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Seasonal phytoplankton dynamics in the coastal waters of the north-eastern Adriatic Sea

Jelena Godrijan [a,*], Daniela Marić [a], Igor Tomažić [b], Robert Precali [a], Martin Pfannkuchen [a]

[a] Center for Marine Research Ruđer Bošković Institute, Giordano Paliaga 5, 52210 Rovinj, Croatia
[b] Division for Marine and Environmental Research, Ruđer Bošković Institute, Bijenička cesta 54, 10000 Zagreb, Croatia

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ABSTRACT

This study describes the dynamics of phytoplankton in relation to environmental factors in coastal waters of the north-eastern Adriatic Sea. The distant Po River's influence is rarely noted on the eastern coastal part of the northern Adriatic, but it does trigger the crucial alternations in the community, e.g. mass development of diatoms in July 2009. A highly variable ecosystem, like the northern Adriatic, sustains high species diversity. Even though quite a few species were present for more than several months, we identified the seminal species of the seasonal succession. During spring *Prorocentrum micans*, *Leptocylindrus minimus*, *Chaetoceros throndsenii*, *Ceratium furca* and *Ceratium fusus* were most characteristic. These species thrive in low salinity and mixed waters. Typical summer diatom species were *Chaetoceros vixvisibilis* and *Proboscia alata*, while *Rhabdosphaera clavigera* and *Syracosphaera pulchra* were identified as distinctive summer coccolithophorids. All the summer species preferred warmer waters with low nitrate and low silica content. The autumn community was characterised by species such as *Calciosolenia murrayi*, *Chaetoceros socialis*, *Asterionellopsis glacialis*, and *Lioloma pacificum*. These species were related not only to high nutrient conditions, but also to low Po River influence. In winter a prevalence of large diatoms *Thalassiosira rotula*, *Neocalyptrella robusta* and *Pseudosolenia calcar-avis* was recorded. The winter assemblage was characterised by species of cold water preference able to grow in well mixed conditions.

1. Introduction

The Mediterranean is a semi-enclosed sea usually thought of as an oligotrophic system (Sournia, 1973), with the exception of several small coastal areas where higher production is primarily influenced by large rivers (Gómez and Gorsky, 2003). One such system is the northern Adriatic Sea, a shallow basin (<50 m) with marked west to east gradients of physical and biological properties. Discharges of the Po River and different circulation patterns were identified as major drivers of nutrient input and distribution (Cozzi and Giani, 2011; Degobbis et al., 2000), and thus phytoplankton community composition in the whole area (Viličić et al., 2009). The Po River exhibits two principal patterns of its influence on the northern Adriatic ecosystem. In mixed conditions the Po River water is confined to the western coast, it flows into the Western Adriatic Current (WAC) and eventually exits the Adriatic (Cushman-Roisin et al., 2001; Mauri and Poulain, 2001). Otherwise, it can extend into the northern Adriatic interior. There it forms the Po River plume, either as a tongue of fresh water or it spreads as a thin surface layer over the entire northern Adriatic basin during stable, stratified conditions (Bignami et al., 2007; Cushman-Roisin et al., 2001). Additionally, the eastern part of the northern Adriatic Sea is under the influence of highly saline, oligotrophic waters by advection of the Eastern Adriatic Current (EAC) from the central Adriatic. Satellite surface chlorophyll *a* maps proved to be important tools in studying the spatial structure and temporal variation of the Po River plume. Surface chlorophyll *a* is considered to be a marker of the spatial productivity patterns in the northern Adriatic ecosystem and the basin's mesoscale dynamics (Mauri and Poulain, 2001).

Detailed knowledge of phytoplankton dynamics is essential for our understanding of the marine ecosystem, particularly in marginal seas, like the northern Adriatic, where responses to external changes are amplified. Generally, the annual pattern of phytoplankton biomass in temperate systems is thought to have two major maxima, in spring and autumn (Legendre, 1990). For the northern Adriatic, though, four major peeks were reported by Bernardi Aubry et al. (2012) (February, May, July and September). These blooms are dominated by diatoms (Marić et al., 2012), with the exception of May when nanoflagellates co-dominate (Bernardi Aubry et al., 2012; Mozetič et al., 2012). Dinoflagellates reach their peak in the summer in offshore waters (Totti et al., 2000), but are rarely more abundant than diatoms in the coastal area of the Gulf of Venice (Bernardi Aubry and Acri, 2004). Revelante and Gilmartin (1976) reported a less pronounced spring bloom (chlorophyll *a* and biomass) in the eastern part of the northern Adriatic if compared to the western part of the northern Adriatic basin. In the last decade a reduction of diatoms was reported in the eastern part of the northern Adriatic, while the development of the spring peak shifted towards summer (Marić et al., 2012; Mozetič et al., 2012). However, scarce

* Corresponding author. Tel.: +385 52 084 763; fax: +385 52 813 496.
E-mail address: jelena.godrijan@irb.hr (J. Godrijan).

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information is available on species succession and phytoplankton dynamics of the eastern part of the northern Adriatic.

In this report we investigate the phytoplankton community and species dynamics in coastal waters of the less investigated eastern part of the northern Adriatic Sea. Observation of species composition provides insight into mechanisms and trophic implications not resolvable with measurements of chlorophyll *a* or other bulk parameters alone (Ji et al., 2010). Moreover, as spatial heterogeneity of the phytoplankton composition can strongly influence the ecosystem stability, dynamics and regional productivity (Martin, 2003), a comprehensive information on this is clearly vital to an understanding of the northern Adriatic ecosystem. This two year study (2008–2009) integrates timing, abundance and spatial distribution of phytoplankton. We compare satellite chlorophyll distributions with in situ measurements of both chlorophyll *a* concentrations and phytoplankton species abundances. We aim not just to detail the spatial distribution and influence of the distant Po River on the phytoplankton community but also to reveal the temporal succession of species in coastal waters of the north-eastern Adriatic.

2. Materials and methods

2.1. Sampling

Eighteen monthly cruises, from March 2008 to November 2009, were carried out with the RV 'Vila Velebita'. Gaps in sampling were due to maintenance of the ship. Samples were collected at seven stations, all one nautical mile from the Croatian coastline (Fig. 1). The stations formed a transect along the Istrian coast. Conductivity–Temperature–Depth (CTD) profiles were recorded with an SBE 25 Sealogger CTD probe (Sea-Bird Electronics, Inc., Bellevue, Washington, USA). Water samples were collected with 5 L Niskin bottles at surface, 5, 10, 20 m and 2 m above seabed for nutrients; and at surface, 10 m and 2 m above seabed for phytoplankton analyses.

2.2. Sample analysis

Nutrients: nitrate (NO_3), nitrite (NO_2), orthophosphate (PO_4) and orthosilicate (SiO_4) were measured by spectrophotometric methods (Parsons et al., 1984). Ammonium (NH_4) was analysed by a modified technique of the indophenol method (Ivančić and Degobbis, 1984). Measurements were performed on a Shimadzu UV-Mini 1240 spectrophotometer with 10 cm cells. In statistical analyses total inorganic nitrogen (TIN, sum of NO_3, NO_2, and NH_4) was used.

A 500 mL subsample for the determination of chlorophyll *a* was filtered onto Whatman GF/C filters and immediately frozen at −20 °C until analysis (within a week). Total chlorophyll *a* concentrations were determined on a Turner TD-700 fluorometer (Parsons et al., 1984) after three hours of extraction in 90% acetone (in the dark, with grinding). Satellite data of the MODIS/Aqua chlorophyll concentration, derived with the OC3 algorithm (O' Reilly et al., 2000) were retrieved from the Ocean Colour Web archive (Feldman and McClain, 2009). Series of satellite images were attained to observe the conditions in the rest of the basin.

Phytoplankton samples, 200 mL, were fixed with neutralised formaldehyde (2% final concentration). Phytoplankton cells were counted in 50 mL subsamples after 40 h of sedimentation time (Hasle, 1978) using an Axiovert 200 microscope (Zeiss GmbH, Oberkochen, Germany) and following the Utermöhl (1958) method. Microplankton

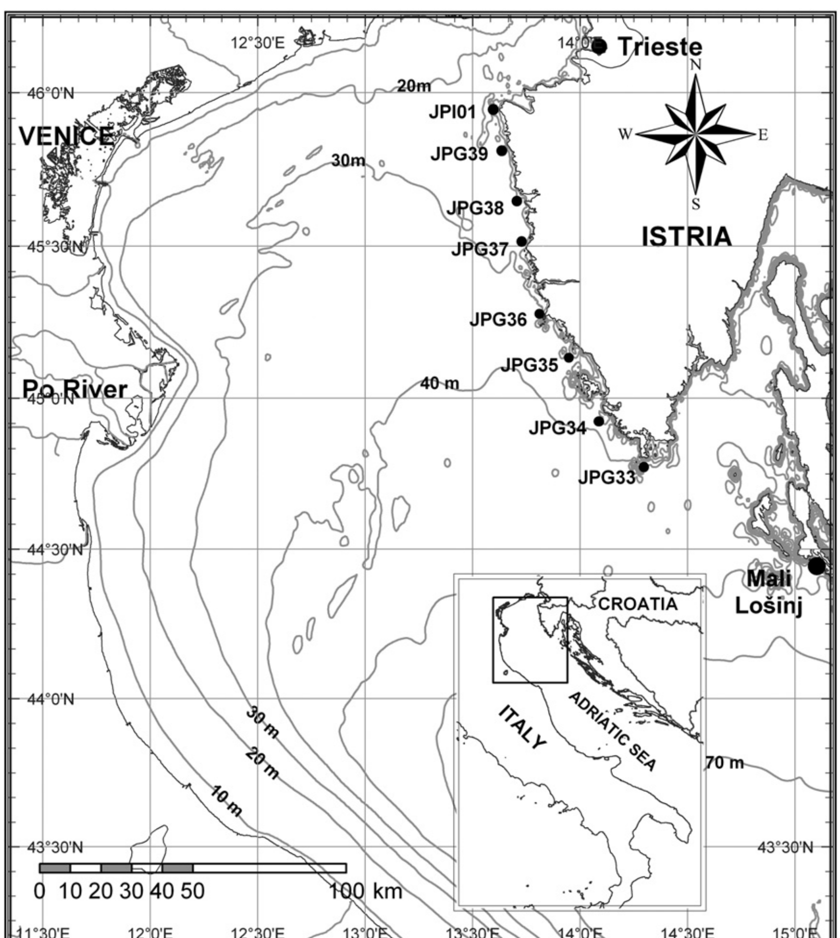

Fig. 1. Map of the investigated area.