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Effects of beach replenishment on intertidal invertebrates: A 15-month, eight beach study.

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ABSTRACT

Beach replenishment is an increasingly popular means to remediate coastal erosion, but no consensus exists regarding how long replenishment affects sandy beach intertidal invertebrates, key components of beach ecosystems. We monitored the intertidal invertebrate community for fifteen months following a replenishment project at eight beaches, each with replenished and control sections, across San Diego County. Nearly all taxa showed major declines in abundance immediately following replenishment. Populations of talitrid amphipods and the bean clam *Donax gouldii* recovered within one year, sooner than in previous studies. On some beaches, populations of the mole crab *Emerita analoga* bloomed four months after replenishment and were more numerous on replenished portions of beaches at that time. Mole crab populations subsequently declined and no longer differed by treatment. The polychaete community, composed of *Scolelepis* sp. and several other numerically important taxa, showed a strong replenishment-induced reduction in abundance that persisted through the end of the study. The large negative effect of replenishment on polychaetes, coupled with their overall importance to the invertebrate community, resulted in a more than twofold reduction in overall invertebrate abundance on replenished beaches at 15 months. Such reductions may have far reaching consequences for sandy beach ecosystems, as community declines can reduce prey availability for shorebirds and fish. As this and other recent studies have revealed longer times for the recovery of intertidal invertebrates than previously observed, longer study periods and more cautious estimates regarding the magnitude, variability, and duration of impacts of beach replenishment for management decision-making are warranted.

1. Introduction

Sandy beaches make up two-thirds of the Earth's shorelines, providing critical ecological, commercial, and cultural resources for communities worldwide. As population growth and the associated pressures of urbanization and climate change place further stress on sandy beaches, the threat of degradation of these ecosystems increases (Brown and McLachlan, 2002; Peterson and Bishop, 2005; Defeo et al., 2009). Because of their economic value, interest in preserving sandy beach environments is growing, and a variety of practices to combat beach loss have been implemented. Solutions range from constructing structures that maintain beach width, to replenishment of beaches using offshore sand (McLachlan and Brown, 2006). Beach replenishment, the loading of sand on depleted beaches, is viewed as an ecologically conscious solution to erosion because it lacks the potential long-term impacts of hard solutions such as sea walls (Hanson et al., 2002; McLachlan and Brown, 2006; Cooke et al., 2012). Nevertheless, replenishment efforts often cite economic concerns such as coastal flooding risk or reduced tourism as motivation for rebuilding beaches, while potential ecological consequences hold less importance (Hanson et al., 2002; Lew and Larson, 2005; Sandag & U.S. Army Corps of Engineers, 2011).

However, perturbations in the intertidal sandy beach community can have cascading effects on higher trophic levels, reducing prey availability for shorebirds, juvenile fish, and a host of other organisms (McLachlan and Brown, 2006). Reductions in foraging rates of shorebirds and fish have been shown to follow human-induced reductions in benthic invertebrate abundance, ranging from simple trampling to replenishment (Dugan et al., 2003; Neuman et al., 2008; Peterson et al., 2006; Quammen, 1984; Wilber et al., 2003). Benthic invertebrates also play an important role in nutrient cycling, breaking down both marine and terrestrial

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organic matter and providing coastal waters with the nutrient inputs essential for processes such as phytoplankton growth (Schlacher et al., 2008; Defeo et al., 2009; Cisneros et al., 2011; Dugan et al., 2011; Leewis et al., 2012). Accordingly, an ill-planned replenishment regime affecting beaches with high rates of shorebird use and nutrient cycling could have far reaching ecosystem consequences.

The limited number of published beach replenishment (also called nourishment) studies show considerable variation in results (Table 1). Although certain taxa (e.g. haustoriid amphipods, *Emerita talpoida*, *Scolelepis squamata*) are repeatedly investigated, no single study has addressed the responses of all core intertidal taxa (Table 1). For most taxa, overall responses to replenishment are uniform; amphipods, mole crabs (*Emerita* sp.), and bean clams (*Donax* sp.) tend to respond negatively, while the polychaete *Scolelepis squamata* responds positively or is unaffected by replenishment. Most of the differences between studies are found in the time it took for organisms to recover; Schlacher et al. (2012) saw complete recovery of lower intertidal haustoriid amphipods within five months, while Peterson et al. (2014) failed to see a return to control levels after three years. *Emerita talpoida*, *Donax* sp., and *Scolelepis squamata* all show variability among studies in time to recovery (Table 1). Another feature of previous studies is that they sampled either a single beach (Schlacher et al., 2012), used a time series design consisting of sampling different beaches replenished at various times in the past (Leewis et al., 2012), or employed designs in which sampled replenished and control beaches were spatially segregated rather than interspersed (Peterson et al., 2006, 2014).

Southern California has a long history of implementing beach replenishment to combat continual erosion (Willis and Griggs, 2003). Sediment contributions from sea cliff erosion and river runoff naturally rebuild the region's beaches (Young and Ashford, 2006) but controls on cliff erosion, in conjunction with dams and jetties, now interrupt the input and flow of sediment in coastal areas (Moore et al., 1999; Sherman et al., 2002; Willis and Griggs, 2003). In light of these changes and the potential economic cost of beach erosion, the county of San Diego has implemented two recent replenishment projects. The first, which occurred in 2001, was largely successful in expanding target beaches for several years post-replenishment and provided impetus for an additional project in 2012 (Sandag & U.S. Army Corps of Engineers, 2011). During the fall of 2012, eight beaches across San Diego County were replenished with a total of 1.76 million cubic meters of sand as part of the Regional Beach Sand Project II (RBSP II; Fig. 1). Only portions of each beach were replenished, leaving unreplenished control sections with the intent of leaving areas for foraging birds and fish. Replenishment sediment was pulled from three offshore sites with fine-medium sand, selected for best match to the grain size structure of recipient sites (Sandag & U.S. Army Corps of Engineers, 2011).

No previous examination of replenishment had the opportunity to examine its effects on the total invertebrate community across so many beaches, with control and treatment regions of each beach. Such a design facilitates the understanding the general affects of replenishment as well as the heterogeneity of responses among beaches. This study examines the effects of the 2012 replenishment in San Diego in order to: 1) Quantify initial impacts and recovery rates of each component of the sandy beach invertebrate community. 2) Quantify variability among beaches both in the invertebrates present and in taxon-specific responses to replenishment. 3) Assess patterns of community diversity and structure following replenishment and the variability of response to replenishment across replicate beaches within a region.

2. Methods

2.1. Study sites and sampling design

Sampling was conducted at four time periods to account for both seasonality and time since disturbance: 1 (Fall 2012), 4 (Winter 2013), 12 (Fall 2013), and 15 (Winter 2014) months after replenishment. Days with the lowest low tides for that season were chosen for sampling, permitting transects to extend from the low tide line to the upper limit of the intertidal. During each sample period, two replicate transects were surveyed in both the replenished and unreplenished sections, totaling four transects per site. 10 cm-wide sample cores were taken at 20 cm depth and 5 m intervals along each transect. Sediment cores were sifted through a 1 mm sieve, and remaining organisms were transferred to 70% or 95% EtOH. Organisms were then identified to the lowest possible taxonomic rank using morphology.

2.2. Taxon-specific abundances

Transects varied in length due to differences in slope, producing unequal numbers of cores per transect. To account for this irregularity, as well as the patchy distribution of organisms in the intertidal, mean abundance of each taxon per core was calculated for each transect. Standard ANOVA was deemed problematic for testing the effects of replenishment on these values, due to the high number of zeroes, especially when analyzing particular taxonomic groups, causing extreme non-normality of the data (Shapiro's test, $p < 0.0001$ for all taxa; Underwood, 1997).

Instead of using classical ANOVA, we ran a series of restricted

Table 1
Summary of findings from peer-reviewed beach replenishment studies. Initial response (R) and time until replenishment effects are no longer observed (T) are listed for intertidal taxa when available. A "-" indicates reduced abundance, a "+" indicates increased abundance, and "=" indicates no significant difference. A ">" indicates that replenishment effects were still observable at the end of the study.

	Amphipods		Isopods		*Emerita* spp.		*Donax* spp.		*Scolelepis squamta*		Other polychaetes	
Citation	R	T	R	T	R	T	R	T	R	T	R	T
Fanini et al., 2000	=	N/A										
Gorzelany and Nelson 1987							=	N/A				
Hayden and Dolan, 1974					–	2 weeks						
Leewis et al., 2012	–	1 year			–	1 year	–	1 year	+	1 year		
Jones et al, 2008	–	1 year										
Manning et al., 2014	=,–	>1 year			=,–	>1 year	=,–	>1 year	=,+	8 months		
Menn et al., 2003	=	N/A							+	>4 months	+	>4 months
Peterson et al., 2000a					–	>10 weeks	–	>10 weeks				
Peterson et al., 2006	–	>9 months			–	4-5 months	–	>9 months	=	N/A	=	N/A
Peterson et al., 2014	–	>3 years			–	1 year	–	>3 years	=	N/A	=	N/A
Schlacher et al., 2012	–	5 months	–	>5 months							–	5 months