Science of the Total Environment 624 (2018) 648–660

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Spatio-temporal benthic biodiversity patterns and pollution pressure in three Mediterranean touristic ports

Eva Chatzinikolaou [a,*], Manolis Mandalakis [a], Panagiotis Damianidis [b], Thanos Dailianis [a], Simone Gambineri [c], Claudia Rossano [c], Felicita Scapini [c], Alessandra Carucci [d], Christos Arvanitidis [a]

[a] Institute of Marine Biology, Biotechnology and Aquaculture, Hellenic Centre for Marine Research (HCMR), Heraklion, 71003, Crete, Greece
[b] Department of Zoology, School of Biology, Aristotle University of Thessaloniki, P.O. Box 134, 54124 Thessaloniki, Greece
[c] Department of Biology, University of Florence (UNIFI), via Romana 17, 50125 Firenze, Italy
[d] Department of Civil-Environmental Engineering and Architecture (DICAAR), University of Cagliari (UNICA), Via Marengo 2, 09123 Cagliari, Italy

HIGHLIGHTS

- Benthic species distribution mainly affected by salinity, copper and antimony.
- Environmental variables and benthic diversity were different between ports.
- Cagliari and Heraklion were the most polluted ports and had lower species richness.
- The shipyard sector was different from the leisure, passenger and cargo sectors.
- Benthic diversity in all the three Mediterranean ports was not severely impacted.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 22 September 2017
Received in revised form 23 November 2017
Accepted 11 December 2017
Available online xxxx

Editor: Daniel Wunderlin

Keywords:
Macrobenthos
Physical variables
Chemical variables
Hydrocarbons
Heavy metals
Harbours

ABSTRACT

The Mediterranean Sea is one of the busiest areas worldwide in terms of maritime activity, facing considerable anthropogenic disturbance, such as pollution by hydrocarbons and heavy metals. The present study has evaluated the environmental and benthic biodiversity characteristics of three touristic ports, Cagliari (Sardinia, Italy), Heraklion (Crete, Greece) and El Kantaoui (Tunisia), based on the combined assessment of physical parameters, chemical variables (i.e. nutrients, pigments), sediment pollution and macrobenthic biodiversity. Different port sectors (leisure, fishing, passenger, cargo, shipyard) and different seasons (winter, before touristic period, after touristic period) were compared. Salinity and sediment concentration of copper and antimony were the three environmental parameters most highly correlated with benthic species composition and diversity. Both the environmental variables and the benthic biodiversity patterns were significantly different between the three ports (i.e. different geographical locations). Heraklion port was heavily polluted by AHs in surface and anoxic sediments and had the highest percentage of opportunistic species, while Cagliari had the highest levels of PAHs and UCM and low species richness. El Kantaoui port was less polluted and characterised by a richer biodiversity. The shipyard sector in Heraklion port was significantly different from all other sectors in terms of abiotic and biotic parameters. Physico-chemical and pollution variables recorded during the period after tourism (late summer) were significantly different from the ones recorded in winter. Seasonal differences were not significant between benthic species diversity patterns, but were revealed when the patterns derived from the aggregation of higher taxonomic levels were compared. The present study indicates that a regular-basis monitoring plan including evaluation of

* Corresponding author at: Institute of Marine Biology, Biotechnology and Aquaculture, Hellenic Centre for Marine Research, P.O. Box 2214, Thalassokosmos, Former US Base at Gournes, Heraklion, 71003, Crete, Greece.
E-mail address: evachatz@hcmr.gr (E. Chatzinikolaou).

https://doi.org/10.1016/j.scitotenv.2017.12.111

environmental health based on benthic biodiversity, can provide a basis for perceiving changes and reveal the degree of anthropogenic disturbance in port environments.

1. Introduction

The Mediterranean Sea is connected to the Atlantic Ocean on the west through the Straits of Gibraltar, and on the east to the Red Sea and to the Black Sea through the Suez Canal and the Bosporus Strait, respectively. The Mediterranean Sea covers approximately 2.5 million km^2, hosts about 480 ports and terminals and is among the world's busiest areas in terms of maritime activity (REMPEC, 2008). Almost 70,000 vessels cross the Straits of Gibraltar every year, 55,000 the Bosporus Strait and 16,000 the Suez Canal, without including ferries and non-merchant vessels (REMPEC, 2008). The shipping of goods between the main EU ports and ports located in the Mediterranean reached 598 million tonnes in 2015, which was equal to 29% of the total EU short sea shipping (Eurostat, 2015). Tankers accounted for 16–19% of the total transits within the Mediterranean and for 24–46% of the total vessel DWT (deadweight tonnage) capacity (values concern ranges between the three access/exit points, i.e. Gibraltar, Bosporus and Suez Canal; REMPEC, 2008). Crude oil shipped through the Mediterranean Sea in 2006 amounted to 421 million tonnes, from which 220 million tonnes were loaded within Mediterranean ports (REMPEC, 2008). A significant amount of this oil (about 400,000 t; UNEP, 2006) are dumped annually into the Mediterranean during routine ship operations, which often take place inside ports or oil terminals (e.g. deballasting, tank washing, dry-docking, bunkering) (Abdulla and Linden, 2008).

Ports can be the recipient and the source of considerable anthropogenic disturbance, both for marine and adjacent land habitats, since they centralize a range of environmental problems, such as emission of air pollutants, noise, sediment dredging and transport, industrial installations, jetties construction, wastewater discharges, oil spill accidents, leaks of petroleum derivatives and antifouling coatings, storage and spillage of hazardous materials, as well as introduction of invasive species (Darbra et al., 2005). The most ubiquitous and long-lived petroleum contaminants in the marine sediments are the polycyclic aromatic hydrocarbons (PAHs), since their hydrophobic character makes them easily adsorbed on suspended particles which are eventually deposited in marine sediments (Abdulla and Linden, 2008). The concentration of PAHs in sediments depends on the distance of an area from the pollution source, while their overall degree of toxicity and bioavailability depends on the physico-chemical properties of particular PAH members (i.e. number of aromatic rings, molecular weight) (Abdulla and Linden, 2008). Abdulla and Linden (2008) highlighted that while oil pollution in marine sediments has been extensively investigated in the north-western part of the Mediterranean Sea, there is a significant gap for such data in other parts of the region. Marine sediments contaminated by weathered and biodegraded oils may represent a persistent and ongoing threat for benthic organisms (Reddy et al., 2002). Raman (1995) indicated that in harbour environments the total number of polychaete individuals was decreased and the number of species was increased when moving away from a pollution source. Disturbance on marine biodiversity may initially result in recruitment by opportunistic taxa, which are gradually replaced by slower-growing "equilibrium species" leading to a re-adjustment phase which might, however, be prohibited if repeated disturbance such as pollution or dredging occur (see Blanchard and Feder, 2003). The recovery potential of benthic macrofaunal communities is primarily determined by the substrate type and the hydrodynamically mediated nutrient availability (Gutperlet et al., 2015).

Port management is not an easy task, as it entails balancing out requirements and conflicting uses by residents, visitors, industry, shipping and other users. Ports are complex systems requiring the involvement of multi-disciplinary authorities and stakeholders from different sectors (e.g. engineers, ecologists, economists, governmental bodies) in order to identify, understand and manage conflicts within their limits (Pearson et al., 2016). Mediterranean ports are sites of significant economic activity, crucial for local and national economic development, which at the same time are located near coastal areas hosting a high number of residents and tourists; therefore, their effective management is essential for their sustainable use and the protection of adjacent habitats. Ports are classified as "Heavily Modified Water Bodies" (HMWBs) since they constitute water bodies substantially altered in character due to human activities, which cannot meet the common good ecological status criteria (WFD 2000/60/EC). Ports are often characterised by low hydrodynamism, reduced oxygen concentration, increased organic content and pollution caused by maritime activities and uncontrolled discharge of effluents. Quality assessment approaches developed for natural water bodies may not be feasible for HMWBs, thus managing authorities need to define more appropriate and customized methodologies for port environments (Ondiviela et al., 2013). Existing sediment quality assessment tools include chemical analyses combined with ecotoxicological and ecological approaches (Moreira et al., 2017). The Sediment Quality Triad (SQT) integrates evaluations of benthic community structure with sediment chemistry and sediment toxicity in order to provide a better assessment of pollution-induced degradation (McPherson et al., 2008). The Strategic Overview of Significant Environmental Aspects (SOSEA) is another port management tool applied to several EU ports, which includes identification of the Significant Environmental Aspects (SEA), evaluation of their significance and assessment of the respective management procedures (Darbra et al., 2005). Macrobenthic communities are an important component of the port biota since they have an active role in biomineralization, bioturbation, oxygen and nutrient cycling, and due to their reduced mobility and short life cycles they are commonly used as indicators in biomonitoring studies (Gray and Elliot, 2010). The establishment of a baseline database regarding benthic biota present in ports can offer valuable background information when port management activities are required for the identification of biological risks, such as pollution events or invasion by alien species (Mandal and Harkantra, 2013).

The negative effects of maritime activities (i.e. pollution, anchoring, noise) in the Mediterranean Sea have been extensively documented for marine mammals, tortoises and marine birds, whereas when it comes to benthic organisms and habitats only consequences on *Posidonia oceanica* beds, algae, coralligenous reefs and maerl beds have been studied (Abdulla and Linden, 2008). The present study attempts to cover this gap by recording and evaluating the environmental status of three touristic ports located along the Mediterranean Sea, based on the combined assessment of physico-chemical conditions, pollution and macrobenthic species composition and diversity. The selected ports besides differences in geographical location (Sardinia, Crete, Tunisia), also host a range of activities (e.g. leisure, fishing, shipyard, passenger and cargo vessels). Therefore, differences and similarities between ports (location), sectors (type of use) and seasons (proximity to the touristic period) were examined. The present study also investigated the hypothesis that a set of environmental and pollution variables was associated with the observed macrobenthic patterns for all ports, sectors and seasons. The degree of environmental disturbance based on the hierarchic-response-to-stress hypothesis (Olsgard et al., 1998) was evaluated through the divergence between the biodiversity patterns produced as the information from species abundance was aggregated to higher taxonomic levels. Under the framework of the ENPI CBCMED project MAPMED, a common