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Benthic ecological status of Algerian harbours

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ABSTRACT

This work is an overview of all available benthic data collected in the Algerian harbours between 1983 and 2001. So, total of 571 stations were reported in the 10 major Algerian harbours along the Algerian coast (1200 km). Two main categories of harbours were distinguished according to their hydrodynamic regime and volume of water exchange between inner harbour basins and the entrance of the harbours. Univariate, multivariate, benthic indices and Biological Traits of Life approaches were applied on stations sampled in the late 1990s and long-term observations in six out of these ten harbours. These approaches assessed the main characteristics and ecological statuses from these south Mediterranean harbours. One of the main characteristics of the Algerian harbours was the very high species diversity (847 species). Although all the fauna was dominated by pollution-tolerant species; some harbours such as Bethioua and Djendjen hosted normal benthic communities as found in the open sea, but also included some pollution indicator species typical of a slight polluted system. On the contrary, the newly constructed port of Skikda showed perturbed benthic communities in relation to hydrocarbon pollution. Biological Traits of Life analysis reinforced the separation of benthic species along a gradient reflecting their sensitivity or tolerance to pollution. This response was related to an increase in organic matter content, probably associated with a general organic and metal contamination, from the entrance of the harbour to the innermost basins in areas with weak circulation, high sedimentation rate and concentrations of pollutants. Except for Oran harbour, where the poor to moderate ecological status remained unchanged with time, the other harbours showed an improvement or a slight degradation. A strategy of long-term monitoring should be promoted, based on a restricted and selected number of stations characteristic of the different basins and water masses occupying the harbours.

1. Introduction

The benthic macrofauna of harbours reflecting semi-enclosed areas with restricted connection to the open sea [via the harbour entrance] is well known at the worldwide scale. In most cases, harbours are coastal embayment's in which water movements and exchanges with the coastal zone are relatively limited (Covazzi Harriague et al., 2012; Grifoll et al., 2013; Chan et al., 2016). It appears that fine particles and Organic Matter (OM) show an increase from the harbour entrance, with high to moderate hydrodynamics, local currents and good oxygenation, towards the inner basins at some distance from the entrance with weak current circulation and high sedimentation rates (Belan, 2003; Covazzi Harriague et al., 2007; Chan et al., 2016). Generally, the harbour fauna responds to the OM gradient according to the Pearson and Rosenberg (1978) model, with a transition from normal communities at the harbour entrance to azoic areas with the highest concentrations of OM in the inner parts of the harbour in zones with low-energy hydrodynamics (Bellan, 1967; Estacio et al., 1997; Dhainaut-Courtois et al., 2000; Breton et al., 2005; Chan et al., 2016). Moreover, sediment quality shows generally high concentrations of hydrocarbons and trace metals, with a marked difference between outer harbour or outside reference stations and inner harbour, which is more affected by pollutants (Warwick et al., 1990; Dhainaut-Courtois et al., 2000; Dhainaut-Courtois and Dhainaut, 2002; Blanchard et al., 2002; Danulat et al., 2002; Belan, 2003; Muniz et al., 2004; Martínez-Lladó et al., 2007; Chan et al., 2016).

In the most polluted basins of harbours, a limited number of species are recorded, dominated by polychaete pollution-tolerant taxa in response to these highly stressed environments. Most of the harbours also show a stage of proliferation of opportunistic species composed mainly of polychaetes including the Capitellid *Capitella capitata* complex, the spionidae *Malacoceros fugilinosus* and some other species of the

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Cirratulid, Spionid and Capitellid polychaete families as well as oligochaetes (see Bellan, 1967; Bellan et al., 1980; Estacio et al., 1997; Dhainaut-Courtois et al., 2000; Dhainaut-Courtois and Dhainaut, 2002; Belan, 2003; Guerra García et al., 2003; Guerra-Garcıa and Garcıa-Gomez, 2004; Covazzi Harriague et al., 2012). Nevertheless, studies on the ecological status of harbours have focused on the more polluted areas, mainly in response to the increasing OM, so other environmental factors have been neglected. It is well known that the concentration of human activities in harbours is due to the industrial and urban development around harbours (Guerra-Garcia et al., 2003; Shin et al., 2008; Cheung et al., 2008). Moreover, in most of the larger harbours in the world, the building of dykes and the extension of land-based facilities, such as used for grain storage or handling containers is associated with numerous other economic activities. The nowadays challenge of harbours is to extend their development outside the original location, with the creation of new harbours situated more or less far away from the cities. This is the case for the Algerian harbours, along with the need to develop new harbours linked to the exportation of hydrocarbons and natural methane gas.

Thus, along the 1200 km of the Algerian coastline, the different harbour zones display a diversity of marine environmental conditions suitable for monitoring the temporary or chronic pressures on the established macrobenthic communities subject to heavy metal and hydrocarbon pollution, as well as excessive OM, hot waters released from power plants and input of nutrients. Numerous studies on the benthic communities were carried out mainly during the 1970s and 1980s, and a summary of their results is available in the PhD thesis of Grimes (2010).

The main objective of this study are 1) to assemble the available data and to describe the status of the macrobenthos of the soft-bottom communities of the Algerian ports since several decades for historic ancient time periods when the quality of coastal water was not a priority and to give a ‘reference’ status for possible future studies planned in a short term; 2) to highlight the source of the different human pressures and their impact on the soft-bottom macrobenthic communities from ancient and recent harbours showing different hydrodynamic regimes and connections with the open sea. Over a period of two decades (1983–2001), seasonal (Algiers) and annual (Oran, Arzew, Bethioua, Bejaia, Jijel and Annaba, as well as the old harbour at Skikda and the new ports at Skikda and Djendjen) surveys have led to a determination of the ecological status of the macrobenthic communities of ten harbours along the Algerian coast (Rebzani-Zahaf, 2003; Bakalem, 2008; Grimes, 2010, and unpublished data). To assess the Degradation, Improvement or Stability (DIS) of the harbour soft-bottom macrofauna, several approaches have been used here involving univariate (benthic indices), multivariate Multi-Dimensional Scaling (MDS) and Biological Traits Analysis (BTA) for the first time in such environment. These analyses provide information on the structural and functional changes in the harbour macrobenthos from this west-southern sector of the Mediterranean Sea, which remain sparsely documented at the scale of the Mediterranean Sea and North Atlantic Ocean.

2. Materials and methods

2.1. Study sites and sampling strategy

Our study concerns ten harbours on the Algerian coastline, from Oran in the west to Annaba in the east (Fig. 1). Two main categories of harbours can be distinguished: old harbours that were built at the end of the 19th century and at the beginning of the 20th century (Oran, Arzew, Algiers, Bejaia, Jijel, Skikda old harbour and Annaba) or more recent harbours (Bethioua and Skikda New Port, constructed at the beginning of the 1970s and Djendjen constructed during the 1980s). Some human pressures are specific to a given harbour, while others are common to several harbours (Table 1). There had been an accumulation of pollution and human pressures in Algiers harbour, and to a lesser degree in the Oran and Annaba harbours, while the pressures were lower in the other harbours (Grimes, 2010).

The physical-chemical analyses of sea water from near the sea bottom revealed the following general features (Grimes, 2010; PhD available on: www.unicaen.fr/m2c/IMG/pdf/grimes_samir_these_2010.pdf):1) a very high homogeneity and high short- and medium-term stability of the bottom waters in the harbours due to their relative isolation and absence of mixing with the outside coastal neighbouring water masses; 2) the shallow depth and summer stagnation conditions reinforced this homogeneity, with an increase of temperature and salinity in the inner basins followed by a decrease in oxygenation but without any real gradient from the entrance towards the inner part of the ports. Nevertheless, in the hydrocarbon harbours of Skikda New Port and Bethioua, and also Djendjen harbour, the physico-chemical parameters (temperature, salinity, pH and oxygen concentration) of the bottom water masses were close to those observed in the neighbouring bays. This could be explained by the absence of separation between water masses within and outside the harbour basins. In these three harbours, which were newly constructed, there was no input of OM, while the Bethioua harbour, moreover, had two entrances favouring the permanent exchange between the inner harbour and outside marine water masses. Moreover during the last period (2002 to 2016), the conditions regarding the nature and intensity of urban and industrial pressures on the seabed of the Algerian harbours had not dramatically changed as we had seen during our numerous personal field observations. Our observations were also associated with the analysis of recent documents on the situation and the industrial activities of the Algerian harbours.

The macrobenthic stations, mainly sampled from April to July, were spatially distributed to cover the entire harbour basin from the entrances to the inner parts of the harbours (Grimes, 2010). After carrying out a single sampling in each of the ten harbours, some stations were selected in six of the harbours (Oran, Arzew, Bethioua, Algiers, Bejaia and Jijel) to ensure a long-term monitoring of the ecological status of the macrofauna (Table 1).

At each station, two replicate samples were taken with a Van Veen grab covering a total surface-area of 0.25 m^2. The sediment was sieved on a 1 mm mesh size and the residue fixed in 10% formaldehyde. The species were then identified in the laboratory, when possible to species level. For samples collected in autumn 1996 and the spring of 1997 and 1998, the data for Algiers harbour are taken from the PhD thesis of Rebzani-Zahaf (2003).

2.2. Database and statistical analyses

Between 1983 and 2001, a total of 571 stations including 17 azoic stations (12 for Algiers and five at Annaba) (Table 1) had been identified in the 10 main harbours of the Algerian coasts. These samples allowed to recognise 847 species. The total number of species per 0.25 m^2 at each station varied between 0 at the azoic station to 50 for some stations located at the entrance of the harbours. The taxonomic richness varied from 72 in Arzew harbour for a total sampling surface-area of 3.25 m^2 to 401 in Algiers harbour for a total sampling surface-area of 53.75 m^2 (Table 1). The sediments were mainly sandy in the entrance of the harbours under high-energy conditions, with gravel present in some cases; in the inner basins, the mud-dominated to putrid mud deposits in the inner basin were enriched by OM in decomposition.

In a first step, all the 554 stations with fauna were taken into account in multivariate analyses; the results were inaccurate and could not be interpreted. Thus, we required to select a smaller number of stations to assess the effects of human pressures in the different Algerian harbours.

In a second step, we selected all the samples collected in spring covering the 10 harbours (only stations with abundance > 20 individuals were retained; this minimum number of individuals per