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Growth and physiological features of *Chaetomorpha linum* (Müller) Kütz. in high density mats

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ABSTRACT

Seasonal changes of high density *Chaetomorpha linum* mats were studied in an eutrophic coastal lagoon. We measured biomass and specific growth rate and analyzed water quality, sediment labile organic matter (LOM), photosynthetic efficiency and pigments in two areas: one subjected to sediment resuspension and algal mass shuffling through specific boats and the other left undisturbed. Low disturbance enhanced algal survival under critical summer conditions, by reducing LOM and promoting growth through thalli fragmentation. *Chaetomorpha linum* grew fast and quickly acclimated its physiology to adverse conditions, although the mat underlayer showed low photosynthetic efficiency. Nevertheless, the ability to respond to the adverse environment was not sufficient to prevent the sudden algal decay, which occurred following a prolonged summer stress. Present results may help to plan the lagoon management through boat operations, to attain a more effective control over the algal growth and a more efficient removal of the mat.

1. Introduction

In the last thirty years, recurrent events of macroalgal bloom of opportunistic species have occurred along the coasts, favored by eutrophication (Raffaelli et al., 1998; Morand and Merceron, 2005; Smetacek and Zingone, 2013) and probably also by climate change underway (Leemans and Eickhout, 2004; Lloret et al., 2008). Particularly, many coastal lagoons have been affected by these phenomena, due to the strong human impact and their structural and morphological characteristics (Sfriso et al., 1987; Viaroli et al., 1996; Casabianca de et al., 1997; Duck and Figueiredo da Silva, 2012). Some macroalgae may grow fast and give rise to high density mats, which results in serious environmental problems. They are a source of labile organic matter (LOM) and are easily attacked by bacteria, whereby their development and persistence, year after year, contributes to the degradation of these coastal environments, leading to increasingly recurrent dystrophic processes, that are fueled by the availability of LOM and the anaerobic activity of sulphate reducing bacteria (Hargrave et al., 2008; Lenzi et al., 2011).

Extensive laboratory work has been carried out on the rate of nutrient uptake and on the photosynthetic capacity of opportunistic species capable of producing high density macroalgal mats (McGlathery et al., 1996; Pedersen and Borum, 1996; Lotze and Schramm, 2000; Menendez et al., 2002; Anderson et al., 2002; Lapointe et al., 2005). However, natural environments are extremely heterogeneous and differ for multiple variables, *e.g.* wind, solar radiation, water flow speed, sediment state, *etc.*; hence, the responses of a macroalgal mass can vary just as much. High density macroalgal mats may reach a thickness of several tens of centimeters and, in laminar environments, the thalli may almost float at the surface of the water column: under these conditions, stratifications of the physico-chemical variables and of dissolved nutrients can be frequent. Mat density and the morphology of macroalgal thalli can affect the release of nutrients from the bottom and the water quality (Lenzi et al., 2013).

Chaetomorpha linum (Müller) Kützing is an opportunistic species of Chlorophyceae that frequently gives rise to abundant vegetative blooms (McGlathery et al., 1996; Bischof et al., 2006; Lenzi et al., 2013; Gao et al., 2013). It thrives under eutrophic conditions, in particular with a high availability of orthophosphate (Lavery and McComb, 1991b; Menendez et al., 2002). The mats of this species may be particularly resilient and persistent (Gao et al., 2013; Lenzi et al., 2013, 2017). Since 2005, a high density mat of *C. linum* is affecting an area of about 400 ha in the Orbetello lagoon (Tuscany, Italy), with a biomass that varies in space and time between 2 and 24 kg m^{-2}. The mat is self-sustained: the dead thalli are decomposed by bacteria and dinoflagellates, sink into the mud and release the nutrients, while the surface of the mat grows almost continuously, owing to the mild winters of these latitudes (Lavery and McComb, 1991a; Krause-Jensen et al., 1996). It is hard to

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keep under control the overgrowth of the opportunistic macroalgae and to prevent its negative effects in environments such as coastal areas, that are characterized by increasingly crowding, intense production and recreational activities and pollution from industrial and agricultural wastes conveyed by the rivers. A feasible solution to mitigate the consequences of eutrophication is focusing efforts on a downstream management. Whatever the choices made in this regard, like macroalgal harvesting (Lenzi, 1992; Runca et al., 1996; Guyoneaud et al., 1998) or their fragmentation *in situ* and the artificial oxidation of sediments (Lenzi et al., 2015, 2017; Martelloni et al., 2016), it is important to achieve a detailed knowledge of the conditions occurring in high density mats and their specific characteristics. Particularly, it is necessary to study the growth and physiology of the dominant macroalgae in relation to the trend of the main environmental factors. This may help to identify the moment when the macroalgal mat enters a critical state, an information of central importance to take the right decision about the time of intervention and the techniques to be used.

In the present study, we performed field measurements in the Orbetello lagoon, in areas where extensive and dense *C. linum* mats develop. The aims were to characterize the mat and some physiological features of this species, to gain more insight into the dynamics of these algal masses and their responses to the environment and to gather information to evaluate the impact of the containment measures that are currently applied. In this regard, the work was carried out both on an undisturbed area and on a lagoon section which underwent recurrent passages of the boats that are presently used for harvesting the algal biomass and for sediment resuspension, within the ordinary management practices of the lagoon.

2. Materials and methods

2.1. Study area and experimental design

This study was conducted in the western basin of the Orbetello lagoon (Fig. 1), a shallow, eutrophic coastal water body with an area of 25.25 km^2 in southern Tuscany (Italian west coast 42°25′–42°29′N, 11°10′–11°17′E). It is an eutrophic lagoon due to fish-farm wastewater, intermittent streams contaminated by agricultural run-off and civil effluents, and historical input stored in sediment (Lenzi et al., 2003). This lagoon is subject to abundant macroalgal proliferation, in the last 15 years mainly by *Chaetomorpha linum* (Müll.) Kütz., which can cause dystrophic crises with die-offs.

In the period under study, an unexpected extensive dystrophic crisis occurred in the adjacent and connected eastern basin: between summer and autumn there was the spread, in a part of the western basin, of anoxic and reducing water with high turbidity, and then colored of intense green, due to the proliferation of cyanobacteria (Fig. 1).

The high density mat of *C. linum* was characterized by analyzing the physiology of this species, by measuring the growth and weight of the whole biomass stand and by evaluating the effect, on these variables, of boat disturbance.

Two experimental areas were identified (A, B). Each of them had a high coverage of *C. linum*, an extension of 2500 m^2 (50 × 50 m), and was marked with bamboo canes, 3 per side. They were distant from each other about 500 m (Fig. 1). The schedule of samplings and measurements of all variables considered. Conducted between May 2015 and May 2016, is reported in Table 1. The area B was located within the 400 ha subjected to sediment resuspension using special boats (Lenzi et al., 2017), while the area A was left undisturbed. Boat passages covered 9 of 15 sectors of about 25 ha each, in which the entire area was divided and were 579 overall, *i.e.* 64 for each sector. Although the frequency of the passages changed during the 13 months of activity, its average was 16.49%, which corresponded to a boat transit every 6 days. A boat passage caused a thorough mixing of the mat, bringing the overlayer to the underlayer and *vice versa*, *i.e.* periodically exposing the entire algal mass to sunlight.

2.2. Water quality in macroalgal high density mats

Dissolved oxygen (DO, mg L^{-1}), pH and temperature (T, °C) values were obtained by a multiparameter probe (MP) on a fixed station, placed in the western basin inside a dense *C. linum* mat, which sent the

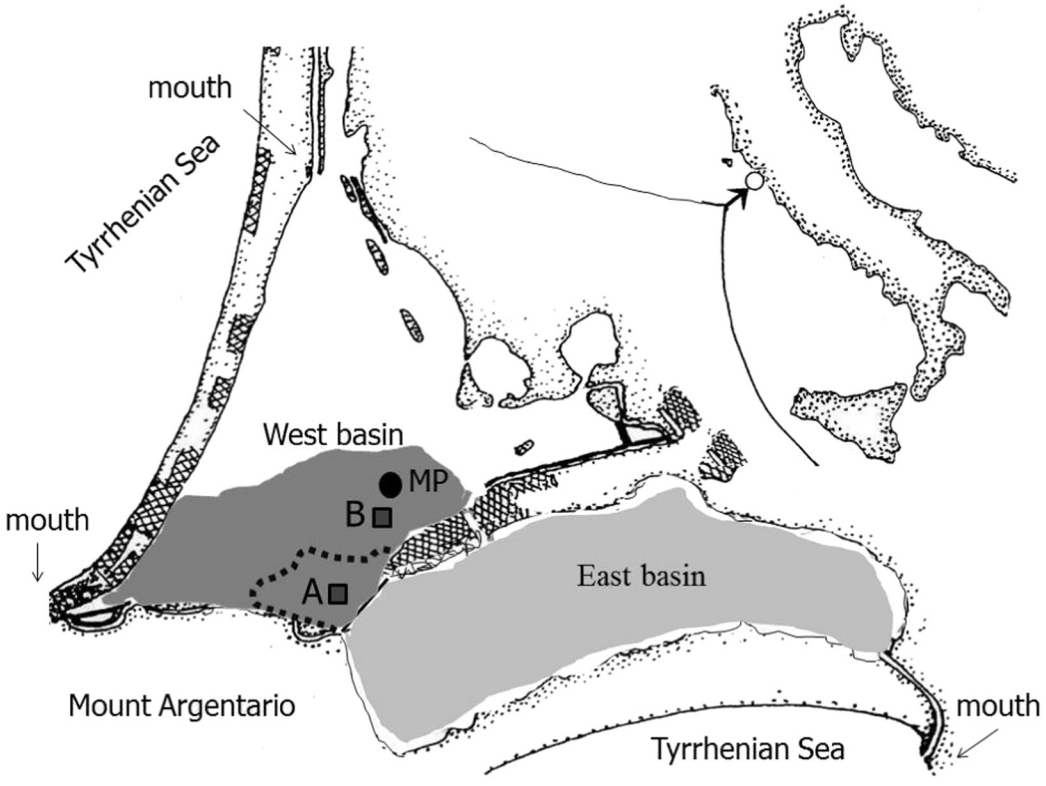

Fig. 1. Lagoon of Orbetello with the two areas A and B (black squares) in which measures on water, sediment and *Chaetomorpha linum* high density mats were carried out. MP (black dot), position of multiparameter probe control unit. In light grey, the dystrophic area developed during summer 2015; dotted line, the area of the western basin affected by the intrusion of anoxic-reducing water from the eastern basin; in dark grey, the extension of the *Chaetomorpha linum* high density mat.