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PHYTOPLANKTON

Red sky at night cyanobacteria delight: the role of climate in structuring phytoplankton assemblage in a shallow, Mediterranean lake (Biviere di Gela, southeastern Sicily)

Rossella Barone · Giuseppe Castelli · Luigi Naselli-Flores

Abstract The hypothesis that climate changes may strongly interfere with the peculiar hydrological patterns in the Mediterranean basin and alter the structure of the aquatic biota was tested in a shallow Sicilian lake. A phytoplankton survey, carried out monthly in the brackish and shallow Biviere di Gela, in 2005–2007, revealed a transformation in the structure of its phytoplankton assemblage as compared with similar data collected in 1987–1988. An analysis of the trends followed by precipitation and temperature over the last 40 years, showed reduced water inflows, due to increased air temperature and evapotranspiration rather than to a decrease in the amount of precipitation. A consequent reduction in water level occurred, which almost caused the disappearing of the lake at the beginning of the century. This reduction in water level disrupted the littoral zone of the lake and transformed it from a clear, macrophyte-dominated environment to a turbid one characterized by huge summer blooms of the cyanobacteria *Aphanizomenon ovalisporum*, *Cylindrospermopsis raciborskii*, and *Pseudanabaena limnetica*. The addition of freshwater from a nearby dam reservoir, to restore water levels, likely opened the way to another alga, *Prymnesium parvum*, whose allelopathic and toxic glycosides further contributed to the transformation of the lake biota. On the whole, the Biviere di Gela is an example of how climate changes, coupled with inadequate management procedures, may negatively impact Mediterranean aquatic ecosystems.

Keywords Climate change · Functional groups · Hydrological deficit · Brackish lake · *Prymnesium parvum*

Introduction

The Mediterranean basin is a densely populated region where an intensification of land use activities has been recorded over the last 50 years (Marchetto et al., 2008). This trend, coupled with climate change, strongly interferes with the hydrological cycle in the region. The increased need of water for human activities (e.g., agriculture, drinking, and industrial waters) may severely endanger Mediterranean aquatic ecosystems. Shallow lakes are one of the most

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common typologies of aquatic environments in the Mediterranean. Several of these are temporary and both their filling and duration directly depends on the amount of precipitation (Marrone et al., 2006). In this area, the need for water has led in the last decades to a large diffusion of man-made aquatic ecosystems by damming temporary or permanent streams and rivers. Man-made lakes are subjected to considerable stress during the recurrent drought periods, which affect the Mediterranean basin (Naselli-Flores, 2003) due to the increase in the amplitude of their water level fluctuations. It has been already shown that these environments are extremely sensitive to such fluctuations, which tend to increase the $z_{\mathrm{mix}}/z_{\mathrm{eu}}$ ratio (Naselli-Flores & Barone, 2007), disrupt the summer thermal structure of the lakes (Naselli-Flores & Barone, 2005) and promote the blooms of toxic cyanobacteria (Naselli-Flores et al., 2007).

Shallow Mediterranean aquatic ecosystems, are much more prone than deeper ones to experience dramatic changes in the structure of their biota when a modification in their water supply occurs, due to climate change and/or overexploitation of water resources. Several predictive models have shown that the Mediterranean climatic region is particularly sensitive to global warming due to the establishment of a drier and hotter climate (Sánchez et al., 2004). This condition of “good weather”, as that forecasted by the popular way of saying “red sky at night, shepherds delight”, could favor cyanobacterial growth and alter the structure of phytoplankton assemblages in freshwater Mediterranean ecosystems. At its extreme, a decrease in the amount of precipitation and higher temperatures, with the consequent enhancement of water losses due to increased evapotranspiration, may result in the disappearing of shallow lakes both permanent and temporary and in a considerable erosion of biodiversity.

The aim of this article is (i) to evaluate, through the analysis of the main meteorological parameters, to what extent climate changes may have constrained Lake Biviere di Gela in the last decades, and (ii) to assess, through the analysis of phytoplankton structure of this shallow Mediterranean lake, what kind of consequences these constraints may have produced in the functioning of the studied aquatic ecosystems. In order to fulfill these tasks, phytoplankton of the largest shallow lake in Sicily was investigated during 3 years (2005–2007) and the structure of the assemblages was compared to that which was present 20 years ago (1987–1988). In addition, precipitation and temperature data recorded over the last 40 years were used to evaluate the trends of climate variability in the area.

Materials and methods

The study site

The “Biviere di Gela” (37°01′20″N, 01°53′30″E) is the largest natural coastal lake in Sicily (1.2 km^2) and one of the few natural wetlands left on the island. The lake has a maximum length of 2.5 km and is located in SE Sicily (Italy), 8 km SE of the town of Gela, 1.3 km from the Mediterranean coast and 8 m a.s.l. (Fig. 1). The lake was already known in the antiquity and is mentioned, as “Lacus Gelonius” by Pliny the Elder in his *Naturalis Historia*. The watershed is characterized by Neogene and Quaternary deposits. The former are made up of clay, marly clay, and evaporitic deposits, which determine the brackish nature of the lake water, with a degree of salinity which varies according to season, amount of rainfall, and inputs of groundwater and surface runoff. The lake has no surface outflow and no important inflow,

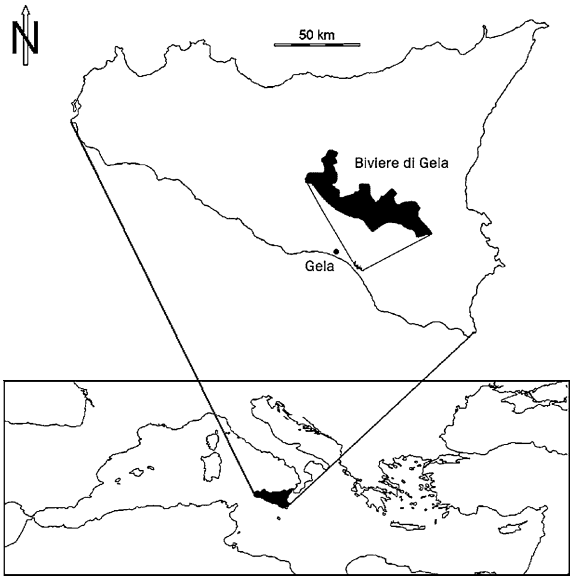

Fig. 1 Location of the studied site

being fed during the rainy season by an ephemeral surface stream. An artificial canal downstream of a dam reservoir (Lake Dirillo) was built to guarantee the lake filling. Water losses from the lake include evaporation from the water surface and underground outflow to downgradient groundwater. When the water level is less than 1.6 m, the lake separates into two units ("Lago Grande" to the east, and "Lago Piccolo" to the west). The study area presents typical Mediterranean climate: the aridity index (De Martonne, 1926) computed for this coastal area is less than 15, and therefore classifies the location as semi-arid. Mild, relatively rainy winters and warm, dry summers alternate and the lake is subjected to seasonal water level fluctuations. The imbalance between precipitation and evaporation rates determines a hydrological deficit in the lake budget, mainly compensated by surface runoff. A hydrogeochemical investigation recently carried out on isotope composition of local rainwater and groundwater has revealed that more than 90% of water recharge of the lake is due to autumn and winter precipitation (Manno et al., 2007). In 1988, the lake has been designated for the List of Wetlands of International Importance and included in the "Ramsar Act". In 1997, a Nature Reserve has been created by the Sicilian Region to preserve the several rare and endangered vertebrate species (e.g., amphibians, turtles, and birds) that inhabit the lake.

Meteorological and hydrological data

The annual hydrological balance D_{tot} was calculated for the period 1968–2006 according to the formula:

$$D_{\mathrm{tot}} = D_{\mathrm{l}} + D_{\mathrm{c}} \tag{1}$$

where D_{l} and D_{c} are the water balance of the lake and of the catchment area, respectively.The lake balance is given by the formula:

$$D_{\mathrm{l}} = (R - E_{\mathrm{d}}) \times A_{\mathrm{l}} \tag{2}$$

where R is the yearly rainfall, E_{d} the yearly evaporation, calculated by the Meyer formula (Natale, 1981), and A_{l} the lake surface.

The contribution of the catchment area was estimated considering an average value of infiltrated water equal to 25% of precipitation (Manno et al., 2007):

$$D_{\mathrm{c}} = (0.75 \times R - E_{\mathrm{c}}) \times A_{\mathrm{c}} \tag{3}$$

where E_{c} is the potential yearly evapotranspiration after Thornthwaite (1948), estimated with a calculator freely available on the internet at http://www.fmulas.net/geologia/evapo/, and A_{c} the planar surface of the catchment area. In computing the yearly values of E_{c}, its monthly contributions E_{i} had to be equal to the monthly rainfall R_{i} when $R_{\mathrm{i}} < E_{\mathrm{i}}$ (Madonia et al., 2006). Groundwater fluxes are generally difficult to calculate and this task goes beyond the aims of this article. According to Manno et al. (2007), we supposed that these must be strictly related to surface runoff.

Precipitation and air temperature data, recorded at the nearby Gela meteorological station during the period 1968–2006, were supplied by the Hydrographic Service of the Sicilian Region.

Phytoplankton data and limnological variables

Phytoplankton was collected monthly, during two distinct periods, from January 1987 to December 1988 and from January 2005 to December 2007, in a station located in the central part of the lake. Water samples for phytoplankton analysis were collected sub-superficially. At the same time, net-plankton samples were taken by towing vertically a 40-μm mesh net and fixed in 4% buffered formaldehyde. Live samples were also taken for species identification using the most up-to date phycological literature. Phytoplankton water samples were immediately preserved in Lugol's iodine solution; cell counting was performed using a Zeiss-Axiovert 100 inverted microscope in accordance with the sedimentation method developed by Utermöhl. Wet weight biomass was calculated from recorded abundance and specific biovolume estimates, based on simple geometric shapes (Hillebrand et al., 1999) and assuming unit specific gravity.

Phytoplankton species were pooled into functional groups according to Reynolds et al. (2002), following the recommendations given by Padisák et al. (2009).

Along with phytoplankton collections, chemical (dissolved oxygen, pH) and physical (temperature, conductivity) parameters in the water, as well as the depth of the station, were recorded using mutiparametric probes (Idronaut mod. 401 in 1987–1988, and

YSI 556 MPS in 2005–2007). Water transparency was measured using a Secchi disk. Water samples for nutrients and TP were collected sub-superficially, refrigerated and taken to the laboratory where the analyses were performed according to Tartari & Mosello (1997). Water level data for the period 2002–2004 were supplied by the Management Board of the Nature Reserve "Biviere di Gela".

Statistical analysis

For both studied periods, the data sets used for statistical analyses consisted of species-specific biovolume estimates of phytoplankton. Phytoplankton taxa that were present with a relative biovolume greater than 5% in more than one sample, were included in the ordination analyses. The monthly biovolume values were log-transformed, $Y_i = \log(X_i + 1)$, to reduce the weight of the most abundant taxa. Three matrices were prepared and analyzed: one phytoplankton matrix (taxa x sampling dates) considering the original data (the biomass of the single species), and two additional synthetic matrices after grouping the algae (i) into functional groups and (ii) into phylogenetic algal classes. For both the studied periods, the three matrices were transformed into dissimilarity matrices by computing the Bray–Curtis' dissimilarity index (Podani, 2000) and then ordinated separately in a two-dimension plane, by means of Non Metric Multidimensional Scaling (NMDS). All the ordinations were performed with the free software PAST (Hammer et al., 2001).

Results

Meteorological patterns

The analysis of the annual precipitation for the period 1968–2006 does not reveal a significant trend and the annual values show a uniform distribution around the average value (360 mm year^{-1}) computed over the whole period (Fig. 2a). However, a time-shift in the occurrence of rain can be observed when comparing the period 1967–1986 and 1987–2006, with a decrease in the average spring amount of rain and an increase in the autumn values (Fig. 2b).

Conversely, a significant increasing trend in the average values of air temperature has been shown over the period 1968–2006 (Fig. 2c). As a consequence, a proportional increase in the values of evaporation and evapotranspiration occurred in the lake and in its catchment as revealed by the computation of the annual hydrological balance, D_{tot}. During the 1980s, the lake level was high due to large inflows from surface runoff, and the groundwater outflows were therefore high as well, maintaining constant high water level. During the following years inflows from surface runoff gradually decreased, the lake level was lowered, and the net groundwater outflows decreased as well, until they were negative. As a consequence, the annual amount of water feeding the lake from its catchment shows a constant decrease over the last 40 years (Fig. 2d).

Limnological variables

By comparing the main trophic state parameters of the lake (Table 1), an ongoing eutrophication process is detectable. In particular, annual average values of productivity proxies (i.d. total phosphorus and chlorophyll *a*) increased by an order of magnitude in 2005–2007 compared to 1987–1988, in accordance with the increased nutrients availability. Accordingly, Secchi depth transparency values were much lower in 2005–2007.

Water level trends in the lake were also different in the two studied periods. As shown in Fig. 3a, during 1987–1988, water level fluctuated seasonally between 6.4 and 7.5 m and conductivity values ranged between 2.3 and 2.7 mS cm^{-1}. In the years 2002–2004, the water depth was constantly less than 1.6 m and the lake was divided into two distinct units. In December 2004, to restore water levels, freshwaters from a nearby dam reservoir were channeled to the Biviere di Gela. This caused a sudden increase in depth and a lowering of conductivity values, from 10 to less than 1.5 mS cm^{-1} (data not shown). Since the beginning of 2005, imprecise amount of water were added from time to time to the lake to maintain its depth above 3.5 m.

Following the increase in air temperature, water temperature recorded in 2005–2006 shows higher values compared to the period 1987–1988 (Fig. 3b) and an increase of more than 1°C was detected in summer and autumn months.

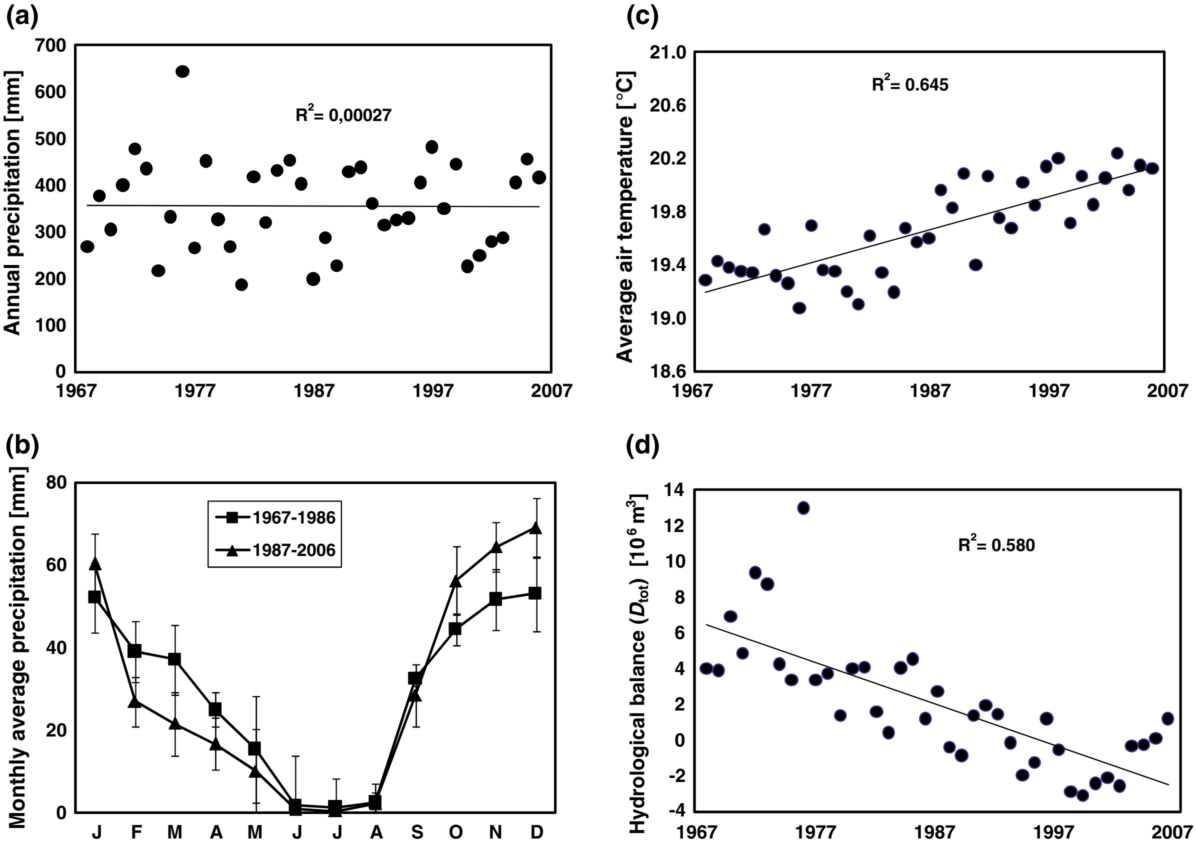

Fig. 2 Trends of precipitation (**a, b**), air temperature (**c**), and hydrological balance (D_{tot}) (**d**) in the studied site over the last 40 years. R: correlation coefficient. *Vertical bars* in (**b**): multiannual standard deviation

Table 1 Average values of the main trophic state descriptors and nutrients concentrations in the studied periods

Parameter	Unit	1987–1988		2005–2007	
		Average	SD	Average	SD
Total phosphorus	µg l^{-1}	45.5	22.4	175.3	93.8
Chlorophyll *a*	µg l^{-1}	4.22	0.93	35.7	9.03
Secchi depth	m	1.92	0.61	0.85	0.63
Phytoplankton biomass	mg l^{-1}	1.02	0.45	23.2	19.9
Reactive phosphorus	µg l^{-1}	3.75	1.84	14.6	10.7
N–NO_3	µg l^{-1}	82.6	65.5	225.4	111.4
N–NH_4	µg l^{-1}	22.5	14.8	47.0	22.4

Phytoplankton composition and abundances

In accordance with the higher nutrients availability, the period 2005–2007 is characterized by phytoplankton biovolumes one order of magnitude higher than those recorded in 1987–1988 (Fig. 4). In particular, the trends show a marked annual peak in spring or early summer due to *Prymnesium parvum* and *Tetraselmis cordiformis* in 2005, *Aphanizomenon ovalisporum* in 2006 and again *Tetraselmis cordiformis* in 2007.

Phytoplankton class composition in 1987–1988 (Fig. 5a) shows a clear seasonal pattern with cryptophytes and diatoms, mainly represented by the brackish species *Chaetoceros muelleri*, dominating in winter, and a rich euglenophytes assemblages accompanied by the dinoflagellates *Ceratium hirundinella* and *Peridinium* spp., co-dominating summer assemblages. A well diversified assemblage of chlorococcalean chlorophytes, both unicellular and colonial, characterized late winter, early spring, and autumn phytoplankton.

Even the period 2005–2007, is characterized by clearly recognizable seasonal patterns (Fig. 5b). However, in this second period of time diatoms were

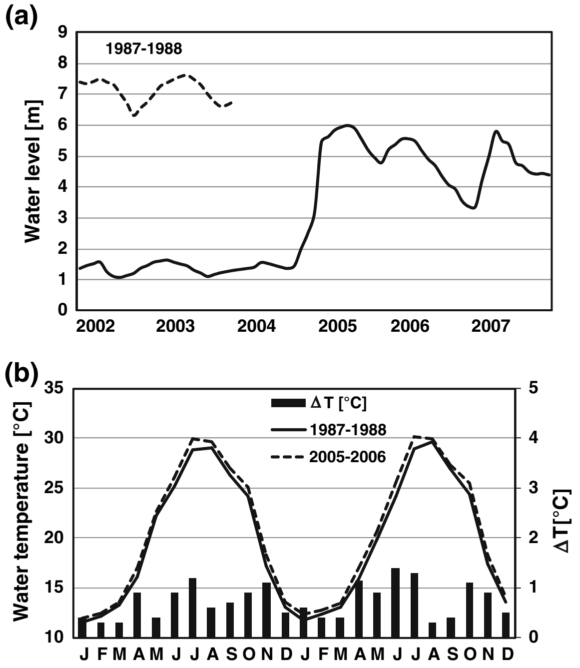

Fig. 3 Trends of water level in the lake in the periods 1987–1988 and 2002–2007 (**a**), and comparison of water temperature (**b**) in 1987–1988 and 2005–2006. Histograms show monthly water temperature difference in the two studied periods

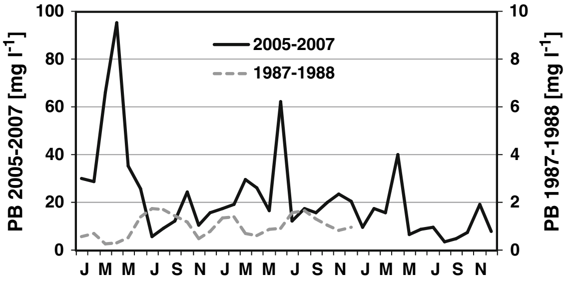

Fig. 4 Trends of total phytoplankton biovolume (PB) in the studied periods

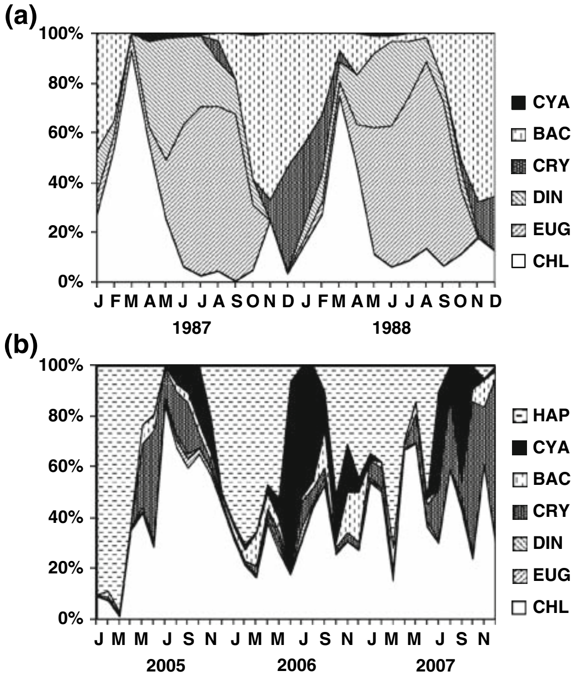

Fig. 5 Percentage composition of phytoplankton biovolume in the two studied periods

replaced by the haptophyte *Prymnesium parvum* in winter, and cyanobacteria, mainly represented by *Apahnizomenon ovalisporum*, *Cylindrospermopsis raciborskii*, and *Pseudanabaena limnetica*, significantly contributed to summer assemblages especially in 2006 when the largest dewatering of the period 2005–2007 was recorded. At the same time, chlorophytes shifted from the dominance of small unicellular and colonial chlorococcalean algae to the large flagellated *Tetraselmis cordiformis* (Volvocales). Moreover, a more long-lasting occurrence of chlorophytes characterizes this period, whereas, dinoflagellates and euglenophytes are almost absent in the phytoplankton.

Phytoplankton ordination

Matrices formed by phytoplankton single species did not result in clear ordinations. Conversely, the configurations of the phytoplankton samples pooled into selected functional groups (Table 2) and obtained by NMDS for both the studied periods are reported in Fig. 6. The stress values (Kruskal & Wish, 1978) of these two NMDS configurations are 0.18 for 1987–1988 and 0.15 for 2005–2007. Ordination obtained using the phylogenetic classes is superimposed to the one obtained using the functional groups. The latter contemporary allows a higher resolution than that offered by classes and offer a higher readability than the single species. Functional groups clearly reveal the temporal ordination of the samples and are divided into two main groups, which may be identified with summer and winter seasons, in both the studied periods. By comparing the two configurations, it is possible to see that the same number of coda characterizes the two periods, but only five of these coda (**C**,

Table 2 Grouping of phytoplankton species into functional groups in the studied periods

Codon	Species	Years		Class
		1987–1988	2005–2007	
C	*Chaetoceros muelleri* Lemmermann	x		BAC
	Cyclotella meneghiniana Kützing		x	BAC
	Cyclotella spp.		x	BAC
	Stephanodiscus sp.	x		BAC
D	*Cylindrotheca closterium* (Ehrenberg) Lewin & Reimann		x	BAC
F	*Dictyosphaerium pulchellum* Wood	x	x	CHL
	Elakatothrix gelatinosa Wille	x		CHL
	Coelastrum microporum Nägeli		x	CHL
	Oocystis sp.	x	x	CHL
G	*Tetraselmis cordiformis* (Carter) Stein		x	CHL
	Chlamydomonas spp. Ehrenberg		x	CHL
H_1	*Anabaenopsis elenkini* Miller		x	CYA
	Aphanizomenon ovalisporum Forti		x	CYA
J	*Scenedesmus quadricauda* (Turpin) Brébisson	x		CHL
	Scenedesmus spp.		x	CHL
	Tetraedron minimum (Braun) Hansgirg		x	CHL
	Crucigenia tetrapedia (Kirchner) West & West		x	CHL
	Siderocelis spp.		x	CHL
K	pico Chlorococcales	x		CHL
L_0	*Peridinium* sp.1	x		DIN
	Peridinium sp.2	x		DIN
L_M	*Ceratium hirundinella* (Müller) Dujardin	x		DIN
	Microcystis aeruginosa	x		CYA
N	*Cosmarium* spp.		x	CHL
P	*Closterium aciculare* West	x		CHL
	Fragilaria sp.	x		BAC
S_1	*Pseudoanabaena limnetica* (Lemmermann) Komárek		x	CYA
S_N	*Cylindrospermopsis raciborskii* (Wolosz.) Seena. & Subbar.		x	CYA
T	*Planktonema lauterbornii* Schmidle	x		CHL
W_1	*Euglena* spp.	x		EUG
	Phacus spp.	x		EUG
W_2	*Strombomonas* sp.	x		EUG
	Trachelomonas spp.	x		EUG
X_1	*Monoraphidium* spp.	x	x	CHL
X_2	*Prymnesium parvum* Carter		x	HAP
	Hymenomonas sp.		x	HAP
	Chrysochromulina sp.		x	HAP
Y	*Cryptomonas erosa* Ehrenberg	x		CRY
	Cryptomonas marsonii Skuja	x		CRY
	Cryptomonas spp.	x	x	CRY

F, **J**, **X_1**, and **Y**) are present in both of them. In some cases, the species included in the group are not the same: codon **C**, mainly formed by *Chaetoceros muelleri* in 1987–1988 is constituted by *Cyclotella meneghiniana* in 2005–2007, and codon **J** is much richer in species in 2005–2007 than in 1987–1988.

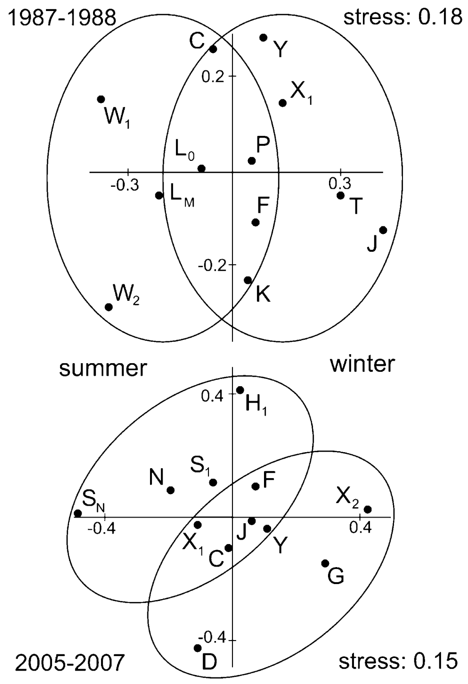

Fig. 6 Non Metric Multidimensional Scaling plots of the phytoplankton in the two studied periods, pooled into functional groups as described in Table 2

Moreover, the seasonal occurrence of these shared groups shows a shift from winter, in 1987–1988, to summer in 2005–2007.

Discussion

Several of the temperature reconstructions carried out at a global scale reveal that the late twentieth century warmth is unprecedented at hemispheric scales (Jones & Mann, 2004 and references therein; Moberg et al., 2005). In particular, the Mediterranean area has been experiencing substantial winter warming since the end of the nineteenth century and the last winters of the twentieth century and the first winters of the twenty-first century were the warmest and driest, in agreement with recent findings from other parts of Europe and the Northern Hemisphere (Luterbacher et al., 2006 and references therein). Consistently, air temperature in the area of the Biviere di Gela has increased by about 0.6°C over the last 40 years. This increase in air temperature has been accompanied by an increase in evapotranspiration and, at the end, in a significantly diminished total amount of water feeding the lake from the catchment, in spite of the unvaried total amount of precipitation. According to Pham et al. (2009), under dry conditions the contribution of surface runoff to shallow lake feeding is much higher than that of groundwater and thus, filling and emptying directly depend on the amount of precipitation, evapotranspiration, and ultimately by land use in the catchment. The decrease of the surface runoff reaching the Biviere di Gela almost caused the disappearing of the water body at the beginning of the century. However, also the spreading of intensive monoculture practices may have further contributed to increase the hydrological deficit.

Conversely to what showed by Beklioglu et al. (2006) in Turkish Mediterranean lakes, the development of submerged macrophytes in the littoral zone of the Biviere di Gela was negatively affected by water level reduction. Actually, in 1987–1988, the lake showed a well-developed littoral zone with dense macrophyte beds mainly formed by *Ceratophyllum demersum* and *Potamogeton pectinatus* (Calvo et al., 1993). These populations almost disappeared by 2005–2007, probably due to the very low water levels suffered by the lake at the beginning of the twenty first century. The extent of this water lowering was so intense to divide the lake into two basins (Manno et al., 2007) with a water level decrease between the periods 1987–1988 and 2002–2004 of about 6 m. In order to counteract the lake emptying, an artificial inflow was created to protect the site and its wildlife. Since then, freshwater from a nearby dam reservoir was added to the lake to maintain its water level. In accordance with the alternative stable state hypothesis in shallow lakes (Scheffer et al., 1993), the disruption of the littoral zone may have favored the increase in nutrient availability in the lake and the shift from a macrophyte dominated, clear water body to a turbid, cyanobacteria-dominated lake. Unpublished data supplied by the management board show that in 2002 the lake was affected by huge blooms due to *Aphanizomenon ovalisporum*, which reached densities above 500 × 10^6 cells l^{-1}. In the Mediterranean basin, this cyanobacterium, whose taxonomic position seems closer to *Dolichospermum* than to *Aphanizomenon* s.str. (Komárek, pers. com.), was first recorded in Lake Kinneret in 1994 (Pollingher et al., 1998) and later in some Greek and Spanish lakes (Gkelis et al., 2005; Quesada et al., 2006). Its occurrence in all these sites was generally related to high water temperature and it was always found to produce cylindrospermopsin, a guanidine alkaloid inhibitor of protein synthesis (Codd et al., 2005). The increase in water temperature recorded in the second period of investigation may have further favored the increase in cyanobacteria biomass. *Aphanizomenon ovalisporum* as well as *Cylindrospermopsis raciborskii* and *Pseudanabaena limnetica* colonized the lake in the years after the macrophyte disappearing, characterized by low water levels and high turbidity, and became the dominant phytoplankton group in summer assemblages (Naselli-Flores et al., 2007), outcompeting euglenophytes and dinoflagellates.

Further to *Aphanizomenon ovalisporum* in summer, *Prymnesium parvum*, a brackish water haptophyte flagellate commonly producing a set of esotoxins in the form of potent hemolytic and ichthyotoxic glycosides (Igarashi et al., 1999), recurrently bloomed in winter reaching in 2005 biomass values higher than 60 mg l^{-1}. This species, which despite its low growth rates usually produces monospecific blooms, was proven to exert an allelopathic effect addressed toward outcompeting other phytoplankton species (Granéli & Johansson, 2003). In this way, this species substituted diatoms as dominants of the winter assemblages. In addition, it was demonstrated to be highly toxic to copepods and fish (Legrand et al., 2003). In the last years, it has been recorded in another Sicilian lake, Lake Pergusa, where in 2007 it formed a dense bloom accompanied by carp killings (Barone et al., 2008). As in Biviere di Gela, also in Lake Pergusa the salinity of the lake, from values above 20 PSU, was significantly reduced to values less than 5 PSU by adding freshwater, to prevent the drying out of the lake. The tolerance to low salinity showed by *P. parvum* may enable it to spread to inland waters and to become dominant when a sudden decrease in conductivity occurs (Harman & Grover, 2008). Moreover, the decrease in conductivity likely caused the replacement of *Chaetoceros muelleri* by *Cyclotella meneghiniana*.

The appearance and seasonal dominance of new phytoplankton species in the lake, is likely due to (i) the disruption of the littoral zone, with the consequent increase in turbidity and increased availability in inorganic nutrients, (ii) the increase in water temperature, which follows the higher air temperature, and (iii) to the lowering in conductivity values which was due to the addition of freshwater to restore the lake water volumes. Moreover, a further top-down effect may be hypothesized. Actually, the zooplankton assemblage in 1987–1988 was largely dominated by the calanoid copepod *Calanipeda aquaedulcis* which reached its population maxima in spring (Calvo et al., 1993) and was virtually the only herbivore zooplankter inhabiting the lake. During the 2005–2007 investigation, not a single specimen was ever recorded, and the zooplankton assemblage of the lake appeared to be formed mainly by a few species of brachionid rotifers. The observed shift in the occurrence of the coda **C**, **F**, **J**, $\mathbf{X_1}$, and **Y** from winter to summer could be due to the disappearing of the calanoid, which in 1987–1988 controlled the populations of these algae in late winter and spring. The extinction of *C. aquaedulcis* in the lake is likely due to the toxic effects caused by *Prymnesium parvum* (Legrand et al., 2003) and *Aphanizomenon ovalisporum* (Nogueira et al., 2006).

As described above, in the recent years the planktic community of the Biviere di Gela underwent a complete re-arrangement, which, in accordance with the climatic trends observed in the Northern Hemisphere, was initiated by a decreased water availability in its catchment, due to a progressive increase in the annual average temperatures of the area. The reduction in the inflow of water to the lake caused a strong reduction of depth and transformed this environment from a clear, macrophyte-dominated shallow lake to a turbid one, dominated by cyanobacteria in summer. The reduction in conductivity caused by the attempt to restore water levels, may have favored the dominance of *Prymnesium parvum*, and further contributed to the community modification. On the whole, the Biviere di Gela is a clear example of how climate changes, coupled with inadequate management procedures, may negatively impact Mediterranean aquatic ecosystems.

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