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The effects of beach nourishment on benthic invertebrates in eastern Australia: Impacts and variable recovery

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HIGHLIGHTS

► Erosion of many sandy shores is accelerating, threatening assets along coastlines.
► Placing large volumes of sand ('nourishment') is a common strategy to combat erosion.
► Nourishment can severely impact the fauna of beaches and recovery can be protracted.
► Placing sand on top of the beach followed by bulldozing creates a gradient of impacts.
► Modifications to engineering practices are suggested to minimize impacts on ecosystems.

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ABSTRACT

Beach erosion is likely to accelerate, driven by predicted consequences of climate change and coastal development. Erosion is increasingly combated by beach nourishment, adding sand to eroding shores. Because a range of engineering techniques exists to nourish beaches, and because these techniques differ in their environmental effects, assessments of ecological impacts need to be tailored and specific. Here we report on impacts and recovery of benthic invertebrates impacted by beach nourishment operations undertaken at Palm Beach (SE Queensland, Australia). Assessments are made based on a beyond-BACI design, where samples were taken once before nourishment and twice afterwards at the impact and two control sites. Because almost all of the sand was deposited on the upper beach and later moved with bulldozers down-shore, we specifically examined whether the effects of nourishment varied at different heights of the beach—a little-studied question which has management implications. Impacts on the fauna were massive on the upper and middle levels of the beach: samples collected two days after the conclusion of nourishment were entirely devoid of all invertebrate life ('azoic'), whereas weaker effects of nourishment were detectable on the lower shore. Recovery after five months also varied between shore levels. The sediment of the upper level near the dunes remained azoic, the fauna of the middle shore had recovered partially, and the lower level had recovered in most respects. These findings indicate that the height and position of sand placement are important. For example, rather than depositing fill sand on the intertidal beach, it could be placed in the shallow subtidal zone, followed by slow up-shore accretion driven by hydrodynamic forces. Alternatively, techniques that spread the fill sand in thin layers (to minimize mortality by burial) and leave unfilled intertidal refuge islands (to provide colonists) may minimize the ecological impacts of beach nourishment.

1. Introduction

Erosion of sandy beaches is a global issue, affecting about 75% of sandy shorelines globally (Bird, 1996), a situation that is likely to worsen as global warming causes the oceans to rise and storms to intensify, become more frequent, or both (Defeo et al., 2009; Bender et al., 2010). Erosion affects humans because sandy beaches deliver numerous goods and services to society (Schlacher et al., 2007, 2008b). It is also an ecological issue because beaches provide habitat for many species including endangered marine turtles and birds, and they play critical roles in bio-geochemical transformations at the land–ocean interface (Armonies and Reise, 2000; Cisneros et al., 2011; Dugan et al., 2011). Society's expectations of sandy beaches are also highly

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complex: people view beaches as prime sites for recreation and dunes as premier real estate, but at the same time desire beach and dune habitats are rich in wildlife (Maguire et al., 2011).

Consequently, erosion is a serious problem that coastal societies have addressed for centuries (Charlier et al., 2005). Traditionally, hard-engineering solutions such as seawalls, breakwaters and groynes were the preferred option, but these structures are not always effective, even causing the loss of the beach in some cases (Pilkey and Wright, 1989). Seawalls also cause large and lasting environmental impacts (Dugan et al., 2008). Instead, soft-engineering alternatives such as beach nourishment have become increasingly popular (Finkl and Walker, 2004).

Although beach nourishment is considered an, arguably, more environmentally friendly option than armouring the shoreline with seawalls and similar structures (Finkl and Walker, 2004), it is certainly not without ecological consequences: nourishment impacts both the habitat and the biota of beaches (reviewed by Speybroeck et al., 2006). Most research documents negative effects on the intertidal fauna (e.g., Peterson et al., 2000; Jones et al., 2008). The immediate impacts are usually very large, caused presumably, by burial or by changes to sediment grade that lowers habitat suitability for the fauna (Menn et al., 2003; Peterson et al., 2006). These effects may be compounded by changes to beach height and morphology (Bilodeau and Bourgeois, 2004). In addition, the engineering process itself can have ecological effects; for example, bulldozing to contour beaches lowers habitat quality by compacting sediments and directly crushes animals (Peterson et al., 2000).

A growing awareness of environmentally-sensitive approaches to beach management (Schlacher et al., 2007; Dugan et al., 2010) requires that the environmental effects of beach engineering works are better understood. If implemented well, nourishment constitutes a pulse disturbance (sensu Bender et al., 1984) and hence is likely to elicit a pulse response (Glasby and Underwood, 1996); this suggests that impacts are temporary and recovery can occur. Accordingly, two aspects of nourishment are of particular interest to both ecologists and managers: i) the magnitude of the impact, and ii) the duration of the impact (i.e., the period of time from initial impact to full recovery).

Although there is some published research addressing the size of impacts and recovery, different engineering techniques exist that can cause different ecological effects (Speybroeck et al., 2006). Consequently, many ecological questions remain to be answered about the effects of beach nourishment. For example, questions of recovery are less studied than those of short-term impacts, and there is little published information on how impacts and recovery vary across the shore (i.e. different effect sizes and temporal trajectories depending on the position along the gradient from the swash zone to the dunes). This question becomes important where fill sand is deposited unevenly across the intertidal zone or other engineering works are concentrated on particular levels of the shore. As a result, this paper has three aims: 1.) to quantify short-term (days) effects of a small nourishment operation on the benthic fauna of an exposed sandy beach; 2.) to determine medium-term (five months) recovery trajectories of the habitat and biota following the engineering works, and 3.) to determine whether nourishment impacts and recovery differ amongst tidal levels across the beach.

2. Methods

2.1. Study site and field collections

In Eastern Australia, the Gold Coast ranks amongst the nation's premier beach tourism destinations (Maguire et al., 2011; Noriega et al., 2012). The area's economy depends heavily on its tourism and recreation industries which are largely underpinned by the region's ocean beaches. However, these beaches suffer erosion, diminishing their value to beach users (Castelle et al., 2008). In practice, the mandate to have wide beaches that are attractive to tourists translates into engineering interventions in the form of sand deposition ('beach nourishment'), groynes, seawalls, or all three (Walker et al., 2008).

The beach nourishment was at the south end of Palm Beach (Fig. 1; 28.126°S, 153.481°E). Here, about 30,000 m^3 of sand from Currumbin Creek, a nearby tidal inlet, were deposited on the upper beach at a thickness of about 1 m and for about 300 m along the beach. The sand was placed on top of the beach in a slurry form: some of this sand moved down to the water line by gravity, but most remained at the top of the shore. When sand deposition works had finished, this accumulated sand was moved with a bulldozer to 'profile' the beach.

We assessed the ecological effects of beach nourishment using a beyond-BACI design (Stewart-Oaten et al., 1986; Underwood, 1992), contrasting data from the impact location with multiple control locations. Control locations were sited to the north (Palm Beach, 27th Avenue, 28.102°S, 153.464°E) and to the south (Tugun Beach, 28.144°S, 153.498°E) of the impact location (Fig. 1). Sampling was conducted once before the nourishment operations (starting 8th October, ending 1st December—'Time 1' = T1) and twice after it (3rd December 2007—'Time 2' = T2, and 2nd May 2008—'Time 3' = T3). Thus, post-nourishment sampling was two days (T2) and five months (T3) after the engineering works were completed.

Across the shore, sampling was stratified into upper, middle and lower tidal levels to reflect the fact that most sand was placed in the upper and middle parts of the beach, whilst initially the lower shore received no sand additions. In each level, 10 random fauna samples were collected within a 10 m × 50 m plot. The longer side of these plots was orientated parallel to the shoreline. The landward boundary of the upper-shore plot was located at the base of the foredunes. The position of the landward boundary of the lower-shore plot was determined by marking 11 consecutive uprushes of the swash at the time of low water. The median position of these marked swashes was taken as the upper plot boundary. The centre of the mid-shore plot was equidistant between the seaward edge of the upper plot and the landward edge of the lower plot.

Fauna collections followed standard protocols described in Schlacher et al. (2008a, 2011b), Schlacher and Thompson (2012). Each sample was the composite of five cores (inner diameter 154 mm, 200 mm deep) taken at haphazard locations within a 2 m radius of the 10 random sample points within a plot. The location of these random points was determined with random number tables. Fauna was separated from the sand by sieving in the swash (1 mm mesh aperture) and preserved in 80% alcohol. All specimens were identified to the lowest possible taxonomic rank.

Sediment samples (cores of 30 mm diameter, 100 mm deep) were excavated from the same locations from which fauna samples were taken (i.e. 10 replicates per 10 m × 50 m plot). In the laboratory, the sediment was dried to constant weight (65 °C, 48 h) to determine sand moisture. Sediment was then sieved for 15 min to determine granulometric properties, using a nested series of sieves with the following aperture sizes: 4000 μm, 2000 μm, 1000 μm, 500 μm, 250 μm, 125 μm, and 63 μm. Sediment statistics (mean grain size, sorting, skewness, and kurtosis) were calculated with the GRADISTAT software, using the Folk and Ward method (Blott and Pye, 2001). Shore profiles were surveyed by professional civil engineers of the local government authority during each time biological samples were taken.

2.2. Statistical analysis

Data from the beyond-BACI design were analysed with asymmetrical Analysis of Variance (Underwood, 1997). Under this approach, an impact is indicated by statistically significant Treatment × Time interactions (i.e. temporal trajectories from before, T1, to after the intervention, T2, differ between treatment and impact locations). Conversely, recovery is indicated by non-significant Treatment × Time interactions (i.e., temporal trajectories of impact and controls from before to after the intervention are