WATER RENEWAL MECHANISMS OF THE BAY OF ALGECIRAS IN THE STRAIT OF GIBRALTAR

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Abstract
The Bay of Algeciras (BA) is a marine environment subject to high levels of anthropogenic pressure. Here we analyze a number of ADCP observations collected at the bay and the results of an ocean circulation model to investigate its circulation, variability, and the mechanisms involved in the water exchange with the adjacent Strait of Gibraltar. It is found that the flushing of the bay, and therefore also its water quality, is largely dependent on the strength of tidal flows.

Keywords: Coastal processes, Coastal models, Gibraltar Strait

The BA is located at the north-eastern end of the Strait of Gibraltar (Fig.1). Covering an area of about 9x11 km and with a maximum depth of nearly 400 m, features by far the mildest surface currents of the strait, a circumstance that has made of this spot the ideal location for the settlement of harbors from the times of early civilizations. Today, the bay is a strategic point within one of the busiest shipping routes in the world and not for nothing holds two major ports in both Algeciras and Gibraltar, along with numerous industrial plants distributed all along its shoreline. Marine pollution is therefore a serious problem in the bay itself and in the surrounding areas.

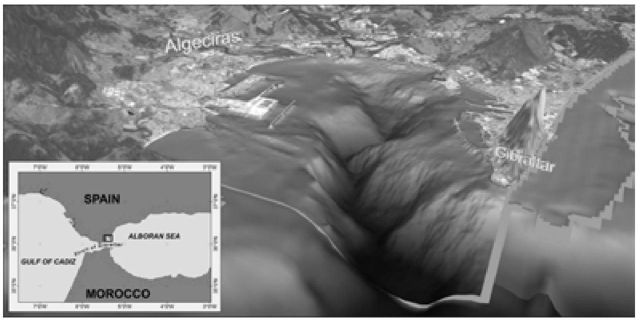

Fig. 1. Location and bathymetry of the Bay of Algeciras.

In order to understanding the circulatory system of the BA and the physical mechanisms involved in its water renewal, water quality, and exchange with the strait's main channel, three mooring lines equipped with autonomous CTs at around 10m above the seafloor and uplooking ADCPs were deployed at different locations of the bay during the Spring and the Fall of 2011. Moreover, with the aim to get a more comprehensible time-spatial data coverage, a high-resolution primitive equation model was used to conduct a hind-cast simulation for the mentioned period, whose results compared very satisfactorily with observations [1, 2].

Model and observations reveal that the mean surface circulation of the BA is characterized by an anti-cyclonic cell fed by a coastal current flowing in opposite direction to the jet of Atlantic Water offshore. The coastal current in question encompasses a narrow stripe along the north coast of the strait of Gibraltar and is within the lateral boundary layer. This circulation pattern is subject to substantial variability and its negative vorticity can be enhanced or diminish, even revert sign, depending upon meridional displacements of the referred jet. These displacements are shown to be linked to atmospheric-pressure driven flows that accelerate or slow down the jet. The second source of variability is due to winds and fulfills the expectations of Ekman dynamics, with surface currents entirely pointing offshore or inshore during westerly or easterly winds, respectively. The third source of variability, though no less important, are tides, able to revert the flow direction with semidiurnal periodicity.

A series of additional model runs tracking the evolution of passive tracers (dye) released in the BA were carried out in order to gain an insight into the mechanisms involved in the water renewal of the BA and discern the most favorable/unfavorable scenario for the flushing of the Bay. The dye was released within both the Atlantic (S<37.5) and the Mediterranean (S>37.5) layers in order to obtain a more complete picture of the process. For each release of the dye the corresponding *e*-flashing time was computed by the exponential fitting the dye concentration curve. The results are shown in Fig.2a and reflect substantial time variability.

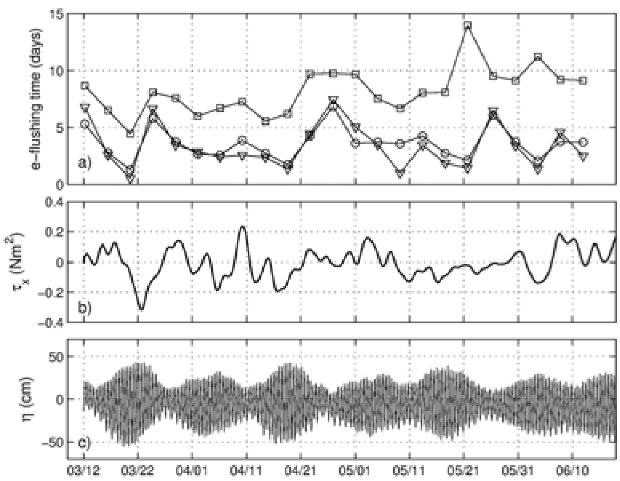

Fig. 2. A) Temporal dependence of the Atlantic (circles), Mediterranean (squares), and surface ($-5 < z < 0$ m; triangles) layer e-flushing times. The marks are located at the time of the passive tracer release. b) Horizontal component of wind stress over BA. c) Mean sea surface height.

The most direct outcome is that minimum (maximum) flushing times of the Atlantic (circles) and the very surface layers (triangles) are obtained for releases of the dye during spring (neap) tides (Fig. 2c), which suggests that tidal flows play a major role in the dispersal of the tracer therein. This does not apply, however, to the bottom Mediterranean layer (squares) in which tidal currents are weak, and ventilation of this layer appears to be connected with the variability of the wind forcing that is stronger during the first half of the simulation (Fig. 2b). These results suggest that the marine environment of the BA benefits from the relatively strong tides of the strait, and that its water quality would be significantly worse if it were located just few kilometers eastwards (within the Alboran Sea), where tides are practically absent.

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RECENT EVIDENCE THAT THE DEEP SEA AROUND MALTA IS A BIODIVERSITY HOTSPOT

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Abstract

Recent ROV surveys of deep-sea areas around the Maltese Islands resulted in the discovery of highly diverse habitats, including extensive rocky areas dominated by living cold water corals and gorgonians at depths of 300–1000 m, a sub-fossil lithistid sponge reef at a depth of *ca*. 300 m, deep-water caves located at 270–450 m, and vast expanses of soft-bottom habitats, each of which had a rich variety of associated fauna. Most of these habitats are of high conservation interest, highlighting the need for the establishment of offshore marine protected areas in order to protect these very diverse, but highly vulnerable, deep-sea habitats.

Keywords: Biodiversity, Deep sea ecology, Zoobenthos, Malta Trough, Sicily Channel

Introduction

The diversity of the Mediterranean deep sea is poorly known, but has received increased research attention in recent years [1]. This is particularly true for hard substratum communities, which could not be studied in detail until the advent of Remotely Operated Vehicle (ROV) exploration that has led to the discovery of highly diverse assemblages such as cold water coral (CWC) reefs [2]. One of the five CWC provinces known from the Mediterranean is located in Maltese waters (the 'South Malta CWC province') [2], but apart from this area, observations of the deep-sea surrounding the Maltese Islands are scant and mainly based on areas with muddy bottoms studied through trawl surveys.

Material and Methods

During June-July 2015, Maltese deep-sea areas were surveyed by the R/V 'Oceana Ranger' using a Saab Seaeye Falcon DR ROV as part of the project 'LIFE BaHAR for N2K' ("Benthic Habitat Research for Marine Natura 2000 Site Designation", http://lifebahar.org.mt/). The surveys were carried out within the 25 nautical mile Fisheries Management Zone (Figure 1) around the Maltese Islands and focused on previously unstudied regions such as the Malta Graben.

Results and Discussion

The ROV surveys resulted in the following new findings regarding deep-sea habitats in Maltese waters:

♦ New areas with extensive and diverse CWC assemblages at depths of 300–1000 m extending some 20 km along the Malta Graben, including black coral (*Leiopathes glaberrima*) forests at 300–400 m and predominantly white corals (*Madrepora oculata* and *Lophelia pertusa*) in waters deeper than 500 m, with some areas dominated by the gorgonian *Callogorgia verticillata*, together with other less abundant habitat-forming species such as *Acanthogorgia hirsuta*, *Villogorgia bebrycoides*, *Paramuricea macrospina*, *Dendrobrachia bonsai*, and *Muriceides lepida* and a high diversity of associated fauna (especially sponges, echinoderms, molluscs and crustaceans).

♦ A dead (possibly fossil) lithistid sponge reef located north of Gozo at a depth of *ca.* 300 m, and extending over a 7 km wide area, serving as a substratum for several species including *Bebryce mollis, C. verticillata, V. bebrycoides, Stenocyathus vermiformis,* bryozoans, sponges, ophiuroids and hydroids.

♦ Deep-water caves located west of Gozo at depths of 270–450 m.

♦ Extensive soft-bottom areas with epibenthic species such as *Funiculina quadrangularis*, *Isidella elongata*, *Pennatula* spp., and in some areas *Kophobelemnon stelliferum* and *Thenea muricata*, as well as motile echinoderms and crustaceans (including *Nephrops norvegicus*).

♦ An overall high species diversity, with some 75 fishes, 55 cnidarians, 35 crustaceans, 32 molluscs, 21 echinoderms and 15 sponges identified so far from a preliminary analysis of the ROV video footage, as well as tunicates, bryozoans, brachiopods and annelids.

These findings indicate that the deep-sea around Malta represents an important biodiversity hotspot with a variety of different assemblages dominated by suspension feeders (mainly cnidarians and sponges) as habitat-forming taxa. The Malta Graben, in particular, seems to serve as a conduit transporting organic matter and nutrients to deep water, thus making conditions favourable for such suspension feeders, which in turn are accompanied by a high diversity of associated fauna. Reefs such as those formed by CWC and lithisthid sponges are included in Annex I of the EU 'Habitats Directive' (Natural habitat types of Community interest whose conservation requires the designation of special areas of conservation) [3], while bathyal muds with facies of *F. quadrangularis* and *I. elongata* and deep-sea caves are also considered to be of conservation interest [4]. The present results highlight the need for the relevant authorities to consider establishment of offshore marine protected areas in order to protect these very diverse, but highly vulnerable, deep-sea habitats.

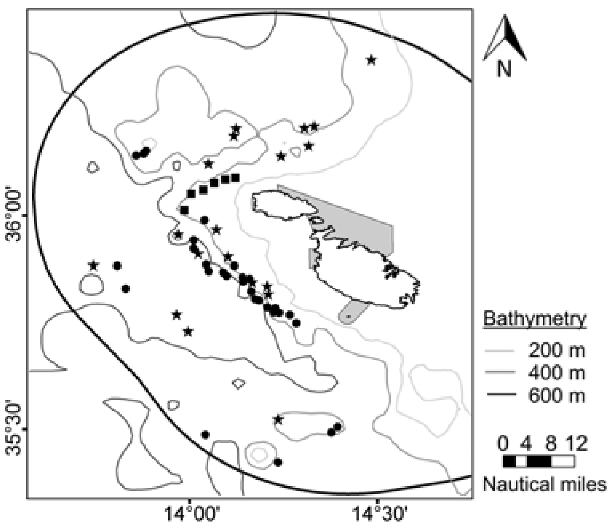

Fig. 1. Map of the Maltese Islands showing the sites with living cold water corals (circles), dead lithistid reef (squares) and muddy bottom (stars) identified through the present survey. The partial extent of the 25 nautical mile Fisheries Management Zone (oval around the Maltese Islands), and the location of current Marine Protected Areas in Maltese waters (grey shading) are also shown.

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