A Pilot Study on the Effects of Temperature on the Blooms of the Benthic Mucilage-Forming Microalga *Chrysophaeum taylorii*

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**Abstract:** *C. taylorii* (*Chrysophaeum taylorii*) Lewis and Bryan (*Pelagophyceae*) are benthic mucilage-producing microalgae recently recorded in the Mediterranean Sea, where its summer blooms are having detrimental effects on benthic communities, fisheries and tourism, especially along the Sardinian coasts (western Mediterranean Sea). Although few informations on the bloom dynamics of this microalga are available in literature jet, recent studies have hypothesized that sea water temperature plays a major role in determining the distribution and abundance of *C. taylorii*. The goal of this pilot study was to verify the above-mentioned statement providing experimental evidence for it. To this purpose, *C. taylorii* presence and abundance were investigated along a temperature gradient near the powerhouse of Torre Valdaliga (Latium coasts), where a stream of hot water is continuously pumped out from the powerhouse into the sea. The obtained data showed that *C. taylorii* abundance was significantly higher in the study sites nearer to the powerhouse and a positive correlation between water temperature and cell densities was found, thus confirming that water temperature is one of the environmental variables directly influencing the bloom dynamics of this microalga in the Mediterranean Sea.

**Key words:** Microphytobenthos, *C. taylorii*, mucilage, bloom dynamics, sea water temperature.

1. Introduction

There is near unanimous scientific consensus that the world is experiencing a period of global warming in response to atmospheric greenhouse gas accumulation produced by human activities [1]. With regard to microalgae, in particular, as sea water temperature is currently considered as one of the main environmental factors determining the abundance and composition of microphytobenthos on the substratum [2-5], climate changes seem to be among the major driving forces behind the stimulation, distribution and intensification of their blooms in the last decades [6]. Indeed, warmer sea water temperatures result in expanded ranges of warm water microalgal species, which blooms at latitudes higher than their original ones seem to be almost completely temperature-dependent [5].

*C. taylorii* (*Chrysophaeum taylorii*) Lewis and Bryan is a benthic mucilage-forming microalga among those recently expanding their distribution. It is native to the tropical and subtropical Atlantic (Bahamas, Bermuda, Grand Cayman and Dry Tortugas [7-9]), Western Pacific (Vega Baja and Porto Rico [10]), Micronesia (Guam [11]) and Australia (Townsville and Great Barrier Reef [11-13]). During the last few years, range expansions of this species into other geographic areas have been reported [14]. In 2005, in particular, the microalga was recorded for the first time in the Mediterranean Sea [15] and nowadays it
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seems to be already established steadily along the Sardinian [16-18], the Latium [19] and the Turkish [20] coasts.

Its cells, despite their microscopic size (< 100 μm), are able to exude large amounts of mucilaginous material that becomes visible to the naked eye when their density reaches quite high values (~ 1,000 cells·mL⁻¹) [16]. During its blooms, usually in the summer months, large portions of hard benthic, sandy and plant substrata are covered by a mucilaginous layer seriously damaging benthic communities. After developing horizontally on the substratum, mucilage starts tearing off from it, due to the gas bubbles produced by microorganisms inside it and to the hydrodynamic stress, reaching the sea surface and forming big patches on it, transported by winds and currents [15]. Mucilage aggregates on the sea surface reduce the penetration of light, potentially negatively affecting the photosynthetic efficiency of macroalgae and seagrasses during the bloom and also cause problems to tourism, making bathing unpleasant, and fisheries, over-loading nets.

*C. taylorii* is considered to be a public nuisance also within its natural boundaries [11], nevertheless its blooms in native habitats are infrequent (at least in the Great Barrier Reef) and their effects are not so detrimental as those of other microalgae such as, for example, *Chrysocystis fragilis* [13]; this is the reason why almost no studies on *C. taylorii* ecology have been conducted till today. Due to the threat of range expansion and invasion of new areas, ecological studies on *C. taylorii* are most urgently needed, especially to better understand its bloom dynamics and to identify the environmental factors influencing its abundance. On this matter, Caronni et al. [18] explained the summer temporal variability observed in *C. taylorii* cell density during a multiannual study on the species, hypothesizing the existence of a relationship with sea water temperature. However, no specific experimental evidence about it has been provided till today.

In this paper, the results of a detailed mensurative experiment conducted in the summer of 2013 along the Latium coasts near Civitavecchia are presented. The research was done near the thermal electric powerhouse of Torre Valdaliga, a thermoelectric coal-fired power station belonging to ENEL (the most important electricity supplier in Italy). The powerhouse uses sea water to cool down machineries, sucking fresh sea water from the sea and pumping it out at high temperatures (~ 30 °C), after the water, passing through the plant, absorbs the heat produced by the machineries. This is the reason why, near the powerhouse, where the water spill is located, a stream of hot water moving opposite to the main current is always visible in the sea.

To test for a correlation between sea water temperature and *C. taylorii* abundance, the density of the microalga was investigated in different sites along the temperature gradient produced by the hot water pumped out from the powerhouse, starting close to the water spill and distancing gradually from it.

2. Methods and Data Analysis

At the end of July, when the *C. taylorii* is particularly abundant on the substratum [17], its cell density was estimated collecting samples of water and epilithic material in four different sites, which were about 500 m apart from the hot water spill near the powerhouse till 1.5 km far from it (control site with natural temperature conditions) (Fig. 1) (three replicates per site).

Samples were collected scraping hard substratum at 1.5 m of depth where the microalga reaches its maximum abundance [18] by means of a brush sampler. A new sampling device (a cylindrical plexiglas tube with two screw threads at both ends and a stainless steel plunger with an exchangeable strip brush) which was recently proposed for sampling epilithic microalgae in lakes and streams [21] was also already used to obtain precise estimates of *C. taylorii* density [18]. All the collected samples were fixed with
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Fig. 1  The location of the study sites along the Latium coasts.

a Lugol’s solution [22] and analyzed in the laboratory in the following months to characterize the microphytobenthic community of each site and to estimate the cell abundance of *C. taylorii*. Cell identification and count were effected with an inverted microscope on two subsamples for each sample according to Utermöhl’s sedimentation method [23]. The cell density of *C. taylorii* was then expressed as the number of cells·mL⁻¹. In each site, three measurements of sea water temperature at the considered depth (1.5 m) were also conducted using a multiparametric probe (°C). Furthermore, at each site, the substratum was carefully observed in order to individuate the presence of mucilage on it to obtain information on the magnitude of a possible bloom of the species.

Differences in *C. taylorii* densities and water temperatures among sites were assessed through two one-way ANOVAs (analysis of variance), where site (four levels) was treated as a fixed factor, using the software GMav5 [24]. Cochran’s tests were performed to check for homogeneity of variances and, a posteriori, SNK (Student-Newman-Keuls) tests (α = 0.05) were used to compare levels of the fixed factor site. Finally, a Pearson correlation was used to test the relationship between the abundance of *C. taylorii* cells and the sea water temperature in the investigated sites.

### 3. Results

In the first study site (S₁), close to the hot water spill, the sea water temperature reached an average value of 29.8 °C (Fig. 2). The microphytobenthic community of S₁ appeared to be very poor and
composed only by few species of *Bacillariophyceae* and by *C. taylorii*. The latter was indeed the most abundant species, with a mean cell density of 9,435 cells·mL⁻¹ (Fig. 2). Finally, in the first study site, some macroscopic mucilaginous aggregates were also present both on the substratum and suspended in the water column.

In the second and in the third study sites (S₂ and S₃), on the contrary, the sea water temperature started decreasing and reached average values of 28.2 °C and 26.2 °C, respectively (Fig. 2). The microphytobenthic community of the two above-mentioned sites was

![Figure 2](image.png)

*Fig. 2* Mean (+ standard error) sea water temperature and *C. taylorii* cell density in each sample (C₁, C₂, C₃) collected in the four study sites (S₁, S₂, S₃, S₄).
characterized by an increasing richness of Bacillariophyceae and by the presence of some Dinophyceae. C. taylorii abundance, on the contrary, notably decreased, reaching mean values equal to 5,676 cells·mL⁻¹ and 1,015 cells·mL⁻¹, respectively (Fig. 2). With regard to mucilage, in S₂, only few macroscopic mucilaginous aggregates were observed on the substratum and no aggregates were found in the water column, while in S₃, no mucilage was found at all.

Finally in the control site S₄, the temperature of sea water appeared to be remarkably lower, with an average value of 24.6 °C (Fig. 2). In this site, the microphytobenthic community reached the maximum richness, with a greater variety of species belonging to both Bacillariophyceae and Dinophyceae while C. taylorii cells were less abundant with an average density of only 445 cells·mL⁻¹ (Fig. 2) and no mucilage was observed neither on the substratum nor in the water column.

Significant variations in both water temperature and C. taylorii cell density were observed among sampling sites (Table 1) and the SNK test evidenced that C. taylorii densities and sea water temperatures were significantly higher in S₁, decreasing in S₂ and S₃ and reaching the lowest values in the control site S₄ (Table 1). Overall, a positive correlation between the two considered response variables was found ($r = 0.97; n = 24$).

4. Discussion

The obtained results provide useful information on C. taylorii ecology and, in particular, on the role played by temperature in its cell density on the substratum and, consequently, in its bloom dynamics in the Mediterranean Sea. As C. taylorii has tropical and subtropical origins, its optimum temperature is expected to be adjusted toward quite high values (almost 30 °C), as the one of other benthic microalgae native of tropical seas [25, 26], and its blooms in the Mediterranean Sea could therefore be considered as temperature-dependent.

This hypothesis is strongly supported by the data collected in the present study, highlighting the importance of temperature in C. taylorii abundance, as already proved for other similar species [5, 6] and recently also suggested by Caronni et al. [18] for the above-mentioned microalga. C. taylorii cells reached the maximum density on the substratum near the powerhouse (S₁), where the sea water temperature was close to 30 °C, and gradually decreased distancing from it along the considered temperature gradient.

These results are consistent with the previous findings obtained from field observations conducted during C. taylorii past blooms along the Sardinian coasts [18] and clearly demonstrate that the growth of C. taylorii is strongly stimulated under high temperatures.

In particular, analyzing data on C. taylorii density collected during this study and comparing them with the other few ones available in literature on the species, it is possible to suppose that a bloom of the microalgae was ongoing in site S₁, where the highest temperature was recorded at the moment of samplings.
Near the powerhouse, indeed, the cell density of the microalga on the substratum (9,435 cells·mL⁻¹) was very similar to the one (10,430 cells·mL⁻¹) recorded during other blooms of the species in the Mediterranean Sea [18]. Furthermore, a remarkable amount of mucilage was present both on the substratum and in the water column as usual when a bloom of this microalga is ongoing [16].

*C. taylorii* density significantly decreased already in sites S₂, where the sea water temperature was only 1.5 °C lower than in S₁, highlighting how notable reductions of *C. taylorii* density could be also related to relatively limited temperature variations, as observed for other benthic species [27]. However, the number of cells on the substratum of the above-mentioned site was still quite high (5,676 cells·mL⁻¹) and typical of areas affected by minor blooms of the species, as also confirmed by the mucilage partially covering the substratum [18]. Moreover, the presence of some *C. taylorii* cells also in sites S₃ and especially in S₄, where the influence of the hot water stream pumped out from the powerhouse notably decreased, suggested that the microalga is capable to survive also with lower sea water temperatures, as observed for similar species [27]. Nevertheless, in such conditions, the population size of the species is remarkably smaller and no blooms seem to occur. These results can be explained considering that temperature is one of the major factors controlling the rate of photosynthesis in microalgae [28, 29]. To photosynthesize efficiently, microalgae have to acclimate to sea water temperature, using strategies having remarkable costs, both in terms of energy and of potentially limiting resources [30], thus leading to a considerable reduction of the resource budget available for their population growth when temperature lies out of their optimum range.

Finally, even if during samplings, some *C. taylorii* cells were present on the substratum already with a sea water temperature of about 24 °C, the species proliferation seemed to start when it exceeded 26 °C and its blooms occur, in particular, when it exceeded 28 °C. However, Aktan and Topaloğlu [20] described the presence of both *C. taylorii* cells and mucilaginous aggregates on the substratum along the Turkish coasts (eastern Mediterranean Sea) when sea water temperature was equal to 18 °C. These contrasting results could be explained supposing that the temperature optimum of *C. taylorii* varies remarkably among geographic areas, also in the same basin, as already observed for other benthic bloom-forming microalgae [5]. With regard to *Ostreopsis ovata* Fukuyo, a benthic microalga with ecological features similar to those of *C. taylorii* (Caronni, S., personal observation), for example, Granéli et al. [5] defined a temperature optimum between 26 °C and 30 °C in the western Mediterranean (Tyrrhenian Sea) while Totti et al. [31] observed higher cell densities of the microalga for decreasing temperatures from 26 °C to 16 °C in the eastern part of the basin (Adriatic Sea) as also reported for *C. taylorii* by Aktan and Topaloğlu [20].

### 5. Conclusions

Even if this is only a pilot study, it provides a basis to deepen its bloom dynamics. The obtained results indeed offer some important insights into the ecology of the bloom-forming microalga *C. taylorii* that can contribute to both understanding the reasons of its remarkable density increase in the Mediterranean Sea in the last few years and planning future strategies for the management of its bloom events. With regard to the first point, in particular, *C. taylorii* proliferation, at least in the western Mediterranean, seems to be strictly related to the presence of quite high sea water temperatures (< 26 °C); therefore, as the basin has been interested by a significant increase of sea water temperature only in the last decade [32], the recurrence of *C. taylorii* blooms can be explained as the affirmation of an originally rare species due to the global climatic changes actually in act as supposed by Aktan and Topaloğlu [20].

Moreover, the increased knowledge on the optimum
temperature of this mucilage-producing species is important for forecasting mucilage production along coastal areas of the Mediterranean and it will allow to start monitoring programs on it only when the sea water temperatures reach values suitable for its proliferation, reducing sampling costs and efforts.

However, in the future, more detailed studies will be required to confirm the above discussed hypotheses.

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References

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