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Temporal trends in live foraminiferal assemblages near a pollution outfall on the Levant shelf

Tadir Roni [a,b], Benjamini Chaim [a], Ahuva Almogi-Labin [b], Hyams-Kaphzan Orit [b,*]

[a] Department of Geology and Environmental Sciences, Ben Gurion University of the Negev, Beer Sheva 84105, Israel
[b] Geological Survey of Israel, Jerusalem 95501, Israel

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ABSTRACT

Long and short term effects of activated sewage sludge input on live benthic foraminiferal assemblages of the shallow shelf off Palmachim, Israel were examined at three stations along the eutrophic gradient. Over ten years from 2003 to 2012, foraminiferal abundance decreased dramatically by >50% in all stations. In 2012, new species were found near the discharge point, relative abundance of the dominant species decreased and in-sediment depth increased. In the remote stations the dominant species failed to bloom seasonally. Each year, dispersion of sludge was accompanied by intense current activity, aeration, and periodic local sediment transport, reintroducing species from nearby. Storm frequency was notably high in 2012. The decrease in numbers over time despite seasonal amelioration indicates that the constant OM input is a permanent source of environmental stress. Aside from this stress, natural variability, changes in Nile input, or a hidden impact of long-term climate change may play a role.

1. Introduction

Eutrophication by nutrient overload, especially of phosphates and nitrates, results in water quality degradation (Paerl, 1995; Smith et al., 1999; Rabalais, 2002). Nixon (1995) established a simple classification for trophic state of marine systems, with <100 gC/m^2 per year of primary production considered oligotrophic, 100–300 gC/m^2 per year considered mesotrophic, and >300 gC/m^2 per year, eutrophic.

On this basis, the natural state of the eastern Mediterranean would make it one of the world's most naturally oligotrophic seas (Azov, 1991; Turley, 1999). Results of a recent 6-year study from 1999 to 2004 based on satellite observations and in-situ measurements in the Mediterranean indicate a primary production gradient decreasing eastwards, ranging on average from >250 gC/m^2 per year in the Alboran Sea to <80 gC/m^2 per year in the Levantine Basin (Lazzari et al., 2012). This gradient may be locally reversed by nutrient overload in the vicinity of marine fish farms, agricultural runoff or sewage input (Carstensen et al., 2001).

The damming of the Nile River in 1965 resulted in decrease in fresh water and nutrient inputs into the Levantine basin (e.g. Inman and Jenkins, 1984; Krom et al., 1991). On the other hand, since 1987 the largest point source of organic pollution on the Israel continental shelf is the Dan Region Wastewater Treatment Plant (Shafdan) near Palmachim (Fig. 1). Approximately 15,000 m^3 of activated sewage sludge (biosolids after secondary treatment) is discharged each day, 5 km offshore at 38 m water depth.

Monitoring of water chemistry and impact on macrobenthos has been carried out since 1992 by the Israel Oceanographic and Limnological Research (IOLR-Haifa), to assess the impact of sludge injection on the ultra-oligotrophic background. The record shows seasonally high levels of organic matter (OM) and heavy metal concentration, and changes in benthic biota (in particular, polychaete worms), affecting the shelf up to 4 km NE of the outfall (Kress et al., 2004). Strong current activity during winter causes mixing of the water column and efficient sludge dispersal, and in spring, relatively diverse benthic faunas have been reported. In the summer and autumn more gentle currents do not disperse the sludge, OM concentration increases, and an abiotic dead zone may develop near the outlet. Heavy metal concentration in the sediment declined by 63–96% from 1998 to 2013 due to improved enforcement of water quality entering the sewage treatment plant (Kress et al., 2016).

Recent studies on the response of foraminiferal faunas to pollutants elsewhere in the Mediterranean, mainly heavy metals and organic load, were carried out by Koukousioura et al. (2011); Frontalini and Coccioni (2011); Barras et al. (2014); Martins et al. (2015, 2016); Dimiza et al. (2016).

On the eastern Mediterranean shelf off of Israel, Hyams-Kaphzan et al. (2009) worked on living foraminiferal assemblages at two sampling sites along the eutrophication gradient in the vicinity of the Shafdan

* Corresponding author.
E-mail addresses: tadirr@post.bgu.ac.il (R. Tadir), chaim@exchange.bgu.ac.il (C. Benjamini), almogi@gsi.gov.il (A. Almogi-Labin), orithy@gsi.gov.il (O. Hyams-Kaphzan).

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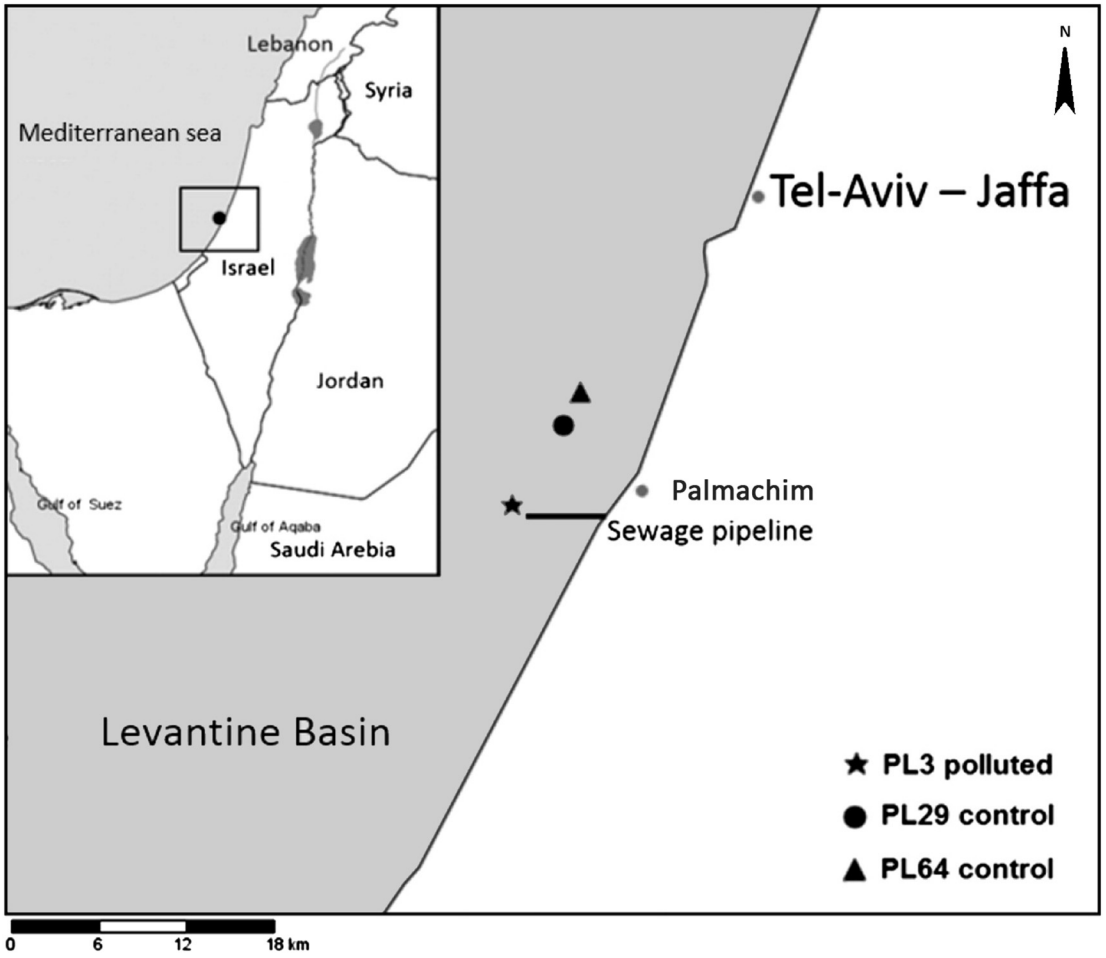

Fig. 1. Location map of Palmachim sampling stations: PL3 - eutrophic station, 200 m north of the outfall and two control stations PL29 and PL64, 5.5 and 7 km NE of the outfall respectively.

outfall. The two sites shared a common pool of species, among which the opportunist *Ammonia tepida* was highly dominant. However, living benthic foraminifera total standing stocks (TSS), species richness, in-sediment living depth and seasonal variability differed significantly at the two sites. The present study is aimed at reviewing the effects of localized OM enrichment on the foraminiferal assemblage in 2012, ten years after the 2003 data were collected (Hyams-Kaphzan et al., 2009).

1.1. Research area

The Israeli shoreline constitutes the southeast margin of the Levantine basin of the eastern Mediterranean. The surface water layer on the shelf from top to 40 m is characterized by high salinity (varying between 38.2 psu in winter and 40 psu in fall), and a temperature range between 17 °C in the winter and up to 30 °C in summer (Hyams-Kaphzan et al., 2009). Offshore the upper 120 m of the water column is well mixed in winter (December–March), while in the summer, a sharp halocline and thermocline appears (Herut et al., 2000).

Wave- and wind-induced long-shore currents drive sediments predominantly from south to north (Emery and Neev, 1960; Golik, 1993; Zvieli et al., 2007). Sedimentation rates calculated for the Mediterranean at 35–50 m water depth were ca. 2 mm/year, decreasing northward. Observations over the last few decades have shown a sharp decrease in the fine (<63 μm) sediment fraction (Almogi-Labin et al., 2009). In addition, an increase in mean wave height (from 2.6 to 2.9 cm/year) and decrease in wave period (from 0.01 to 0.26 s/year) was reported over 25 years period from 1985 to 2010 in the Egyptian coast (Iskander, 2013). Their model predicts a further increase of ca. 20% in storm wave energy over the next 50 years.

Subsequent to the damming of the Nile in 1965, the longshore fresh water and nutrient input into the eastern Mediterranean fell drastically, and productivity on the Israeli continental shelf became ultra-oligotrophic (e.g. Berman et al., 1984; Inman and Jenkins, 1984; Krom et al., 1991; Yacobi et al., 1995; Herut et al., 2000).

The sediment along the Palmachim shoreline at ~36 m water depth lies between fair weather wave base (FWWB) and storm wave base (SWB). Sediments were fine to very fine prior to the 1960's (~50% clays and ~40% silts, 10% sands) (Tapiero et al., 2003; Mor-Federman et al., 2013), while over the past 50 years (since the damming of the Nile) they became coarser, composed of silty to muddy sand with ≥10% $CaCO_3$, and total organic carbon of 0.3–0.5 wt.% (Almogi-Labin et al., 2009, 2012). Sludge is injected continuously forming an outfall plume. In the winter, strong current activity causes water column mixing and efficient sludge dispersal. In the summer and autumn, currents are more sluggish and sludge accumulates from the outfall to 1 km towards NE (Kress et al., 2004). The affected sediment appears fluffy and dark-colored with high organic carbon up to 15 wt.% and finer grain size then distal sediments (Hyams-Kaphzan et al., 2009).

2. Material and methods

2.1. Sampling procedure

For the present study, three permanent stations (PL3, PL29, PL64) were visited by the R/V Etziona and sampled for benthic foraminifera,

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