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Impacts of dredged-material disposal on the coastal soft-bottom macrofauna, Saronikos Gulf, Greece

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HIGHLIGHTS

- Dumping of dredged-material was monitored (prior, during and post).
- Significant direct (burial) and indirect (smothering) impacts were detected.
- Degradation remained significant in the spoil-ground, post to dumping.
- Outside the spoil-ground, the macrofauna diversity indices showed recovery patterns.
- Elevated contaminants in the area show that benthos remains under stress.

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ABSTRACT

Dredged sediments derived by the low course and estuary of the metropolitan river of Athens (Kifissos River) were dumped every day for 21 months to an open-sea site in the Saronikos Gulf. The spoil-ground and surrounding area was monitored prior, during and post to dumping for 24 months, over 6-month intervals. Dumping significantly changed the granulometry of the pre-existing superficial sediments to finer-grained only in the spoil ground and increased the sediment contamination load (aliphatic, polycyclic aromatic hydrocarbons and heavy metals) throughout the study area. Microtox® SPT showed that sediment toxicity levels were high at almost all sampling stations. During dumping, burial of natural soft-bottom habitats degraded severely the communities of the spoil-ground resulting in an almost azoic state, as well as significantly declined the species number and abundance of benthic communities in locations up to 3.2 km away from the spoil-ground, due to dispersion of the spoil and smothering. Benthic indices on the surrounding sites were significantly correlated with hydrocarbon concentrations and sediment toxicity levels. Post to dumping, the macrofauna communities of the spoil-ground were still significantly degraded, but the surrounding areas showed patterns of recovery. However, the high concentrations of aliphatic, polycyclic aromatic hydrocarbons and levels of toxicity persisted in the sediments after the ceasing of dumping operations in the study area, implying the ecological hazard imposed on the area.

1. Introduction

Dredging and dumping of dredged-material are common human activities causing significant environmental problems in coastal and marine areas (Bolam and Rees, 2003). Several alternate treatments of dredged-material have been examined in order to minimize environmental impacts, such as screening the material clear of contaminants, disposing on naturally unstable habitats, distributing the disposal on shallow layers, or capping contaminated disposed material (for extensive information see: Brannon and Poindexter-Rollings, 1990; UNEP MED/POL, 1999; Essink, 1999; Bolam and Rees, 2003; OSPAR Commission, 2008). However, often due to economic considerations, the direct disposal at open sea without treatment is still a priority management option (Harvey et al., 1998).

Sediment disposal may be more harmful to benthic communities than any other component of the aquatic ecosystem because of the relative immobility of the benthic organisms (Morton, 1977). Dumping of dredged-material in the marine environment impacts the benthic communities by either directly burying of organisms at the spoil-ground, or indirectly by suspension and relocation of the dredge-spoil (usually described as smothering) in the adjacent areas. Direct burial often leads to immediate mortality, especially when the thickness of the sedimentary cap exceeds 15 cm (Wilber et al., 2007). However, the effective thickness varies according to local species tolerance to sedimentation and the characteristics of the sediment (OSPAR Commission, 2008). When relocation occurs, habitat alterations to a lesser complexity have been

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observed due to deposition of fine-grained dredged sediment on coarser-grained natural sediments (Zimmerman et al., 2003). Suspension of the spoil also causes higher turbidity, which may affect growth and survival of benthic organisms in many ways, such as clogging of respiratory and feeding apparatus (Essink, 1999). Furthermore, resuspension of contaminated sediments and remobilization of chemicals can also affect benthic communities (Roberts, 2012).

The degree of impact depends on numerous factors, such as the method and intensity of dumping operations, the season, the physical and chemical characteristics of the dredged material, the ecology of species compromising the local communities (reproduction strategy and tolerance to sediment disturbance), and the hydrodynamic and geological state of the spoil-ground (Simonini et al., 2005; references within). Over the last decades, several studies have investigated the impacts of dumping on marine benthic communities (e.g. Harvey et al., 1998; Roberts and Forrest, 1999; Smith and Rule, 2001; Stronkorst et al., 2003; Zimmerman et al., 2003; Witt et al., 2004; Wilber et al., 2007; Bolam et al., 2011); however, due mainly to this variety of governing factors, there are some considerable controversial results among them. In some cases, investigations have demonstrated severe and long-termed changes. For example, Harvey et al. (1998) have detected sediment composition changes and increases of tolerant species at the expense of sensitive species abundance, or Witt et al. (2004) reported a severe decline of species number and the elimination of important habitat structures. On the other hand, other studies have not determined remarkable modifications (e.g. Roberts and Forrest, 1999; Smith and Rule, 2001). Furthermore, the variety of governing factors among different cases of dumping are only part of the reason for controversial results, since it is often overlooked that some studies are focused on one-off placements and recently relinquished sites, while other focus on ongoing disposal activities (Bolam et al., 2011).

Among the most sensitive ecological indicators used to detect impacts by dumping are the species number (S), the abundance (N) and Shannon–Wiener diversity (H′); their high linkage to such human activities and physical disturbances was also verified by a performance evaluation of eleven different indicators (Ware et al., 2008). Other forms of recorded impacts are shifts in dominance patterns between sensitive and opportunistic species, feeding traits and the elimination of important habitat structures (Harvey et al., 1998; Witt et al., 2004; Simonini et al., 2005; Simboura et al., 2007). In addition to benthic community structure, geochemical analyses and toxicity bioassays can be carried out to determine dumping effects of contaminated dredged-material (Chapman, 1990), although contaminant concentrations are not always correlated with macrofauna responses (e.g. Roberts and Forrest, 1999; Stronkorst et al., 2003; Bolam et al., 2011). The divergent results obtained in the various study areas show that the potential environmental effects must be evaluated on a case-by-case base (Harvey et al., 1998). In addition, most of the above studies occurred in North Atlantic and Baltic Sea, while the number of articles referring to the effects of dumping dredged-material to macrofauna of Mediterranean habitats is considerably limited (e.g. Toumasiz, 1995; Simonini et al., 2005).

The present paper aims to describe the benthic community response to dredged-material disposal, by estimating the degree of impact on macrofauna derived by the physical and chemical pressure of discharged sediments and assessing recovery patterns in the case-study of Saronikos Gulf.

2. Material and methods

2.1. Study area and sampling design

Inner Saronikos Gulf surrounding Athens metropolitan area is subject to a number of anthropogenic pressures, with urban waste effluents and resulting organic enrichment being the main source of pollution (Simboura et al., 2014). The degradation of benthic communities due to urban wastes around the study area is well studied and opportunistic species range within 62–75% of the total macrofauna abundance (Simboura et al., 2005, 2014). Nearby, Kifissos River operates as the major drainage channel for the city of Athens. The river bed and flow are completely altered by artificial embankments and other constructions. A recent evaluation of sediment quality in the river lower course and estuary demonstrates relatively elevated aliphatic and polycyclic aromatic hydrocarbon concentrations, but low heavy metal concentrations (except of Cu and Zn) (Panagiotopoulos et al., 2010). In the same study, grain-size distribution has showed that fine-grained sediments (muddy sand, sandy mud and mud) dominate in the area around the river mouth. From May 2010 to January 2012, dredging of the Kifissos estuary had as a result the production of significant amounts of sediment, which were licensed to be dumped further seawards in a designated open sea area of surface 1 nmi^2 (ABCD area, Fig. 1). For 21 months, a total of ~700,000 m^3 of dredged-material were dumped, with a mean monthly discharge of 33,333 m^3.

The two factors taken into account in the sampling design are the distance from the spoil ground (inside and outside the spoil ground) and time in relation to dumping operations. Lack of a possible control site (according to Before-After-Control-Impact approach; Underwood, 1991) is due to the absence of an undisturbed similar biotope in terms of depth and substrate in the area. Saronikos Gulf is characterized by a deep western sector with homogenous muddy substrates and eastern heterogeneous substrates with lower depths (Simboura et al., 2014). In addition, Saronikos Gulf is influenced by several anthropogenic coastal activities which should be considered when selecting a control site.

In total, five stations were sampled (Fig. 1). Two stations (Stations 1 and 2) were located inside the licensed disposal area and the other three stations (Stations 3, 4 and 5) were located in the surrounding area, outside the spoil-ground. Positions and depths of sampling station are given in Table 1. The sampling prior of dumping was done in April 2010. During dumping the stations were monitored over 6-month intervals (October 2010, April 2011, October 2011), while a sampling was done 4 months after dumping operations ceased (April 2012). Although dumping operators were licensed for the whole ABCD area, until October 2011 only the location of Station 1 was used.

2.2. Macrofauna

Two replicate samples were collected from each station with the use of a Van Veen grab (0.1 m^2) and were washed separately through a 1.0 mm sieve. Residuals were preserved with a buffered 4% formalin/seawater solution, stained with Rose Bengal. At the laboratory, organisms were sorted from the sediment and were identified to species level.

2.3. Environmental variables

Water samples were collected from the bottom-layer of the water column, using Niskin bottles of 8lt. Measurements of dissolved oxygen (D.O.) were performed immediately after the sampling using the Winkler method modified by Carpenter (1965). The quality control/quality assurance (QC/QA) was achieved with the daily standardization of thiosulphate solution with 'fresh' standard solution of potassium iodide. The precision of the method is estimated at 2.2 μmol O_2/L.

Sediment samples were collected from the uppermost 2 cm of the sea bottom using a Van Veen sampler. The granulometric analysis (applying wet sieving) of the samples comprised of separation of the coarse-grained fraction (>63 μm) from the fine-grained fraction (<63 μm). Further classification of the sand and mud fractions was accomplished by the use of a standard set of sieves and a grain-size analyzer (Sedigraph 5100), respectively. At silt abundance >5%, the precision and accuracy of both weight percentage and mean grain size are estimated at <5% (Bianchi et al., 1999). Sediment texture was classified according to Folk (1974) nomenclature. Polycyclic aromatic (PAH) and aliphatic hydrocarbon (AH) concentrations were measured by gas chromatography–mass spectrometry on an Agilent 7890 GC, equipped