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Effects of the harmful dinoflagellate *Ostreopsis* cf. *ovata* on different life cycle stages of the common moon jellyfish *Aurelia* sp.

Valentina Giussani [a,*], Elisa Costa [b], Danilo Pecorino [a], Elisa Berdalet [c], Giulio De Giampaulis [d], Miriam Gentile [c], Veronica Fuentes [c], Magda Vila [c], Antonella Penna [e,g,h], Mariachiara Chiantore [a,g], Francesca Garaventa [i], Silvia Lavorano [f,g], Marco Faimali [i]

[a] DISTAV – University of Genoa, Corso Europa 26, 16132 Genoa, Italy
[b] CNR – Institute of Marine Sciences (ISMAR), Arsenale-Tesa 104, Castello 2737/F, 30122 Venezia, Italy
[c] ICM-CSIC – Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta, 37-49, 08003 Barcelona, Catalonia, Spain
[d] Department of Science and Biological and Environmental Technologies, University of Salento, S.P.6., Lecce – Monteroni, 73100 Lecce, Italy
[e] DISB – University of Urbino, via Saffi 2, 61029 Urbino, Italy
[f] Costa Edutainment S.p.A., Acquario di Genova, Area, Porto Antico, Ponte Spinola, 16128 Genoa, Italy
[g] CoNISMa – Consorzio Interuniversitario per le Scienze del Mare, P. le Flaminio 9, 00196 Roma, Italy
[h] CNR – Institute of Marine Science (ISMAR), Largo Fiera della Pesca, 60125 Ancona, Italy
[i] CNR – Institute of Marine Science (ISMAR), Via De Marini, 6, 16149 Genova, Italy

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A B S T R A C T

The frequency and geographic extension of microalgae and gelatinous zooplankton blooms seem to have been increasing worldwide over recent decades. In particular, the harmful dinoflagellate *Ostreopsis* cf. *ovata* and the Schyphozoan jellyfish *Aurelia* sp. are two of the most frequent and long lasting species forming blooms in the Mediterranean Sea. A kind of interaction among any of their life cycle stages (i.e. planula-polyp-ephyrae vs *Ostreopsis* cells) can likely occur, although in this area there are no data available on the co-occurrence of these species.

The aim of this study was to investigate, for the first time, the potential noxious effect of *O.* cf. *ovata* on different life stages of *Aurelia* sp. (polyps and ephyrae), testing several concentrations of whole algal culture.

Rsults of toxicity bioassay highlighted that ephyrae, but not polyps, are affected by this harmful dinoflagellate and comparisons among other model organisms show that *Aurelia* sp. ephyrae are the most sensitive model organism tested so far ($EC_{50-24\ h}$ = 10.5 cells/mL). These findings suggest an interesting scenario on the interaction of these two bloom forming species in the natural marine environment.

1. Introduction

Dense proliferations of microalgae and gelatinous zooplankton (including different groups of medusae, comb jellies and salps) are part of the normal functioning of marine ecosystems, however the frequency and geographic extension of these blooms seem to have been increasing worldwide over recent decades (Nastasi, 2010; Anderson et al., 2012). In the case of microalgae blooms, a combination of natural and anthropogenic factors (e.g. increased use of coastal environments, nutrient enrichment of coastal waters, species translocation by aquaculture activities or ballast water, and global warming) seem to be main triggers, although it is actually possible that improved detection and implementation of monitoring programs provide a larger awareness of phenomena which were already taking place. In the Mediterranean and in temperate waters, for instance, blooms of the benthic dinoflagellate *Ostreopsis* sp. recurrently occur (Mangialajo et al., 2011; Totti et al., 2010; Rhodes, 2011; Parsons et al., 2012) with cascading effects on the environment (Simoni et al., 2003; Vila et al., 2008) and on human health (Brescianini et al., 2006; Tubaro et al., 2011). On the other hand, jellyfish blooms are common episodic events caused and maintained by a combination of physical and poorly understood behavioral and physiological processes (Lotan et al.,

* Corresponding author at: DISTAV – University of Genoa, Corso Europa 26, 16132 Genoa, Italy.
E-mail address: giussani.valentina@gmail.com (V. Giussani).

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1994; Purcell et al., 2000; Lucas, 2001; Graham et al., 2003; Faimali et al., 2014) that may also be aggravated by anthropogenic factors including, for example, eutrophication and overfishing (Mills, 2001; Purcell, 2012).

Blooms of microalgae and gelatinous plankton exert negative impacts on economy of coastal regions, in particular on fisheries-aquaculture industry, tourism and human health. It is well known that jellyfish are an important cause of fish mortality since they are predators of fish eggs and larvae. Furthermore they compete with fish larvae and juveniles by feeding on the same source of crustacean food (Boero, 2013). By contrast, several species of microalgae are toxins producers and/or high biomass producers; their toxins released and/or accumulated along the food web and the high oxygen demand caused by the large densities of cells during blooms can lead to fish distress and also mortalities of other marine organisms (e.g. GEOHAB, 2001; Sellner et al., 2003). Regarding human impacts, people can be stung severely by jellyfish (Purcell et al., 2007; De Donno et al., 2009; Boero, 2013), whereas harmful microalgae (mainly dinoflagellates) cause several human health syndromes due to consumption of contaminated seafood, direct contact with dense aggregations of harmful cells and/or inhalation of sea aerosol which can contain cells and/or toxins (see e.g., review in Berdalet et al., 2015).

Some authors have suggested a link between algal and jellyfish blooms. For instance, the outbreaks of *Pelagia noctiluca* that occurred during 1980s in Adriatic Sea, caused the decrease of algal grazer (zooplankton) favoring the opportunistic dinoflagellates in the water column and leading in turn to benthic mass mortalities (Boero, 2001; Boero and Bonsdorff, 2007). Concurrently, some studies suggest that a continued increasing trend of dinoflagellate abundances as well as hypoxic conditions could favor the growth of jellyfish. Nutrient enrichment in coastal waters, indeed, can increase phytoplankton biomass which could support a higher abundance of zooplankton, which is the main food source of jellyfish. Moreover, the greater tolerance of polyps and medusae to low-oxygen waters compared to fishes provides them a competitive advantage in eutrophic waters (Purcell et al., 2007; Dong et al., 2009).

Worldwide several bloom-forming organisms, generally belonging to the gelatinous plankton, have been reported (Purcell et al., 2007; Kogovsêk et al., 2010), but the most frequent and long-lasting events in the Mediterranean areas are related to the jellyfish genus *Aurelia* which can form dense populations (Mariottini and Pane, 2010). The common moon jellyfish *Aurelia* sp. (Linnaeus) is a widespread genus occurring mainly in coastal embayments, fjords and estuaries, from 0.3 to around 20 m depths, where there are suitable substrates for benthic polyps (Albert, 2011). This organism can be considered both euryhaline and eurythermal in its distribution because of its great adaptability to a large range of temperatures (from 0 to 31 °C; Rasmussen, 1973; Hamner et al., 1982; Hernroth and Gröndahl, 1983, 1985; Dawson and Martin, 2001) and salinity (from 14 to 38; Papathanassiou et al., 1987; Olesen et al., 1994), as well as other environmental variables. Moreover, the genus *Aurelia* reveals a great diversity in its metagenetic life cycle (Fig. 1) and population dynamics characteristics such as timing of reproduction, growth and abundance. Strobilation occurs in late winter/early spring, resulting in the release of ephyrae in the water column (Thiel, 1962; Möller, 1980; Van Der Veer and Oorthuysen, 1985; Lucas and Williams, 1994; Omori et al., 1995; Di Camillo et al., 2010). The recruitment of planulae to the seabed depends on sexual maturation of adult medusae, which can be either continuous or occur during summer-autumn season. In some areas, a year-round presence of ephyrae has also been reported (Yasuda, 1968, 1971; Hamner et al., 1982; Schneider, 1989; Omori et al., 1995; Lucas, 1996).

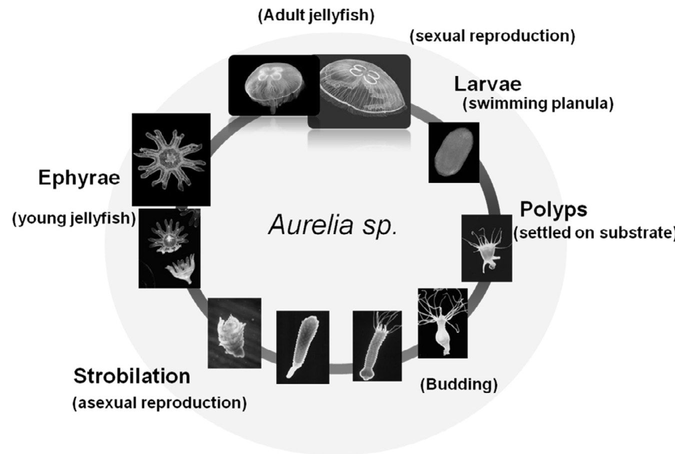

Fig. 1. Generalized life cycle of a scyphozoan jellyfish, *Aurelia*.

As far as harmful microalgae, the genus *Ostreopsis* (e.g. Rhodes, 2011; Parsons et al., 2012) has been raising in interest in the last decades, since their outbreaks seem to be expanding all over the world. Some of most common Mediterranean harmful outbreaks generally occurring in the summer period is caused by *Ostreopsis* cf. *ovata*. This species has a predominantly epiphytic or benthic habitat but it is frequently found swimming in the water column at relatively high concentrations. It typically proliferates in shallow and sheltered waters and produces a wide range of palytoxin-like compounds, such as palytoxin and several ovatoxins (Ciminiello et al., 2011, 2012a,b). It also produces large amounts of a rusty-brown mucilaginous matrix, which can cover the sea bed (Guerrini et al., 2010). Studies focusing on this mucilaginous matrix suggest its key-role in growth strategy, defense against grazing, increased buoyancy and metabolic self-regulation (Reynolds, 2006, 2007) and also in the toxicity mechanism (Barone, 2007; Giussani et al., 2015).

Toxins of *Ostreopsis* cf. *ovata* affect mainly marine benthic organisms (e.g. Durando et al., 2007; Deeds and Schwartz, 2010; Ramos and Vasconcelos, 2010; Tubaro et al., 2011; Crinelli et al., 2012; Gorbi et al., 2012; Privitera et al., 2012; Vila et al., 2012) and cause human intoxications through both inhalation and contact (Gallitelli et al., 2005; Barroso Garcia et al., 2008; Tichadou et al., 2010).

To date, there are no data available on the co-occurrence in space and time of *Ostreopsis* cf. *ovata* and *Aurelia* sp. blooms, anyway a kind of interaction among any life cycle stages of the moon jellyfish and this dinoflagellate (i.e. planula-polyp-ephyrae vs *Ostreopsis* cells) can likely occur, both, in the Mediterranean Sea and in other regions. This is particularly made possible by the benthic-pelagic "stages" of both species, which are likely to interact both in the benthic and the pelagic system, enlarging potential for spatial and temporal interactions (positive or negative). Interaction among the two species could also be mediated (through toxic effects but also by simple mechanic effects) by the mucilaginous matrix that embeds the microalgae when attached to the substrate, which could interfere with polyps activity.

This study stems in this context, with the aim of investigating for the first time the potential noxious effects of *Ostreopsis* cf. *ovata* on two life cycle stages of *Aurelia* sp. (polyps and ephyrae), which represent crucial phases for a jellyfish bloom formation. Our study also contributes to test the potential harmful effect of *O.* cf. *ovata* on marine fauna, using bioassays on the model organism *Aurelia* sp. Since the use of jellyfish in routine ecotoxicological bioassays is an innovative practice, our experiments illustrate the sensitivity and reliability of this approach for that purpose.