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Surface activity patterns of macrofauna on pocket, tidal beaches: Insights into the role of wrack and artificial lighting[☆]

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ABSTRACT

This study targets surface activity of mobile macrofauna on pocket tidal beaches, undergoing different human use. We considered two beaches in Pittwater (NSW, Australia): Tennis beach on Scotland Island features artificial structures and provided with artificial lighting, while Portuguese beach (Ku-Ring-Gai Chase National Park) is only accessible by boat and has no artificial structures. At each site we placed pitfall traps across the littoral zone, with replicates at an opposite tidal period. Traps were kept active for 24 hours and emptied every three hours. The beach-hopper *Platorchestia smithi* was dominant in abundance at both sites; however Portuguese had a higher species number, including the burrowing isopod *Actaecia bipleura*. Circular summaries and behavioural models were calculated for abundant species. We found two different activity peaks for adults (nocturnal) and juveniles (sunrise) of *P. smithi*, consistent across sites, and a complex, tide-related pattern for *A. bipleura*. We also remarked the relevance of wrack presence on the littoral: this factor was found to modulate the activities of specific categories of macrofauna, such as females and juveniles of *P. smithi*, and *A. bipleura*. Results finally indicated no effect of artificial lighting on surface activity of abundant beach species.

1. Introduction

Sandy beaches are physically-driven environments, where physical constraints are expected to shape biotic interactions within macrofauna communities (McLachlan and Brown, 2006). Mobile resident macrofauna on sandy beaches is adapted to move across the littoral consistently with periodical flows of energy and material. As sandy beaches are also extremely diverse between each other, the local dimension is highly relevant to understanding ecological and behavioural patterns. To this aim, a range of local studies is needed across different physical conditions, and consequently different resident beach communities. In our case, we focused our study on two tide-dominated, pocket beaches in Pittwater (New South Wales, Australia), differing in terms of human use.

Tide-dominated, dissipative beaches are considered to be a more benign environment for biota, hosting higher species number as an overall characteristic across macroareas (McLachlan and Brown, 2006; Defeo and McLachlan, 2011). At the same time, their width is expected to allow habitat partitioning in space, and a clear zonation of resident fauna (McLachlan and Brown, 2006). However the target beaches of our study are pocket beaches and are mostly covered by water during high tide (the width of the supralittoral during high tide being 2–4 m, personal observation during preliminary assessment and Short, 2006). This poses questions regarding the activity of macrofauna in such a context: is the periodical reduction of habitat driving resident populations to local adaptations towards habitat partitioning in time rather than in space?

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Behavioural adaptations, including the timing of surface activities, have already been indicated as key tools for survival of supralittoral species (Brown, 1996). In particular time partitioning of surface activities was reported for resident sandy beach organisms at community level (starting from Dahl, 1952), but also at intra-specific level, at least for the most abundant species: talitrid amphipods, usually dominant in abundance on sandy shores worldwide, displayed temporal differentiation of surface activity by cohorts, with adults and juveniles active at different times of the day (Jaramillo et al., 2003; Fallaci et al., 2003). In particular, the pattern depicted for the beach-hopper *Orchestoidea tuberculata* was explained by Duarte et al. (2010) as the need of juveniles to avoid cannibalism by conspecific adults.

Our study targeted the activity of resident arthropod fauna on selected sites, firstly to test whether the patterns already described on wave-dominated and microtidal beaches are consistent to those on pocket, tide-dominated beaches. Furthermore we investigated two main features of ecological relevance: (1) the effect of wrack presence on the activity patterns of resident arthropod fauna and (2) the effect of artificial lighting on the activity patterns of resident arthropod fauna. Both phenomena are common worldwide, are related to beach management and finally to the capability of a beach for maintaining healthy resident communities.

Stranded wrack represents a food supply and/or a shelter for some beach resident species, providing an overlapping habitat with respect to the sand (Orr et al., 2005). Species burrowing in the substrate, thus substrate-modifiers, can be distinguished by species related to stranded material, thus non-substrate-modifiers (starting from Pérès and Picard, 1964). The provision of fresh stranded material is also connected to tides, therefore introducing a temporal (periodical) component into the dynamics of resources availability. As a consequence, wrack colonizing communities can be discriminated on temporal-based categories, such early-intermediate and late colonizers (Inglis, 1989; but see Ruiz-Delgado et al., 2014 for mangrove propaguli). We are here investigating whether the supply of freshly stranded wrack brought in by the tide may have an effect on the activity of resident populations. In this case we would expect activity during the daylight, after the high tide (similarly to what reported by Jaramillo et al., 2003).

Artificial lighting was found to affect the behaviour of local populations of talitrid amphipods (Hartwick, 1976). Namely, the orientation of *Talitrus saltator* was affected by the presence of a lighthouse, which was integrated as a local landmark for orientation of resident populations. However there is no clear statement about the effect of artificial lighting (in field experiments) on activity rhythms of resident sandy beach populations. Here we hypothesize that if an artificial lighting is disrupting the tuning of the clock and compass mechanism by disturbing Zeitgebers such as sunset and sunrise (Fleissner and Fleissner, 2002), activities of the populations affected by the lighting would be more scattered than the non-affected ones.

The questions mentioned above were approached through field study, analysing the activity of mobile macrofauna across 24 h, and pairing it with the record of periodical and immediate abiotic factors.

2. Materials and methods

2.1. Study sites description

We selected two beaches in Pittwater, New South Wales, Australia (Fig. 1), Tennis beach (33°38.196′S151°17.567′E) and Portuguese beach (33°36.656′S 151°18.096′E). Their Relative Tide Ratio (RTR, as maximum tide (m)/breaker height (m); dimensionless. RTR values <3 indicated wave dominated beaches; 3–12 indicate tide modified beaches; >12 tide-dominated fronted by sand flats Masselink and Short, 1993) was estimated via Bascom method during preliminary surveys before the experiments. Portuguese beach had an RTR $= 8$, described as a reflective high tide beach with low tide terrace. Tennis had a RTR $= 13$, and was classified as dissipative beach with flat and featureless intertidal zone (Short, 1996).

2.2. Study sites an their human use

The human use of the two beach sites is extremely different. Tennis beach is surrounded by artificial hard structures and groynes, a bitumen/concrete access road and a wooden pylon public wharf. Artificial lighting is provided from behind the beach to the end of the wharf. Portuguese beach is instead located within the Ku-Ring-Gai Chase National Park, has no infrastructures, and it is only accessible by boat. Visitors are restricted to visiting during daylight, with overnight presence and camping forbidden at the site. To summarize this framework, we assessed for the two beaches the Conservation Index (CI) and Recreation Index (RI) after McLachlan et al. (2013). These resulted to be CI $= 0$ out of 10 and RI $= 7$ out of 10 for Tennis (i.e. intensive recreation use without conflict), while Portuguese scored CI $= 9$ out of 10 and RI $= 2$ out of 10 (i.e. primarily conservation use without conflict).

On both beaches wrack, mainly *Zostera* sp. and mangrove propagules reaches the beach and is not removed from the littoral, decomposing *in situ* (JKL pers.obs.).

2.3. Sampling

Sampling sessions lasted 24 h, starting on the low tide; two sampling replicates were carried out at each site, with alternated tidal regimens for each sampling event (tidal regimen is mixed tides at both sites; spring and neap tides were avoided). This approach allowed "tide" to be inserted as a factor in the analyses. During the experiment tides ranged from 0.35 m to 0.49 m (low tide) and 1.63–1.77 m (high tide), data retrieved from www.bom.gov.au/australia/tides/, locality Fort Denison. The whole study was carried out within one month, to avoid relevant variation in sun ephemerids, and consequent shift of the Zeitgebers for activity rhythms (Saunders, 2002). Within the study, sunrise varied between 5:52 AM and 5:38 AM and sunset between 7:26 PM and 7:47 PM, with ca. 14 h daylight (data retrieved from Timeanddate) (www.timeanddate.com (Timeanddate)). Artificial lighting at Tennis beach was turned on at 7:20 PM and off at 6:40 AM (LF pers.obs. during the preliminary observations for the preparation of the study). Beach profiles were also measured in occasion of the experiment: one profile at high tide and one at low tide were recorded per each replicate. Beach width (m), beach face slope (°, measured by clinometer Silva CM-360-LA), sand penetrability (cm of penetration into the substrate of an iron rod falling from 1 m height, more details in Fanini et al., 2009) were measured at high tide and low tide for each replicate.

Immediate variables such as substrate temperature (supralittoral and intertidal, °C measured with thermometer Hanna Instruments Checktemp HI98505) and wrack presence (as presence/absence in correspondence of 0.5 m distance from each trap) were measured at the time of each collection, to be related to the capture data from single traps in further analyses. Wrack was also estimated as percentage of the cover along the transect (Dugan et al., 2003).

Pit-falls traps (plastic cups with 9 cm diameter and 15 cm depth) were placed every two metres along two parallel transects distant 5 m from each other. When above 15 cm (the depth of a pitfall), the pressure of the water table forced the traps out of the substrate. Therefore the water table was used as lower limit for the