fig. 6
Crespo & Figueiras
Fig. 7
Crespo & Figueiras
Fig. 8
Crespo & Figueiras
Fig. 9
Crespo & Figueiras