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Twenty two years of sewage sludge marine disposal monitoring in the Eastern Mediterranean Sea: Impact on sediment quality and infauna and the response to load reduction

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ABSTRACT

Effects of sewage sludge disposal on sediments and infauna are presented in a unique long-term (22 years) data set from the Eastern Mediterranean. While organic carbon (C_{org}) and metals affected sediment quality in an area which size varied seasonally, the infauna exhibited seasonal "boom and bust" cycle. Metal concentrations declined following load reduction. However, C_{org} did not decrease and infaunal abundance, closely related to C_{org}, varied with changes in environmental forcing. Mild winters affected the infaunal populations at the heavily impacted stations, due to anoxic conditions. Planned cessation of disposal is estimated to reduce Corg and metal concentrations to pre-discharge levels. Yet the resettling biota is expected to differ significantly from the pre-discharge one and consist in large part of Erythraean non indigenous species.

1. Introduction

Marine disposal of sewage sludge, a common practice worldwide, was discontinued in the USA and Europe following pollution abatement measures and ratification of international conventions (e.g. Ocean Dumping Ban Act (O'Connor, 1998; Swanson et al., 2004), OSPAR Convention (Whomersley et al., 2007), Barcelona Convention (http://www.unepmap.org/index.php?module=content2&catid=001001004)). The environmental changes caused by the sewage sludge disposal and the recovery of the site following the cessation of the disposal were widely studied: among others, the Firth of Clyde, Scotland (Moore and Rodger, 1991; Rodger et al., 1992); the Tyne estuary (England) (Rees et al., 1992; Rees and Rowlatt, 1995) the 7 mile sludge outfall off Santa Monica, CA, USA (Dorsey et al., 1995; Bay et al., 2003); the 12 mile dumpsite at the New York bight, USA (Studholme et al., 1995; Vitaliano et al., 2007); Barcelona, Spain (Palanques et al., 1991; Kruge et al., 2010). The prevailing recovery pattern is of improvement in sediment quality and in benthic assemblages with diversity and abundance restored to reference values. However, the rate of recovery varied and depended on load decline, remaining pollution sources and hydrographic conditions.

The 1996 amendment of the protocol for the protection of the Mediterranean Sea against pollution from land-based sources of the Barcelona Convention entered into force in Israel in 2009. However, excess activated sewage sludge, 38% of Israel's production of 118,350 tons dry matter as of 2012, is still discharged into the Mediterranean Sea (EEA-UNEP/MAP, 2014). It originates at the Dan Region treatment plant (Shafdan) that has been treating domestic and industrial sewage of the Tel-Aviv Metropolitan area since 1987 (at present, ca. 2.5 million inhabitants and 7000 industrial plants; load of 140 million $m^3\ y^{-1}$). The excess sewage sludge (at present 15,000 $m^3\ day^{-1}$) is discharged 5 km offshore through a 360 mm HDPE seabed pipeline (Fig. 1). Though the amount of sewage treated has increased over the years, the excess sewage sludge discharged at sea has remained essentially constant due to improvements in treatment technology (D. Salomon, personal communication). The sludge contains approximately 1% particulate matter, consists primarily of organic biomass and nutrients, and may contain potentially harmful constituents, among them metals (Renner, 2000). The annual loads decreased over the years due to source control following strict regulation of metal load entering the treatment plant (Table S1) (UNEP/WHO, 1999; Malester and Marek, 2006; D. Salomon, personal communication). Since 2012, 15% of the excess activated sewage sludge is treated on land and marine disposal is scheduled to cease by the end of 2016 (D. Salomon, personal communication in October 2015).

Environmental monitoring of the disposal site dates back to the outfall activation in 1987. The initial monitoring protocol was inappropriate and failed to show environmental impacts, and was replaced in 1992. Monitoring data (1992–2002) provided evidence that the disposed sludge has had a marked localized, seasonally dependent impact on

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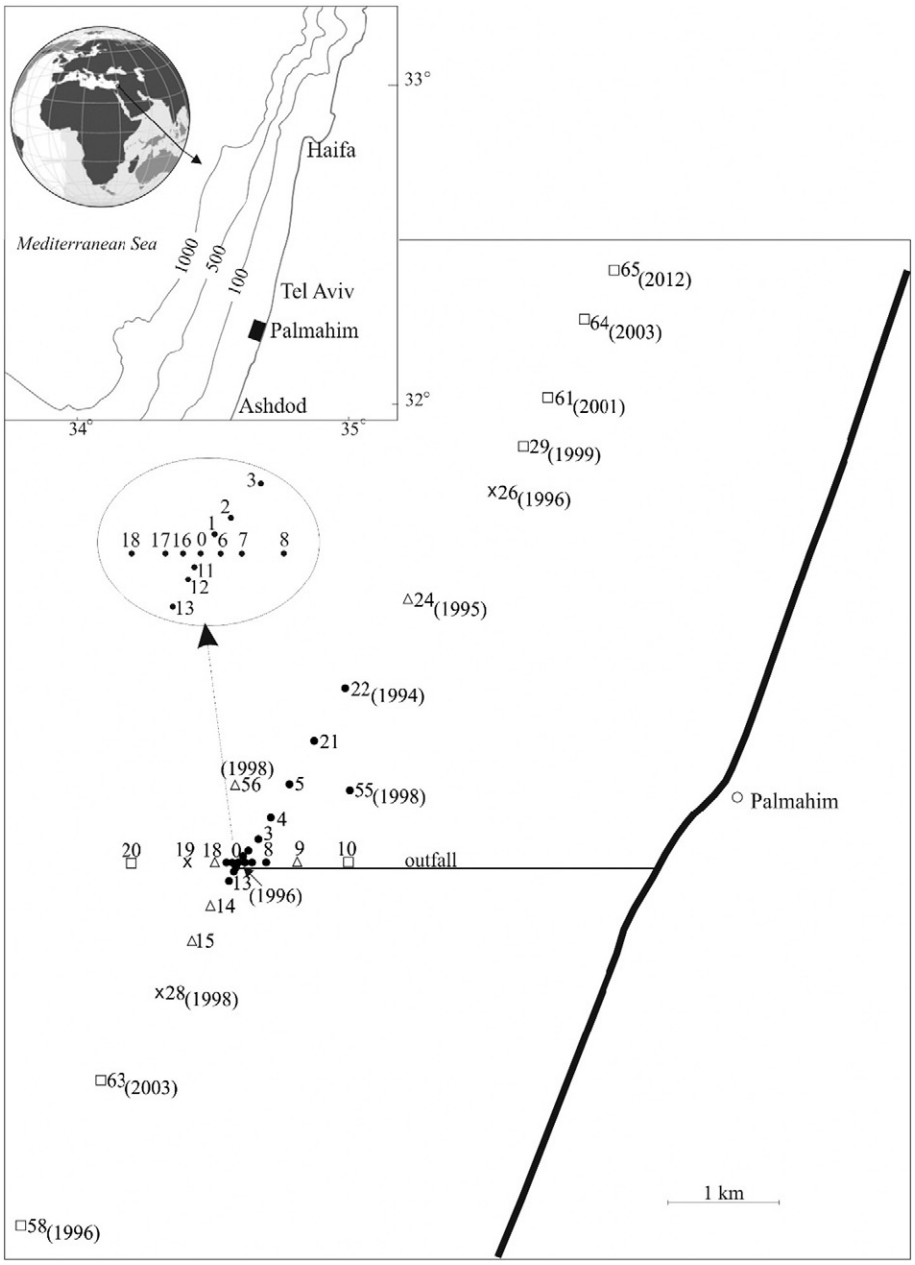

Fig. 1. Map of the study site and the temporal evolution of the sampling scheme, 1992–2013. The year the station was added to the monitoring program is in parenthesis. Stations 1,6,11 and 16 were discontinued in 1996 and stations 2,7,12 and 17 in 1998. Near-field stations are marked by black dots, mid-field stations by triangles, and far-field stations by squares. Data from stations 19, 26, 28, represented by x, were not used because they could not be classified as mid nor as far-field stations.

sediment quality and benthic assemblages (Kress et al., 2004). Briefly, elevated concentrations of organic carbon (C_{org}), sludge associated metals (Hg, Cd, Cu, Zn, Pb) and large populations of eutrophication-tolerant opportunistic polychaetes were detected mainly northward of the outfall, in the direction of the prevalent longshore current, the polychaetes appearing in spring and declining in fall. Similarly, the sewage sludge depleted the assemblages of opportunistic benthic foraminifera (Hyams-Kaphzan et al., 2009) but dead and live shelled molusc assemblages were too conservative to track the impact of the sludge (Leshno et al., 2015). The spatial extent of the impacted area varied seasonally and inter-annually: the sludge accumulates throughout the quiescent periods of the year (spring to fall) and disperses by winter storms. No evidence of multiannual sludge accumulation was found (Kress et al., 2004).

With an additional decade's worth of data (2003–2013 for chemistry; 2003–2012 for biota), the objective of the present work is to follow the long-term effects of sewage sludge disposal on the concentrations of C_{org} and metals in the sediments, and the infauna abundance and relative composition. The seasonal and temporal variability based on the reduction in pollutant loads and changes in environmental forcing are examined. The environmental status of the area was assessed and the prospects of its recovery following cessation of sewage sludge disposal discussed.

2. Methods

2.1. Study area

The Eastern Mediterranean is an ultra-oligotrophic sea, warm and saline due to its anti-estuarine circulation, low fresh water inflow and intensive evaporation (Kress and Herut, 2001; Krom et al., 2010; Siokou-Frangou et al., 2010; Kress et al., 2014). Oligotrophy subsides