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The role of forcing agents on biogeochemical variability along the southwestern Adriatic coast: The Gulf of Manfredonia case study

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ABSTRACT

This study investigates how multiple forcing factors such as rivers, surface marine circulation and winds affect hydrology and biogeochemical processes in the Gulf of Manfredonia and the seas around the Gargano peninsula, in the south-western Adriatic Sea. The study adopted an integrated approach, using *in situ* and remote sensing data, as well as the output of current models. The data reveal variability in the area's hydrography induced by local freshwater sources, the Western Adriatic Current (WAC) flowing from the north along the Italian coast, and the current patterns under different wind regimes. Specifically, exchange with offshore waters in the gulf induces variability in salinity and biogeochemical content, even within the same season, i.e. winter, in our case. This strong dependence on physical and biogeochemical factors makes the Manfredonia-Gargano ecosystem vulnerable to climate change, which could compromise its important role as a nursery area for the Adriatic Sea.

1. Introduction

Coastal areas are highly dynamic environments, where local-scale natural processes and anthropogenic pressures affect biogeochemical and optical processes, leading to continuous changes in the ecosystems and their services (Mancinelli and Vizzini, 2015). Mixing of terrigenous waters and seawater represents a key process for the biological productivity of marine coastal environments, with important implications for the functioning of the whole coastal system. Recently, there has been an increase in studies of physical, biological and chemical processes in coastal systems over narrower time and space ranges (Cherukuru et al., 2014; Organelli et al., 2014; Tremblay et al., 2014). This interest reflects the rising frequency of short-term phenomena resulting from climate change, especially the increase in intense rainfall events and consequently in terrigenous loads entering coastal waters from rivers. Intensive regional research programs have also been carried out in coastal waters in order to study optical variability and its dependence on biogeochemical processes (Erga et al., 2012; Li et al., 2014; Retelletti Brogi et al., 2015; Sasaki et al., 2005). In coastal systems affected by river discharge, physical processes such as wind and surface currents, as well as freshwater inflow, influence the input of organic matter, phytoplankton production and trophic transfer (Bowers and Brett, 2008; Philips et al., 2012). The consequences of altered patterns of freshwater input on the biogeochemistry of coastal systems have been reported in many studies (Vignudelli et al., 2004; Berto et al., 2010; Buzzelli et al., 2014; Marini et al., 2015).

Within the Mediterranean Sea area, the Adriatic Sea represents a complex basin characterised by diverse biogeochemical dynamics and circulation, from north to south. The general surface circulation pattern is cyclonic, flowing southward along the Italian coast as the Western Adriatic Current (WAC) and carrying fresh waters originating from the largest north Italian river, the Po (Artegiani et al., 1997; Marini et al., 2008). Several studies have highlighted a clear WAC signal extending as far south as the "spur" of the Italian boot, i.e. the Gargano Peninsula (Fig. 1) and beyond, into the Ionian Sea

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(Bignami et al., 2007; Lipizer et al., 2014; Marini et al., 2015). The Gargano peninsula forms the northern limit of the Gulf of Manfredonia, an area of oceanographic and ecological relevance, as it is a nursery zone for small pelagic fish (Borme et al., 2013; Monticelli et al., 2014). The Gulf (Fig. 1) is affected by two main rivers, the Candelaro (67 Km long, catchment area 2200 Km^2) and the Ofanto (165 Km long, catchment area 2790 Km^2), which receive wastewaters from major towns (~300,000 inhabitants) and together drain a large catchment area subject to intensive agriculture (De Girolamo et al., 2014; Focardi et al., 2009).

The presence of multiple forcing factors in the area (rivers, surface marine circulation, winds) and its ecological importance prompted us to investigate how these variables affect the area's hydrology and biogeochemical processes and thus its productivity. To address this question, we used *in situ* and satellite observations as well as model output to assess: 1) the effects of small local rivers with season-dependent flood periods on the hydrological structure of the marine water masses; 2) the biogeochemical variability related to river discharges; 3) the influence of the WAC on regional coastal dynamics; 4) the ecological implications of the observed features.

2. Materials and methods

2.1. Sampling design

Bi-monthly field samplings were performed in 2013 (February 22nd, April 23rd, June 18th, August 29th, October 23rd, December 12th) at 6 stations (Fig. 1, Table 1). Site M (4 km from the coast with a depth of 20 m) was located north of the Gargano as a reference point for WAC waters, and sites A-E were located in the Gulf of Manfredonia, along a transect from the Candelaro river delta eastwards. Site A was located 0.3 km from the river mouth, sites B-C-D were spaced about 7 km from each other and the outermost site E was 25 km from the coast, with depths of 9, 15, 17, 19, 20 m, respectively. Details on sampling dates and times are shown in Table 1.

At each site, the hydrographic temperature (T) and salinity (S) profiles were recorded with a calibrated SBE 19Plus probe (Sea-Bird Electronics, Inc.). Two depths (surface and bottom) were sampled in duplicate (144 discrete seawater samples) for nutrient analyses (ammonia NH_4^+, nitrite NO_2^-, nitrate NO_3^-, soluble reactive phosphorous SRP, soluble reactive silicate SRSi, total phosphorous TP), chlorophyll *a* (Chl *a*) and CDOM. Water samples for dissolved nutrients were directly filtered on board through a syringe with Whatman GF/F filters and stored at −20 °C for about two weeks until laboratory measurements. For Chl *a*, 1000 ml water samples were drawn directly from Niskin bottles into dark polyethylene bottles and stored at 4 °C until laboratory filtration. For CDOM, 200 ml samples were drawn into polyethylene syringes and filtered through sterile Whatman GD/X 0.2 μm filters. All glassware and syringes were previously soaked with 10% HCl and thereafter rinsed with Milli-Q water. Samples for phytoplankton analysis were directly drawn into dark polyethylene bottles (500 ml) with 4% formaldehyde.

2.2. River-wind data and current model output

Data for the Candelaro and Ofanto rivers were measured just off their mouths at the observation stations of the Hydrographic and Mareographic Service of Puglia Regional Administration and were provided by the “Centro Funzionale”. River data were supplied for

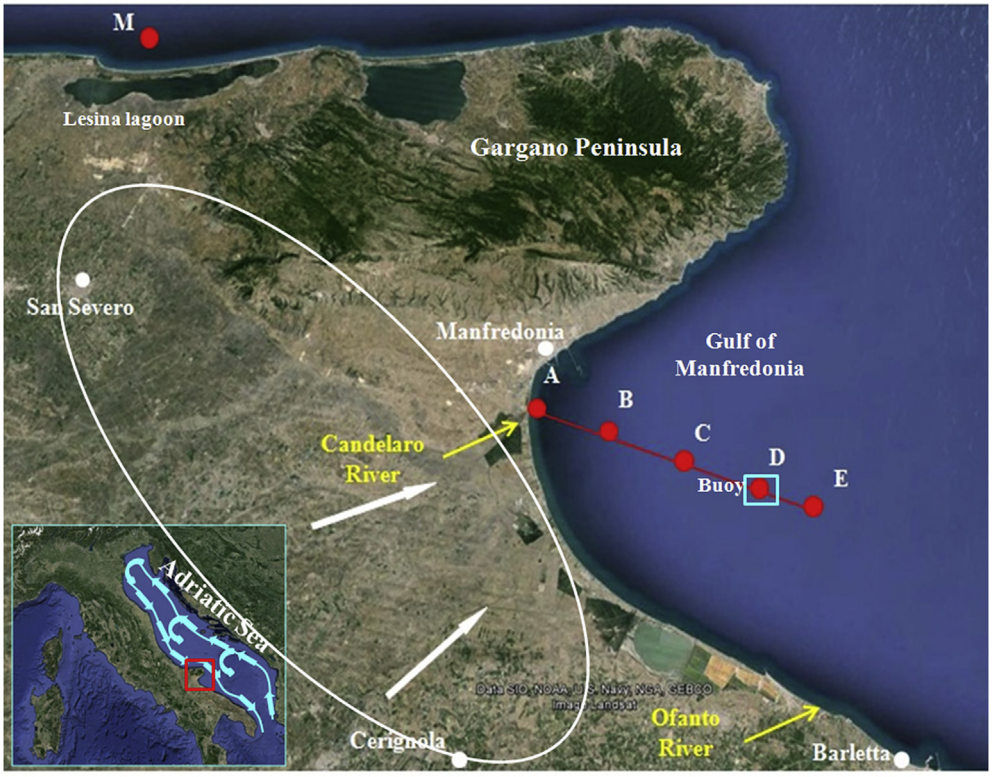

Fig. 1. -The study area and its position in the Adriatic Sea (inset, with main surface circulation redrawn, after Fig. 1 of Lipizer et al., 2014); red circles: sampling station M north of the Gargano peninsula and the stations A-E along the transect in the Gulf of Manfredonia. The Meda Gargano buoy (light blue square, for *in situ* wind measurements) is located at site D; the agricultural area is indicated by the white arrows and the river mouths with yellow arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)