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Research paper

Walkways as an environmental enrichment tool on sandy beaches? A case study with ghost crabs (Crustacea, Ocypodidae)

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Abstract

Walkways as an environmental enrichment tool on sandy beaches? A case study with ghost crabs (Crustacea, Ocypodidae). Confined to a few favorable patches of habitat within a mosaic of physical drivers, many species disappear from human-disturbed beaches. However, mobile species may change their distribution and select more appropriate habitats as a response to disturbance. Ghost crabs are one of the few beach resident animals capable of moving over considerable distances, but usual habitat homogeneity of urban beaches theoretically prevents them from finding refuge. Here, I tested whether access walkways provide a habitat for ghost crabs on four beaches in southeastern Brazil. I counted and measured burrow opening diameter under walkways and in surrounding transects located at various distances from these structures between June 2020 and May 2021. Mean burrow density was three times higher in transects out of walkways than under the walkways. However, burrows were larger and positioned farther from the waterline under walkways. Walkways thus possibly provide protection for ghost crabs from trampling and vehicle traffic in urban beaches and could therefore be applied as an environmental enrichment tool in the management and conservation of sandy beach biodiversity.

Key words: Ecological indicator, Bioindicator, Ocypode, Management, Conservation

Resumen

¿Las pasarelas como herramienta de enriquecimiento ambiental en las playas de arena? Un estudio de caso con cangrejos fantasma (Crustacea, Ocypodidae). Confinadas a unos pocos parches favorables de hábitat dentro de un mosaico de factores físicos, muchas especies desaparecen de las playas alteradas por los seres humanos. Sin embargo, las especies móviles pueden cambiar su distribución y seleccionar hábitats más apropiados en respuesta a las perturbaciones. Los cangrejos fantasma son uno de los pocos animales residentes en las playas que pueden recorrer distancias considerables, pero la homogeneidad habitual de estos hábitats les impide encontrar refugio en teoría. En este estudio, examiné si las pasarelas de acceso a cuatro playas del sureste de Brasil constituyen un hábitat para los cangrejos fantasma. Entre junio de 2020 y mayo de 2021, conté y medí el diámetro de apertura de las madrigueras situadas debajo de las pasarelas y en transectos circundantes ubicados a diferentes distancias de esas estructuras. La densidad media de madrigueras fue tres veces mayor en los transectos fuera de las pasarelas que debajo de ellas. Sin embargo, debajo de las pasarelas las madrigueras eran más grandes y estaban ubicadas más lejos de la línea de flotación. Las pasarelas posiblemente brinden protección a los cangrejos fantasma del pisoteo y el tráfico de vehículos en las playas urbanas y, por lo tanto, podrían utilizarse como una herramienta de enriquecimiento ambiental en las prácticas de manejo y conservación de la biodiversidad de las playas arenosas.

Palabras clave: Indicador ecológico, Bioindicador, Ocípodo, Manejo, Conservación

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Introduction

Sandy beaches are typical ecotones at the interface between aquatic and terrestrial environments. As such, marine, semi-terrestrial and terrestrial species coexist along the sea-land gradient. As this gradient is practically the only source of fine-scale spatial heterogeneity, animals are naturally exposed to physical and climatic weathering. In this relatively homogeneous and open system, allochthonous and often erratic materials become important refuges for wildlife (Dugan et al 2003). The reintroduction of allochthonous organic detritus constantly removed by cleaning services, for example, has been target of environmental enrichment proposals to mitigate human impact on sandy beaches and increase their habitat heterogeneity (Schlacher et al 2017).

Human stressors that affect ocean sandy beaches are mostly physical (Defeo et al 2009). They result from overuse and urbanization, which degrade coastal vegetation, increase the propensity for erosion, and decrease coastal resilience to storm events (Defeo and Elliott 2021). Confined to a few favorable patches of habitat within a mosaic of natural physical drivers, many species disappear or become less abundant on beaches disturbed by human stressors (Costa et al 2022). On the other hand, mobile species are able to change their distribution and select habitats that have more favorable conditions and meet their specific demands for resources (Meager et al 2012, Rangel et al 2022).

Ghost crabs (Crustacea, Ocypodidae) are one of the few beach resident animals capable of moving over long distances (Schlacher and Lucrezi 2010). They have wide reaction norms, and this phenotypic plasticity added to larval dispersion has allowed their colonization of urban beaches. In rare cases, the population density may be even higher than in protected areas (Tiralongo et al 2020), but it is almost always lower on urban beaches (Costa and Zalmon 2019, Barboza et al 2021). In this scenario, ghost crabs are threatened by the suppression of coastal vegetation, trampling, cleaning services and vehicle traffic (Schlacher et al 2016, Costa et al 2020, Barboza et al 2021). Although ghost crab species are considered excellent indicators of condition, sandy beach management for their conservation, assuming the benefit of multiple coexisting species (Barboza et al 2021, Costa and Zalmon 2021), has not been applied. Indeed, sandy beach management worldwide remains overwhelmingly focused on tourist demands and ecological components are often neglected (Schlacher et al 2008, Defeo et al 2021).

Aligned with the idea of management for tourism, walkways are important components of accessibility to beaches (Diniz et al 2022). Indirectly, the walkways can also minimize trampling of coastal vegetation and provide a physical barrier to vehicle traffic. Here, we tested whether these structures (arranged perpendicularly to the coast) provide habitat for *Ocypode quadrata* (Fabricius, 1787), the only species of ghost crab found in southeastern Brazil. A case study was performed on four sandy beach sectors to test the null hypothesis that density, opening diameter and distribution of ghost crab burrows under the access walkways are similar to the patterns found in adjacent areas without these structures.

Material and methods

Study site

An extensive beach arc (Grussaí) in the north coast of Rio de Janeiro state, south-eastern Brazil (-21.694339°, -41.023783°) was chosen to monitor the Atlantic ghost crab populations. The municipality of São João da Barra receives ~150,000 tourists during the summer, mostly on Grussaí Beach Arc, which has a regional touristic value and offers leisure activities, food, hotels, and shows (Suciu et al 2017). The Grussaí Beach Arc has a set of micro-tidal beach sectors with intermediate morphodynamics and areas with distinct human disturbance levels. Walkways (~160 m length, 2 m width and 0.5-1 m height) perpendicular to the coast were built in 2012 in the most frequented urban beaches to enhance accessibility, for example, for disabled persons, the elderly, pregnant women and families with children (Diniz et al 2022). Despite these facilities, urban beaches have been subjected to high vehicle traffic (~2 vehicles/hour/100 m in the intertidal zone), litter pollution (~4 items/m^2) and beach cleaning, activities which occur in all urban sectors at the same frequency (daily during the high tourist season) and intensity (use of rakes to collect litter and a tractor to transport this) (Suciu et al 2017, Costa et al 2020). Consequently, previous data revealed lower ghost crab burrow densities (~4 occupied burrows/100 m^2) at high-impact sites than on low-impact sectors (~16 occupied burrows/100 m^2).

Sampling design and data analysis

Fifteen sampling campaigns (biweekly or monthly) were carried out between June 2020 and May 2021 at four beach sectors with walkways (fig. 1). Opened burrows were counted and measured with a calliper rule (burrow opening diameter) along five 3 m wide transects (beyond walkways) at varying distances from the walkways (left side), and arranged perpendicularly to the waterline from the upper swash limit to the beginning of the roadway (end of coastal vegetation). The same procedures were conducted under the walkways (as a transect), totalling six transects per sampling campaign. The transect length ranged from 210 to 250 m. All surveys were performed in the morning (6:00 to 10:00 hours) and when tide was low enough (≤ 0.5 m) to avoid covering the main distribution area of ghost crab burrows (Costa and Zalmon 2019).

A two-way ANOVA was used to compare burrow density (burrows/m^2), burrow opening diameter (mm) and distance of burrow to the waterline (m) among 'locality' (under walkways vs. out of walkways) and beaches (four beaches). Burrow density was transformed by square root to ensure linearity, homoscedasticity and normality of the ANOVA model. Transformation of the variables 'burrow opening diameter' and 'distance of burrow to the waterline' was not necessary.

Fig. 1. Map of the study area showing the beach sectors on Grussaí Beach Arc, south-eastern Brazil. These urban areas have similar walkway accesses to the beach and ghost crab burrows can be found under these structures.

Fig. 1. *Mapa de la zona de estudio en el que se muestran los sectores de la playa en el Arco de la Playa de Grussaí, al sureste de Brasil. Estas zonas urbanas tienen accesos peatonales a la playa similares y debajo de estas estructuras se pueden encontrar madrigueras de cangrejos fantasma.*

An ANCOVA was applied to test whether burrow density, burrow opening diameter and distance from the burrow to the waterline varied according to the distance of transects from the walkways; 'beach' was included as a categorical covariate. Burrow density and burrow opening diameter variables were transformed by square root to ensure linearity, homoscedasticity and normality. We used graphic inspection of residuals to validate the aforementioned linear models (Zuur et al 2010). Statistical analyses were carried out using the R software (R Core Team 2019).

Results

Mean burrow density was three times higher ($F_{walkway}$= 26.904; p = 0.0000) in transects outside of walkways (3 ± 3 burrows/m^2) than under the walkways (1 ± 1 burrow/m^2) (fig. 2A). This difference did not depend on the beach according to ANOVA ($F_{walkway\ x\ beach}$ = 1.975; p = 0.1170). Furthermore, burrows were usually larger under walkways (45 ± 19 mm) than in adjacent transects (24 ± 12 mm) ($F_{walkway}$= 135.770; p = 0.0000) (fig. 2B; fig. 1s in supplementary material). According to ANOVA, the magnitude of the difference between the opening diameter of burrows under walkways and out of walkways depended on the beach ($F_{walkway\ x\ beach}$8.512; p = 0.0000) (fig. 1s in supplementary material). Similarly, burrows were found at higher distances to waterline when sampled under walkways (83 ± 32 m) than in adjacent transects (18 ± 9 m) (fig. 2C), but this difference also depended on the beach ($F_{walkway\ x\ beach}$= 6.649; p = 0.0002) (fig. 2s in supplementary material).

According to ANCOVA, burrow opening diameter ($F_{distance\ to\ walkways}$= 2.343, p = 0.1270) and distance of burrows to waterline ($F_{distance\ to\ walkways}$= 1.493;

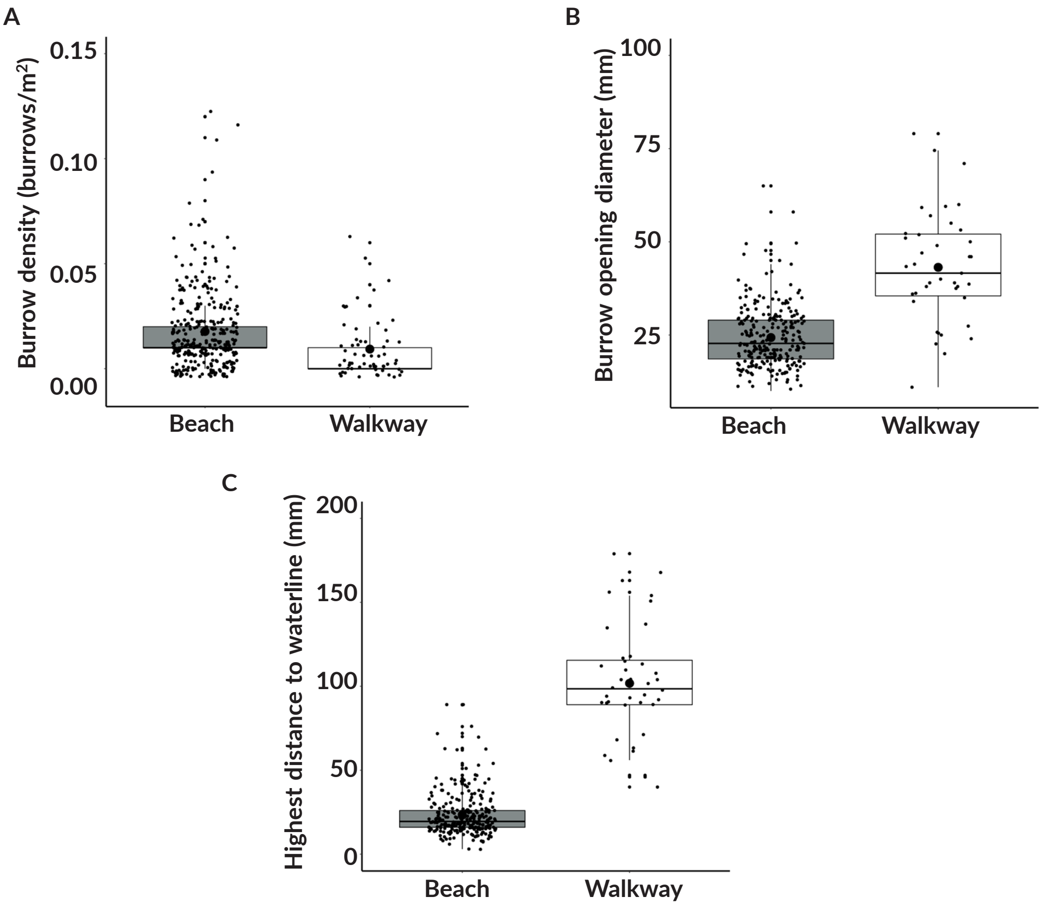

Fig. 2. Burrow density (A), burrow opening diameter (B) and largest distance of burrows to the shoreline (C) under walkways and in adjacent transects. Small dots within boxes represent each burrow sampled; lines within boxes are medians; the largest dot within boxes is the mean; boxes are interquartile intervals; and bars above and below boxes are upper and lower non-outlier intervals.

Fig. 2. *Densidad de las madrigueras (A), diámetro de apertura de las madrigueras (B) y mayor distancia de las madrigueras a la línea de flotación (C) debajo de las pasarelas y en los transectos adyacentes. Los pequeños puntos dentro de los diagramas de caja representan las madrigueras estudiadas, las líneas dentro de las cajas representan la mediana, el punto más grande dentro de las cajas representa la media, las cajas representan los intervalos intercuartílicos y las barras superior e inferior de las cajas indican el intervalo superior e inferior no atípico.*

p = 0.2230) did not vary in relation to the distance of transects to the walkways, regardless of the beach sampled. The burrow density increased slightly with increasing distance of transects from the walkway ($F_{distance\ to\ walkways}$= 4.182; p = 0.0418).

Discussion

The hypothesis that density, opening diameter and distribution of ghost crab burrows under access walkways are similar to the patterns found in adjacent areas without these structures was not corroborated. Indeed I found more burrows outside of walkways. However, burrows under walkways were usually larger and located farther from the sea. Thus, the lower burrow density under the walkways occurred because only adults thrived, at least in the spatial and temporal scale of the present study. These results show that access walkways provide additional habitats, especially for adult crabs, mainly because they have built burrows in zones where they would not conventionally do so. Juvenile crabs do not seem to use the walkways as often as adult crabs. Possible explanations for this observation are scarcity of food detritus, risk of cannibalism and competitive exclusion by adults.

Gül and Griffen (2019a) found that when larger ghost crabs were excluded from the system after a hurricane, the smaller individuals occupied upper parts of the beach. They argued that risk of cannibalism and competitive exclusion are major mechanisms determining the scarcity of juveniles in upper supralittoral, dunes and coastal vegetation. However, most studies suggest that the risk of desiccation is greater among juveniles and they thus select more moist areas close to the sea to build their burrows (Turra et al 2005, Lucrezi and Schlacher 2014). Walkways provide shade and certainly allow greater sediment moisture; however, the settlement of adult crabs inhibits the colonization of this habitat by juveniles. In addition, if the movement of adults away from the beach results in reduced antagonistic interactions, it is conceivable that the walkways, which primarily attract adults, could indirectly benefit juveniles. This might enable juveniles to thrive more readily on urban beaches, and as they mature into adults, they could further derive benefits from the presence of these walkways. This extends the potential environmental enrichment role that walkways can provide to urban beaches. On the other hand, if walkways also attract juveniles, they could function as ecological traps, potentially increasing the risk of cannibalism. Manipulative experiments are, however, necessary to determine why juveniles are not colonizing the sediment under the walkways, and whether they benefit from the displacement of adults.

Occupation of the habitat under the walkways by adult crabs is possibly the result of an amelioration of the physical environment. In addition to providing shade to the sediment, the columns of walkways clearly increase sediment stability and extend ghost crab burrow longevity. Because burrowing represents the most energetically expensive behavior among ghost crabs, they may adjust habitat selection and various activities to optimize this process (Gül and Griffen 2019a, 2019b). For instance, sedimentary stability has been conjectured as a reason why ghost crabs build burrows near large anthropogenic litter items and around other physical barriers to sediment transport (Schlacher et al 2016, Costa et al 2018).

Neves and Benvenutti (2006) also perceived that ghost crab burrows were distributed mainly in zones where vehicles were not present, specifically nearby kiosks. Thus, walkways also provide protection against excessive collapse of burrows caused by trampling and vehicle traffic (Costa et al 2020). In addition, Schlacher et al (2007) showed that vehicles can kill ghost crabs even when they are buried. Walkways thus also protect ghost crabs from being crushed, since vehicles do not travel through these areas. Finally, because cleaning services do not remove detritus that accumulates under the walkways this habitat also seems to provide enough food for the ghost crabs, including human-derived food left by visitors (Blankensteyn 2006, Schlacher et al 2011). These arguments therefore strengthen the idea that access walkways resemble environmental enrichment tools and can be purposefully applied to mitigate the impact of tourism on sandy beaches.

Mobile species other than the ghost crabs, especially those that inhabit the dunes and coastal vegetation such as lizards, were not considered in this study. Caution is thus needed regarding the positive effect of access walkways on coastal biodiversity. Carpio et al (2017) argued that walkways over coastal dunes can be a barrier to lizards; they strengthened this argument when finding that walkways reduced the mobility of the spiny-footed lizard *Acanthodactylus erythrurus* (Schinz, 1833) in a beach in Spain. However, the walkway studied by Carpio et al (2017) was built parallel to the beach, mainly because it was designed to let the people walk through the dunes rather than to link the inner zone with the beach. In addition, the said walkway was raised about 20 cm above the sand level, preventing the natural dynamics of the dunes and the movement of various animals (Carpio et al 2017). The walkways on the beaches in the north of Rio de Janeiro state were built perpendicularly to the coast and were raised more than 1 m above the sand, although the dynamics of the dunes have been causing some of the walkways to be covered by sand in recent years and need constant maintenance.

Conclusion

In summary, walkways built on four sandy beaches in southeastern Brazil were found to provide habitat for ghost crabs. Specifically under walkways, mainly adult crabs constructed burrows in upper parts of the beach, where they would not conventionally do. This opens a new field of investigation regarding ecology and management for the conservation of sandy beach biodiversity. Management interventions on ocean beaches are generally applied to promote tourism, and almost all of them produce socio-ecological conflicts. Environmental enrichment coupled with monitoring can be a solution to mitigate the impact of beach overuse. In addition to improving people's access to the beach, walkways, can now be considered a possible management intervention for the conservation of ghost crabs, which are a main ecological indicator on sandy beaches. Future studies could verify whether the perpendicular walkways affect the physical dynamics of the ecosystem and the movement of other animals, including those of conservation concern, such as lizards.

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Conflicts of interest
No conflicts declared

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Supplementary material

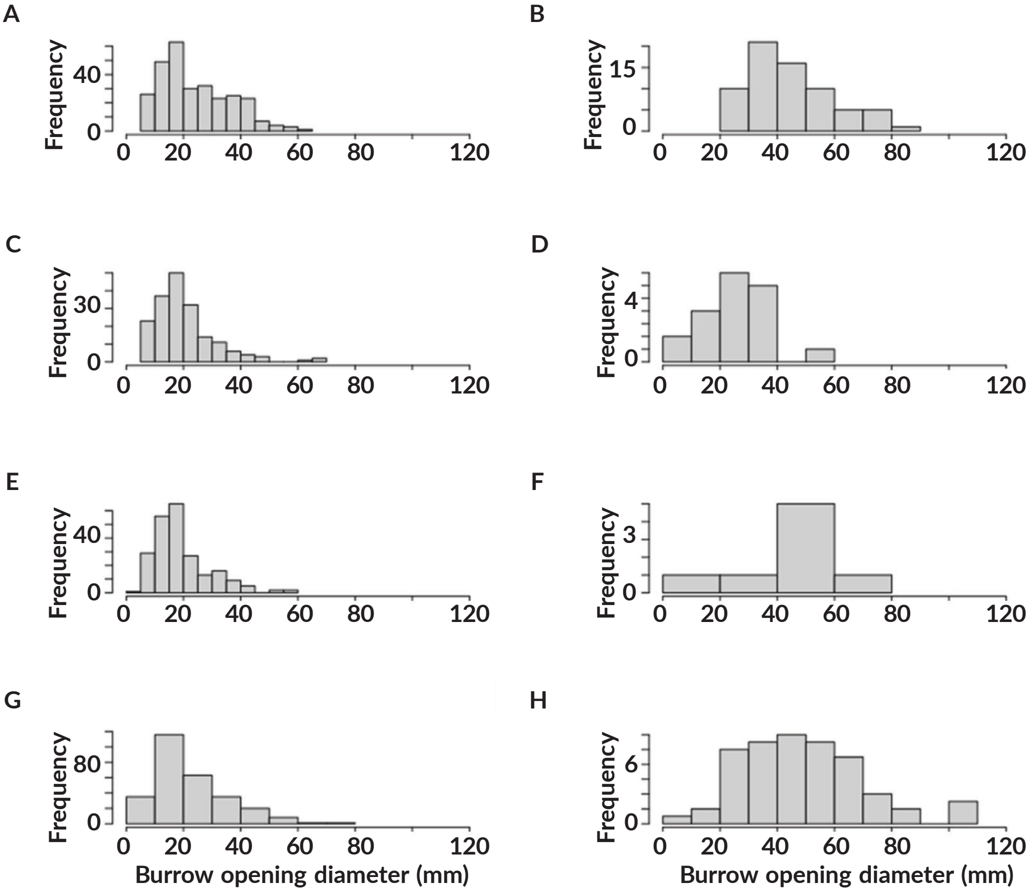

Fig. 1s. Histograms showing the frequency of burrow opening sizes on four beaches (A-B, C-D, E-F and G-H) under walkways (B, D, F and H) and in adjacent transects (A, C, E and G).

Fig. 1s. *Histogramas en los que se muestra la frecuencia de los tamaños de la abertura de las madrigueras en cuatro playas (A-B, C-D, E-F y G-H) debajo de las pasarelas (B, D, F y H) y en los transectos adyacentes (A, C, E y G).*

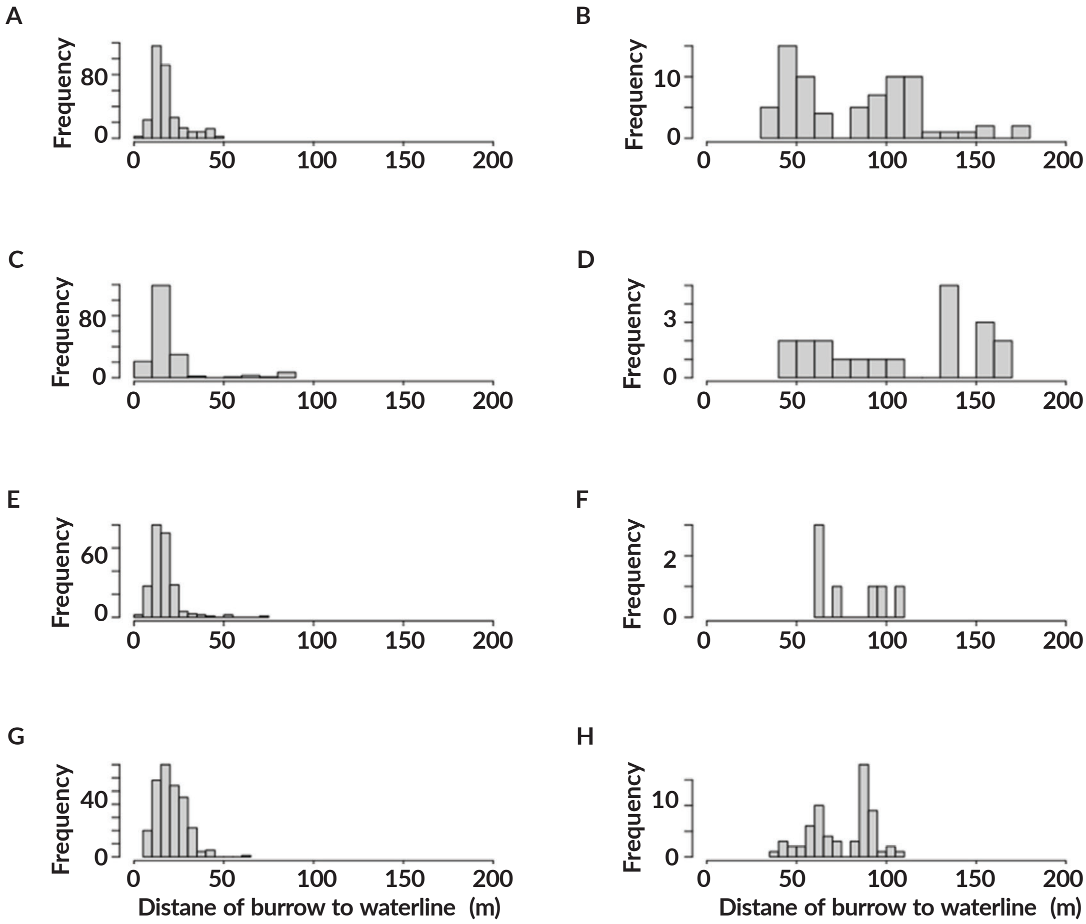

Fig. 2s. Histograms showing the distance of burrow to waterline at four beaches (A-B, C-D, E-F and G-H) under walkways (B, D, F and H) and in adjacent transects (A, C, E and G).

Fig. 2s. *Histogramas en los que se muestra la distancia de la madriguera a la línea de flotación en cuatro playas (A-B, C-D, E-F y G-H) debajo de las pasarelas (B, D, F y H) y en los transectos adyacentes (A, C, E y G).*