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Detecting, sourcing, and age-dating dredged sediments on the open shelf, southern California, using dead mollusk shells

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ABSTRACT

Molluscan shell debris is an under-exploited means of detecting, sourcing, and age-dating dredged sediments in open-shelf settings. Backscatter features on the Southern California shelf are suggestive of dredged sediment hauled from San Diego Bay but deposited significantly inshore of the EPA-designated ocean disposal site. We find that 36% of all identifiable bivalve shells >2 mm (44% of shells >4 mm) in sediment samples from this 'short dump' area are from species known to live exclusively in the Bay; such shells are absent at reference sites of comparable water depth, indicating that their presence in the short-dump area signals non-compliant disposal rather than natural offshore transport or sea level rise. These sediments lack the shells of species that invaded California bays in the 1970s, suggesting that disposal preceded federal regulations. This inexpensive, low-tech method, with its protocol for rejecting alternative hypotheses, will be easy to adapt in other settings.

1. Introduction

The disposal of uncharacterized dredged sediments in open waters can have multiple negative effects on benthic communities, especially local smothering and the delivery of contaminants from bays and harbors to less-impacted shelf environments (Newell et al., 1998; Harvey et al., 1998; Cruz-Motta and Collins, 2004; Bolam et al., 2006; Parnell et al., 2008; Bolam, 2012). Open-water disposal has consequently been highly regulated in many countries since adoption of the London Convention of 1972 (updated in 1996; http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx), including the United States (e.g., EPA, 1987, 2011; Smith and Rule, 2001). Sediments proposed for dredging and disposal at EPA-designated sites (ODMDSs) must pass rigorous physical, chemical, and biological tests, and only suitable (non-toxic) sediments are allowed to be disposed there. The dynamics of material dispersal during release, during burial-exhumation cycles on the seafloor, and during ecological recovery are now fairly well understood, and a series of techniques have been developed to monitor and minimize impacts (for reviews, see Rhoads et al., 1978; Solan et al., 2003; Fredette and French, 2004).

Nonetheless, although the London Convention has global reach and since 1996 has stressed beneficial re-use of materials on land, disposal proceeded in many regions before regulations and responsible agencies were established. Determining the spatial extent of dredged sediments on open seafloors thus remains an important first step in determining the degree to which unregulated disposal influences a region, for example through persistent release of contaminants (Fredette and French, 2004; Wienberg and Bartholomä, 2005; Parnell et al., 2008; Okada et al., 2009; Nizou et al., 2015).

Here we evaluate molluscan shell debris as a novel, retrospective method of detecting, sourcing, and age-dating dredged sediments ('spoil') on the open continental shelf of southern California off San Diego, a major urban area. San Diego Bay has a long history of dredging for commercial and naval ship traffic (Smythe, 1908; Smith, 1976). Bright spots and lines on side-scan backscatter radar images of the adjacent continental shelf compiled by Dartnell and Gardner (1999) suggest that many barge loads of spoil were disposed in middle to outer shelf waters short of and outside of the LA-5 ODMDS boundaries, a site that was designated for offshore disposal in 1987 (Fig. 1). Parnell et al. (2008) estimated ~250 'short dumps' in this field of view, and this area has historically yielded some of the highest contaminant concentrations in the region (CSD, 2013a).

Are these features dredged sediment deposits, and if so, what is their age and impact on benthos? We use the extensive existing knowledge on the environmental preferences of mollusks in southern California,

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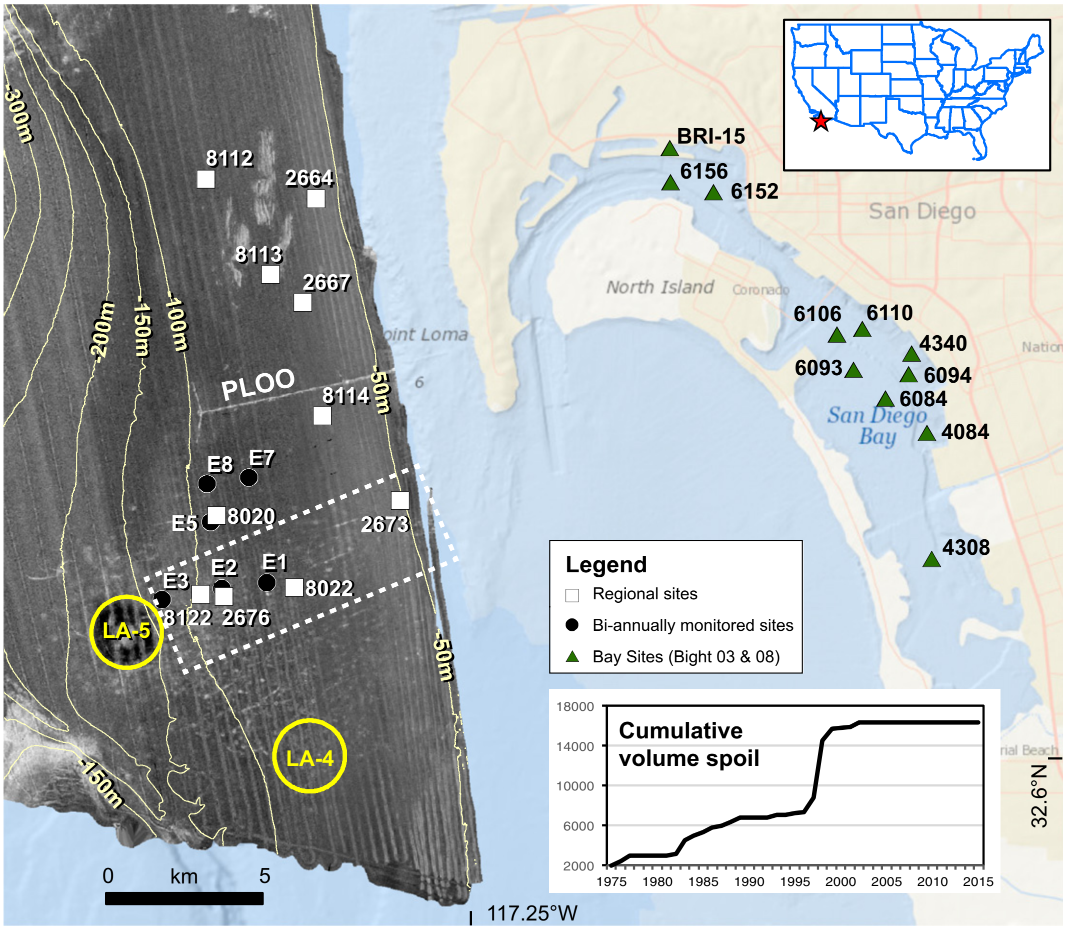

Fig. 1. Map of study area, with side-scan backscatter imaging of the open shelf compiled by Dartnell and Gardner (1999). LA-5 is the EPA-approved disposal site for sediments from the San Diego region, first used in 1976; nearby LA-4 was used only between 1976 and 1978. The linear and point features in the image between LA-5 and San Diego Bay are suspected heaps of dredged sediments. The Point Loma Ocean Outfall (PLOO) pipe, which discharges treated wastewater, is also clearly evident. Bivalve death assemblages were examined from ten Van Veen samples from seven sites in the non-compliant areawith greatest density of side-scan scars (inside dashed rectangle; "in-track sites"), from 22 samples from nine "reference sites" in similar water depths lacking scars, and from single samples from 11 sites within San Diego Bay, the primary source area of dredged sediments destined for LA-5. Inset map: location of San Diego (star). Inset graph: cumulative dredge spoil in thousands of cubic meters approved for disposal at LA-5 since 1976 (data from ODD, 2016), by which time ~2 million m^3 had already been disposed on the shelf (Smith, 1976). Basemap from ESRI (accessed 2013).

and dead-shell assemblages from benthic samples taken during ocean monitoring of the open shelf by the City of San Diego, to test for the anomalous occurrence on the middle to outer shelf of dead shells from bay-dwelling species. If the suspicious bright spots and lines on the side-scan images of Fig. 1 are "dribbles" and short-dumps of dredge spoil deposited by barges *en route* to LA-5 from San Diego Bay, then benthic samples from this non-compliant but "in-track" area should differ from reference sites of comparable water depth in several ways. Samples from in-track sites (1) should contain a higher concentration of dead shells, (2) should include shells of species that are not encountered alive on the shelf, and (3) those species found dead-only at in-track sites should not be found as dead shells at similar water depths elsewhere on the San Diego shelf, showing that their presence in-track is not the result of some widespread natural process, such as post-glacial sea level rise. These bay-derived "signal" species encountered dead-only in-track should also (4) be known to live in bays and harbors in southern California and (5) occur as dead shells in seabed samples from San Diego Bay, showing that they could be a common constituent of spoil material. Finally, if the backscatter features are dredge spoil, then (6) in-track sites might have a distinctive living community compared to reference sites at the same water depth, for example if spoil material affects benthic colonization and survival.

2. Background and study area

2.1. History of San Diego Harbor and dredged-sediment disposal

The strategic value of San Diego Bay was recognized by European explorers in 1542, but the Bay did not become an active port until the Spanish permanently colonized the area in 1769. After a short period of control by Mexico, the United States claimed the territory by military force in 1848 as the only land-locked harbor along the ~1000 km coastline between San Francisco, California, and San Quintín, Baja California (Smythe, 1908, pt. 1.1, 7.2; and see extensive web resources of the San Diego History Center, www.sandiegohistory.org).

The need for channel maintenance was recognized very early. By 1874, the U.S. Coast Survey advocated removal of ~50,000 m^3 of material from the harbor, largely to contend with sediment input from the San Diego River. In 1877, the San Diego River was permanently diverted directly to the Pacific Ocean through what is now Mission Bay (Smythe, 1908, pt. 7.2; Smith, 1976; straight channel evident along north edge of map in Fig. 1). Although this modification greatly reduced sediment load into San Diego Bay, the City of San Diego started dredging the bar at the entrance of the Bay in the early 1900s (Smythe, 1908, pt. 6.7), and channel maintenance for commercial shipping and the large US