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## Phytoplankton size changes and diversity loss in the southwestern Mediterranean Sea in relation to long-term hydrographic variability

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### Abstract :

Structural changes in plankton primary producers have large implications for food web dynamics, energy fluxes and the vertical export of biogenic particulate carbon. Here we examine phytoplankton data spanning the period 1993–2008 from the Bay of Tunis, southwestern Mediterranean Sea, in relation to long term hydroclimate variability. We show a conspicuous shift in the structure of the phytoplankton community characterized by an increase of small-sized species and diversity loss, revealing a dominance of smaller blooming diatoms and cyanobacteria. Such changes were concurrent with marked modifications in hydroclimatic patterns experienced in the Bay of Tunis consisting of a shift towards enhanced winter precipitation together with rising temperatures. This novel study shows an overall rise in the proportion of small phytoplankton cells and a decreasing trend in phytoplankton diversity in the southern Mediterranean area. These findings warn of a potential decline of trophic efficiency and lesser food web stability resulting from mean size reduction and the diversity loss.

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## Highlights

► Marked changes were found within phytoplankton in the SW Mediterranean from 1993 to 2008. ► Shifts were concurrent with rising winter precipitations and SST. ► An increase was found in the relevance of small-sized phytoplankton species. ► A diversity loss was captured in the total phytoplankton community and diatoms. ► Results warn on potential lesser predictable and stability ecosystem functioning.

**Keywords** : Size structural changes, Diversity loss, Ocean warming, Nanophytoplankton, Phytoplankton diversity, Southwestern mediterranean

## 1 **1. Introduction**

2 Understanding how climate variability influence the dynamics of marine communities is  
3 essential to cope with climate impacts into resources management risks under scenarios  
4 of global change. Marked ecological modifications fostered by climate warming, so far  
5 documented, include (i) changes in latitude/altitude species' ranges (Root et al., 2003),(ii)  
6 in the timing of seasonal ecological events in organisms' life-cycle, i.e. phenology  
7 (Edwards and Richardson, 2004), and (iii) a decrease in the mean body size of  
8 communities (Daufresne et al., 2009); the latter being considered the third universal  
9 response to warming (Peter and Sommer, 2013). Body size is a key ecological trait  
10 driving physiological processes, the dynamics of trophic interactions and energy fluxes  
11 in marine food webs. At the bottom of pelagic food webs, changes in dominant cells size  
12 further impact biogenic particulate carbon export towards the seabed, as larger  
13 phytoplankton cells sink faster than smaller ones. Hence, deciphering underlying  
14 causalities of size reduction in marine ecosystems is a current ecological challenge and  
15 a pressing endeavor in a changing world ocean.

16

17 Temperature influences phytoplankton both directly, via physiology, and indirectly,  
18 through factors controlling nutrient availability. For instance, in temperate marine  
19 ecosystems, high temperature foster stratification, thereby shaping light and nutrients  
20 availability. Indeed, recent investigations based on meta-analysis of large data sets have  
21 pointed out a leading role of resource availability in the phytoplankton size structure  
22 (Marañón et al., 2015, 2012). Likewise, mesocosms experiments have shown that  
23 temperature effects on cell size are mainly mediated by nutrient limitation (Peter and  
24 Sommer, 2013). That is, by promoting a higher stratification, warming indirectly reduce  
25 nutrients supply and primary production in surface layers, which foster a decrease of  
26 large cells along with a decline in biogenic carbon export (Chust et al., 2012; Falkowski  
27 and Oliver, 2007). The relationship between temperature and resource supply is however

1 not trivial. It varies among ecosystems as nutrient inputs are also affected by upwelling  
2 processes, riverine discharges or even human impact. Hence, underlying factors linking  
3 warming and phytoplankton size structure are case-specific, and therefore difficult to  
4 model (Marañón et al., 2015).

5  
6 To date, a number of studies have documented a significant increase in the proportion  
7 of small-sized species concurrently with warmer conditions in a variety of systems,  
8 including freshwater (Strecker et al., 2004; Daufresne et al., 2009), estuaries (Guinder  
9 et al., 2012) and marine ecosystems (O'Connor et al., 2009; Suikkanen et al., 2013). In  
10 the Mediterranean basin, research efforts have mainly focused on northern coasts, i.e.  
11 the Gulf of Naples (Ribera d'Alcalà et al., 2004), the central Adriatic (Mozetič et al., 2012)  
12 and the Ligurian Sea (Goffart et al., 2002; Marty et al., 2002), where phytoplankton  
13 responses to warming have shown structural changes unveiling a decline of larger cells  
14 in the community. In contrast, little is known on phytoplankton dynamics in southern  
15 coasts, although such areas may be more vulnerable to global anthropogenic changes  
16 due to the coastal concentration of anthropogenic activities due to the increasing of  
17 population density (IPCC, 2014). Furthermore, there is a lack of reports on phytoplankton  
18 variability covering recent years when Mediterranean surface waters have shown  
19 pronounced rising temperatures (Macias et al., 2013). Here, we compiled field data over  
20 the period 1993 to 2008 from a shallow ecosystem in the northern Tunisian coast,  
21 southwestern Mediterranean. We assessed hydroclimate trends, as shown by SST and  
22 precipitation, and their influence on the phytoplankton community structure, e.g. size,  
23 biomass, abundance and species shifts. We discussed on the impending consequences  
24 on phytoplankton size structure and diversity in highly productive neritic areas under  
25 projected warming scenarios in the Mediterranean Sea.

## 26 27 **2. Methods**

1 Hydrological features of the Bay of Tunis are influenced by the inflowing Atlantic waters  
2 in the northernmost part (Millot, 1999), whereas the southern area is characterized by  
3 shallow, eutrophic coastal lagoons (Supplementary Information SI Fig. 1) (Daly Yahia-  
4 Kéfi et al., 2005). The nutrient dynamics shows a zonal trophic gradient from the  
5 eutrophic southwestern region to the mesotrophic northeastern area (Souissi et al.,  
6 2000).

7

## 8 **2.1. Biological data**

9 Plankton samples were collected from the 5 m depth surface layer in two shallow stations  
10 at the most inner bay (36.76 N, 10.50 E; 36.80 N, 10.32 E), mainly with a monthly  
11 frequency over the period 1993 to 2008. The sampling was interrupted during the years  
12 1996-1999, and there are as well some gaps during 2005-2006 (SI Table I). At each  
13 sampling site, 1L of seawater was collected using 2L Ruttner bottle from the surface  
14 water (- 0.5 m) for chemical analyses and for phytoplankton counting. Samples treatment  
15 over the whole period was done consistently by the same senior expert taxonomist (O.  
16 Kéfi - Daly Yahia). Samples were fixed by addition of formaldehyde and acid Lugol's  
17 solutions, considered at 0.4% and 3% final concentration, respectively. Subsequently,  
18 samples were stored in the dark at room temperature until analysis and for long term  
19 storage, samples were kept in cold place.

20 Phytoplankton cells from 25-ml subsamples were counted under an inverted microscope  
21 (Hund) using 200 and 400 magnifications (Edler and Elbrächter, 2010; Utermöhl, 1958).

22 Different counting methods were used to account for the diversity of the sample  
23 (Andersen and Thronsen, 2004): (i) when species are characterized by low  
24 abundances, all species were counted by sweeping the entire sedimentation 25 mL  
25 chamber up and down and vice versa; (ii) one or more dominant species; cells were  
26 counted along two or more transverse lines using a counting grid placed in the eyepiece.

27 Phytoplankton size fractionation for was done based on the longest axis of the cells

1 following techniques, as described by Munawar and Munawar (1986). Phytoplankton  
2 size was examined on 30 to 50 individuals of each dominant species in the sample in  
3 order to ensure representativeness.

## 4 **2.2. Physical data**

5 We used regional climate data covering the period 1993-2009. Sea surface  
6 temperature (SST) relative to the Bay of Tunis was obtained from Copernicus Marine  
7 Environmental Monitoring Services (<http://marine.copernicus.eu/>). This Level-4 product  
8 is specific for the Mediterranean Sea and has a 0.04 x 0.04° resolution  
9 (SST\_MED\_SST\_L4\_REP\_OBSERVATIONS\_010\_021) (Buongiorno Nardelli et al.,  
10 2013; Pisano et al., 2016). Precipitation rates relative to the Bay of Tunis were obtained  
11 from ERA5 climate reanalysis dataset, with 0.25° of horizontal resolution (Copernicus  
12 Climate Change Service, C3S, DOI: 10.24381/cds.f17050d7). We extracted monthly  
13 means of daily precipitations for the entire time series.

14 In addition, we used Chlorophyll a estimates from the inner Bay of Tunis derived from  
15 satellite, available from Copernicus Marine Environmental Monitoring Services  
16 (<http://marine.copernicus.eu/>). This Level-4 product is specific for the Mediterranean  
17 Sea and has a 1 Km resolution  
18 (OCEANCOLOUR\_MED\_CHL\_L4\_NRT\_OBSERVATIONS\_009\_041; Volpe et al.,  
19 2012); chlorophyll monthly means were extracted for the available period, 1998 to  
20 2009.

## 21 **2.3. Statistical analysis**

22 Due to some gaps in the data series, and in order to use the longest and most coherent  
23 temporal data, we pooled together phytoplankton data from the two sampled stations to  
24 show the interannual variations during winter (DJFM) and summer (JJA) (SI Table I). The  
25 two stations are located in shallow areas (5m, Fig. SI 1) and present a similar nutrient  
26 dynamics (Souissi et al., 2000).

1 SST series were seasonal detrended prior computing monthly anomalies and annual  
2 average means. Precipitations, which occurs mainly during winter season, was averaged  
3 using the same months as for phytoplankton winter variability (DJFM).  
4 Periods with predominantly positive or negative anomalies were assessed by means of  
5 the cumulative sum method (cusum or cusum transformed). To do this, we  
6 standardized the time series to zero mean and unit variance, and then cumulate the  
7 standardized values over time. Each data point,  $y_t$ , corresponding to time  $t$  ( $t$  from 1 to  
8  $n$ ) was added to the preceding data point according to the equation:

9 
$$S_t = \sum_{i=1}^t y_i \text{ (equation 1).}$$

10 The interpretation is based on the slope of the line on the chart. A constant deviation  
11 from the mean of the time series shows a constant slope. Persistent changes from the  
12 mean of the time series cause a persistent change of the slope. The cumulative sum  
13 enables us to detect in a simple way local changes and homogeneous periods in a time  
14 series (Ibanez et al., 1993).

15 In addition, we computed a driver-response plot using paired observations, on a monthly  
16 basis, with a potential driver (SST and precipitations) and the chlorophyll monthly  
17 anomalies as potential response. The observations were ordered following an ascending  
18 order of each of the driver variable and then the chlorophyll data was transformed in a  
19 cusum following equation 2. This method has been previously used to assess thresholds  
20 and underlying driver-response in complex environmental time series (Regier et al.,  
21 2019).

22 Diversity changes in the phytoplankton community were assessed by means of the  
23 Shannon Index ( $H'$ ) of phytoplankton community, following:

24 
$$H' = \sum_{i=1}^R (p_i * \ln p_i) \text{ (equation 2),}$$

1 where  $p_i$  is the proportion of individuals belonging to a species  $i$  per sample and  $R$  the  
2 total number of species per sample. A heat map was used to display interannual  
3 variations of the ten most abundant species of phytoplankton, diatoms and  
4 cyanobacteria. To do so, data (cells L<sup>-1</sup>) were ranged and a specific color was assigned  
5 denoting low (blue) to high abundance values (yellow), respectively.

### 6 7 **3. Results**

8 The annual pattern of salinity displayed average values of  $36.34 \pm 2.61$ , with maximum  
9 reached 38–38.8 in August, while minimum values, ca. 26.6–27, were registered during  
10 rainy periods (from September to June). In turn, the annual pattern of SST showed an  
11 average of  $19.6 \text{ }^\circ\text{C} \pm 4.2$ , although during the last years of the series (2005-2009) an  
12 upward trend was observed (Fig. 1 a, Table I). Regional climate drivers in this shallow  
13 ecosystem, SST and winter precipitations (DJFM) showed statistical significant changes,  
14 as described by the cusum-transformed time series (Fig. 1 a,c) (Table I). The cusum  
15 results displayed two main periods, statistically significant (t test,  $p < 0.05$ ) characterized  
16 by low values during (1993-2002), followed by a shift towards higher values during the  
17 years 2003-2009.

18 Chlorophyll a, as a proxy of phytoplankton biomass, followed a seasonal cycle denoted  
19 by maxima during summer months in both aforementioned periods, before and after  
20 2002. Minima were found during November-December ca.  $0.5 \text{ mg m}^{-3}$  and maxima during  
21 June-July ca.  $1.3 \text{ mg m}^{-3}$  (Fig. SI 2). This pattern following the seasonal sunlight cycle  
22 suggests there is no nutrient limitations via stratification in this shallow ecosystem  
23 affected by anthropic nutrients loads from small rivers and coastal lagoons (Sommer et  
24 al., 2012). Regarding the interannual variability, both summer and winter chlorophyll data  
25 showed an upward shift since 2002 (Fig. 1 b,c; Table I). Both trends are tightly correlated  
26 with winter precipitations, particularly summer chlorophyll values when maximum levels  
27 were registered (Fig 1,c and Fig. SI 2 b). In addition, chlorophyll concentrations shifted

1 from negative monthly anomalies to positive overcoming a precipitation threshold around  
2  $2 \text{ Kg m}^2 \text{ d}^{-1}$  (Fig. SI 4).

3  
4 Phytoplankton abundance showed a marked intra-seasonal variability along with an  
5 overall upward shift since 2002, reaching ca. a higher order of magnitude at the end of  
6 the series, from  $10^4$  to  $10^5$  cells  $\text{L}^{-1}$  for winter values and finally reaching  $10^6$  cells  $\text{L}^{-1}$   
7 during summers (Fig. 2 a,b). The abundance change was mainly driven by small cells  
8 (Fig. 2 b), as showed by the interannual variability of small phytoplankton (2-20  $\mu\text{m}$ ,  
9 nanophytoplankton), which displayed a significant abundance increase from  $10^2$  to  $10^5$   
10 cells  $\text{L}^{-1}$  during both seasons since 2002 (Fig 2 c,d). Structural changes in the  
11 phytoplankton community were further evidenced in diversity, indexed by the Shannon  
12 Index ( $H'$ ). Phytoplankton and diatoms, the most dominant group presenting blooms  
13 here, showed both a pronounced loss of diversity in winters and summers (Fig. 2 e,f; Fig.  
14 SI 3).

15  
16 The ten most abundant species recorded throughout the investigated period are shown  
17 in Figure 3. Coastal areas were mainly dominated by diatoms and showed the highest  
18 diversity over the years 1994-2002 (Fig.2 b,d and 3). *Bellerochea horologicalis* and  
19 *Bellerochea malleus* were initially the most representative diatom species, reaching  
20 typical bloom abundances in 2001-2003 ( $10^6$  cells  $\text{L}^{-1}$ , Fig. 3 and Fig. SI 5)(Hallegraeff,  
21 1993). Other species, such as *Thalassionema nitzschioides* showed a scattered pattern  
22 through the whole time series. We noticed, however, an increase of small diatoms, falling  
23 within nanoplankton sizes, since 2002 with blooms of *Nitzschia closterium* and  
24 *Phaeodactylum triconutum*. Particularly, *P. triconutum* presented high abundances  
25 reaching up to  $10^6$  cells  $\text{L}^{-1}$  (Fig. 3 and Fig. SI 5). To the best of our knowledge, this is  
26 the first time that such high field abundances have been reported for this diatom widely  
27 used in laboratory conditions. Furthermore in the last years, cyanobacteria reached

1 marked peaks with *Merismopedia elegans* as the dominant species within this group  
2 (Fig. 3 and Fig. SI 5).

3

#### 4 **4. Discussion**

5 We have investigated temporal changes in phytoplankton in the northern Tunisian coast.  
6 The analysis revealed structural changes in the phytoplankton community, which shifted  
7 towards a dominance of smaller cells along with a loss of diversity.

##### 8 **4.1. Hydroclimate variability and phytoplankton responses**

9 The observed phytoplankton changes closely covaried with the long-term weather  
10 conditions in the southwestern Mediterranean Sea that have displayed a conspicuous  
11 SST increase (Giorgi, 2006; Macias et al., 2013). Moreover, rising chlorophyll  
12 concentrations in summer suggest: (i) that nutrient limitation via stratification unlikely  
13 drive the phytoplankton seasonal cycle in this shallow and eutrophic area (Sommer et  
14 al., 2012) and (ii) an increasing resource availability or nutrient supply (sensu Marañón  
15 et al., 2015). This shallow area is affected, via precipitations, by highly eutrophic systems  
16 such as coastal lagoons, small rivers and harbors receiving anthropic nutrient loads from  
17 sewage and fertilizers used in agriculture (Souissi et al., 2000). Our analysis brings  
18 quantitative analysis of these processes, describing a threshold of precipitations that lead  
19 on high chlorophyll levels as a proxy of eutrophic conditions here (ca. 2 Kg m<sup>-2</sup> d<sup>-1</sup>, Fig.  
20 SI 4).

21

22 The changing environmental conditions yielded a shift from an initial dominance of  
23 microphytoplankton or large cells (>20 µm) before the early 2000s to a final dominance  
24 of nanophytoplankton (2-20 µm) after 2003. Nanophytoplankton fall within the medium  
25 size range that dominates the unimodal size-growth curve for phytoplankton, where  
26 several bloom-forming species are represented (Marañón et al., 2013). Small cells may  
27 outcompete large cells under increasing and less intermittent nutrient inputs, mainly due

1 to the higher growth rates, although their storage capacity is lower. For instance, we  
2 noticed a succession towards smaller diatoms, such as *Phaeodactylum tricornutum*,  
3 which falls in the intermediate sizes presenting high growth rates (Marañón et al., 2013)  
4 (see Fig. 3). Theoretical work has shown that higher and constant nutrient alters the  
5 dynamics of diatoms size structure promoting a shift towards a dominance of smaller  
6 diatoms (Litchman et al. 2009). In line with this, recent works stress the overlooked role  
7 of small diatoms, being occasionally major contributors within phytoplankton blooms and  
8 carbon export in nutrient-rich and turbulent marine ecosystems (Leblanc et al., 2018)

9

10 Regarding the rising abundance of cyanobacteria, an increasing presence of this group  
11 has been related to warmer and eutrophic conditions (Paerl and Paul, 2012).  
12 Cyanobacteria proliferations have been shown favored by higher temperatures (often  
13 above 25°C) and nutrient loads, where they grow better than do other phytoplankton  
14 species, such as diatoms and green algae (Paerl and Huisman, 2008). We refer here the  
15 cyanobacteria that fall within nano- size range, but no other smaller within  
16 picophytoplankton, as *Synechococcus* and *Prochlorococcus* sp., which play a key role  
17 in oligotrophic open sea ecosystems (Platt et al., 1986).

18

#### 19 **4.2. Biodiversity, ecosystem functioning and food web response**

20 The conspicuous loss of diversity shown in the phytoplankton community is in agreement  
21 with the reported global trend of marine biodiversity losses (Sala and Knowlton, 2006)  
22 (Fig. 2 c and 3). Such diversity decline warns on wide consequences at several scales,  
23 as diversity stabilize resource use efficiency and overall the aquatic ecosystem  
24 functioning (Ptacnik et al., 2008). In species-poor communities, resources use is less  
25 efficient, which promotes available niche-space situations that may favor species  
26 invasion or resource monopolization, such as the *P. tricornutum* blooms we observed

1 during the last years of the period investigated (Fig. 2, 3). Overall, these processes within  
2 less diverse communities, point to a reduced stability and predictability of the ecosystem.  
3  
4 Regarding the potential contribution of top down control, with the caveat that no  
5 quantitative zooplankton data was available, it is worth noticing that gelatinous  
6 zooplankton have significantly increased in the Western Mediterranean over the last  
7 decades (Licandro et al., 2010; Molinero et al., 2008). Particularly in the Gulf of Tunis,  
8 mild winters has been related with optimal conditions favoring *Pelagia noctiluca*  
9 reproduction and outbreaks (Daly Yahia et al., 2010). This scyphozoan jellyfish could  
10 promote trophic cascades derived from their high predation capacity (Acuña et al., 2011;  
11 Brotz et al., 2012; Tiselius and Møller, 2017). Jellyfish diet consists mainly of copepods,  
12 but also meroplankton, ichthyoplankton and other gelatinous zooplankton (Purcell et al.,  
13 2014). However contrarily to the observed pattern, larger abundances of these voracious  
14 predators may foster microphytoplankton growth by reducing copepods biomass (Stibor  
15 et al., 2004; Tiselius and Møller, 2017). Hence, we suggest that the top down control by  
16 copepods did not play a leading role in the observed phytoplankton changes, instead we  
17 hypothesize a bottom up control driving the observed response of the phytoplankton  
18 community, e.g. such as resources supply increase in this period. Moreover, these  
19 structural changes in the phytoplankton community, e.g. shift in the mean community  
20 size, along with larger abundances of jellyfish might further affect food web carbon  
21 pathways and permeate the entire food web.

22

### 23 **4.3. Insights for Mediterranean ecosystems in the next future**

24 A concomitant warming with shrinking phytoplankton sizes has been reported in northern  
25 Mediterranean regions (Marty et al., 2002; Mozetič et al., 2012, 2010; Zingone et al.,  
26 2019). Nevertheless, the suggested driving mechanisms of such patterns point out a  
27 leading role of an increasing stratification, as the main driver of the mixed layer dynamics

1 and resources availability for phytoplankton. We stress that in neritic ecosystems, such  
2 as the coastal sites we investigated, local or regional factors could drive the  
3 environmental conditions or resource availability, leading on different responses of the  
4 phytoplankton communities. For instance, a positive trend was recently registered in  
5 chlorophyll from satellite data around the Nile Delta, also in the southern Mediterranean  
6 coast (Lazzari et al., 2012), whereas a decrease in nutrient inputs and eutrophic  
7 conditions in the Po delta (North Adriatic Sea) did not show a significant link with the  
8 trend in phytoplankton size changes (Aubry et al., 2012).

9  
10 Climate projections for the Mediterranean Sea warns on a warming trend along with a  
11 decline in precipitations and more frequent extreme events (see Fig. 1 b,d) (Alpert et al.,  
12 2002; Hertig and Jacobeit, 2008). This scenario suggests modifications in the amount  
13 and frequency of the natural nutrient supply that might foster changes in the  
14 phytoplankton community (Litchman et al., 2009; Macias et al., 2010). It is worth noticing  
15 however that anthropogenic nutrient loads could mask all these processes. As described  
16 in previous works, the Mediterranean “tropicalization” threaten this diversity hotspot  
17 (Bianchi, 2007; Vergés et al., 2014). This phenomenon is not only supported by warmer  
18 and/or more oligotrophic conditions as formerly described, it also depend on local factors,  
19 i.e. riverine and/or anthropogenic inputs, that may open ecological niches for tropical  
20 invasive species from eutrophic systems, which may be introduced in the Mediterranean  
21 Sea via ballast waters (Coll et al., 2010).

22  
23 The analysis of long-term field data sheds light on pelagic ecosystem responses to  
24 warming conditions. Phytoplankton communities are adapted to local temperatures  
25 (Thomas et al., 2012), while optimum temperatures of locally adapted phytoplankton are  
26 higher than the annual mean temperature they experience, and therefore the warmer the  
27 local mean temperature the closer is to species optimum. This is not trivial if we consider

1 the negative skewness of the thermal tolerance curve, which suggests that the  
2 phytoplankton growth response to variations in temperature may be more sensitive to  
3 warming than cooling conditions. Therefore, subtropical communities are more  
4 vulnerable to warming, which may foster losses in diversity, as recently predicted by  
5 global synthesis on the phytoplankton-temperature interactions (Thomas et al., 2012).  
6 During the sampled period the annual mean temperature raised ca. 1°C, while a  
7 sustained increase is expected in the next century, particularly during summer months  
8 (ca. 1.5-2°C)(Gualdi et al., 2013; Shaltout and Omstedt, 2014). This warns on drastic  
9 changes phytoplankton diversity, likely shifting towards a more tropical community  
10 (Thomas et al., 2012).

11

## 12 **5. Conclusions**

13 Our results pointed out conspicuous shifts in the structure of phytoplankton communities  
14 likely fostered by the compound effects of rising precipitations and temperatures  
15 experienced in the Bay of Tunis during the last decades. The observed changes in the  
16 structure of phytoplankton community suggest a reorganization in the plankton food web.  
17 Hence, southern Mediterranean warming projections, together with anthropogenic  
18 nutrient inputs warn on the high vulnerability these ecosystems experience to invasions,  
19 but also substantial changes in the phytoplankton diversity and size structure, which  
20 ultimately will yield to a less predictable and stable system.

21

1 **Aknowledgements**

2 We gratefully acknowledge the support of the European Commission: OCEAN-CERTAIN  
3 (FP7-ENV-2013-6.1-1; no: 603773). Eduardo Ramirez Romero thanks the funding from  
4 “Govern de les Illes Balears—Conselleria d’Innovació, Recerca i Turisme, Programa  
5 Vicenç Mut.”

6

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9

1 **Figures**

2 **Figure 1.** A- SST yearly averaged anomalies (black dot) and winter precipitation  
3 (DJFM, blue dot) along the monitoring period.

4 B-Seasonally averaged chlorophyll time series for: winter (black dot, DJFM) and  
5 summer (red square, JJA).

6 C- Cumulative sums for different variables: SST (red square); precipitations (blue dots);  
7 chlorophyll winter (dark green diamond); chlorophyll summer (light green diamond).

8 **Figure 2.** Phytoplankton time series pooled by summer months (red square, JJA) and  
9 winter (black dot, DJFM). Cells abundance ( $\log_{10}$  cells  $L^{-1}$ ) of total phytoplankton  
10 community and derived cusum transformed (A,B); small cells (nanophytoplankton, 2-20  
11  $\mu m$ ) and derived cusum transform (C,D). Biodiversity of diatoms, collected by the  
12 Shannon Index ( $H'$ ) and derived cusum transform (E,F)

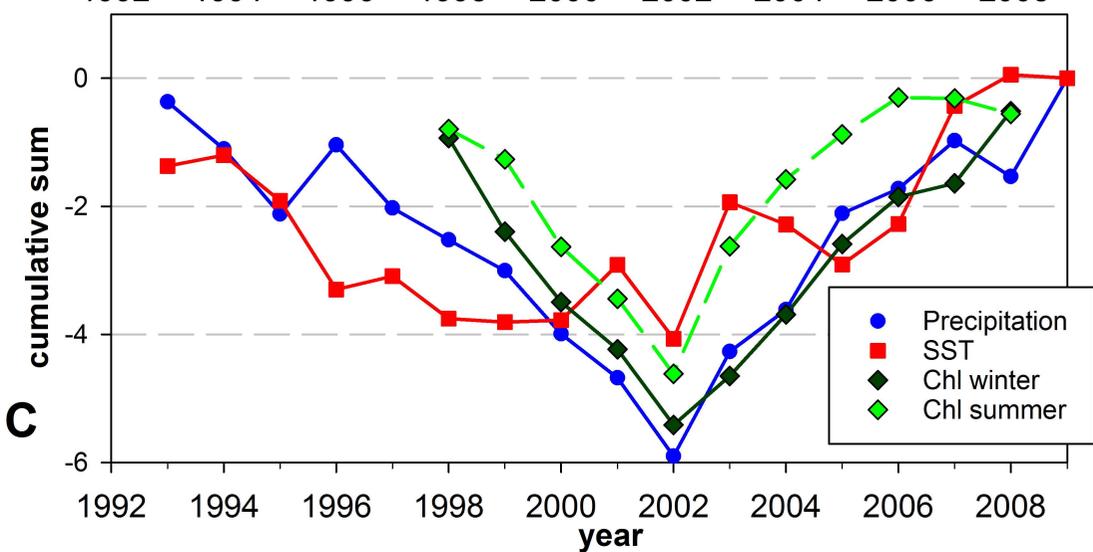
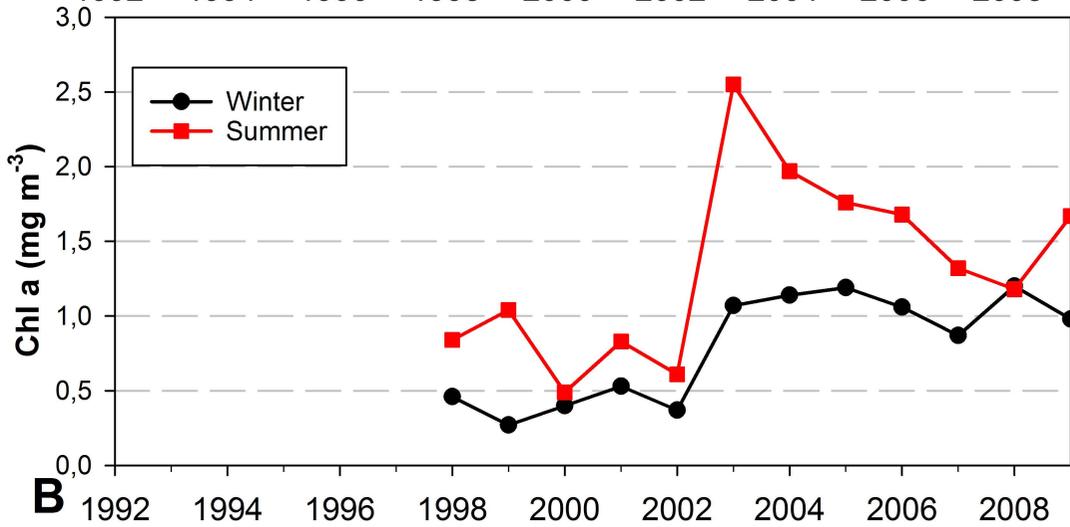
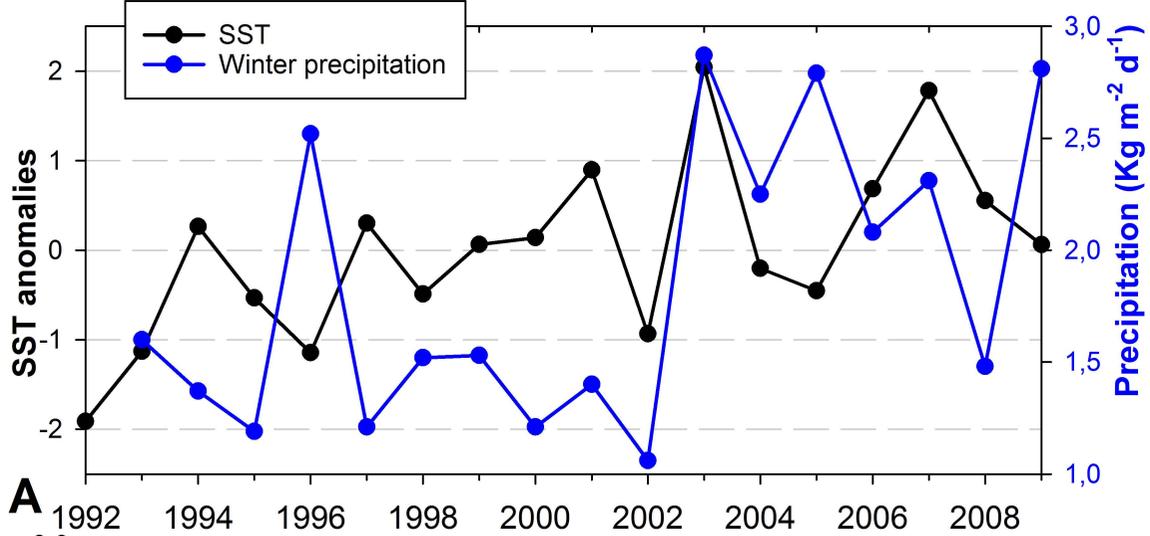
13 **Figure 3.** Cell abundances ( $\log_{10}$  cells  $L^{-1}$ ) for the ten most representative species  
14 along the time series: *Bellerochea malleus*; *Bellerochea horologicalis*; *Thalassionema*  
15 *nitzschioides*; *Thalassiosira levanderii*; *Asterionella spp.*; *Skeletonema costatum*;  
16 *Nitzschia closterium*; *Merismopedia elegans*; *Phaeodactylum triconutum*.

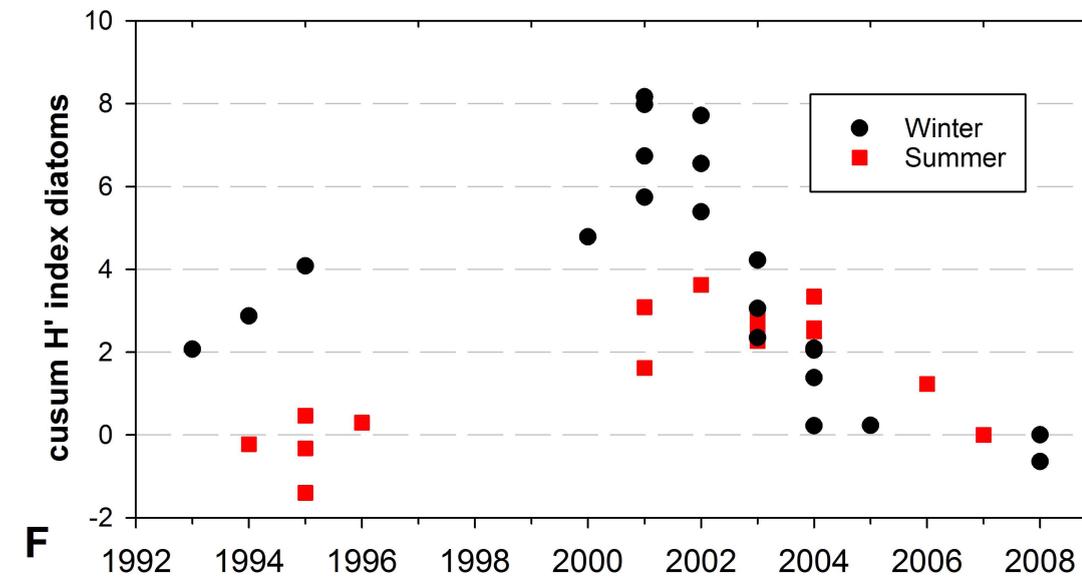
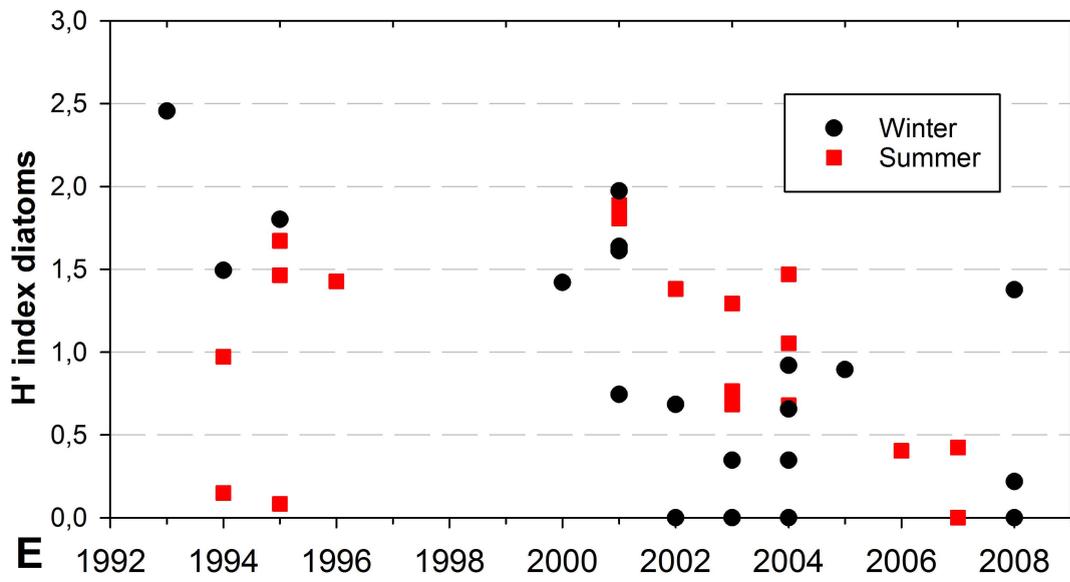
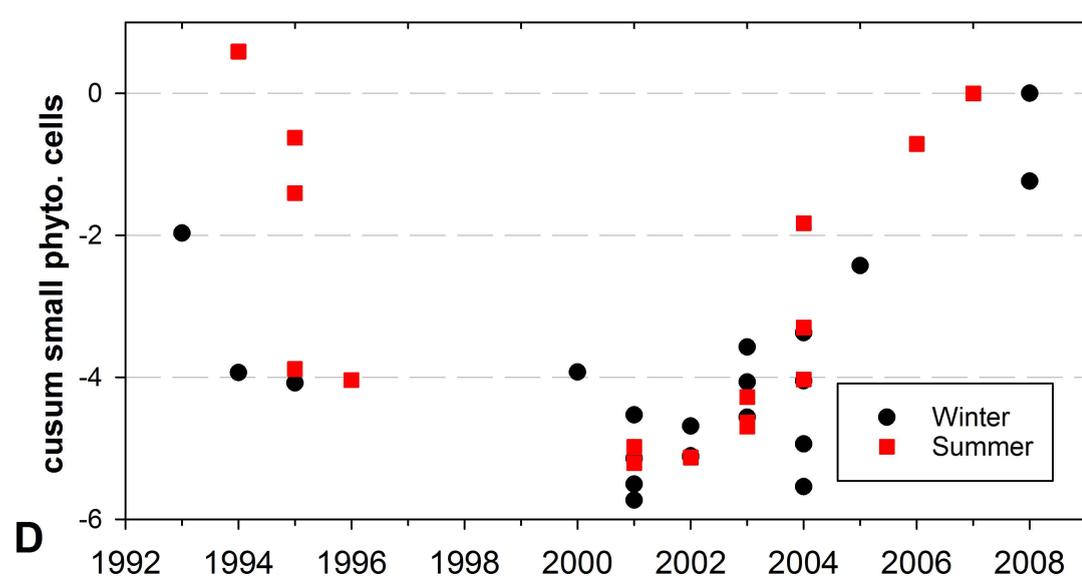
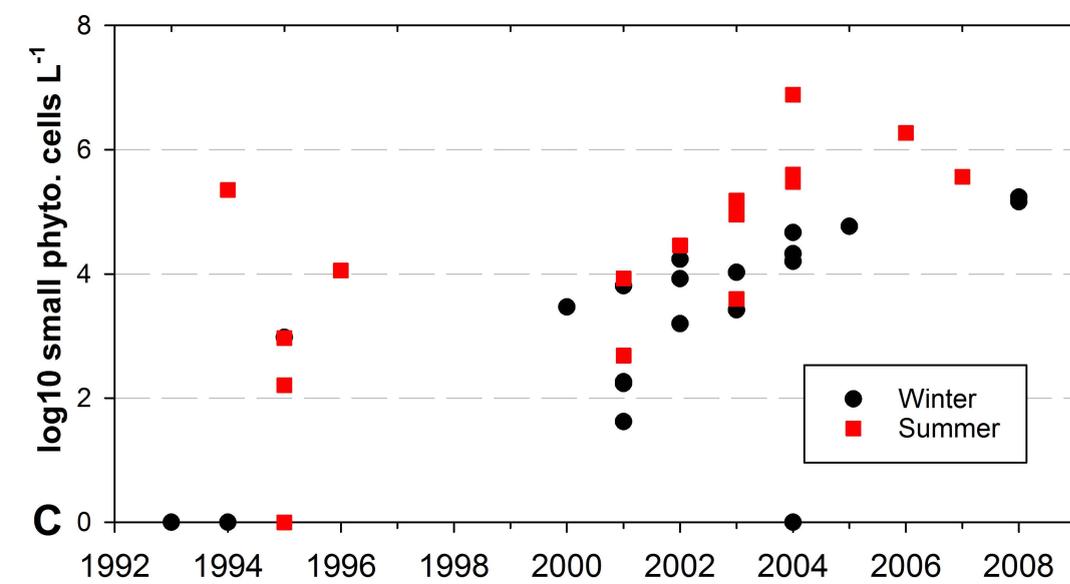
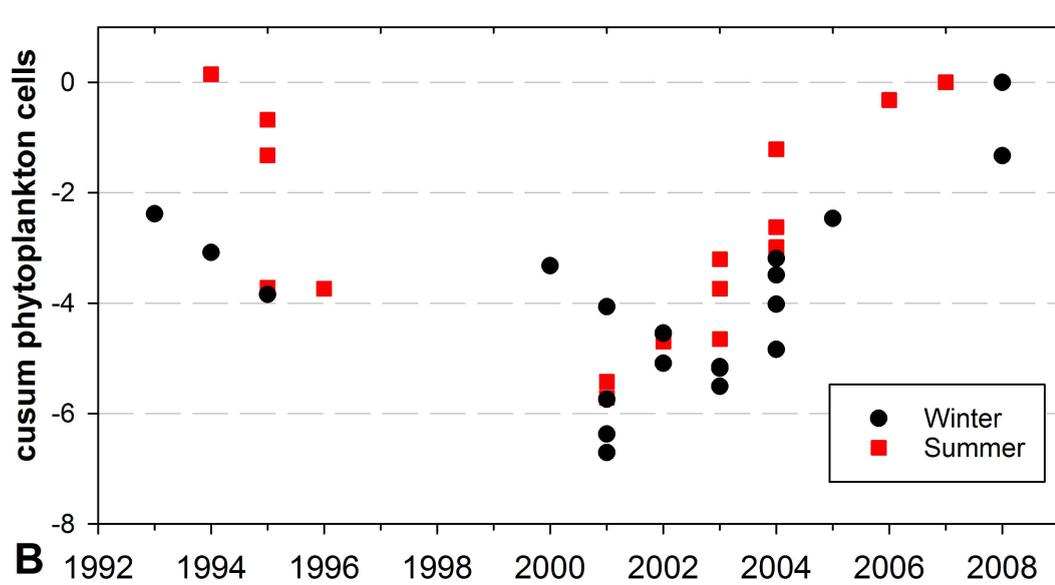
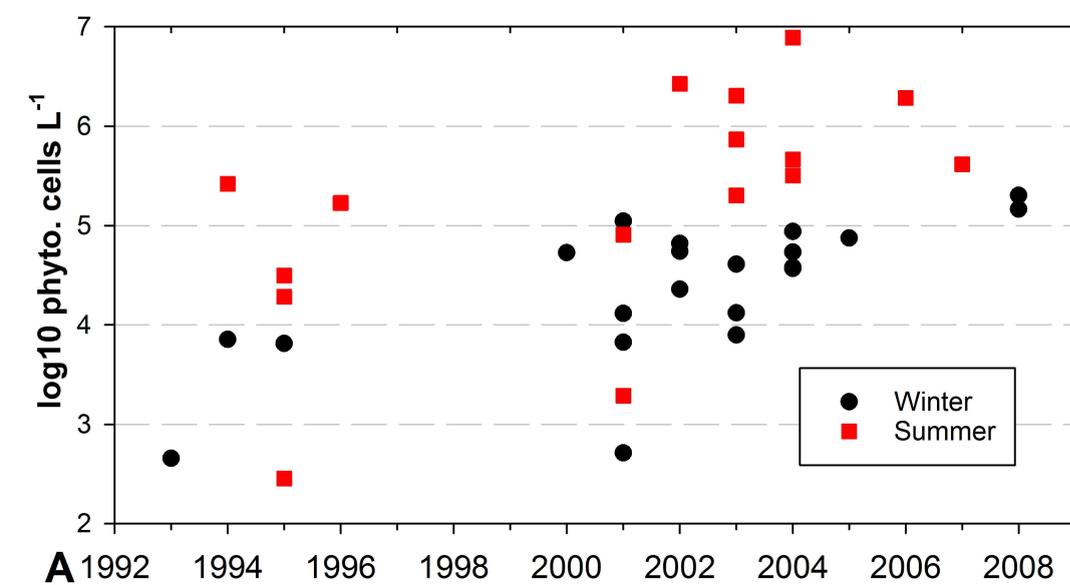
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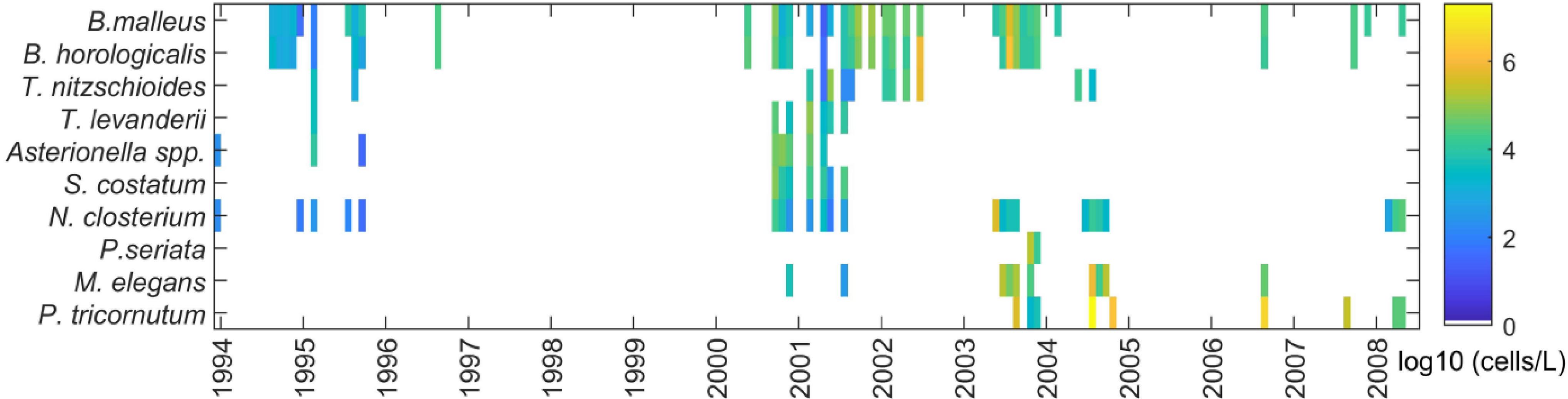
1 **Table I:** Results of average anomalies before/after 2002 after cumulative sums  
 2 (cusum) analysis (Fig. 1). All variables present before/after 2002 statistically significant  
 3 differences, t test,  $p < 0.05$ .  
 4

Average anomalies of climatic drivers			
Variable		First period (1993-2002)	Second period (2003-2009)
SST		-0.407	0.581
Winter precipitations		-0.590	0.843
Average anomalies of phytoplankton variables			
Variable		First period (1993-2002)	Second period (2003-2009)
Chlorophyll	Winter	-1,083	0,773
	Summer	-0,923	0,659
Phytoplankton cells	Winter	-0.412	0.454
	Summer	-0.587	0.587
Small phytoplankton cells	Winter	-0.426	0.469
	Summer	-0.641	0.641
Phytoplankton biodiversity Index H'	Winter	-0.437	0.481
	Summer	-0.565	0.565
Diatoms biodiversity Index H'	Winter	-0.489	0.538
	Summer	-0.452	0.452

5

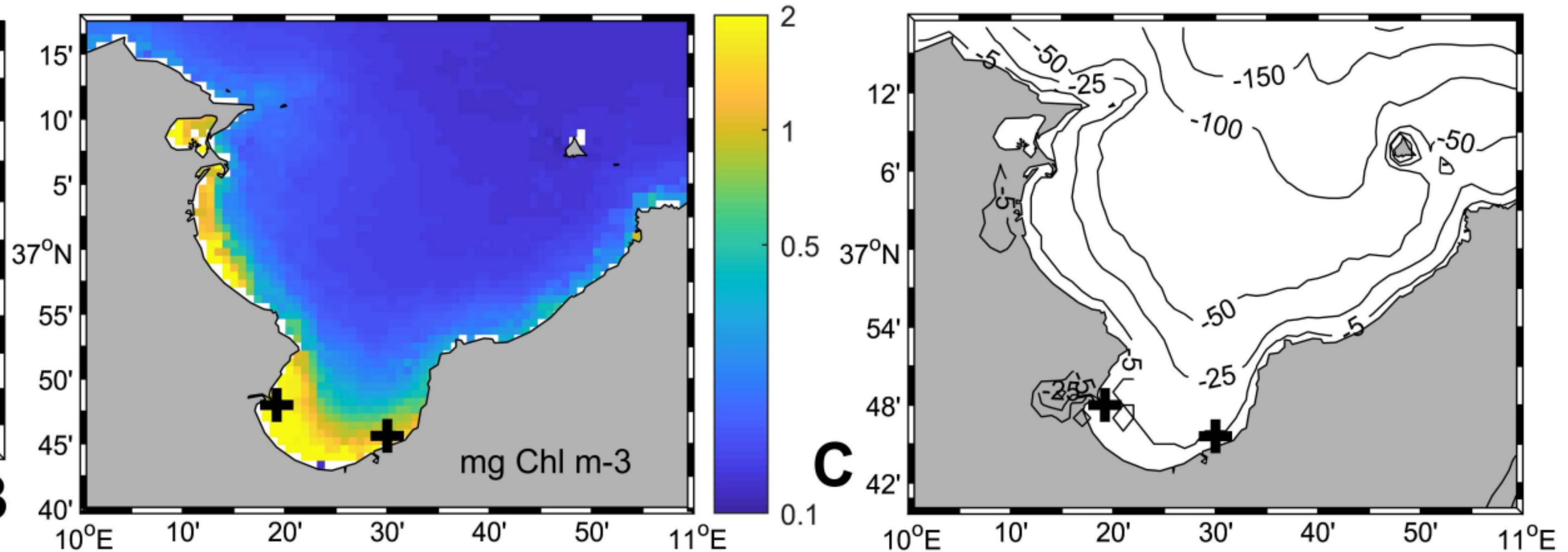
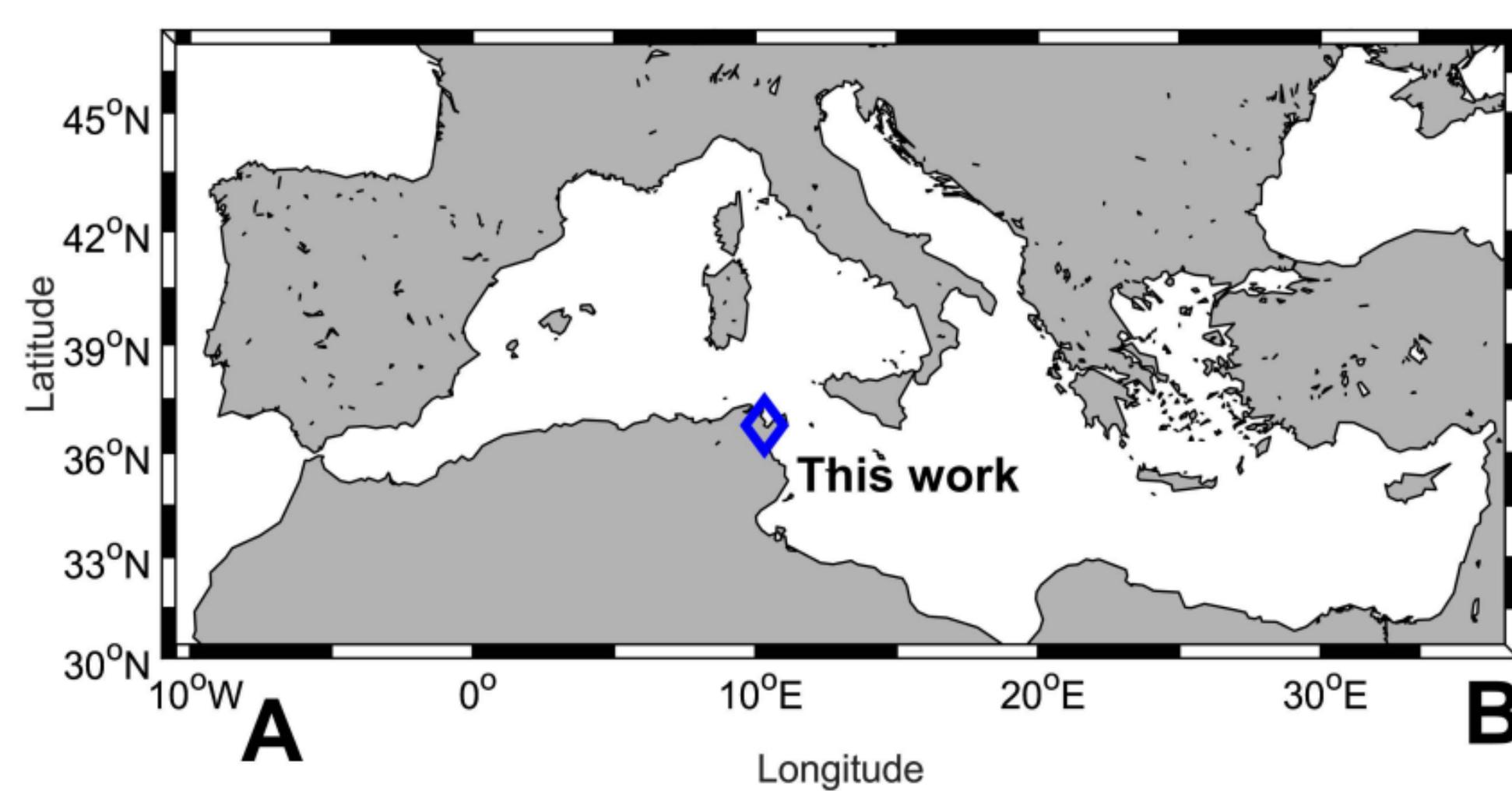


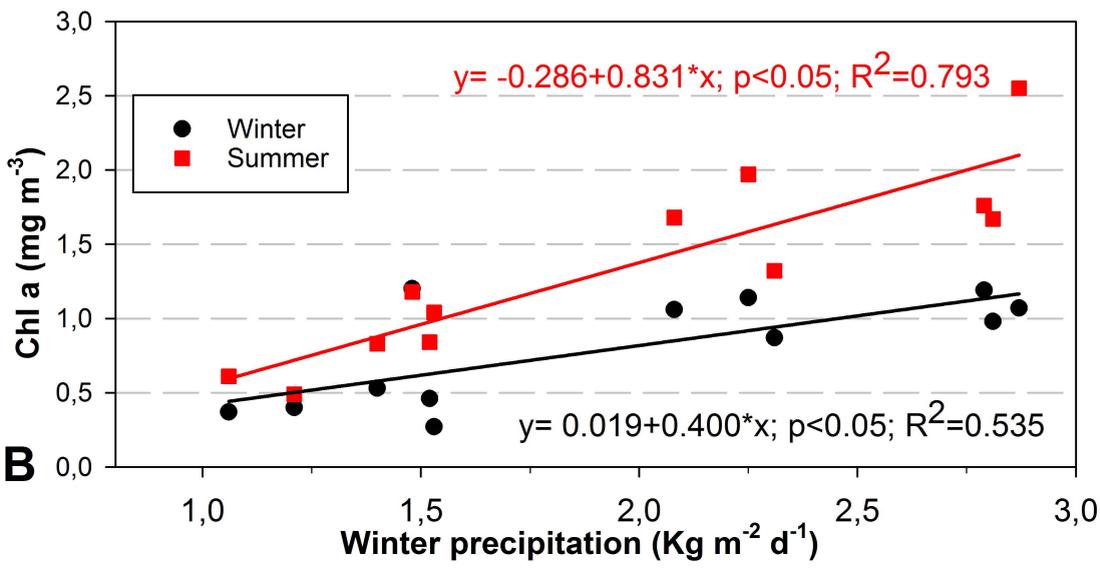
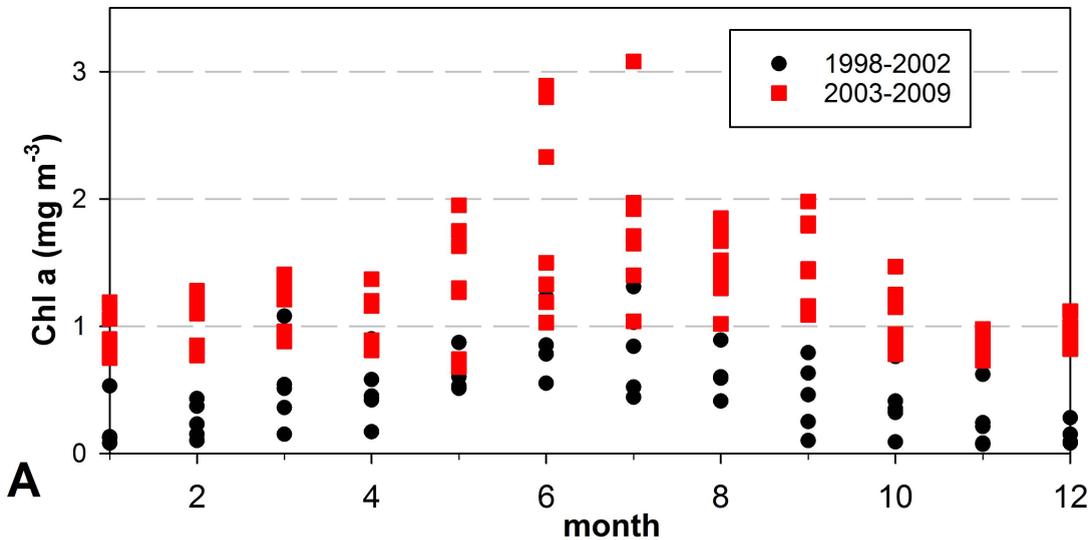


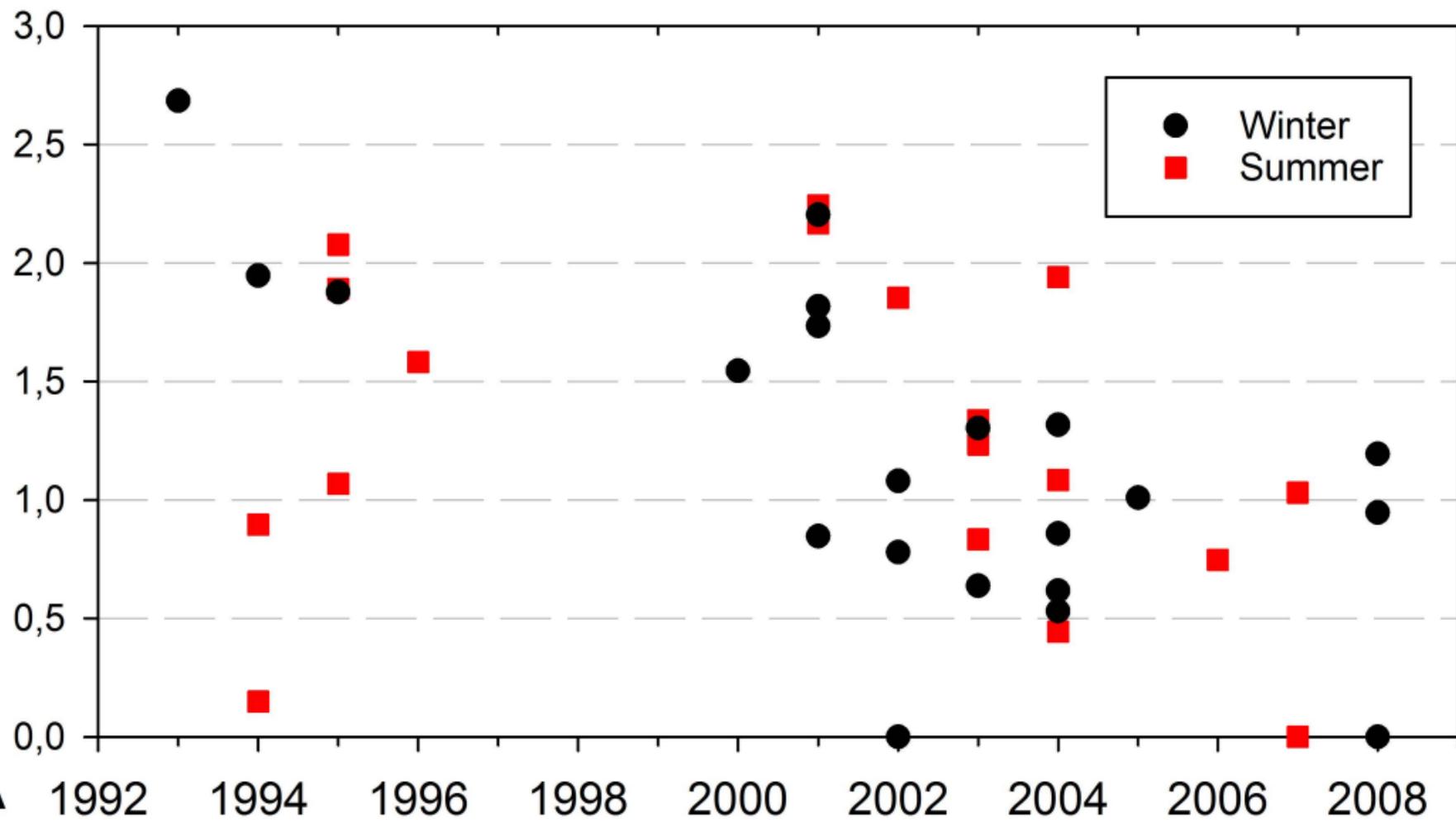


**Supplementary Table I:** Samples analyzed included in the analysis (Fig.2)

Year	Winter months (DJFM)	Summer months (JJA)
1993	3	-
1994	12 (1993)	8
1995	2	6,7,8
1996	-	8
2001	12 (2000),1,2	6,7
2002	12(2001),1,2,3	6
2003	2,3	6,7,8
2004	12(2003),1,2,3	6,7,8
2005	12(2004),1	-
2006	-	8
2008	1,3	8





**H' index phytoplankton****B**