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Molluscan live and dead assemblages in an anthropogenically stressed shallow-shelf: Levantine margin of Israel

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ABSTRACT

Mismatches between live and dead molluscan assemblages associated with recent, rapid, anthropogenic changes, can be used to track these changes. The eastern Mediterranean is naturally oligotrophic, but recent urbanization of the Israeli coastal plain has enriched the littoral environment by injection of large amounts of treated wastewater onto the shelf. The largest point source is the Dan region wastewater project (Shafdan). Taxonomy and species rank order of abundance of modern (sediment-top) death assemblages were compared to live-collected mollusk assemblages, from two clean control stations (PL29, PL64) and a polluted site (PL3), near the Shafdan sewage sludge outlet at 36 m water depth. Seasonal variability was captured by dredge and box-core sampling in winter (January), spring (May), summer (July) and fall (November) of 2012.

Over 11,000 individuals of bivalves and gastropods were collected and analyzed. Diversity indices and nMDS and cluster analysis showed significant differences between live and dead assemblages from all stations and seasons. However, the rank order of the abundant live and dead species remained similar at each sampling station, resulting in high live–dead agreement of Jaccard-Chao index and Spearman's rho similarity coefficient. Live–dead agreement of molluscan assemblages was preserved in the Shafdan area by the naturally high abundance of species that are tolerant to pollution, and by the annual dispersion of the sludge by winter storms, which prevent development of long-term anoxia. Moreover, the high frequency of storms in the winter of 2012 prevented a substantial amount of sludge from accumulating on the seafloor, explaining the similarity between the live assemblages of the polluted and the control sampling sites. Live–dead agreement is a test that is too conservative to track the impact of the Shafdan sludge on the macrobenthic fauna in the Israeli shelf. Other tests, especially the increase in the abundance of deposit-feeding pollution-tolerant species in the live assemblage, show that there is an ongoing impact of the sludge on the benthic community.

1. Introduction

Human modification of marine environments has led to the deterioration of sea-floor ecosystems worldwide (Magni, 2003; Halpern et al., 2008, 2012). The introduction over time of excess nutrients and contaminants to the biologically rich and economically valuable coastal areas has degraded marine biodiversity and changed the distribution of the marine biota (Jackson et al., 2001; Lotze et al., 2006). Despite a growing awareness of the danger to macrobenthic communities, in most cases monitoring of live benthic assemblages starts only after the onset of human activity; and information on the natural conditions prior to modification is incomplete (Kidwell, 2008, 2013). A record of the community prior to disturbance is preserved in time-averaged death assemblages of shelled faunas that serve as a baseline for the composition and structure of pre-anthropogenic live communities (Kidwell, 2007). Death assemblages are formed by the constant accumulation of remains of dead shells of macrofauna in the sediment top. As shells from consecutive generations are mixed together by bioturbation, physical reworking and other taphonomic processes, they construct a time-averaged record that flattens out short-term variability and represent the summation of subannual and year-to-year variations in the live community (Kidwell, 2007, 2009).

Quantitative tests in unaltered modern environments have shown that the composition and relative abundance of the local living community may be well preserved in molluscan death assemblages (Kidwell and Bosence, 1991; Aller, 1995; Kidwell, 2001, 2002). Live–dead agreement of molluscan assemblages, termed live–dead fidelity, has been applied in recent years to determine the degree of anthropogenic impact to marine environments (Kidwell, 2009; Zuschin and Stachowitsch, 2009; Weber and Zuschin, 2013; Korpanty and Kelley, 2014). Dead specimens of macrobenthic fauna sieved from the top sediment are

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used to reconstruct an ecologic baseline, which are then compared to the local living fauna (Kidwell, 2007, 2013). Live–dead fidelity is measured by changes in the abundance and the presence or absence of species between the live and dead assemblages and can be quantified by univariate (comparison of species richness, evenness, dominance, changes in the relative abundance of species or their taxonomic similarity) and multivariate (dendrograms and ordinations of species abundances) methods. Rapid and intense anthropogenic changes create a time lag between the composition and structure of the live assemblage and the local dead counterpart. In this case, the time lag of response of death assemblages results in a decrease in live–dead fidelity, rendering it valuable in environmental assessment (Kidwell, 2007). However, it has been considered a ‘conservative tool’, as not all areas with known anthropogenic stress exhibit low fidelity (Kidwell, 2007), and is more likely to fail to detect anthropogenic eutrophication than to falsely indicate it. Notably, most cited studies were limited to intertidal or shallow subtidal environments to ca. 20 m.

Kidwell (2007) performed a global meta-analysis of 73 live–dead datasets to test the use of live–dead fidelity of molluscan assemblages as a proxy for ecological change. Live–dead similarities across a gradient of increasing anthropogenic eutrophication were presented in the form of a cross-plot in which live–dead taxonomic similarity (Jaccard-Chao index, y axis) was plotted against live–dead agreement in species rank order of abundance (Spearman's rho, x axis) (Fig. 1 in Kidwell, 2007). Datasets from open shelf, pristine and naturally nutrient-poor environments fell in the upper right quadrant of the cross plot; this is the field of high live–dead agreement. Datasets from areas of mild to severe anthropogenic impact showed a wider spread into the lower left quadrant of the cross plot, associated with lower live–dead agreement. Kidwell (2007) concluded that a Jaccard-Chao <0.6 and Spearman's rho <0.1 can operationally distinguish areas impacted by anthropogenic eutrophication using live — dead disagreement.

The Levantine basin is the southeastern-most part of the Mediterranean Sea. The damming of the Nile River in 1965 reduced the flow of nutrients to the eastern Mediterranean, which then became highly-oligotrophic (Inman and Jenkins, 1984). Subsequently, urbanization of the Israeli coast has led to considerable nutrient input in the form of treated wastewater via direct outfalls (EEA, 2001; Kress et al., 2004). The largest single contributor of nutrients is the Dan region wastewater project (Shafdan) that has been discharging sewage sludge onto the shelf at 38 m water depth, since 1987 (Kress et al., 2004; Hyams-Kaphzan et al., 2009). This recent point-source eutrophication of the Israeli Mediterranean shallow proximal shelf is particularly suited to test for live–dead fidelity as a proxy for ecosystem modifications, presenting a unique opportunity for an actualistic study of live–dead agreement over an eutrophication gradient. Previous studies on the effects of the discharge of sewage sludge in the in the Levantine basin focused on living foraminifera (Hyams-Kaphzan et al., 2009) and soft-bodied macrofauna (polychaetes) (Kress et al., 2004). The present study on shelly macrobenthos evaluates the level of fidelity between the coastal community composition and relative abundance of modern (sediment-top) death assemblages and live-collected molluscan assemblages, at one polluted and two control stations near the Shafdan. The hypothesis that was tested was that the live–dead fidelity of the polluted station would be low as a result of the anthropogenic activity in the area, while the control stations would yield high live — dead fidelity. An important by-product of this study was the characterization of the live molluscan fauna at 35–40 m, depths at which molluscan communities in general are poorly known.

2. Study area

The Levantine coast of Israel trends in a N-NE–S-SW line over 180 km. The bathymetry of the southern sector is relatively simple, with contours aligned sub-parallel to the coastline. The width of the shelf is 25–30 km in the south, narrowing to ca. 10 km in the north (Inman and Jenkins, 1984; Rosentraub and Brenner, 2007). The upper 120 m of the Levantine water column is stratified during most of the year but becomes homogenous during winter, when surface cooling causes deepening of the mixed layer (Herut et al., 2000; Rosentraub and Brenner, 2007). High accumulation rates of sediments characterized the continental shelf of Israel (Schilman et al., 2001) but were strongly reduced following the construction of the High Aswan Dam in 1965 (Stanley, 1988). The majority of transported sediments today are siliciclastics originating from the erosion of the Nile River delta, with a lesser contribution from local sources (Nir, 1984; Zviely et al., 2007).

The naturally oligotrophic Levantine basin is characterized by primary production estimated at ca.45 gC/m^2y (Berman et al., 1984; Kress and Herut, 2001; Kress et al., 2004) and Chlorophyll a values that range between 0.009 and 0.4 μg/l (Yacobi et al., 1995). The extreme nutrient depletion is caused by westward transport of deep water and nutrients as part of the anti-estuarine circulation in the Mediterranean (Coll et al., 2010).

The Shafdan project treats the domestic and industrial waste water of the population of 2 million residents in the Tel-Aviv Metropolitan area, producing 292,000 dry tons of activated sewage sludge annually (biosolids after secondary treatment), 55% of which is redirected to agriculture and landfill. Since 1987, some 16,000 m^3/day of excess sludge produced at the Shafdan has been discharged through a single seabed pipe line, emptying 5 km offshore 15 km to the south of Tel Aviv (Kress et al., 2004) (Fig. 1). The activated sewage sludge is composed mostly of organic biomass and nutrients, ca. 1% non-degraded particulate matter, and may contain bacteria (including pathogens), synthetic organic compounds, and some heavy metals (Kress et al., 2004). The area was not polluted prior to the outfall activation (Galil and Lewinsohn, 1981). Permanent polluted and control monitoring stations have been established in the area (Kress et al., 2004; Hyams-Kaphzan et al., 2009), and the present sampling program took place at three of these stations: one polluted station, PL3, located 200 m NE of the outfall at 36 m water depth; control station PL29 at 5.5 km NE of the outfall at 34 m water depth, and control station PL64, located 7 km N-NE of the outfall at 35 m water depth (Fig. 1). The sludge was continuously injected from the Shafdan, yet there is no long term accumulation of sludge from year to year (Kress et al., 2004; Hyams-Kaphzan et al., 2009). The thickness of the sludge layer on the seafloor at the polluted station PL3 depends on the seasonal storm and current regimes (Kress et al., 2004), or biotic consumption, that tend to rework and reduce the concentration of the organic particles in the sediment (Kress et al., 2004; Hyams-Kaphzan et al., 2009).

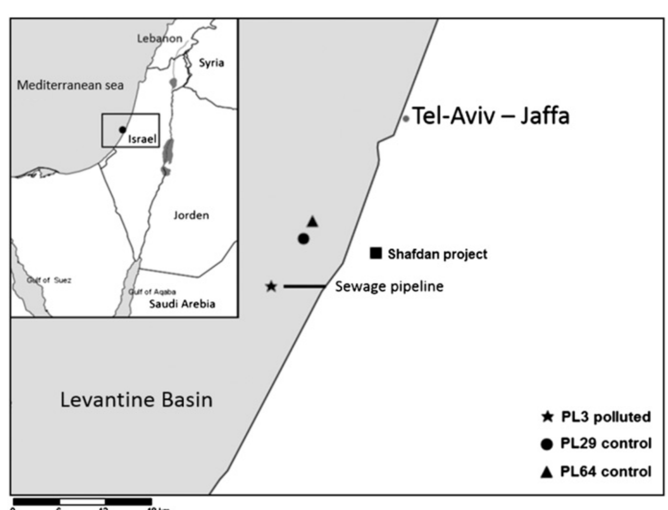

Fig. 1. Location map of the Shafdan sewage sludge outlet and polluted and control sampling stations.