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Vegetation and ghost crabs in coastal dunes as indicators of putative stressors from tourism

Thomas A. Schlacher*, Rudolf de Jager, Tara Nielsen

Faculty of Science, Health & Education, University of the Sunshine Coast, Maroochydore DC, Q-4558, Australia

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ABSTRACT

Coastal dunes provide important ecosystem services and are susceptible to human disturbance such as vehicle traffic and human trampling. Notwithstanding, on several Australian beaches dunes serves as camping areas, where camping sites are located on the primary dunes landwards of the foredunes. Because these activities have the potential to impact on the biota of the foredunes directly adjoining the camping zones, sustainable management of dunes for multiple uses requires that putative impacts are identified. Consequently, we quantified: (1) effects of dune camping on the vegetation in the foredunes abutting the camping zones, (2) ghost crab (*Ocypode cordimana*) abundance, distribution, body size, and body condition as biological indicators of human stressors, and (3) the degree to which habitat attributes are correlated with ghost crab abundance. Two percent of the foredune surface was disturbed by human activity (vehicle tracks, trampling, dog prints, litter). Camping in the primary dunes had some minor effects on the vegetation of the foredunes, but widespread changes in plant assemblages were not detected. Ghost crabs were attracted to camp sites, significantly changing their distribution across the dune field and increasing their body condition near camp sites—presumably a trophic subsidy from food scraps. Except for vegetation height which had a positive influence on crab density, there were no other strong and consistent predictors of ghost crab density either in terms of physical habitat attributes (e.g. dune width and height) or vegetation characteristics (e.g. plant cover, diversity). Because coastal managers must increasingly reconcile multiple uses of the environment with its protection, robust data on the type, extent and magnitude of impacts are critical to formulate efficient management strategies for dunes. Monitoring the efficacy of such strategies requires robust indicators, and we show that ghost crabs may be good candidate species for this.

1. Introduction

Coastal dunes provide essential habitat for plants and invertebrates, as well as feeding and nesting sites for birds and turtles (Baird and Dann, 2003; Groom et al., 2007; Lastra et al., 2010). They also deliver critical ecosystem services to humans, forming natural barriers that protect coastal communities against the effects of severe weather events, storing and filtering large amounts of water, and acting as sediment reservoirs for beach nourishment (Short, 1999).

A burgeoning human population in the coastal strip is placing escalating pressures on coastal dunes, and many dune systems around the world have been severely modified (Nordstrom, 2000; Coombes et al., 2008). Human pressures on dune systems are diverse, including the removal of dunes for infrastructure development, shore armouring, removal of vegetation, introduction of invasive species, vehicles and trampling, and camping (Nordstrom, 2000; Comor et al., 2008; Thompson and Schlacher, 2008; Defeo et al., 2009; Kutiel et al., 2000; Bonte and Maes, 2008). Frequent disturbance of dunes by human activity usually leads to reduced biodiversity, loss of habitat, destruction of native vegetation, and increased erosion during storms (Nordstrom and Mauriello, 2001; Feagin et al., 2005).

Beaches are prime sites for human recreation and rank amongst the most intensively used ecosystem types by humans (Houston, 2008). This is especially true in Australia, where 85% of the population lives within 50 km of the coast, and tourism centred around sandy beaches is an important component of the economy (Australian Bureau of Statistics, 2004; Houston, 2008). Tourist activities can, however, have negative ecological consequences for beaches and dunes. Ecological impacts linked to recreation include changes to sediment properties, dune morphology, stability and dynamics (Kutiel et al., 1999), destruction of dune vegetation, often resulting in increased erosion (Rickard et al., 1994), and injuries, disturbance and kills of wildlife such as turtles (Hosier et al., 1981), birds (Williams et al., 2004; Weston and Elgar, 2005, 2007), and

* Corresponding author. Tel.: +61 754302847; fax: +61 754301276.
E-mail address: tschlach@usc.edu.au (T.A. Schlacher).

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invertebrates (Moss and McPhee, 2006; Schlacher et al., 2008a,c; Sheppard et al., 2009; Bonte, 2005; Comor et al., 2008).

Camping on coastal dunes is a popular form of recreation, and causes ecological changes mainly associated with the clearing of vegetation and the use of vehicles in the dunes (Rickard et al., 1994; Hockings and Twyford, 1997; Groom et al., 2007). Although generally less severe, intense human trampling can cause similar impacts (Yu et al., 2008; Grünewald, 2006). Campers also bring dogs which threaten birds (Burger et al., 2007), and disposal of food scraps by tourists (Strachan et al., 1999) may modify trophic dynamics in invertebrate consumers of dunes. Many of these ecological responses to human use of coastal dunes are likely to be species-specific and depend on local site conditions, making generalisations for particular locations problematic. Thus, our first objective is to determine whether human disturbance associated with camping results in measurable changes to plant assemblages in the foredunes seawards of the camping zones.

Ghost crabs (Genus Ocypode) are abundant, large, widespread, and they have predictable responses to human pressures; this makes them potentially good biological indicators of human stressors on beaches (Barros, 2001; Lucrezi et al., 2009a,b; Lucrezi and Schlacher, 2010). In crustaceans, the hepatopancreas is critical for nutrient storage and the metabolism of energy reserves (Kennish, 1997; Connell et al., 1999; Verri et al., 2001). The ratio of hepatopancreas mass to body mass (Body Condition Index—BCI) indicates body condition (Kennish, 1997; Young, 2008). In the present situation, we predicted that food discarded by campers changes the trophic status of crabs in the dunes; this was tested using changes in their BCI. Our second aim was to assess whether changes in the density and distribution of ghost crabs can detect putative camping impacts on the adjacent foredunes.

Despite the large amount information on the distribution and abundance of ghost crabs on sandy beaches (Barrass, 1963; Jones, 1972; Lucrezi et al., 2009b), little is known about which environmental factors influence ghost crab populations in coastal dunes. However, such information is important to identify measures of habitat management and restoration that maximize benefits for crab populations. More widely, coastal managers are increasingly required to minimize environmental impacts from leisure activities (Schlacher et al., 2008b). To this end, biological indicators are needed to monitor the efficacy of management interventions.

Here we addressed three main objectives: (1) assess the impact of dune camping on the vegetation in foredunes abutting camping zones, (2) evaluate the suitability of ghost crabs (*Ocypode cordimana*) as biological indicators of human stressors in coastal foredunes, and (3) determine which habitat attributes are correlated with ghost crab abundance.

2. Materials and methods

2.1. Study site

North Stradbroke Island is a sand barrier island, forming the eastern rim of Moreton Bay, in south-east Queensland, Australia. Being close to the major metropolitan centre of Brisbane, it is a popular holiday destination, attracting 400 000 visitors annually. A major attractions is 'beach camping', where visitors camp on the coastal dunes with close access to surf beaches. Camping is highly popular, with up to 600 campers occupying a single camp zone during peak periods (Carter, 2005). Visitors often combine camping with other recreational pursuits such as fishing, swimming, surfing, walking, bird watching, and four-wheel driving.

Flinders Beach is one of the most popular recreational beaches on the island. It forms the northern edge of the island, is 4.6 km long, and is protected from the predominant south-easterly swells and winds (Fig. 1). The beach is of the reflective to intermediate morphodynamic type, 50–80 m wide at low tide, with fine sands of 260–350 μm (Schlacher and Thompson, 2007; Schlacher and Morrison, 2008). Four camping areas are situated in the primary dunes just landward of the foredunes. All camping areas show signs of human impacts, such as vehicle ruts and tracks, footpaths, campfires, cleared vegetation, litter and 'bush toilets'.

2.2. Field collections

The main design principle of the study centred on a spatial mapping of dune attributes and biological properties at a resolution that is fine enough to allow for use zoning by the local government authority. Consequently, available resources were allocated primarily to maximize spatial information. While it is recognised that there will be some variation in human pressures and possible biological response over time, the biological variables chosen integrate human pressures over time (e.g. ghost crab populations, plant assemblage structure), justifying a synoptic survey approach for this particular application.

We quantified vegetation community structure and ghost crab populations along the length of Flinders Beach (Fig. 1 and Electronic Appendix Table 1). Twenty-two sites were sampled where foredunes were present. Sites were positioned using a stratified random design where the entire length of the beach was divided into 200 m wide sections; sampling positions within each of these sections were determined also random, but constrained to fall within 50 m of the centre point of each section to achieve dispersion of sites amongst sections. To further avoid sampling bias, the entire site selection process was done in Google Earth before field work started. All foredunes at the southern end of the beach were completely eroded during the time of the survey (April–June 2009) and there were no foredunes at two other pre-determined locations (nominal sites 21 and 22).

At each site, five cross-shore transects were placed along the shore with individual transects separated by 30 m. Transects extended from the unvegetated beach 3 m seaward from the base of the foredune (level 1) to the edge of the vegetation line which marks the boundary between the foredune and the primary dune (level 9). This boundary was distinct, marked by a change from low grasses and herbs to trees, mostly *Casuarina equistifolia*. Distance between levels varied between 3 and 10 m depending on the width of the foredune. Dune profiles were measured at every transect using a theodolite, with the base of the foredune (level 2) as the reference point.

The typical dune profile was characterised by a small crest (mean elevation: 0.75 ± 0.04 m) inland from the driftline, followed by a concave depression (swale) from levels 5 to 7 (mean elevation: 0.59 ± 0.02 m). On average, slopes were steepest ($4.73 \pm 0.29^{\circ}$) at the seaward face of the incipient foredune, and gentlest (1.11 ± 0.09) in the centre of the swale (Fig. 2a). The width of the foredune ranged from 18 m (site 23) to 99 m (site 3), while the maximum rise – as measured from the base of the foredune – varied between 0.82 m (site 23) and 2.42 m (site 5).

As a diagnostic check for any possible confounding of habitat topography on contrasts for biological variables between camping and non-camping zones, key habitat metrics related to dune morphology were compared between camping and non-camping zones (i.e. mean, maximum and coefficient of variation of elevation, slope, and dune width). There was no significant separation of camping zones (ANOSIM; $R = -0.184$, $P = 0.93$), and hence the foredunes are fundamentally very similar in terms of their physical habitat properties in camping and non-camping zones. It is therefore improbable that any differences documented for biota between camping and non-camping zones resulted from physical habitat differences and not from human use.