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ORIGINAL RESEARCH ARTICLE

Eutrophication influence on phytoplankton community composition in three bays on the eastern Adriatic coast

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Summary This study shows the influence of eutrophication pressure on the phytoplankton community structure, abundance and biodiversity in the investigated bays with different hydromorphological features. Šibenik Bay is a highly stratified estuary of the karstic river Krka; Kaštela Bay is a semi-enclosed coastal bay, which is influenced by the relatively small river Jadro; and Mali Ston Bay is located at the Neretva River estuary, the largest river on the eastern part of the Adriatic Sea. All of the areas are affected by urban pressure, which is reflected in the trophic status of the waters. The greatest anthropogenic influence was found in Kaštela Bay while the lowest influence was found in Mali Ston Bay. In this study, the highest biomass concentration and maximum abundance of phytoplankton were recorded at the stations under the strongest anthropogenic influence. Those stations show a dominance of abundance compared to the biomass and a dominance of opportunistic species, which is reflected in the lower biodiversity of phytoplankton community. Diatoms were the most represented group of the phytoplankton community in all three bays, followed by the dinoflagellates. Diatoms that were highlighted as significant for the difference between the bays were *Skeletonema marinoi* in Šibenik Bay, *Leptocylindrus minimus* in Kaštela Bay and the genus *Chaetoceros* spp. in Mali Ston Bay. Dinoflagellates were more abundant at the stations under the strongest anthropogenic influence, and most significant were *Prorocentrum triestinum* in Kaštela Bay and *Gymnodinium* spp. in Šibenik Bay and Mali Ston Bay.

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1. Introduction

Phytoplankton biomass and community composition were analyzed in three bays on the eastern Adriatic coast, with different hydrological and trophic statuses. Phytoplankton is very sensitive to changes in its environment and, therefore, provides good insight into water quality before it becomes visible on higher trophic levels and the excessive eutrophication of certain areas commences (Brettum and Andersen, 2005). Eutrophication is an enrichment of water with nutrients, primarily nitrogen and phosphorus, which stimulates primary production. In some cases, that leads to visible blooms and accumulation of submerged and floating organic material in the water (Vollenweider, 1992). Eutrophication can have natural and anthropogenic origins. A natural one occurs due to substrate remineralization, upwelling and increase of rivers inflow. Resuspension of particulate matter can enhance primary production because of the intrusion of the pore water rich with nutrients from the sediments into the bottom layer and consequentially into the whole water column (Guinder et al., 2015; Su et al., 2015). A previous study of the investigated areas shows that sediment resuspension is one of the sources of ammonia, nitrate and phosphate regeneration (Barić et al., 2002). Upwelling brings nutrient rich waters from the deeper layers, and rivers' inflow bring the bulk of total nitrogen to the sea. Anthropogenic eutrophication occurs due to various human activities in the vicinity of the coastal area, such as the inflow of urban and industrial wastewaters, rinsing of agricultural land and atmospheric pollution. A causal link between anthropogenic sources of nutrients and the eutrophication of the system is generally accepted (McQuatters-Gollop et al., 2009; Smith, 2006), although it is very important to take into account systems-specific features of a certain area to distinguish changes in the ecosystem resulting from natural seasonal and interannual dynamics. Given the scale, the eutrophication process could be beneficial for the ecosystem, but it could have adverse effects depending on the different characteristics of each ecosystem (Crossetti et al., 2008; Marasović and Pucher-Petković, 1985; Skejić et al., 2014; Su et al., 2015). The beginning of eutrophication causes an increase in phytoplankton biomass, but the composition of the phytoplankton community becomes more uniform. Certain species disappear, while at the same time, opportunistic species of phytoplankton begin to dominate (McQuatters-Gollop et al., 2009). Species diversity is reduced because of the competitive exclusion between species, whereas with a slight increase of eutrophication, competition is relaxed, thus resulting in increased diversity. With a further increase in eutrophication, diversity drops again because of species reduction due to stress (Spatharis et al., 2007). Eutrophication tends to favour small and fast-growing organisms, which usually means that the proportion of the dominant taxa to the total biomass is relatively low, meaning that the biodiversity values are higher than when large-sized taxa dominate (Uusitalo et al., 2013).

In highly eutrophicated systems, the trophic chain is lacking higher links, and autotrophic processes exceed heterotrophic, which significantly affects the balance of the system (Richardson et al., 1998). The responses of phytoplankton to the eutrophication process have been reported mostly through chlorophyll *a* concentrations (Edwards et al., 2003; Gowen et al., 1992; Vollenweider, 1976). The phytoplankton biomass (chl *a*) is a common indicator of eutrophication because it provides consistent insights of a certain area, but it should be monitored with the compositional changes of the community structure (McQuatters-Gollop et al., 2009; Ninčević Gladan et al., 2015). The Water Framework Directive (WFD) (European Commission, 2008) states that phytoplankton and its biodiversity are one of the crucial biological elements in the assessment of the ecological status of the sea. Previous studies of researched bays along the eastern Adriatic coast, revealed that these are the areas with the highest nutrient concentration and primary productivity. These are the semi-enclosed areas and salt-wedge estuaries with a high urban nitrogen and phosphorus loading, and a high natural nitrate and silicate loading by the rivers' inflow (Barić et al., 1992; Legović et al., 1994). In previous studies, the trophic status of investigated bays has been determined using the phytoplankton abundance and volume (Čalić et al., 2013; Marasović and Ninčević, 1997; Viličić, 1989).

The aim of this study is to determine a difference between the stations considering the specific nutrients, to quantify the potential anthropogenic pressures and to determine the relationship between abiotic parameters and biomass. In addition, we determine the similarity of the phytoplankton community regarding the abundance of species and define how much individual species affect the diversity observed between the investigated stations. The aim is to establish the relationship between biomass and phytoplankton abundance and use it as a way to define the level of disturbance in the investigated areas. Overall, the aim of this study is to investigate the impact of anthropogenic pressures on phytoplankton community structure and biodiversity.

2. Material and methods

2.1. Study area

Šibenik Bay is a highly stratified estuary of the karstic river Krka, with small tidal amplitudes and permanently brackish surface water (Svensen et al., 2007). The Krka River is one of the most pristine European rivers, characterized by low concentrations of nutrients and extremely low input of terrigenous material (Legović et al., 1994). Freshwater discharge from the Krka River has been systematically monitored since 1947 (Bonacci and Ljubenkov, 2005), and it can vary between 5 and 565 $m^3 s^{-1}$ with an annual average discharge of 52.9 $m^3 s^{-1}$ (1950—1998). The Krka River estuary is a typical salt-wedge, highly stratified estuary (Žutić and Legović, 1987) that is 25 km long and relatively narrow except for two wider parts, Prokljan Lake and Šibenik harbour. The depth gradually increases from 5 to 43 m at the mouth. The town of Šibenik is located in the estuary's middle reach, and it is the only source of direct anthropogenic eutrophication (Gržetić et al., 1991; Legović et al., 1994). Šibenik harbour has reduced exchange with the waters of the open sea, and it is under a direct anthropogenic influence (Kušpilić, 2005). The phytoplankton community in the estuary is dependent on seasonal cycles of temperature and salinity (winter—spring and summer—autumn), and on the degree of eutrophication, which can