

Diatoms
Portugal
Upwelling
Sediments
Productivity

Diatomées
Portugal
Upwelling
Sédiments
Productivité

Diatom assemblages in surface sediments reflect coastal upwelling off Southern Portugal

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ABSTRACT

Regional upwelling along the west coast of Southern Portugal is reflected in the surface sediments by relatively high abundance of diatom valves, dominated by the species *Paralia sulcata*. Loci of more intense or persistent upwelling have high relative abundance of *Chaetoceros* spores, which are characteristic of late-stage succession in the plankton. Sediment chemistry is a less reliable indicator of productivity and upwelling in this case, because organic carbon and nitrogen are concentrated in the fine-grained sediment fraction and thus partly dependent on the turbulence of the depositional environment.

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RÉSUMÉ

Diatomées dans les sédiments superficiels et upwellings côtiers au sud du Portugal.

Les upwellings au long de la côte ouest du Portugal méridional sont marqués dans les sédiments de surface par une abondance relativement forte des valves de diatomées, l'espèce *Paralia sulcata* étant dominante. Là où les upwellings sont plus intenses ou persistants, l'abondance relative des spores de *Chaetoceros* est élevée, celle-ci étant caractéristique du stade final d'évolution du plancton. Dans cette région, la composition chimique du sédiment est un indicateur moins caractéristique de productivité et d'upwelling, car le carbone organique et l'azote sont concentrés dans la fraction fine du sédiment, et dépendent donc en partie de la turbulence des milieux de déposition.

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INTRODUCTION

Previous work has suggested a correlation between abundance of diatom frustules in coastal sediments and primary production related to hydrography of the overlying waters (e.g. Diester-Haas *et al.*, 1973; Richert, 1977). However, few studies have tested the hypothesis that taxonomic composition of the diatoms might also be useful to identify a sedimentary record of upwelling (Schuette, Schrader, 1981;

Sancetta, 1981). If such a relationship can be demonstrated in various geographic regions, it may be possible to use older sediments from cores or rock outcrops to identify ancient loci of coastal upwelling. In this study we report data suggesting that occurrence and intensity of coastal upwelling is reflected in the abundance and taxonomic composition of diatom assemblages in surface sediments of the southern Portuguese continental shelf.

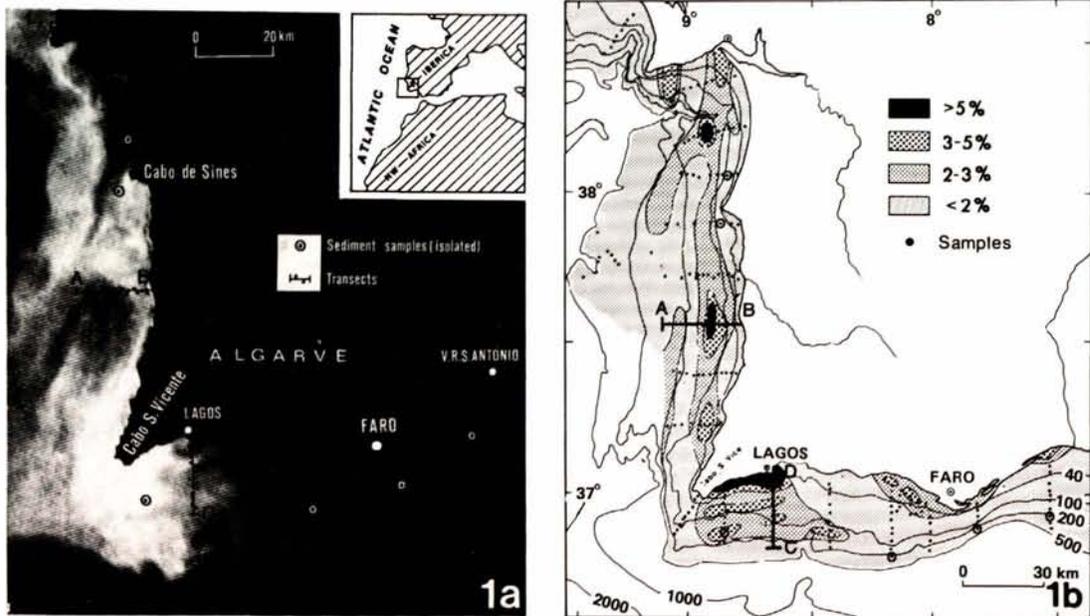


Figure 1

Upwelling and distribution of diatom valves in sediments of the south Portuguese continental shelf. Transects AB, CD and isolated samples are shown: 1 a) TIROS-N AVHRR infrared image during maximal upwelling event (11 August 1980). Lighter shades correspond to cooler water. Photo courtesy of A. Fiuza, University of Lisbon; 1 b) relative abundance (as percentage of grains) of diatom valves in the $< 20 \mu\text{m}$ fraction (after Monteiro *et al.*, 1983)

BACKGROUND

Upwelling occurs throughout the summer along the west coast (Fig. 1 a), driven by northerly winds, with the intensity maximum occurring south of Cabo de Sines (Fiuza *et al.*, 1982; Fiuza, 1983). The west-coast upwelling also shows an offshore eastward extension south of Cabo São Vicente, generally paralleling the 100 m isobath. Along the southern (Algarve) coast, upwelling only occurs during occasional local westerly winds, and is very rare east of Lagos.

Monteiro *et al.* (1983), in a reconnaissance survey, examined the sediment chemistry and lithologic composition of the fine fraction ($< 20 \mu\text{m}$) in a series of transects across the shelf. They concluded that the relative abundance of diatom valves within this material generally reflects the upwelling pattern (Fig. 1 b), with higher concentrations between 100 and 200 m water depth on the western shelf and south of Cabo São Vicente. We decided to examine the species population of diatoms in untreated sediment samples, to test whether such data would confirm or amplify the conclusions of Monteiro *et al.* (1983).

MATERIAL AND METHODS

We chose two transects of surface sediment grab samples in regions of high upwelling, in addition to several isolated samples in areas of lower concentration of diatoms (Fig. 1). Unfortunately, some of the samples used by Monteiro *et al.* (1983) had been exhausted, so that our sample density along the transects is about half of theirs.

Coarse sand- and gravel-sized clastic material comprises 70-90 % of all sediment samples. Consequently, Monteiro *et al.* (1983) had used size separation by wet sieving in their study, in order to concentrate the diatom component, which generally falls into the silt size class. Recognizing the possible bias inherent in size separation, we used untreated bulk sediment samples in our study. Approximately 1 cc of sediment was added to 50 ml of distilled water and subjected to ultrasonic disaggregation for one minute. An aliquot of 0.01 ml was mounted on glass slides, dried, and sealed under a cover slip with Permount medium. Three replicate slides were made for each sample.

We did not quantify the abundance of diatoms relative to other sediment components. As stated above, clastic grains overwhelmingly dominate the material; diatoms are less than 1 % of the particles present, so that any apparent variation in abundance might not be statistically significant (a criticism which may also be applied to the data of Monteiro *et al.*, 1983).

We counted whole valves or centric fragments larger than one-half valve as 1; apices of pennate diatoms were counted as 1/2. No attempt was made to quantify smaller fragments. In most cases, each specimen was identified to the species level — the exceptions were spores of the *Chaetoceros* and valves of small *Navicula* species, which were counted as genera. At least 200 specimens were identified in each sample, and the counts transformed to percent of diatom population. In all samples from the transects, diversity was generally low, due to high dominance, so that a 200 minimum was believed adequate to

characterize population trends. Diversity was much greater in the isolated samples from non-upwelling regions; however in these cases diatoms were so rare that barely 200 specimens could be found on three slides (24 cm^3). The cut-off in this case was a matter of practicality. A total of 126 species representing 44 genera were identified (Appendix). Only the more common and consistently present taxa are considered below.

RESULTS

Preservation of diatom valves (in terms of fragmentation and dissolution) appears to be uniform and moderate in samples from the two transects. Inter-costal membranes of larger *Nitzschia* species are visible; *Coscinodiscus* species are represented by whole valves as well as fragments. The preservation is generally similar to that observed by one of us in sediment samples from the shelf of the Bering Sea (Sancetta, 1982). Dissolution is slightly greater in

samples from the eastern Algarve coast — a small ($10\text{ }\mu\text{m}$) centric diatom (probably a species of *Thalassiosira*) could not be identified and areolae in *Coscinodiscus* species appear to be somewhat enlarged.

Samples underlying regions of common upwelling are dominated by two taxa, *Paralia sulcata* (Ehrenberg) Cleve and resting spores of the genus *Chaetoceros* Ehrenberg. *P. sulcata* shows consistently high values throughout the upwelling region, with significantly lower abundance to the east of Lagos (Fig. 2). *Chaetoceros* spores are also common in the upwelling region, but show a more restricted distribution, being dominant in the west coast transect (Fig. 2) and of lesser importance in the Algarve transect, where upwelling is less frequent (Fiuza *et al.*, 1982). Samples from the eastern part of the Algarve coast, where upwelling is very rare, have lower numbers of diatoms, and a diverse flora lacking dominant taxa and including many littoral and brackish-water forms.

Closer examination of the transects reveals several further trends (Fig. 3). In both cases the abundance

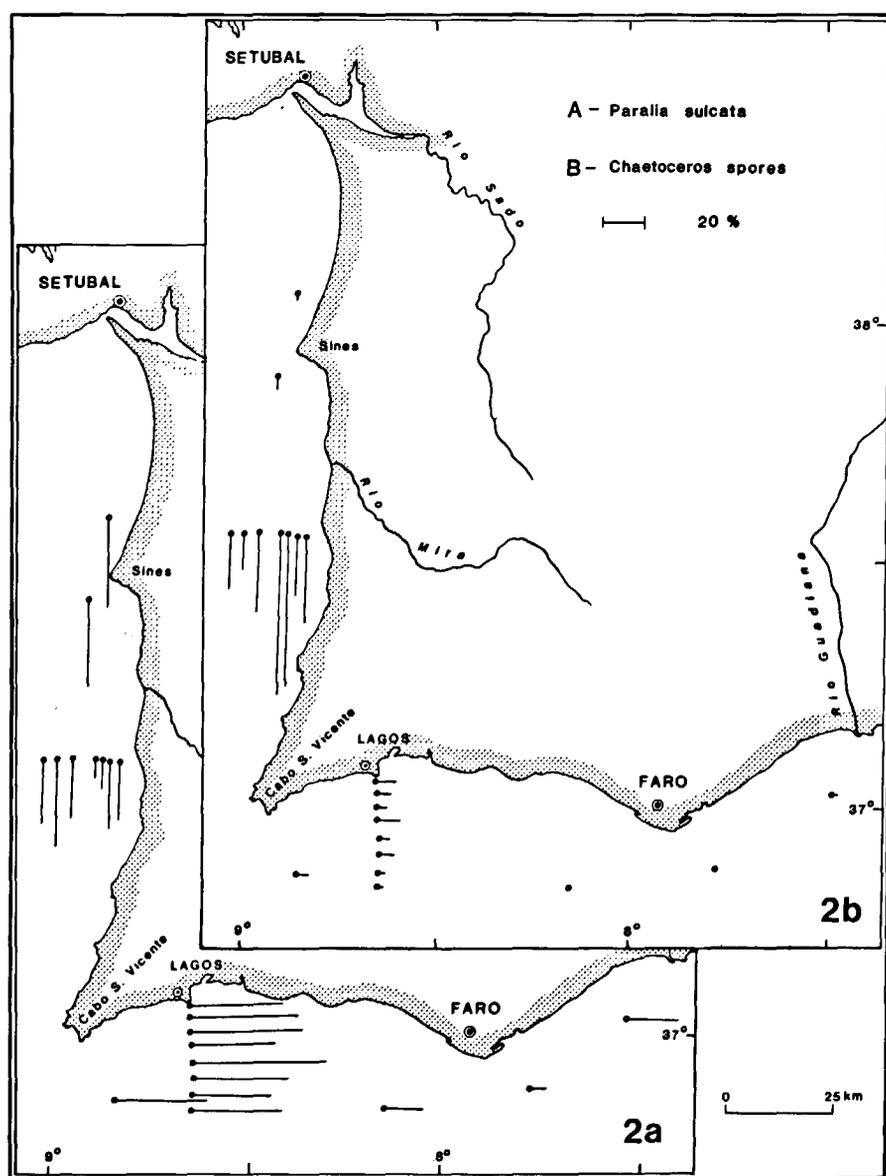


Figure 2
Relative abundance of a) *P. sulcata*
and b) *Chaetoceros* spores in surface
sediment samples, as percentage of spe-
cies population.

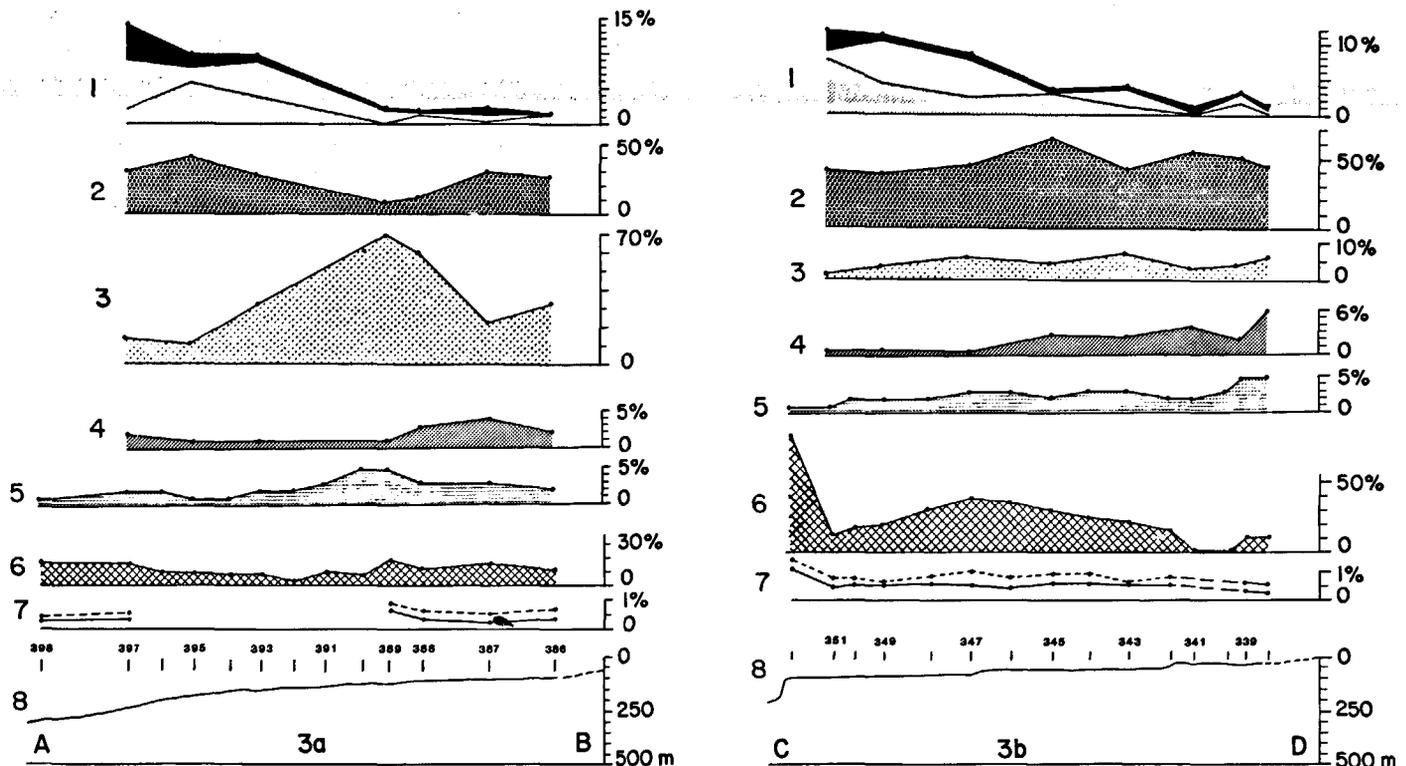


Figure 3

Distribution of parameters along transects AB (west coast) and CD (Algarve coast) of Figure 1. 1 = Cumulative abundance of pelagic species of *Nitzschia* (black), *Thalassiosira* (white), and *Coscinodiscus* (stippled). 2 = Relative abundance of *P. sulcata*. 3 = Relative abundance of *Chaetoceros* spores. 4 = Relative abundance of *Delphineis*. 5 = Abundance of diatoms in < 20 μm fraction (Monteiro et al., 1983). 6 = Concentration of fine-sized fraction (< 63 μm). 7 = Weight percent of nitrogen (dashed line) and organic carbon (solid line) in sediments. 8 = Bathymetric profile along transect. Numbers show location of sample stations.

of diatoms valves in the fine fraction (Monteiro et al., 1983) does not correspond to the concentration of the fine fraction itself (silt- and clay-sized particles). Thus, the concentration of diatom valves is not a direct function of particle size. However, the trend of organic carbon and nitrogen concentration does follow that of the fine-grained particles, suggesting that the sediment chemistry may be affected by particle size and composition, as well as productivity of the overlying waters. Diester-Hass and Müller (1979) found a similar relationship in coastal sediments from northwest Africa. Unfortunately, it was not possible to measure chemistry in some of the samples from the west coast transect, due to the very low occurrence of fine-grained material in which the carbon and nitrogen is concentrated (Monteiro, pers. comm.). For the samples analyzed, the correlation of organic carbon with concentration of silt-sized particles is $r = 0.839$, and for nitrogen $r = 0.958$. The relative abundance of *Chaetoceros* spores in the two transects shows a positive correlation with total abundance of diatoms ($r = 0.806$ and 0.644 for the west and Algarve coasts, respectively). *P. sulcata* is common in both transects, but does not show such a correlation. The genus *Delphineis* Andrews is more common in sediments of the inner to mid-shelf zones (less than 100 m water depth), while pelagic species of *Coscinodiscus* (*C. radiatus*, *C. nodulifer*). *Thalassiosira* (*T. eccentrica*, *T. leptopus*), and *Nitzschia marina* Hassal show increasing abundance with water depth.

DISCUSSION

The abundance distribution of the diatom taxa can be interpreted as a sedimentary record of the occurrence and intensity of local upwelling. Plankton studies in the nearby northwest African upwelling (Blasco et al., 1980; 1981) showed that *P. sulcata* is most common in the inner shelf zone, but occurs across the entire shelf during periods of strong upwelling, possibly due to reseeding by alternate suspension and settling. Sancetta (1981) found that *P. sulcata* was the dominant species in sediments of the inner mid-shelf of the Bering Sea, a region of very high productivity. The uniform abundance of the species on the Portuguese west coast and western Algarve coast, throughout the entire region influenced by upwelling, and its lesser occurrence in non-upwelling regions of the Algarve coast (Fig. 2), suggest it is a good marker for general regional upwelling.

Chaetoceros species are also characteristic in the plankton during upwelling periods, and spores of the genus are common during the last stage of species succession, when nutrients are almost exhausted in the photic zone (Guilard, Kilham, 1977; Margalef, 1978; Blasco et al., 1980). Richert (1977), Schuette and Schrader (1981) and Sancetta (1982) all report high abundance of *Chaetoceros* spores in sediments underlying regions of maximum productivity off

Africa, Peru, and the Northwest Pacific. The high abundance of *Chaetoceros* in the west coast transect of Portugal, and lesser occurrence in the Algarve transect, clearly reflect the more persistent and/or stronger upwelling in the former region.

The inverse trends of *Delphineis* and the pelagic group of species are intriguing, but may be independent of the upwelling and consequent high productivity. Instead, they may relate to parameters associated with water depth. Pelagic waters are generally warmer and of higher salinity than shelf water influenced by runoff and upwelling; the offshore increase of *Coscinodiscus*, *Thalassiosira*, and *Nitzschia* species may reflect temperature or salinity gradients in the outer shelf zone, offshore from the locus of upwelling. Similar trends for other pelagic diatoms have been reported in regions as diverse as the Bering Sea (Sancetta, 1981) and the east coast of the United States (Marshall, 1976).

Little is known of the ecologic significance of *Delphineis* species. The genus was named from fossil material (Andrews, 1977) and may not be familiar to planktologists. *D. karstenii* is a common species during the first stage of coastal upwelling off southwest Africa (Hart, Currie, 1960; Schuette, Schrader, 1981), but no species of the genus were

reported from the upwelling region of northwest Africa (Blasco *et al.*, 1981), perhaps due to problems in identification. In the sediments, *Delphineis* species have been reported as common in the inner and mid-shelf zones of southwest Africa and Peru (Schuette, Schrader, 1981) and of the Bering Sea (Sancetta, 1982), a trend also seen on the Portuguese shelf. This distribution may reflect first-stage upwelling closer to the coast, as distinguished from the later-stage *Chaetoceros*-dominated flora further offshore. However, it is also possible that *Delphineis* species are not directly related to the upwelling, but are responding to parameters such as light penetration or lower salinity in the inner shelf zone.

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APPENDIX

Taxa of diatoms identified in the samples. C = common (taxon was found in all samples), R = rare (taxon was found in several samples), U = unique (taxon was found only as single specimens).

Centrales		
<i>Actinocyclus curvatus</i>	R	
<i>octonarius</i>	R	
<i>surirella</i>	U	
<i>Actinoptychus adriaticus</i> var. <i>pumila</i>	U	
<i>senarius</i>	C	
<i>vulgaris</i>	U	
<i>Analus</i> sp.	R	
<i>Asteromphalus heptactis</i>	R	
<i>Aulacodiscus kittonii</i>	R	
<i>Auliscus sculptus</i>	R	
<i>Biddulphia anala</i>	R	
<i>pulchella</i>	U	
<i>regia</i>	R	
<i>tuomeyi</i>	R	
sp. 1	U	
sp. 2	U	
<i>Cerataulus smithii</i>	U	
<i>turgidus</i>	C	
<i>Chaetoceros</i> spores		
<i>Coscinodiscus apiculatus</i>	R	
<i>asteromphalus</i>	R	
<i>crenulatus</i>	R	
<i>nitidus</i>	R	
<i>nodulifer</i>	R	
<i>obscurus</i>	R	
<i>radiatus</i>	R	
<i>stellaris</i>	R	
<i>tabularis</i> var. <i>egregius</i>	U	
<i>Cyclotella ocellata</i>	U	
sp. 1	U	
<i>Hemidiscus cuneiformis</i>	R	
<i>Hyalodiscus</i> cf. <i>radiatus</i>	C	
<i>Melosira granulata</i>	C	
<i>Paralia sulcata</i>	U	
<i>Podosira maxima</i>	C	
sp. 1	R	
<i>Rhizosolenia bergonii</i>	R	
cf. <i>bifragiles</i>	U	
sp. 1	R	
<i>Stephanodiscus</i> cf. <i>dubius</i>	R	
sp. 1	R	
<i>Thalassiosira anguste-lineata</i>	U	
<i>decipiens</i>	C	
<i>eccentrica</i> group	R	
<i>leptopus</i>	R	
<i>monoporocyclus</i>	R	
sp. 1	R	
sp. 2	U	
sp. 3	U	
sp. 4	U	
<i>Triceratium antediluvianum</i>	U	
cf. <i>alternans</i>	C	
sp. 1	U	
Cysts of unknown origin		
Pennales		
<i>Achnanthes dispar</i>	U	
<i>lillyeborgei</i>	R	
<i>longipes</i>	R	
<i>Amphora grevilleana</i>	U	
<i>hyalina</i>	U	
<i>ostrearia</i>	R	
<i>Cocconeis costata</i>		R
<i>disculus</i>		U
cf. <i>distans</i>		R
<i>pseudomarginata</i>		R
<i>quaenerensis</i>		R
<i>scutellum</i>		C
<i>Delphineis</i> sp.		C
<i>Denticula</i> sp.		R
<i>Dimerogramma dubia</i>		R
<i>fluva</i>		U
<i>marina</i>		R
<i>minor</i>		R
<i>Diploneis bombus</i>		C
<i>chersonensis</i>		U
<i>crabro</i>		C
<i>fusca</i>		R
<i>incurvata</i>		U
<i>lineata</i>		U
cf. <i>minuta</i>		U
cf. <i>parma</i>		U
<i>smithii</i>		C
sp. 1		C
sp. 2		U
<i>Epithemia zebra</i>		U
<i>Eunotia pectinalis</i>		U
<i>Fragilaria capucina</i>		U
<i>Grammatophora oceanica</i>		C
<i>Navicula</i> cf. <i>directa</i>		U
<i>elegans</i>		R
<i>laevistriatae</i>		R
<i>lyrae</i> group		R
<i>lyratae</i> group		C
<i>palpebralis</i>		R
<i>punctata</i>		R
sp. 1		U
sp. 2		U
<i>Nitzschia angularis</i>		U
<i>bicapitata</i>		U
<i>elegans</i>		U
<i>fraudulenta</i>		R
<i>marina</i>		C
<i>navicularis</i>		R
<i>palpebralis</i>		R
<i>panduriformis</i>		C
<i>punctata</i>		R
<i>subpacificae</i>		R
sp. 1		R
sp. 2		R
<i>Opephora marina</i>		R
<i>martyi</i>		R
<i>Plagiogramma interrupta</i>		R
<i>pulchella</i>		C
<i>Pleurosigma strigosa</i>		R
<i>Pseudoeunotia doliola</i>		R
<i>Raphoneis amphiceros</i>		U
<i>Stauroneis amphioxys</i>		U
sp. 1		U
sp. 2		U
<i>Surirella americana</i>		U
<i>fastuosa</i>		U
sp. 1		R
<i>Synedra</i> sp.		R
<i>Thalassionema nitzschioides</i>		C
<i>Thalassiothrix longissima</i>		R
<i>Trachyneis aspera</i>		C