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Ultra- and microplankton assemblages as indicators of trophic status in a Mediterranean lagoon

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ABSTRACT

The seasonal abundance distribution of heterotrophic prokaryotes, pico- and nanophytoplankton, was investigated in connection with environmental variables and microplankton abundance at five stations in Ghar El Melh Lagoon (northeastern Tunisia). Flow cytometry analysis of ultraplankton resolved (i) five heterotrophic prokaryote groups labelled LNA1, LNA2 (low nucleic acid content), HNA1, HNA2 and HNA3 (high nucleic acid content) and (ii) at least 14 ultraphytoplankton groups assigned to picoeukaryotes, picoprokaryotes, nanoeukaryotes, cryptophyte-like cells and some unknown communities. Redundancy analysis (RDA) revealed (i) autumn-summer outbreaks of heterotrophic prokaryotes dominated by HNA groups and (ii) winter-summer proliferation of ultraphytoplankton dominated by nanophytoplankton groups. Generalized additive models (GAM) highlighted the role of (i) water temperature and orthophosphate concentrations in heterotrophic prokaryote distribution and (ii) water temperature and salinity in ultraphytoplankton abundance variation. Based on Spearman's rank correlation, significant negative correlations were established between ultra- and microplankton communities suggesting that, through grazing pressure, microplankton may be behind the drastic decrease in ultraplankton abundances in spring.

1. Introduction

Ghar El Melh Lagoon (GML, northeastern Tunisia) fulfills the Ramsar criteria (Ramsar, 2007) as a wetland of international importance, representative of lagoons within the southern Mediterranean Sea and as a habitat for migrating fish and birds (Ayache et al., 2009). Unfortunately, and in contrast with the ultra-oligotrophic eastern Mediterranean Basin (Berman et al., 1984; Krom et al., 2003, 2005), GML has mostly exhibited eutrophic conditions due to the combined effects of agricultural drainage from the Utica floodplain, raw sewage discharge from the town of Ghar El Melh and local summer tourism (Chakroun, 2004; Ayache et al., 2009). This eutrophic status is amplified by the shallowness of GML waters (<2 m) as well as the limited connection with the sea through a single channel that undergoes continuous silting, leading to an exacerbation of both salinity and temperature gradients, which may well allow fair assessment of the ecological role of each specific environmental parameter (Oksanen and Minchi, 2002).

As an expression of this eutrophication, GML is characterized by a remarkable abundance of phytoplankton including harmful species (Turki et al., 2007; Dhib et al., 2013a, 2015), ciliate communities (Dhib et al., 2013b) and macrophytes, all bioindicators of water quality deterioration (Shili et al., 2002; Dhib et al., 2013c). In contrast, and as far as we know, no data concerning the smaller planktonic communities have been reported from this site, nor from any other Tunisian lagoon. Indeed, ultraplankton studies in Tunisian waters have been conducted in open ecosystems (Rekik et al., 2013; Hamdi et al., 2015). In oligotrophic waters, a number of studies using flow cytometry (FCM), showed that ultraphytoplankton (<10 μm) comprise the most abundant phytoplankton fraction (Siokou-Frangou et al., 2010) and is mainly composed of cyanobacteria, with dominance, in the Mediterranean Sea, of *Synechococcus* over *Prochlorococcus* (Martin, 1997; Denis et al., 2000; Casotti et al., 2003) and of eukaryotes belonging to the group of Chlorophyceae, Prasinophyceae and Prymnesiophyceae (Psarra et al., 2005). In a previous study of ultraphytoplankton distribution in 24 Mediterranean coastal lagoons that display wide trophic

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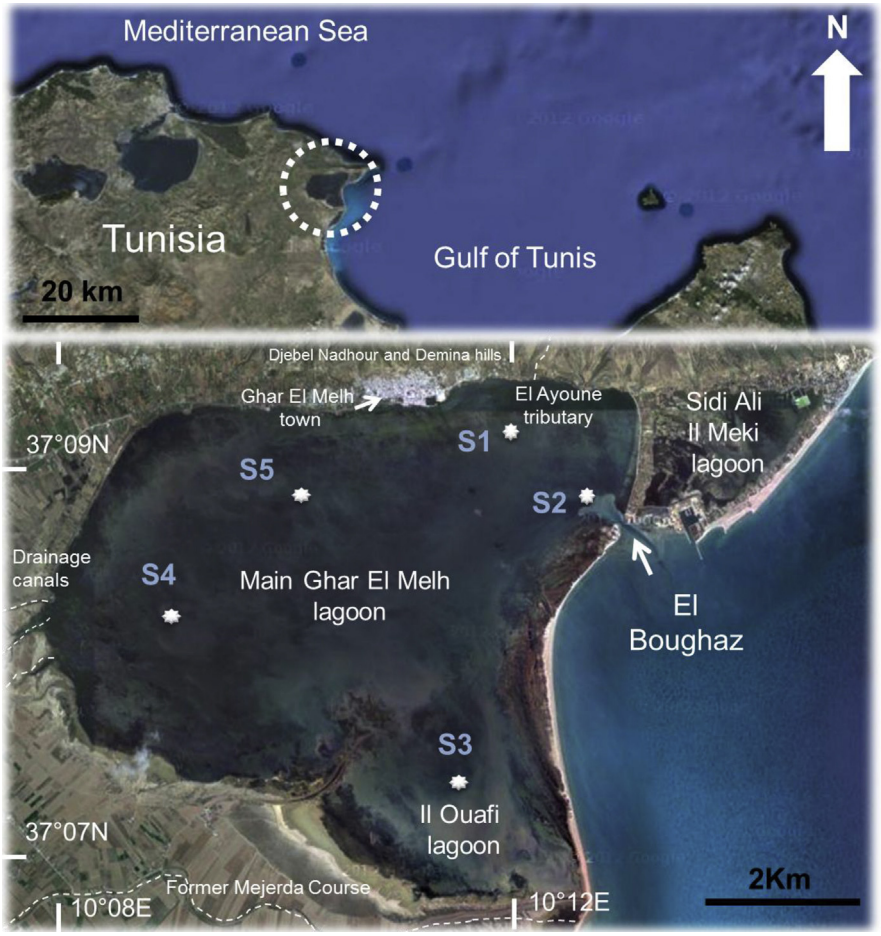

Fig. 1. Geographic situation of Ghar El Melh Lagoon and location of sampling stations from S1 to S5.

gradients, Bec et al. (2011) found that (i) the picocyanobacteria are more competitive than picoeukaryotes and are also the most numerous phytoplankton to acquire nutrients in resource-limited systems, and (ii) picoeukaryote abundance increases along the anthropogenic trophic gradient.

Over all, eutrophic waters and samples containing coastal or freshwater populations as in GML, are especially heterogeneous in terms of size, morphology and concentration. For instance, lagoons exposed to large and continuous inputs of freshwater were distinguished by partial consumption of nutrients and reduced phytoplankton biomass (Puigserver et al., 2002). In other lagoons, a long residence time may contribute to biomass accumulation and high standing crops of phytoplankton due to low tidal amplitudes (Knoppers, 1994; Fertouna-Bellakhal et al., 2015; Zaaboub et al., 2015). Hydrological variations may also alter the phytoplankton community structure by differentially affecting taxonomic groups depending on their growth characteristics (Aleya, 1991; Paerl et al., 2003).

Altogether, FCM is a potentially useful tool for investigating these communities. Indeed, it has proved to be highly efficient in the field of aquatic microbiology (Troussellier et al., 1993; Legendre et al., 2001; Wang et al., 2010) and FCM detection of specific microorganisms still occurs (Corzo et al., 1999; Hamdi et al., 2015).

In this context, it was of great interest to conduct an FCM survey in GML, our aims being (i) to discover new information about heterotrophic prokaryotes and ultraphytoplankton (pico- and nanophytoplankton) in GML waters and thus resolve the most abundant groups, and (ii) to document the seasonal variability of these communities in relation to both abiotic (temperature, salinity and nutrients) and biotic (microalgae and ciliates) factors. Apart from its intrinsic interest, this study may help us to learn more as to how ultraplankton communities shape their ecological response to specific niche properties caused by the wide range of environmental parameters in lagoon systems.

2. Materials and methods

2.1. Presentation of the study site

Ghar El Melh Lagoon is located in the western Mediterranean Basin on the north coast of Tunisia (37°06′–37°10′ N and 10°08′–10°15′ E) and is influenced by regional water circulation (Ben Ismail et al., 2012) (Fig. 1). GML covers an area of about 3000 ha including 2 small sub-lagoons, namely Sabkhet El Ouafi and Sabkhet Sidi Ali El Mekki. The main lagoon is permanently connected with Sabkhet El Ouafi, but isolated from Sabkhet Sidi Ali El Mekki by embankments. GML is connected to the Mediterranean Sea via a permanent channel called “El Boughaz” that passes through the coastal sand bars.

2.2. Sampling

Five stations (S1–S5) were chosen to study the different environmental conditions found within GML (Fig. 1). S1 is located in the northeastern part of the lagoon, a shallow area influenced by freshwater input from ‘El Ayoune’, with mats of limnetic plants (reeds) growing around the edges. S2 faces El Boughaz Channel which is a permanent 70-m-wide connection with the Gulf of Tunis; the