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Circulation and biomass distribution during warm season in the Gulf of La Spezia (north-western Mediterranean)

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ABSTRACT

Hydrographic and current measurements permitted to attain some insight in the dynamic conditions of the Gulf of La Spezia. It was shown that its circulation is the result of the interaction of two driving mechanisms: the estuarine circulation present in its interior and the large scale coastal circulation influencing the Gulf through its open boundary. The response of the Gulf to the wind is mainly baroclinic, in agreement with the expected response of the background two-layer system. The good correspondence between physical and biochemical parameters evidences the key role played by circulation in determining the biomass distribution along the Gulf littoral.

1. Introduction

Coastal areas are frequently of considerable interest due to high anthropogenic pressure and need to protect them against pollution. These issues become even more relevant in towns and ports, which may be affected by industrial discharges and anthropogenic contaminants (Darbra et al., 2005). If the ecosystem can not assimilate the organic material, the trophic state can reach harmful levels. In small regions characterized by restricted exchange of water masses, circulation within the harbors and between the harbors and the surrounding water bodies has a key role in the transport and removal of material that enters the water bodies.

The Gulf of La Spezia (Fig. 1) is a good example, where several of the above mentioned characteristics are present. It is located on the eastern side of the Ligurian coast (northwest Italy) and has approximately 100,000 inhabitants. The most relevant activities are a commercial harbor, several naval industries, a military base and an electric power-plant. Furthermore, industrial and commercial activity develops very close to areas of high environmental value (UNESCO site: http://whc.unesco.org/en/list/826) and tourist interest.

Delimited by Tino and Palmaria islands on the west and by Punta Bianca promontory on the east, the Gulf is surrounded by mountains. Northwest–southeast oriented, it is 5 km wide while its length is about 10 km. A dam (length of 2.2 km) separates the Gulf in two areas: inside the dam there is the harbor having a mean depth of about 10–11 m; the outside part, representing transition to the open sea, is deeper and has an irregular bathymetry. Depth of the Gulf progressively increases in a westward direction: the maximum depth (about 25 m) is in proximity of Palmaria and Tino islands, where the bathymetry becomes very steep. Two passages, at the dam ends, permit exchange between the inside and outside part of the Gulf (Fig. 1). The western opening is wider (360 m) than the eastern one (180 m), and is deeper: 15–16 m in the west against 11–12 m in the east. While the main connection with the open sea is through the Gulf open boundary and the passage between Palmaria and Tino islands, some exchange is also possible through the Portovenere channel (between land and Palmaria island), although the channel is very narrow (150 m wide) and very shallow (the sill depth is 3 m).

During the past years the Gulf has been the object of some studies related to anthropogenic activities along its borders. The investigations concentrated on the internal part of the Gulf, inside the dam, but only a small number of publications are available, most results being presented in the internal technical reports (ENEA, 1996 and 2000). From published information (Marri et al., 1991; Borella et al., 1992) we know that the freshwater discharges (natural and anthropogenic) of the town of La Spezia and the cooling system of an important electric power-plant, located inside the harbor (Fig. 1), are able to significantly influence hydrographic conditions and circulation of the Gulf interior. As for the two dam openings, major exchange occurs through the western one, primarily because it is wider and deeper and therefore

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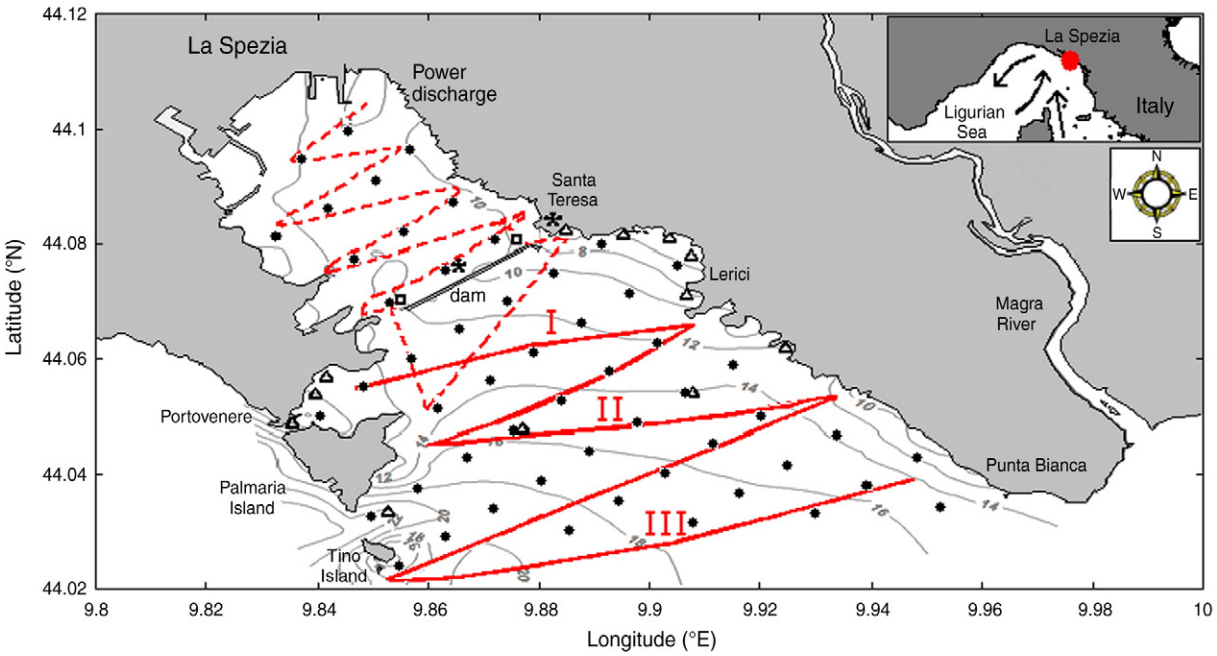

Fig. 1. The Gulf of La Spezia. Stars indicate hydrographic stations, open triangles biological stations, open squares current meter moorings, asterisks meteorological stations; ADCP tracks corresponding to 19 June 2007 and 4 May 2006 are indicated by continuous and dotted lines, respectively. Roman numbers refer to vertical sections of the current field presented in Fig. 9. The large scale circulation is indicated by arrows in the small map.

ensures a more efficient connection with the open sea. The eastern opening, being narrower and shallower, seems to have a minor role (ENEA, 1996). Direct current measurements evidenced the importance of high frequency variability. More specifically, a 70 min period oscillation accounts for a high percentage of current variability, while tidal components and inertial oscillations appear to be significantly less important (Borella et al., 1992).

Little information exists on the outer part of the Gulf, where it is subjected more to open sea dynamics. The wide open-sea boundary puts the Gulf under the influence of the large scale Ligurian circulation (Astraldi et al., 1979; Astraldi and Gasparini, 1985), which is characterized by a cyclonic, east-to-west flow (Fig. 1). Furthermore, the Gulf is located in a transition region where Ligurian and Tyrrhenian currents meet: the Tyrrhenian current is more important during the colder seasons, while during the warmer ones the Ligurian current prevails (Astraldi and Gasparini, 1992). The Magra river runoff may have certain relevance for the hydrodynamics of the Gulf: characterized by a large variability (from 5 m^3/s to more than 1000 m^3/s and a mean value of 40 m^3/s), its signature is mainly evident during the rainy periods (Astraldi et al., 1979).

The objective of the present study is to describe oceanographic conditions of the entire Gulf, using previously unpublished data, especially those collected inside the dam, and considering new observations, concentrated outside it. The available data, even if not always homogeneous in space and time, may support a comprehensive overview of the Gulf dynamics. Possible relationship between physical conditions and chemical (nutrients)/biological (phytoplankton) signature observed in the Gulf is also considered.

The new observations have been acquired in the framework of the MREA (Marin Rapid Environmental Assessment) experiment LASIE (Ligurian Air Sea Interaction Experiment, http://geos2.nurc.nato.int/lasie07/) in the Ligurian Sea, and in particular as a part of the coastal experiment POET (Predictive Oceanographic Experimental Trial) that focused on the Gulf of La Spezia. This paper intends to provide researchers involved in the POET experiment, mainly addressing the MREA objectives, with a background knowledge of main circulation patterns and related hydrographic conditions.

2. Data and methods

A hydrographic cruise has been carried out on 18 June 2007, covering the entire Gulf with 53 stations and using the multiparametric probe IDRONAUT measuring CTD, dissolved oxygen and fluorescence. Outside the dam, at nine littoral stations of particular environmental interest (Fig. 1), sampling was performed with the CTD probe as well as using the water bottles in order to determine nutrients (nitrates, silicates and orthophosphates) and chlorophyll concentration (which also permitted the fluorimeter calibration by a linear regression). These stations have also been visited in order to determine the distribution of potentially toxic benthic microalgae (*Ostreopsis ovata*).

Sea water samples were taken using a 5 l Go-flo bottle. The nutrients have been determined through colorimetric analysis by a continuous flow system multichannels (AutoAnalyzer Bran+Luebbe III Generation), following the Hansen and Koroleff (1999) procedures.

The chlorophyll concentration (μg/l) was measured by a spectrophotometer (ULTROSPEC 2000, Pharmacia Biotech) following the method of Strickland and Parsons (1968). The trichromatic formula of Lorenzen and Jeffrey (1980) was applied to calculate the pigment concentration.

Furthermore a net (diameter 35 cm and pore size 20 μm) was used for the phytoplankton sampling at each station. Samples were fixed with Lugol solution and the Utermohl method (Hasle, 1978) was applied for the phytoplankton qualitative/quantitative analysis.

One day later (i.e. on 19 June 2007), a vessel mounted RDI 300 kHz ADCP was used to collect data along the water column in the external part of the Gulf, along five tracks (Fig. 1). The ADCP cell size was 1 m. The ADCP data have been submitted to post-processing with the RDI WinADCP Software. No detiding procedure has been applied due to the smallness of tidal signal (Borella et al., 1992). Nevertheless, the possible influence of the 70 min oscillation had to be taken into account.

Data from the Santa Teresa meteorological station, positioned on the eastern side of the Gulf at about 50 m above sea level (Fig. 1), have also been considered. The examined parameters were atmospheric