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Phytoplankton composition, growth and production in the Guadiana estuary (SW Iberia): Unraveling changes induced after dam construction☆

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ABSTRACT

Water quality and quantity problems in the Guadiana estuary due to a recently built dam have been predicted, including an enhancement of cyanobacteria blooms. The main goal of this work was thus to describe the present phytoplankton dynamics in relation to its environmental drivers and to evaluate the effects of damming on phytoplankton in the Guadiana estuary. Sampling campaigns were conducted during 2007–2009 in 4 locations of the Guadiana estuary, covering the salinity gradient. Phytoplankton-related and physical–chemical variables were analyzed. Throughout our study, light availability was mainly controlled by suspended sediments and it was much lower than saturating intensities described for phytoplankton growth. Therefore, light was probably limiting to phytoplankton growth throughout the year, especially in the middle and upper estuarine zones. Nitrogen limitation of phytoplankton growth occurred occasionally throughout the study period, especially during spring and summer. Overall, light and nutrient availability were mainly controlled by river flow; anthropogenic sources of nutrients to the estuary were negligible. Phytoplankton showed a unimodal cycle with biomass maximum in late spring/early summer, and the typical seasonal succession of freshwater phytoplankton (diatoms, green algae, cyanobacteria) was observed. Diatoms were the main component of the phytoplankton community and their variability closely followed nitrate and river flow variability. The relative abundance of the main phytoplankton groups changed in relation to the period before dam construction, with a decrease on cyanobacteria contribution to total abundance. The environmental perturbation induced by dam construction has now stabilized and resulted in an overall decrease in nutrient concentrations, an increase in light availability and a decrease in cyanobacteria abundance.

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1. Introduction

Dam construction has been an essential feature in the social and economic development of many countries. Dams are meant to provide several services to humans, such as hydroelectric power, irrigation of dry areas, modulation of river flow between wet and dry periods, and also creation of bodies of water for recreation and transport. However, even the most carefully engineered dams can create unforeseen problems (Milliman, 1997). Increase in eutrophication, pollution, coastline erosion and saltwater intrusion upriver, and decreases in offshore catches of fish, are just a few problems usually associated to water and sediment trapping in dams.

Alteration of the nutritional environment for primary producers is one of the main problems associated to dam construction. Whilst nutrient loadings to rivers and coastal areas decrease due to the removal of nutrients in reservoir sediments (Humborg et al., 1997), other anthropogenic activities may promote an enhancement of nutrient loading to these areas. Nutrient removal in dams can be overcompensated by inputs of anthropogenic N and P, but no such compensation has been observed for silica (Si) (Humborg et al., 1997), given that chemical weathering of silicates on land is the main process that supplies dissolved and particulate silicate to rivers (Ittekkot et al., 2000). Therefore, changes in nutrient supply are often accompanied by alterations in nutrient ratios (Yin et al., 2001), which often promote a shift from diatom-based communities to non-diatom assemblages, especially composed of flagellates and cyanobacteria (e.g., Humborg et al., 1997). This shift may be a potential risk to human health, given that many cyanobacteria and dinoflagellates are able to produce potent toxins (e.g., Carmichael, 1997; Errera and Campbell, 2011). Furthermore, cyanobacteria represent an undesirable food-source for higher trophic levels, whereas a diatom-based community usually contributes to large fish and shellfish populations (Officer and Ryther, 1980).

Light availability is of paramount importance for phytoplankton, especially in turbid ecosystems (Cole and Cloern, 1984; Kromkamp and Peene, 1995; Kocum et al., 2002), but it has not yet received the

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same attention as nutrients as an environmental driver of phytoplankton dynamics. Light availability is extremely heterogeneous in space and time and it is highly dependent on the incident solar radiation, the depth of the mixed layer and the degree of light attenuation in the water column. In estuaries, light availability is mainly regulated by turbidity, which in turn is mostly driven by suspended particulate matter (SPM). In addition, phytoplankton in turbid, nutrient-rich estuaries is more controlled by variations in SPM rather than by the seasonal irradiance cycle (Adolf et al., 2006). Trapping of sediments behind dams may thus increase light availability downriver and counteract the effects of decreased nutrient inputs (e.g., Barbosa et al., 2010).

The Guadiana estuary is located in a region highly vulnerable to climate change, due to a predicted decrease in rainfall (IPCC, 2001), and it has been increasingly subjected to human disturbances, namely urban development. In addition, the large Alqueva dam, operational since early 2002, restricts a significant amount of freshwater, promoting major impacts on the estuarine ecosystem downriver. Nutrient concentration and stoichiometry (Morais et al., 2009) and light availability (Barbosa et al., 2010) have been particularly affected by water and sediment retention behind the Alqueva dam. Phytoplankton succession in the Guadiana estuary, especially in the freshwater tidal zone, has been classically linked to nutrient molar ratios (Rocha et al., 2002), but the low light availability probably plays an important role on phytoplankton growth, both on intra- and inter-annual time scales (Domingues et al., 2005). During the first years (2002–2005) of water retention by the Alqueva dam, a trend of decreasing turbidity and decreasing chlorophyll was observed in the Guadiana upper estuary, suggesting a shift from a potentially light-limited environment to a more nutrient-limited one (Barbosa et al., 2010). In this work, we aimed 1) to describe phytoplankton dynamics in the Guadiana estuary in relation to its environmental drivers, mainly nutrients and light, and 2) to understand whether the above-mentioned shift was a transient or a non-transient effect of the recently built dam, and thus to evaluate the overall effect of dam construction on phytoplankton. To accomplish these goals, we analyzed several phytoplankton-related variables (composition, abundance and biomass) and environmental drivers (e.g., nutrient and light availability) throughout three annual cycles (2007–2009) in four representative stations along the salinity gradient of the Guadiana estuary. We also present the first estimates of phytoplankton primary production for this estuarine system.

2. Materials and methods

2.1. Study site and sampling strategy

The Guadiana River arises in Spain, flows for 810 km and drains between SE Portugal and SW Spain (Fig. 1). Its last 70 km correspond to the estuarine zone, located in a Mediterranean climate area. The estuary is influenced by semidiurnal, mesotidal tides, and it is usually partially stratified in its lower and middle sections, depending on river flow and tidal stage, and well mixed in the upper section. In the last years, intense damming has promoted a more regular and reduced river flow (2007–2009: 22 ± 19 $m^3 s^{-1}$), contrasting with sharp variations between dry and humid months (1995–2000: 333 ± 1096 $m^3 s^{-1}$, http://snirh.pt) that occurred before the Alqueva dam construction (140 km from the river's mouth).

Sampling campaigns in the Guadiana estuary were carried out fortnightly throughout 2007–2008, and monthly during 2009. Four representative locations along the estuary were sampled: Mértola (70 km from river mouth) and Alcoutim (38 km) in the upper estuary; Foz de Odeleite (22 km; hereafter Odeleite) in the middle estuary; and Vila Real de Santo António (2 km, hereafter VRSA) in the lower estuary (Fig. 1). Sampling occurred in each station immediately after high tide of neap tides, so all the stations were sampled at the same tidal stage, to avoid tidally-induced dissimilarities between sampling stations.

2.2. Physical–chemical variables

Data on daily river flow at Pulo do Lobo hydrometric station (85 km from river mouth), daily rainfall at Alcoutim and hourly solar radiation, used to derive daily solar irradiance, at São Brás de Alportel (50 km eastwards from Alcoutim) were obtained from the Portuguese National Water Institute public database (http://snirh.pt). Vertical profiles of water temperature and salinity were determined in situ using a YSI 556 MPS probe. Vertical profiles of photosynthetically active radiation (PAR) intensity were determined using a LI-COR radiometer. The light attenuation coefficient (k_d, m^{-1}) was calculated using an exponential function (Eq. (1)):

$$I_Z = I_0 e^{-K_d Z} \tag{1}$$

where I_z represents the light intensity at depth Z (m) and I_0 is the light intensity at the surface. Daily solar irradiance ($W\,m^{-2}$) was used to estimate daily photosynthetically active radiation (PAR) at the surface (I_0), considering that PAR constitutes 45% of the total radiation reaching the water surface and a 4% reflection at the surface (Baker and Frouin, 1987). I_0 values were then converted to μmol photons $m^{-2}\,s^{-1}$ after multiplying by 4.587 mmol photons $s^{-1}\,W^{-1}$ (Morel and Smith, 1974). Mean light intensity in the mixed layer for each sampling date (I_m, μmol photons $m^{-2}\,s^{-1}$) was subsequently calculated according to Eq. (2):

$$I_m = I_0 \left(1 - e^{(-K_e Z)}\right) (K_e Z_m)^{-1} \tag{2}$$

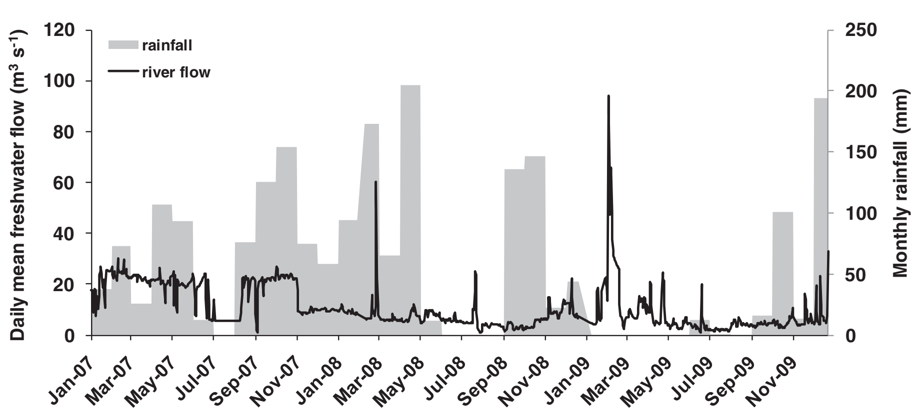

Fig. 1. Location of the Guadiana estuary and sampling stations.

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