The toxic dinoflagellate *Gymnodinium catenatum*: an invader in the Mediterranean Sea

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The distribution of the toxic dinoflagellate *Gymnodinium catenatum* Graham in the Mediterranean Sea was once restricted to the eutrophic waters of the Alborán Sea. In September 1999, this taxon was found for first time in the Algerian basin, being the dominant species at subsurface depths (~1 cell mL^{-1}) associated with low salinity waters. The geographical expansion of this exotic species is not only deleterious due to its toxicity, but its recent presence is associated with changes on the structure of the Mediterranean pelagic food web.

Key words: Phytoplankton, *Gymnodinium catenatum*, toxic dinoflagellate, Mediterranean Sea.

Introduction

Over the last few decades, Mediterranean marine biodiversity has been undergoing rapid alterations due to climate change and human impact (TURLEY 1999), and has become exceptionally susceptible to fish, invertebrate or macroalga invasions (BIANCHI and MORRI 2000, GALIL 2000, MEINESZ et al. 2001, BOUDERESQUE and VERLAQUE 2002).

In the pelagic ecosystem, it is to be expected that a change in nutrient ratios will shift the phytoplankton composition to non-siliceous species such as flagellates and dinoflagellates (TURLEY 1999, BÉTHOUX et al. 2002). Consequently, together with a modification of the coastal habitats, an increase in red tide events is expected, in conjunction with the spread of toxic dinoflagellates, as already reported (GARCÉS et al. 2000, VILA et al. 2001). Since the early 1900s, at least 16 exotic species of phytoplankton has become an integral part of European Atlantic waters (NEHRING 1998, ELBRÄCHTER 1999). However in the Mediterranean Sea, little is known about the invasion of exotic phytoplankton taxa.

Gymnodinium catenatum Graham is a naked, chain-forming dinoflagellate that produces saxitoxin, the first metabolite responsible for Paralytic Shellfish Poisoning intoxication (PSP). The species produces cysts that survive prolonged darkness and nutrient-poor conditions and can travel considerable distances in ships´ ballast water (HALLEGRAEFF 1998). Many studies have reported the historical presence of the species in European At-

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lantic waters based on cysts (NEHRING 1995), but these records corresponded to non-toxic species *Gymnodinium nolleri* Ellegaard *et* Moestrup further described (ELLEGAARD and MOESTRUP 1999). The origin of *Gymnodinium catenatum* in Atlantic European waters is still unresolved. The taxon was for first time reported in 1976 after a PSP event in the Galician Rías (NW Spain) (ESTRADA et al. 1984). WYATT (1992) hypothesised that the taxon was introduced by the Galician fishing fleet, which during the 70s operated in Argentinan waters, where this species is common.

The first records in the Mediterranean Sea appeared in the NW Alborán Sea (DELGADO 1990, BRAVO et al. 1990) probably transported by currents from the Atlantic Ocean according to the circulation through the Strait of Gibraltar (GÓMEZ et al. 2000a). Nowadays this taxon has become an abundant and well-established species in the Alborán Sea and is associated with frequent toxic events (e.g., TALEB et al. 2001, CALBET et al. 2002). The Almería-Oran frontal system seemed to restrict the distribution of the species to the eutrophic conditions of the Alborán Sea, preventing any eastward expansion along the western Mediterranean Sea. This study reports the expansion of the species along the southern basin of the Western Mediterranean Sea.

Material and methods

Ten stations from the NW Alborán Sea to the oligotrophic Eastern Mediterranean were sampled during the PROSOPE cruise on board R/V *Thalassa* (September 14–30, 1999) (Fig. 1). Discrete water samples for microphytoplankton (>15 µm) composition were collected usually around 11–12 hours GMT from casts using a CTD-rosette system outfitted with 10 litre Niskin bottles. From the surface to 100–110 m depth, 4–6 discrete depths were sampled, with a higher number (up 10 depths) in the permanent stations (MIO and DYFAMED). From each bottle, 0.5 L phytoplankton samples were immediately fixed by adding Lugol solution (2% final conc.) and stored in dark and cool conditions until analysis. Sub-samples (50–100 mL) were allowed to settle for 24–48 h on Utermöhl chambers
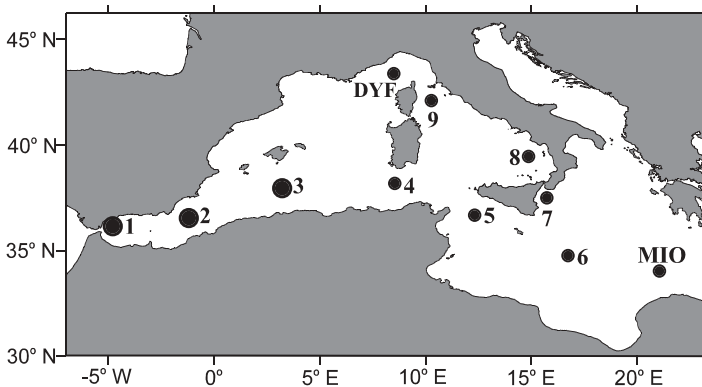

Fig. 1. Sampling stations during the PROSOPE cruise in September 1999. Gross points represent the stations where *Gymnodinium catenatum* Graham was recorded. St. 1 NW Alborán Sea; St 2. Almería-Oran Front (ALMOFRONT); St. 3 Algerian basin; St 4 Sardinia Channel; St. 5 Sicily Strait.

and observed by inverted light microscopy (see GÓMEZ and GORSKY 2003). It must be stressed that the agitation of the fixed samples affects the average number of cells per colony, which is smaller than in the samples of living cells due to fracture of the colonies.

Results

Physical structure

The longitudinal distribution of the temperature along the southern basin of the Western Mediterranean was characterised by surface temperatures around 24–25 °C, with a well-established thermocline. Station 1 (NW Alborán Sea) constituted an exception with surface temperatures of around 21 °C. The salinity of Atlantic origin waters at two stations of the Alborán Sea ranged from 36.6–36.8. At Station 1, close to the Strait of Gibraltar, the lower temperature near the surface and salinity values higher the typical values of the Atlantic inflowing waters at the Strait of Gibraltar (~36.3–36.4) are usually associated with the mixing of colder and saltier deep Mediterranean outflowing waters (e.g., GÓMEZ et al. 2000b, GÓMEZ et al. 2001). The salinity in the upper layer of stations of the Alborán Sea presented salinity values of 36.6–36.8. However the station located in the Algerian basin (Station 3) presented lower values (36.47 at 20 m depth) associated with the Atlantic Current waters. At the stations of the Sardinia Channel (St. 4) and Strait of Sicily (St. 5) salinity showed values around 37.8, clearly different from the previous stations (Fig. 2).

Phytoplankton distribution

Gymnodinium catenatum was recorded in 3 of the total 11 stations during the cruise (Fig. 1). In Station 1 (NW Alborán Sea), microphytoplankton abundance showed a subsurface maximum between 40–60 m depth with an assemblage dominated by small diatoms (e.g*., Dactyliosolen fragilissimus* (Bergon) Hasle, *Leptocylindrus danicus* Cleve, *Pseudo-nitzschia* spp.) and larger diatoms (*Chaetoceros* spp., *Thalassiosira* spp.) between 60–100 m depth. *Gymnodinium catenatum* was observed between 20–40 m depth (Tab. 1).
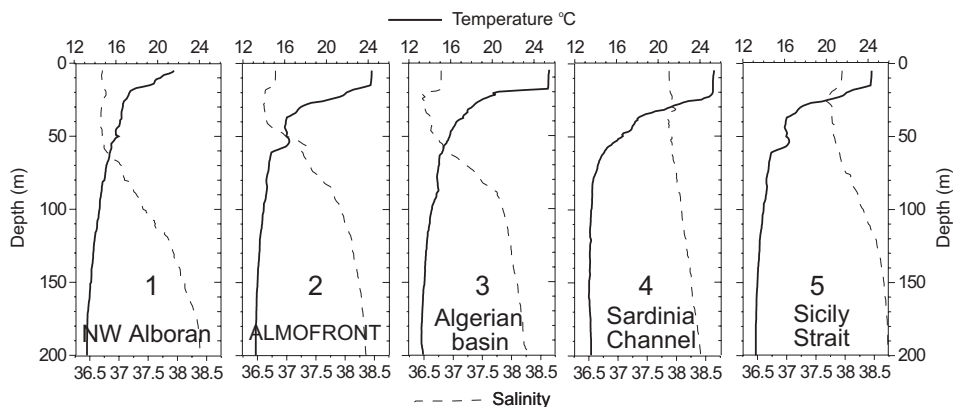

Fig. 2. Temperature-salinity profiles at five stations along the southern side of the western Mediterranean Sea in September 1999.

Tab. 1. Abundance (cells mL^{-1}) of total microphytoplankton (>15 µm) and *Gymnodinium catenatum* in five stations from the southern basin of the western Mediterranean Sea.

NW Alborán St.1			ALMOFRONT St. 2			Argelian basin St. 3			Sardinia Channel St. 4		Sicily Strait St. 5	
depth	total	*G. cat.*	depth	total	*G. cat.*	depth	total	*G. cat.*	depth	total	depth	total
5 m	2.6	**0**	5 m	0.94	**0**	–	–	**–**	7 m	0.64	6 m	0.66
20 m	10.26	**1.68**	30 m	9.37	**0.31**	25 m	2.89	**0.21**	27 m	0.6	23 m	0.6
39 m	14.22	**0.68**	45 m	6.46	**0.07**	55 m	2.47	**0.98**	60 m	0.24	55 m	1.28
59 m	12.4	**0**	70 m	1.87	**0**	80 m	0.49	**0**	90 m	0.62	80 m	0.5

At Station 2 (Almería-Oran Front), maximum phytoplankton abundance was observed between 30–45 m depth, and was mainly composed of *Leptocylindrus minimus* Gran, *L. danicus*, *Dactyliosolen fragilissimus*, *Guinardia striata* (Stolterfoth) Hasle, *Pseudo-nitzschia* spp. and *Skeletonema costatum* (Greville) Cleve. *Gymnodinium catenatum* was abundant at 30 and 45 m depth.

At Station 3 (Algerian basin), the abundance of phytoplankton was very low, and was mainly composed of the diatoms *Pseudo-nitzschia* spp., *Thalassionema nitzschioides* (Grunow) Mereschkowsky and the dinoflagellate *Gonyaulax spinifera* (Claparède *et* Lachmann) Diesing. The assemblage was clearly dominated by *Gymnodinium catenatum* (0.2–1 cells mL^{-1}), which reached up to 40% of the total microphytoplankton abundance with colonies usually higher than 20 cells. At Station 4 (Sardinia channel), only one colony of *G. catenatum* was observed, but this record previously reported by GÓMEZ and CLAUSTRE (2001) has been now discarded due to possible contamination of the sample. The microphytoplankton abundance was very low and dominated by non-identified small athecate dinoflagellates. In the surface waters only the diatom *Hemiaulus hauckii* Grunow *in* Van Heurck was observed. Station 5 (Sicily Strait) presented a similar assemblage with a slight higher abundance of *Hemiaulus hauckii* and a non-identified small pennate diatom. At subsurface depths, *Pseudo-nitzschia* spp. showed a relative dominance.

Discussion

The worldwide expansion of the toxic events relating to *Gymnodinium catenatum* (ZINGONE and ENEVOLDSEN 2000, VAN DEN BERGH et al. 2002) can be attributed its capacity to adapt to different trophic conditions such as oligotrophic offshore waters in the Algerian basin and eutrophic areas of the Alborán Sea. The capacity of this species to colonise different environments could be explained by the chain-forming strategy that might represent an advantage in comparison with unicellular dinoflagellates. FRAGA et al. (1989) reported that long chains increase the swimming speed of *G. catenatum*. This could facilitate the exploitation of nutrients in subphotic depths during the night and photosynthesis during the day in the upper waters. During this study, sampling was performed during the daytime and the species was not observed either near the surface (probably due to photo-inhibition) or in deep waters. This could be indicative of the control of the vertical position in the water column. On the other hand, the trophic versatility of the species with the capacity of uptake dissolved organic nutrients also constitutes an advantage (OH et al. 2002).
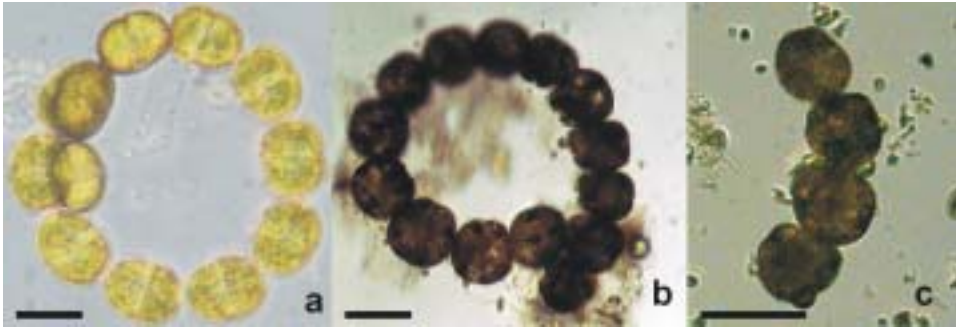
Fig. 3. Light photomicrographs of a) live colony of *Gymnodinium catenatum* Graham from the Strait of Gibraltar, b) Lugol fixed colony of *G. catenatum* collected in the Algerian basin (St. 3) during the PROSOPE cruise, and c) Lugol fixed colony of *Gymnodinium impudicum* (Fraga *et* Bravo) G. Hansen *et* Moestrup from the Bay of Palma de Mallorca (Balearic Islands). Scale bar 50 µm.

In the Mediterranean Sea, *G. catenatum* was previously reported in a coastal lagoon of the Tyrrhenian Sea (CARRADA et al. 1991), but this record corresponded to the non-toxic *Gyrodinium impudicum* Fraga *et* Bravo, further described in (FRAGA et al. 1995). This taxon, transferred to the genus *Gymnodinium* Stein as *G. impudicum* (Fraga *et* Bravo) G. Hansen *et* Moestrup (DAUGBJERG et al. 2000), is non-toxic, typically formed of colonies of 2, 4 or rarely 8 cells whereas *G. catenatum* can form colonies of up to 64 cells (ESTRADA et al. 1984) and it is smaller in size than *G. catenatum*. For example the specimens of *G. catenatum* collected in the Algerian basin showed a cingulum diameter of ~49 µm in comparison with the ~36 µm of *Gymnodinium impudicum* from the Bay of Mallorca (Balearic Islands) (Figs. 3a–c). Before the description of *G. impudicum*, the presence of short colonies was attributed to the morphological adaptation to new environments (CARRADA et al. 1991). In the Sicily Strait, GIACOBBE et al. (1995) reported two linked cells and single forms of *G. catenatum* that probably related to *Gymnodinium impudicum*. SANNIO et al. (1997) reported *Gymnodinium* cf. *catenatum* and the close species *Cochlodinium polykrikoides* Margalef in the Sardinia coasts, but probably this record was also *G. impudicum*. Based on cyst observations, MONTRESOR et al. (1998) reported the presence of *G*. cf. *catenatum* in the Bay of Naples that according to BOLCH and REYNOLDS (2002) referred to the non-toxic *Gymnodinium microreticulatum* Bolch *et* Hallegraeff further described (BOLCH et al. 1999b).

LABIB (1998) reported the presence of *G. catenatum* in the coast of Alexandria. The Suez Canal is an intensive ship route and constitutes a possible vector for the entrance of species into the Mediterranean Sea, as has occurred with more than 300 macroscopic species (GALIL 2000). Despite *G. catenatum* can present a genetic variation among strains (BOLCH et al. 1999a) and can the production of toxins depend on the environmental conditions (FLYNN et al. 1996), this record should be considered cautiously. MIKHAIL (2001) did not report the presence of *G. catenatum* in Egyptian waters.

The abundance of *G. catenatum* observed in the Algerian basin (~1 cell mL^{-1}) was close to the values that caused high PSP toxicity levels in the Alborán Sea (BRAVO et al. 1990). The lack of studies along the Algerian coast hampers the monitoring of the eastward expan-

sion of the species. *G. catenatum* showed a high capacity to colonise different trophic environments, sometimes being the dominant species.

The harmful consequences of this species in the Mediterranean Sea seem not to be restricted to any future toxic events there might be. Recently, CALBET et al. (2002) hypothesised that presence of the *Gymnodinium catenatum* in the Alborán Sea might have altered the transfer of carbon to higher trophic levels and consequently produced changes in the Mediterranean pelagic food chain.

Acknowledgements

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