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The response of Tufted Ghost Crab, *Ocypode cursor*, populations to recreational activities in an urbanized coast with small-scale protected zones

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Tufted Ghost Crabs (*Ocypode cursor*) experience local population declines and also range contractions at larger spatial scales due to increasing anthropogenic pressures on coastal ecosystems. Therefore, the environmental drivers of the decline in ghost crab populations and the efficiency of protection measures are needed to be better understood for more efficient coastal management. We surveyed Tufted Ghost Crab populations along a 3 km coastline in the Levant Basin of the Mediterranean, which hosts two protected with low and two public beaches with intense human recreational use. Abundance and distribution of the crabs were surveyed along 24 transect counts. The protected beaches hosted more burrows than corresponding nearby public beaches and the ghost crabs in the protected beaches inhabited a larger habitat band. Furthermore, Tufted Ghost Crab populations in the protected beaches consisted of more diverse age groups than that of public beaches, which lacked the smaller size crabs. Overall, our survey corroborated the role of Tufted Ghost Crabs as indicator species of coastal ecosystems and demonstrated the potential role of small protected zones within urbanized coastal regions as refugia for Tufted Ghost Crabs.

Keywords: Coastal management and conservation; indicator species; metapopulations; size diversity

Introduction

Habitat degradation and loss due to anthropogenic pressures have been increasing globally and coastal ecosystems as well as the associated biodiversity have been severely affected (Newton et al., 2020). Therefore, understanding the consequences of these anthropogenic pressures and their effects especially on indicator species is crucial for a better coastal ecosystem management.

Ghost crabs (*Ocypode* sp.) construct burrows on sandy beaches in tropical and subtropical regions and are mostly nocturnal (Karleskint et al., 2009). They feed on insects, macroalgae and Crustacea (Chartosia et al., 2010) as well as predate on sea turtle eggs (Marco et al., 2015). Some ghost crab species (*O. quadrata*, *O. cordimanus*, *O. ceratophthalma*) have been experiencing population declines globally (Schlacher et al., 2016) especially due to human activities including urbanization and habitat loss (Barros, 2001), vehicle use (Costa et al., 2020) and intense human trampling (Lucrezi et al., 2009). A previous study in the Mediterranean area has indicated that the abundance of Tufted Ghost Crabs (*O. cursor)* was negatively affected by habitat loss and degradation (Barakalı et al., 2020). However, there are also studies in the Mediterranean area suggesting a potential positive effect of human beach use on ghost crab populations mostly

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due to increased resource availability (Strachan et al., 1999; Tiralongo et al., 2020). Furthermore, demographic changes in ghost crab populations due to varying degrees of disturbance have also been documented (Corrêa et al., 2014). Overall, ghost crabs have been suggested as an indicator species for the pressures on coastal ecosystems due to their sensitivity to anthropogenic impacts (Gül & Griffen, 2018a, 2020; Ocaña et al., 2020). However, the extent of the response of Tufted Ghost Crabs to the anthropogenic drivers as well as the efficiency of coastal protection management practices require further research, especially in under-studied regions like the Levant Basin in the Mediterranean area.

In the present study, we aimed at understanding the effects of human beach use and coastal protection on the abundance and population size structure of Tufted Ghost Crabs under contrasting anthropogenic pressures in the Levant basin of the Mediterranean. We hypothesized that human recreational beach use would decrease the abundance and alter the age composition of Tufted Ghost Crab populations.

Material and Methods

Study area. The studied coastline (3 km in total), which consists of two protected and two public beaches, is a part of a densely-urbanized region of the East Mediterranean coast of Turkey (Figure 1). The protected beaches are located in the Middle East Technical University Erdemli Campus, where public access to the beach is controlled and eco-friendly coastal management policies are applied. The protected beaches cover 800 and 300 m coastline and in this study they are named as Protected 1 and Protected 2, respectively (Figure 1). The protected coastline has vegetated natural sand dunes and host sea turtles (*Caretta caretta* and *Chelonia mydas)* which regularly nest on these beaches (Oğul et al., 2019). The two public beaches (Kocahasanlı and Limonlu beaches) are located neighbouring the protected beaches and they are open to human use without any management policy. The public beaches are covering 900 and 300 m coastline and they are named as Public 1 and Public 2, respectively (Figure 1). The public beaches, in contrast, have no sand dunes and coastal vegetation and are subject to high human activity especially in summer months. Also, Public 1 beach has a camping area which comprises seasonally used large tents. The site has very limited tidal activity (<40 cm).

Field surveys. The abundance and habitat use of Tufted Ghost Crabs and characteristics of their habitats were surveyed during a two-month period in June and July 2016. The survey was conducted using 25 m-long transects perpendicular to the shoreline, located 100 m apart from each other. 25 m transect length was selected as no Tufted Ghost Crab burrows were observed at a distance of more than *c.* 25 m from the shoreline. In total 25 transects were surveyed along 2.3 km coastline: 9 transects in Protected 1, 3 in Protected 2, 9 in Public 1 and 3 in Public 2 (Figure 1). Burrow counts on the transects were conducted between 05:30 and 08:00 am – before any human activity - on 15 consecutive days in the first half of June. First, each transect was marked by a scaled rope fixed on pegs and each transect was divided into habitat types: swash, wet sand, dry sand and vegetated zones. The location of each habitat zone on the transect was recorded as the distance to the shoreline. Second, any burrow within a 2-m distance from the transect (4 m total transect width) was surveyed. The occupancy of the burrow was not verified to minimize the disturbance on the crabs. Distance to the coastline, altitude from the shoreline, habitat type and burrow opening size were recorded for each burrow. The burrow opening size was taken as an indicator of crab size as burrow opening size and ghost crab size are correlated (Turra et al., 2005; Strachan et al., 1999; Türeli et al., 2009). The altitude of the burrow (from the shoreline) was calculated by using the inclination measured using a smartphone (iPhone 6S) located on the scaled rope which was tightly positioned as a straight line. The altitude was later calculated using trigonometric equations as a function of the distance to the shoreline and the inclination. If the slope was not monotonous (i.e. break points like presence of ditches or humps) the altitudes were calculated relative to the altitude of the break point. Weather conditions were favourable (no strong wind or precipitation) throughout the study period and there is no strong tidal activity in the region.

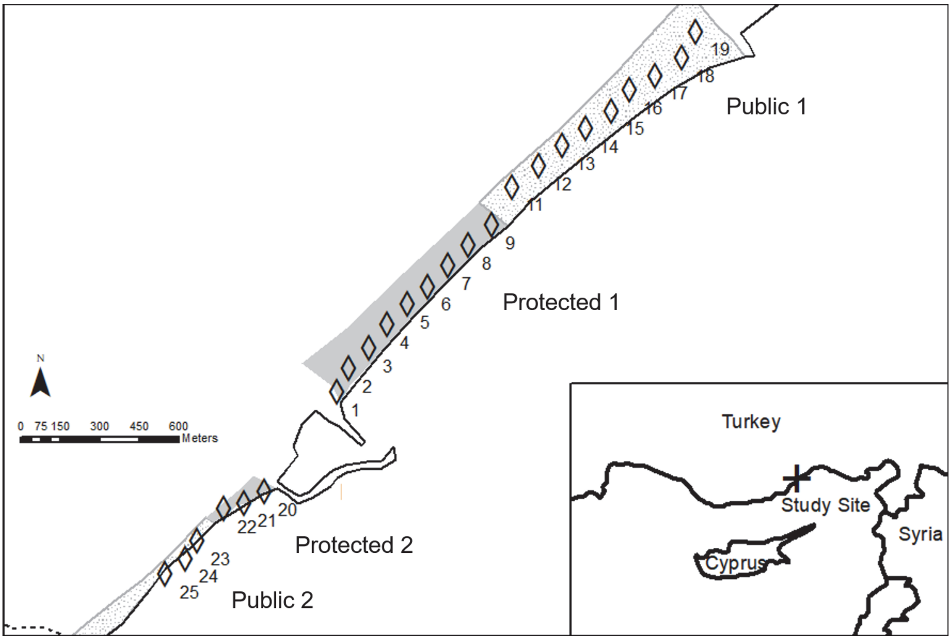

Figure 1. Study area at the Turkish Mediterranean coast. Protected 1 and Protected 2 are located in the Middle East Technical University Erdemli Campus with controlled human use, whereas Public 1 and Public 2 beaches are open to the public with intensive use. The survey transects are shown as diamond symbols.

Sand moisture and granulometry were quantified in each habitat at selected transects (T2, T4, T6 in Protected 1; T11, T13, T15 in Public 1, T21 in Protected 2 and T24 in Public 2). Randomly located duplicate samples in each habitat zone up to 20 cm sand depth were taken using a tube sampler (63 mm diameter) and stored in sealed plastic bags until laboratory analyses. Dry and wet weight as well as percent moisture were measured in each sample. Each sample was dried at 105°C until there was no weight loss in consecutive measurements. Samples with inconsistent moisture measurements (due to malfunction of sealed bags) in duplicate samples (T4 dry habitat and entire T11) were excluded from the analyses. Sand granulometry spectrum (as percent weight) of dried samples was analysed using a sieve set consisting of apertures: 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, 63 µm.

The anthropogenic pressure in each beach was estimated as human activity. The number of people on each beach was recorded every four hours from 11:30 to 18:30 hrs. on every Tuesday, Thursday and Saturday for two weeks in the entire beach.

Statistical analyses. Differences between public and protected beaches in burrow density, burrow abundance, burrow opening size and their variance, burrow distance from the shoreline and burrow altitude as well as human activity were analysed using Wilcoxon Rank Sum Test for non-normally distributed data and Welch's t-test for normally distributed data. The normality of the data were checked using Shapiro Wilk normality test. The correlation between burrow opening size and distance to the shoreline was tested using Pearson's correlation (Campbell, 2006).

The effect of habitat quality and human beach use on the abundance of burrows and burrow opening sizes of Tufted Ghost Crabs were modelled using Generalized Linear Models (GLM). Beach protection status, sand habitat quality and coverage of favourable habitat were selected as predictor variables. The transects were categorised as protected and public for protection status; fine and coarse grain size for sand habitat quality. The coverage of wet sand habitat was

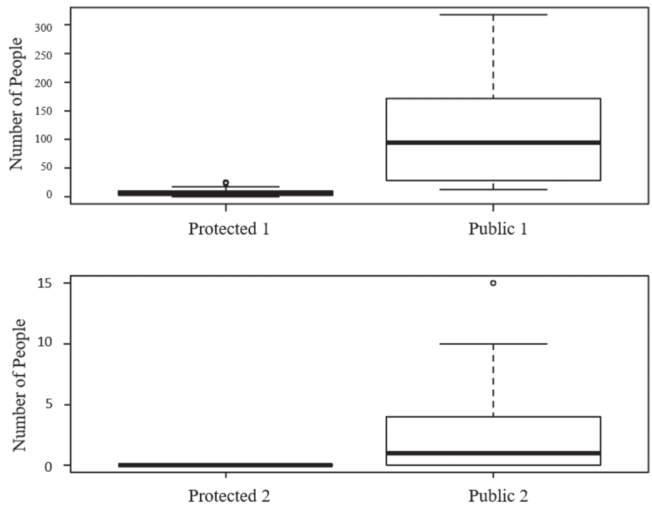

Figure 2. The intensity of human beach use in the studied beaches as expressed by the number of people using the beach for recreational activities.

quantified as percent coverage for each transect. The ghost crab abundance and burrow opening size were modelled both with Poisson and Gaussian error distributions. All the analyses were conducted in R environment (R Core Team, 2018).

Results

The beaches differed significantly in their habitat characteristics (Table 1, Table S1, Figure S1). Protected 1 and Public 1 beaches consisted of fine-grained sand (92% weight <250 µm; 1.7% weight >2000 µm), whereas Protected 2 and Public 2 beaches had larger grained sand (71% weight <250 µm; 10% weight >2000 µm) with frequent pebbles (Figure S1). Mean grain size sorting coefficient (logarithmic, Tanner, 1995; Gilbert et al., 2012) was 0.56 for Protected 1, 0.60 for Public 1, 1.33 for Protected 2 and 0.83 for Public 2. Protected beaches had larger wet sand habitat than public beaches and Protected 1 beach had a large vegetated zone within 25 meters to the shoreline (Table 1). Whereas, public beaches were dominated by dry sand zone with a uniform topography (Table 1). The humidity differed considerably among different habitat zones in all beaches, while humidity as percent weight was as high as 20% for the wet sand and swash zone (Figure S1).

The public beaches had significantly higher human activity than the protected beaches ($W = 277.5$, $P < 0.001$, Figure 2). The human activity in Public 1 beach was mostly in the form of recreational use like swimming and camping behind the shore. Evidence of infrequent mechanical beach cleaning, occasional vehicle tracks on T15, T16, T17 transects and large tents on T12, T13, T14 transects were also observed in Public 1 beach. The human activity in Public 2 beach was mostly in the form of recreational fishing. Human activity was more intense during the weekends and peaked in 18:30 o'clock counts and homogeneously distributed along the beaches. The human activity in Protected 1 and Protected 2 beaches were very limited (Figure 2).

Table 1. Habitat and burrow characteristics of the Tufted Ghost Crab, *Ocypode cursor*, in four beach sections with different levels of human activity. Standard deviations have been provided along with the mean values, when relevant.

	Protected 1	**Public 1**	**Protected 2**	**Public 2**
Transects (total)	9	9	3	3
Swash zone (mean % cover)	15.3	6.8	9.3	12
Wet sand zone (mean % cover)	40	23.7	77.4	30.1
Dry sand zone (mean % cover)	26.9	65.1	13.3	57.9
Vegetated zone (mean % cover)	17.8	4.4	0	0
Abundance of burrows (total)	71	33	7	2
Mean number of burrows per transect	7.9±3.9	3.66±1.3	2.3±2.1	0.7±1.15
Mean burrow density (ha^{-1})	857±408	367±173	233±208	67±115
Mean burrow density in wet sand (ha^{-1})	2162±1280	1769±1442	375±326	225±390
Mean burrow opening size (mm)	34.5±11.6	39.03±7.64	34.6±4.0	34.0±5.7
Burrow opening size range (mm)	5-60	22-56	25-35	30-35
Mean distance to shoreline (m)	9.2±3.4	4.65±1.55	10.1±3.0	8.7±1.1
Range of distance to shoreline (m)	4-18	2-9	5-15	8-10

Table 2. Relationship of burrow abundance and burrow opening size of the Tufted Ghost Crab, *Ocypode cursor*, with the level of human beach use, sand size quality extent of the wet sand zone in the beach transects. A GLM Model was used.

	Burrow abundance		Burrow opening size	
	Coefficient Estimate	P value	Coefficient Estimate	P value
Beach use (Protected vs. Public)	-0.82	<0.001	3.14	0.14
Sand size composition (Coarse vs. Fine)	-0.79	<0.05	-1.00	0.80
Wet sand habitat coverage	-0.006	0.3	-0.02	0.99

A total of 113 burrows were identified during the surveys (Figure 3, Table 1). Tufted Ghost Crab densities in beaches with fine sand (Public 1, Protected 1) were three times higher than in beaches with coarse sand (Public 2, Protected 2) (Figure 4, Table 1). No burrow with openings less than 25 mm were observed in beaches with coarse sand (Table 1, Figure 3). Burrows were observed only on wet sand and dry sand zones in all beaches (Figure 4). The number of burrows located on wet sand zone was 10 times higher than those on dry sand zone (Table 1, Figure 4) and no burrow openings smaller than 29 mm was observed in dry sand zone. The burrows in the protected beaches had higher mean distance to the shoreline (P<0.001) with larger variance (11.08 vs. 3.20 m^2) than that of the public beaches (P<0.001, Table 1, Figure 3). The burrows in the protected beaches had also higher mean altitude from the shoreline (P=0.03) with larger variance (0.093 vs. 0.027 m^2) than that of the public beaches (Table 1, Figure 3). No significant relationship was found between burrow opening size and distance to the shoreline for all beaches combined and also separately (P=0.59, Figure 3).

Tufted Ghost Crab abundance and burrow opening size were significantly different between protected and public beaches (Table 2, Figure 3 and 5). Transects on the protected beaches had significantly more burrows (P=0.02) with smaller mean burrow opening size (P=0.027, Figure 5) than that of the public beaches. The burrow opening sizes had higher variance in the protected beaches than that of the public beaches (P=0.01, Figure 3) and small size burrows less than 22 mm opening size were not observed in the public beaches (Table 1, Figure 3). In Public 1 beach, no burrows were

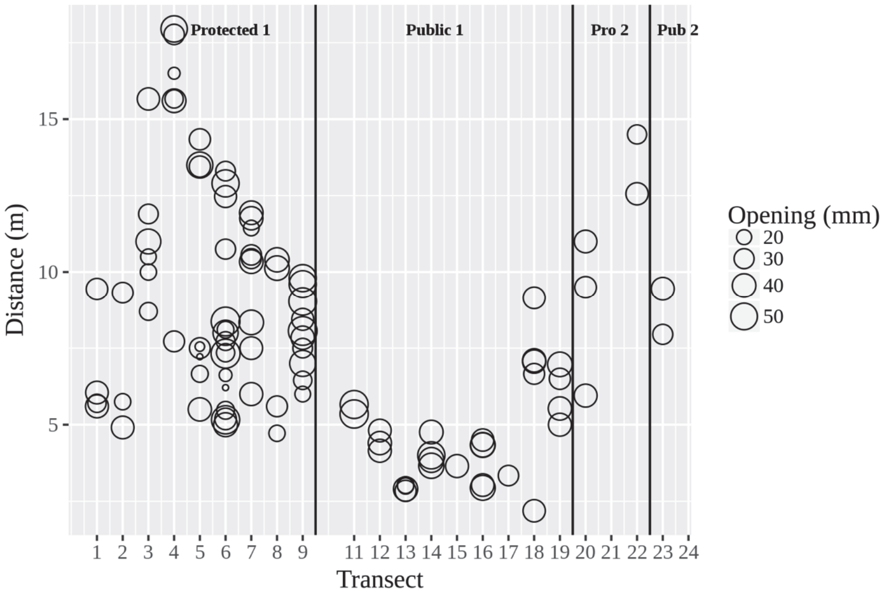

Figure 3. Distribution of the burrows of the Tufted Ghost Crab, *Ocypode cursor*, along the transects in the four beach sections studied. y-axis represents distance to the shoreline and x-axis shows the transects distributed in each beach. The size of the circles is proportional to the size of burrow openings (see legend).

observed beyond 9 m distance from the shoreline when there were large tents present. Moreover, the number of burrows were 80% lower in the transects with vehicle tracks in comparison to the remaining transects in the same beach.

GLM results indicated that public beaches (P<0.001) and beaches with coarse sand (P=0.012) had significantly lower crab abundance, whereas percent cover of wet sand habitat zone had no significant effect (P=0.30, Table 2). GLM model for the burrow opening sizes suggested that the public beaches hosted larger burrow opening sizes, however it did not attain statistical significance (P=0.143), probably due to small sample size (N=24).

Discussion

Ghost crabs are strongly affiliated with coastal habitats and therefore they have been suggested as good indicators of the extent of anthropogenic pressures affecting these habitats (Barros, 2001). The negative effect of human beach use, such as vehicle use (Costa et al., 2020) and pedestrian trampling (Lucrezi et al., 2009) on ghost crab abundance have been widely documented (Schlacher et al., 2016). However, no (Wolcott & Wolcott, 1984; Steiner & Leatherman, 1981) or positive (Schlacher et. al., 2011; Strachan et al., 1999) effect of human beach use on ghost crab populations have also been suggested, mostly due to an increase in food supply (Steiner & Leatherman 1981; Schlacher et al., 2011). We documented a negative effect of human beach use on Tufted Ghost Crab abundance and burrow opening size distribution; corroborating the previous findings on the negative impact of anthropogenic pressures on ghost crab abundances (Lucrezi et al., 2009; Gül & Griffen, 2018a, 2020).

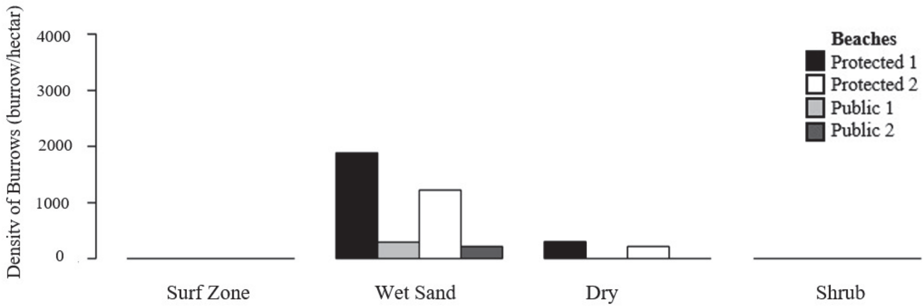

Figure 4. Density of Tufted Ghost Crab, *Ocypode cursor*, burrows in the four habitat types present in the study area. Wet sand zone hosts more burrows than the other habitat types.

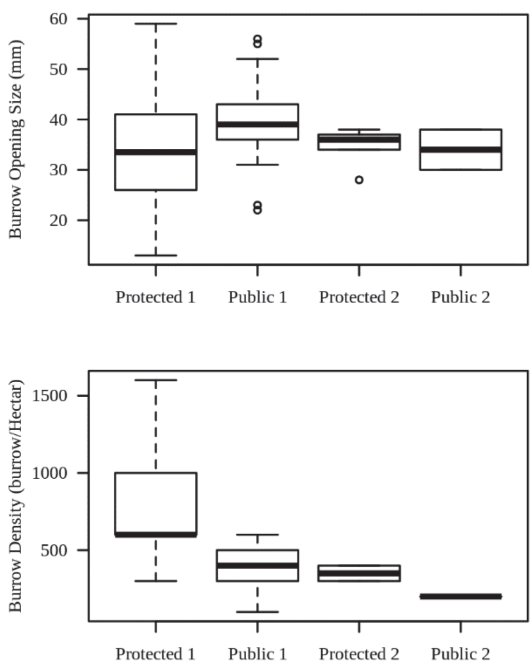

Figure 5. Comparison of the opening size (top) and density (bottom) of Tufted Ghost Crab, *Ocypode cursor*, burrows in the beach sections studied.

The number of burrows has been widely used as an indicator of the number of ghost crabs (Warren, 1990). However, burrow occupancy rate may change under different pressures (Pombo & Turra, 2013; Pombo et al., 2017) and the number of burrows does not always perfectly correlate with ghost crab abundances (Silva & Calado, 2013), especially due to human activities like trampling (Lucrezi et al., 2009). Experimental studies showed that human trampling negatively affect burrow detectability, however, ghost crabs restore burrow openings overnight (Lucrezi et al., 2009). All our surveys were conducted in early morning before any human activity on the beaches and therefore we did not expect any significant effect of day-time human activity on burrow detectability. However, it should also be noted that the present study is conducted along a limited coastline and the present results should only be generalized for the wider region with caution.

We observed a higher diversity of burrow opening sizes in the protected beaches than that of the public beaches. The public beaches specifically lacked the smaller burrow opening size classes (<25 mm, cf. Deidun et al., 2017). Changes in ghost crab burrow opening sizes, specifically a decrease, with increasing human use intensity have been documented in the United States of America (Gül & Griffen, 2018a, 2018b), mostly reflecting behavioural alterations and consequent physiological changes in ghost crab populations (Gül & Griffen, 2020). We observed, on the other hand, the lack of smaller ghost crab burrow opening size classes in disturbed sites, which might suggest that younger crabs with shallower burrows were more sensitive to disturbance, especially to the effects of humans trampling and vehicle use (Lucrezi, 2009; Costa et al., 2020). Furthermore, considering that these beaches were located next to each other, the protected and public beaches might have been functioning as a connected metapopulation and the protected beaches might have been functioning as a refugia for developing larvae and younger crabs, and supported neighbouring public beaches via emigration (Leibold et al., 2004; Burgess et al., 2014). However, such mechanism is likely to be possible at very small spatial scales as in the present study due to the limited dispersal capacity of adult ghost crabs (Schlacher & Lucrezi, 2010). Overall, our results corroborated the previous findings on the utility of scattered small protected areas for large scale coastal habitat conservation (Batista et al., 2014).

Habitat quality had also pronounced influence on ghost crab populations. Both the protected and public beaches with coarse sand had significantly lower Tufted Ghost Crab abundance than beaches with fine sand, as also documented in Türeli et al. (2009). All burrows were located in wet and dry sand habitats. No burrows were observed in the vegetated and swash zone, due to primarily water and physical stress (Vinagre et al., 2007). The number of burrows were significantly higher in wet sand habitat than that of dry sand habitat reflecting ghost crab's moisture requirements (Wolcott, 1976). Ghost crab burrows in the Public 1 beach were located closer to the shoreline as a narrow band; probably due to the lower sand moisture content and the higher human activity in the back parts of the beach (Gül & Griffen, 2018b).

Our results demonstrated that the anthropogenic pressures due to the recreational human beach use affected the abundance and burrow opening size composition of Tufted Ghost Crabs along an urbanised coastline in the Levant Basin of the Mediterranean Sea. Protected beaches harboured a more abundant Tufted Ghost Crab population, which utilised a larger coastal area and consisted of more diverse age groups. By contrast, the abundance and burrow opening size diversity of Tufted Ghost Crab burrows significantly decreased with more intensive human disturbance and only larger and older ghost crabs were observed in public beaches.

Supplementary Material

Supplementary material is given as a Supplementary Annex, which is available via the "Supplementary" tab on the article's online page (http://dx.doi.org/10.1080/09397140.2021.1877383).

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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