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The impact of *Acacia saligna* and the loss of mobile dunes on rodent populations: a case study in the Ashdod-Nizzanim sands in Israel

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ABSTRACT

The Mediterranean coastal dune habitat of Israel is diminishing rapidly, mostly due to massive urbanization, changes in habitat characteristics caused by dune stabilization and the presence of *Acacia saligna*, an invasive species brought to Israel for the purpose of dune stabilization. In this study we document the effect of sand stabilization on the composition of small mammal communities in the Ashdod-Nizzanim sands, Israel. We analyzed differences in species diversity and abundance for species of rodents in four types of habitat: unstable (mobile) sand dune, semi-stabilized dune, inter-dune depression and a plot of the invasive *Acacia saligna*. Rodent communities were found to undergo gradual changes concurrently with the stabilization of the sands. The mobile dune was the only habitat in which the strict psammophiles *Jaculus jaculus* and *Gerbillus pyramidum* were captured in abundance. No species commensal with human were captured neither in the mobile nor in the semi-stabilized dunes. However, in the inter-dune depression there was quite a large representation of *Mus musculus*, a rodent commensal with humans. The *Acacia saligna* plot had the lowest number of captures and the lowest rodent biomass calculated, with *Mus musculus* composing nearly half of the captures. The results of this study demonstrate that stabilization of the sands in Ashdod-Nizzanim area is associated with the disappearance of psammophile rodents and the appearance of species commensal with humans. In order to preserve the habitat for psammophile rodents, measures should be taken to halt the spread of acacia and the continuing stabilization of the sands.

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Introduction

Biological invasion has been identified as a serious global threat to biodiversity (Schmitz and Simberloff 1997; Walker and Steffen 1997), second only to habitat loss. Biological invasion occurs when an alien species penetrates into an environment beyond its original range, usually due to (often inadvertent) human aid. In this new environment the invasive species maintains itself unaided, and eventually proliferates (Mack et al. 2000). Rosenzweig (2001) argues that reduced species diversity is not the main problem caused by the invaders, but rather their effect on endemic organisms, which are outcompeted by the introduced species, or decline due to damage to the local ecosystem.

The coastal sand dunes are classified by the Israel Nature and Parks Authority as an ecological system on the verge of extinction (Shkedy and Sadot 2000). They lie along the Mediterranean coast as a narrow strip 190 km in length, 1 km wide in the north of Israel and 7 km wide in the south, encompassing an area of 580 km^2. These are young sands (on a geological time scale), less than 1000 years old (Tsoar 1990). The coastal sands of Israel are "desert islands" in the mesic Mediterranean region. In spite of the humidity and rain in this region, the plant community characterizing the coastal plain is Saharo-Arabian, due to the low water capacity characteristic of the sands (Danin 1999). This results in low nutrition due to low availability of nitrogen and organic matter for the plants. The coastal dunes are also unique in being continuous with the sands of the western Negev and Sinai and because they are relatively arid (Bytinsky-Salz 1953 in Werner 1990), thus enabling Saharo-Arabian species to penetrate. Accordingly, the coastal dunes habitat is rich in plants and animals, some of which are endemic to Israel – out of 155 endemic plant species in Israel,

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15 (9.7%) occur in the coastal dunes (Shmida 1982). This habitat is also home to psamophilic rodents, such as the endemic sand-living *Gerbillus andersoni allenbyi* (Mendelssohn and Yom-Tov 1999) and reptiles, such as the grey monitor *Varanus griseus* (Shacham 2010).

All of these species are in great danger of extinction because of the destruction of this habitat, mainly as a consequence of massive urbanization and fragmentation. This is the most densely populated area in the country, where more than half of the countrie's population lives. At present, only ca. 17% of the Israeli coastal dunes are still of good or reasonable ecological value, while less than 5% of this area has been designated as protected (Cohen and Bar (Kutiel) 2017), and is actually composed of "islands" bounded by heavily populated areas.

Sand mining is another major cause of scenery change and loss of habitat, as is recreation, both by hikers and even more so by off-road vehicles. Species commensal with humans also harm the naturally occurring species through predation (feral dogs – Manor and Saltz 2004; cats – Mendelssohn and Yom-Tov 1999), and outcompetition of psammophile rodents by rats and mice.

Another threat to the psammophile species is that of the ongoing disappearance of the active dune areas, while the vegetated areas are increasing due to diminished human pressure, such as the reduction of grazing, which took place since the 1940s (Tsoar and Blumberg 2002; Levin and Ben-Dor 2004). Wind power on the Israeli coast is low, thus enabling the vegetation recovery once human pressure was curtailed (Tsoar 2005). Stabilized sands change their characteristics, becoming richer in organic matter and clay compounds and increasing their ability to absorb water (Danin and Yaalon 1982). This process has been shown to have a negative impact on fauna diversity (Nijssen et al. 2005). Sand stabilization has enabled a succession of more generalistic plant species to settle in the sands.

At the beginning of the 20th century migrant sands were perceived as a problem in Israel. They covered agricultural areas and damaged major transportation routes. Extensive planting of dune stabilizing plants, native (e.g. *Artemisia monosperma*, *Ammophila arenaria* and *Tamarix aphylla*), as well as introduced species (e.g. *Acacia saligna* and other *Acacia* species, various species of *Eucalyptus* and others) has already started almost a century ago (Liphshitz and Biger 1997).

The Australian *Acacia saligna* is a single-stemmed tree or spreading shrub considered to be an invasive weed in Chile, Spain, Portugal, Cyprus, Jordan, Egypt, Israel and South Africa. In South Africa the spread of the *Acacia saligna* in the Mediterranean biogeographic region is recognized as the major threat to the globally significant Cape Floristic Region (Morris 1997; Yelenik et al. 2004; Nsikani et al. 2017).

In Israel *A. saligna* poses a threat to the fragile coastal sand dune habitat. Studying the dynamics of vegetation in the Ashdod-Nizzanim sands, Bar (Kutiel) et al. (2004) showed that during 34 years, the area covered by *A. saligna* grew by 166%, at a mean annual rate of 2.92%. This species forms a monotonous landscape of dense acacia thickets in the Aeolian-calcareous sand stone cliffs and the valleys in between, thus creating a problem in conservation of habitat and species diversity. In a recent study at that area, Cohen and Bar (Kutiel) (2017) concluded that "The presence of *A. saligna*, whether planted or invasive, is detrimental to nature conservation, in terms of the indigenous vegetation cover, diversity, and composition. … About 50% of the psammophyte [plant] species, which are characteristic of mobile sand dunes, and some of them are endemic to the region, disappeared from the sand dunes as a result of *A. saligna* invasion."

The aim of our study was to examine the effects of the invasion of *A. saligna* and the stabilization of the sand dunes on the distribution and abundance of the small mammal communities, thus adding the faunal perspective to the already reported botanic outcomes. In particular, we examined the effect on three species of psammophilous rodents and a rodent commensal with humans that has invaded this habitat.

Methods

Study site

The Ashdod-Nizzanim sands (17 km^2, about 40 m above sea level) constitute the largest sand area in the Mediterranean coastal plain in Israel, and the only one with large areas of mobile dunes (Achiron-Frumkin et al. 2003). The climate is Mediterranean, and the proximity to the sea moderates weather conditions and causes high humidity. The total annual rainfall is 450–500 mm, all of which occurs during the winter months (October–March). The study area was in the northern part of these sands, mostly in the Nizzanim Sand Park (31°46' N, 34°39' E). The borders of the study area comprise the city of Ashdod to the north, the Evtach stream to the south, the Mediterranean Sea to the west and the alluvial soil around Nizzanim youth village to the east. Since the 1950s most of this area has been undergoing a gradual stabilization process. The vegetation is composed of dwarf shrubs and herbaceous species, except for the alien tree *A. saligna* and individual trees of common date palm (*Phoenix dactylifera*) and sycamore (*Ficus sycamorus*) (Bar (Kutiel) et al. 2004).

The area can be divided into several types of habitats based on the different characteristics of the dune fronts and depressions (e.g. Achiron-Frumkin et al. 2003; Bar (Kutiel) et al. 2004; Wasserberg et al. 2006):

1) Acacia groves – These are areas with a high percentage (60–100%) of invading *A. saligna* coverage. In these areas the sands are stable. The area chosen for the study was a high-density acacia plot, adjacent to the Evtach stream, comprising trees less than 10 meters apart, which is defined as the spreading stage of this invasive species.
2) Stabilized dunes – These are usually in the areas protected from wind and in the inter-dunes (depressions between dunes). These areas are densely vegetated with 60–100% plant coverage.
3) Semi-stablized or semi-fixed dunes – These are characterized by coverage of perennial and annual vegetation. The stabilization of the dunes usually begins on the dune crest, where there is equilibrium between erosion and deposition of sand. The settling of plants improves water retention in the soil, and other plants are able to settle. The plant coverage in this area is between 20–60%.
4) Active or mobile dunes – The perennial vegetation coverage in this area is less than 20%. Most of the dunes are parabolic, usually on their south-western side, which is exposed to high wind intensity and as a result plants are not able to settle there (Bar (Kutiel) et al. 2004).

Animal species examined

The study focused on small mammals, granivorous rodents in particular. These were selected as indicators of the effect of acacia invasion because they are relatively abundant and easy to catch and measure.

Allenby's gerbil (*Gerbillus andersoni allenbyi*) is an endemic sub-species common throughout the Mediterranean coast of North Africa, Sinai and Israel (Harrison 1972; Osborn and Helmy 1980). In Israel this species occurs in relatively stabilized dunes along the coastal dune sands as well as in the western Negev sands.

The greater Egyptian gerbil (*Gerbillus pyramidum*) is common throughout North Africa, Sinai and Israel (Harrison 1972). In Israel it occurs among unstable sand dunes south of Tel Aviv and in the Negev sands (Mendelssohn and Yom-Tov 1999).

The lesser Egyptian jerboa (*Jaculus jaculus schlueteri*) is an endemic sub-species found on unstabilized dunes in the coastal plain south of Tel Aviv and in the northern Negev (Dolev and Perevolotsky 2002).

These three species are mainly granivorous and partly feed on leaves (Mendelssohn and Yom-Tov 1999).

The common house mouse (*Mus musculus*) is commensal with humans and found throughout Israel except for the driest parts of the Negev desert (Boursot et al. 1993). It is omnivorous, feeding mostly on grain, but also on insects and other arthropods, vegetation and garbage (Mendelssohn and Yom-Tov 1999).

In addition to the above species we also caught several individuals of three other small mammals: common rat (*Rattus rattus*), Tristram's jird (*Meriones tristrami*) and lesser white-toothed shrew (*Crocidura suaveolens*).

Study design

The study was conducted between April 2003 and late April 2004. Due to logistic constrains (e.g. avoiding heavy disturbance by off-road vehicles), only four plots, one for each of four habitats: acacia grove, inter-dune depression (between stable dunes), semi-stabilized dune and mobile dune (measuring 3.69, 0.95, 2.59 and 5.18 ha, respectively), were chosen in the Ashdod-Nizzanim sands.

We estimated the percentage of plant coverage of each habitat by measuring this variable in 15 different random transects (10 × 1 m each) for each plot. This was done during April 2005.

In each plot, 45 traps were deployed in fixed locations, which were determined using GPS, for studying the rodent population in the various habitats. The traps in most plots were scattered in a grid-like format, 10 m apart in the inter-dune depression plot, and at a slightly greater distance apart for the mobile and the semi-stabilized plots in order to avoid heavily used recreational vehicle pathways. The traps in the acacia plot were placed under the acacia plants at a minimum of 10 m apart. The distance between traps was preset according to the reported home ranges of the species investigated (Abramsky 1984; Aram 1999).

We used standard traps (10 × 10 × 23 cm metal box traps) with a door attached by a spring onto a hook on which we placed peanut-flavored corn snack bait. The traps were set approximately one hour before sunset, left until sunrise, and their contents were then examined. The location of the point of capture for each individual was registered, and the traps were collected and not left in the field because of intensive human activity in the area.

Data collected for all captured mammals included: species and gender; weight to 1 g accuracy (using a Pesola spring balances); tail, ear and hind leg (tarsus-metatarsus) length (measured with a metal ruler to 1 mm accuracy).

In order to preclude effects of moonlight on capture rates (Kotler 1984a,b; Randall 1993), each lunar month comprised of two trapping sessions: one session was conducted at the beginning of the month (seven days before the full moon) and the other was conducted seven days after the full moon. At each session two plots were examined, interchangeably, each during a series of two consecutive capturing nights. Thus, each plot was examined once on every month, during a series of two consecutive nights. The total number of capture nights was 58. Data from all 45 traps of each plot were used to calculate the rodent species diversity and the biomass of each habitat, and for cluster analysis which demonstrated the similarity between habitats (see below).

Data analysis

Simpson's diversity index $D = 1 - \sum_k \frac{n_k(n_k - 1)}{N(N-1)}$ (where n_k is the number of captures of species k and N is the total rodent captures in a plot) and Shannon-Wiener's diversity index $H' = -\sum_k p_k \ln p_k$ (where p_k is the proportion of number of captures of species k relative to the total rodent captures in a plot) were calculated for small mammal diversity in the different plots (Lehmann and Perevolotsky 1992; Kutiel 2000). Similarity between habitats with regard to rodent species distribution was calculated using the modified Morisita's similarity index. Thus, the similarity between habitats i and j is

$$MMSI_{ij} = \frac{2\sum_k x_{ik}x_{jk}}{\left[\sum_k (x_{ik}^2/N_i^2) + \sum_k (x_{jk}^2/N_j^2)\right] N_i N_j}$$

where x_{ik} is the total number of captures of species k in habitat i, and $N_i = \sum_k x_{ik}$ is the total number of rodents captured in habitat i. Cluster analysis was used to generate a dendrogram which demonstrates similarities between habitats in their species composition (Shenbrot et al. 1999). Nearest neighbor, single linkage procedure was used based on the smallest linkage between the groups.

Total rodent biomass was calculated as the sum of weights for the small mammals in each plot during the research period, divided by the area of the plot. Since there were great differences in the rodent weights, the total biomass presents a better measure of the effect of the rodent populations on the environment (Abramsky et al. 1985; Abramsky 1988; Lehmann and Perevolotsky 1992).

Results

Mean plant coverage of the various plots are given in Fig. 1. While plant coverage of the acacia (86.10 ± 2.85%, mean ± standard error) and the inter-dune depression (93.87 ± 1.03%) plots did not differ significantly, they were significantly higher than that of the semi-stabilized dune (36.30 ± 3.05%), which was significantly higher than that of the mobile dune (11.13 ± 2.91%). (Pairwise t-tests with Bonferroni correction).

During the 13 months of our study (58 capture nights, 1186 captures), six different species of rodents were captured: *Gerbillus andersoni allenbyi, Gerbillus*

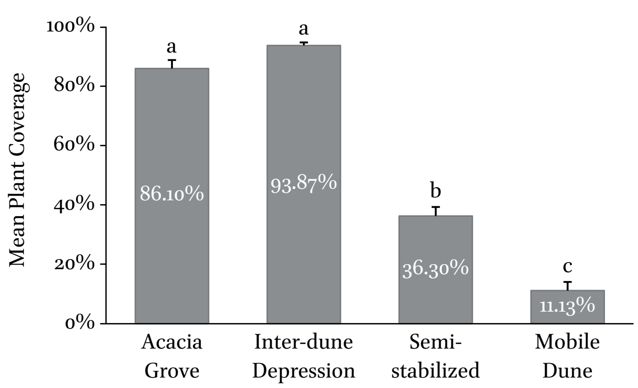

Figure 1. Mean plant coverage (+se) of the four different habitats. Different letters indicate significant differences.

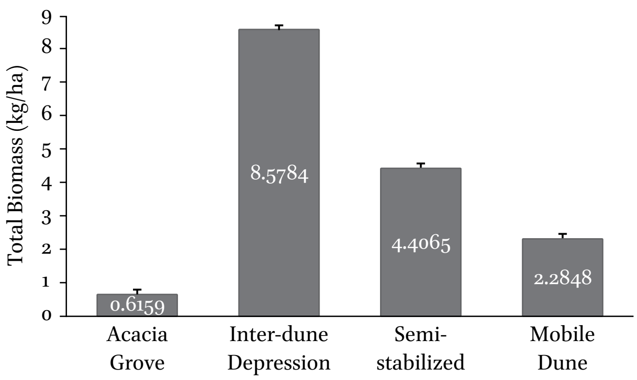

Figure 2. Estimated total biomass per hectare (+se) of small mammals caught in the four different habitats. All pairwise comparisons are significant.

pyramidum, Jaculus jaculus, Mus nusculus, Rattus rattus and *Meriones tristrami.* In addition, one species of shrew, *Crocidura suaveolens,* was captured in the acacia and the inter-dune depression plots. The highest biomass (8.58 ± 0.14 kg/ha, mean ± se) was recorded for the inter-dune depression, while the lowest biomass (0.62 ± 0.02 kg/ha) was recorded for the acacia plot. The semi-stabilized (4.41 ± 0.04 kg/ha) and the mobile (2.28 ± 0.04 kg/ha) dunes exhibited intermediate values. Mean and standard errors were estimated by a bootstrap procedure (1000 simulated samples in each plot). All pairwise comparisons were significant, using *t*-tests with Bonferroni correction (Fig. 2).

Data on species composition of the rodent population in the various plots were analyzed only for the four most abundant species: *Mus musculus*, *Gerbillus andersoni allenbyi*, *Gerbillus pyramidum* and *Jaculus jaculus*. The less abundant species, *Rattus rattus*, *Meriones tristrami* and *Crocidura suaveolens* composed a minute part of the captures. Species composition is presented in Table 1 and Fig. 3. The Means with their standard errors and 95% confidence intervals were estimated by a bootstrap procedure (1000 simulated samples in each plot). For both the Simpson's and the Shannon-Wiener's indices of rodent diversity, the acacia plot exhibited the highest value, whereas the semi-stabilized dune attained the lowest diversity (see Fig. 4 for all pairwise comparisons). The Means with their standard errors were estimated by a bootstrap procedure (1000 simulated samples in each plot).

The dendrogram in Fig. 5 demonstrates the close similarity between the inter-dune depression and semi-stabilized plots in the composition of their rodent populations, and that the acacia is not very different from these two plots. The mobile dune, however,

Table 1. 95% confidence intervals for the mean number of individuals of each rodent species caught in the four different plots. Numbers are given per hectare.

	Mus musculus	*Gerbillus andersoni allenbyi*	*Gerbillus pyramidum*	*Jaculus jaculus*
Acacia grove	(8.9 , 24.1)	(8.9 , 19.5)	–	–
Inter-dune depression	(42.1 , 74.7)	(225.3 , 295.8)	(1.1 , 34.7)	–
Semi-stabilized dune	–	(149.4 , 184.6)	(0.8 , 6.2)	–
Mobile dune	–	(1.5 , 5.6)	(37.3 , 52.7)	(4.63 , 11.39)

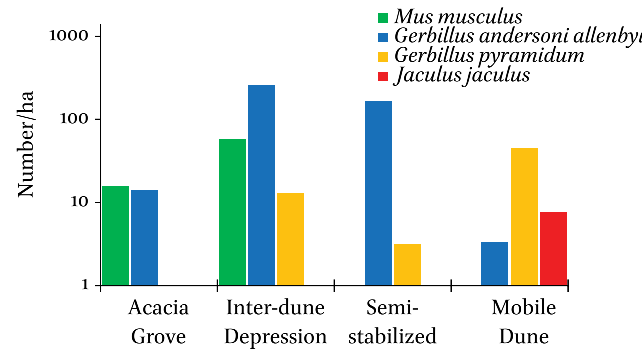

Figure 3. Species composition (number of individuals per hectare) of the rodents caught in the four different habitats. Note the logarithmic scale of the vertical axis.

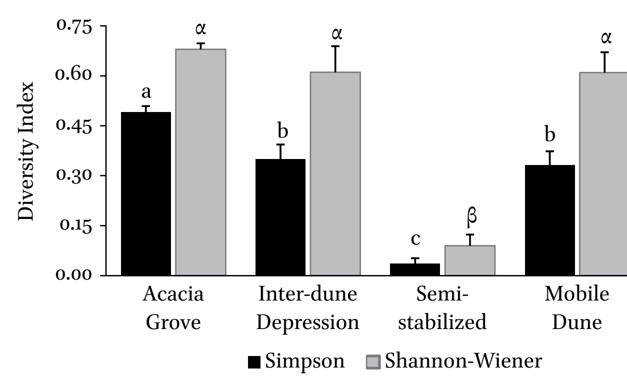

Figure 4. Estimated Simpson's and Shannon-Wiener's indices of rodent diversity (+se) of the four different habitats. Different letters indicate significant differences.

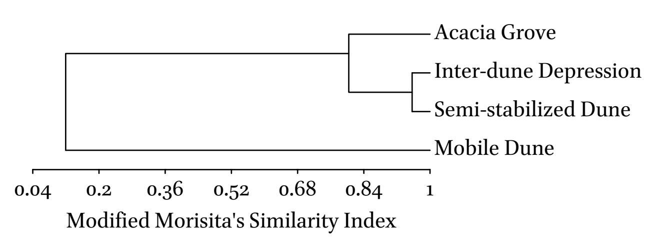

Figure 5. Dendrogram exhibiting the similarity between habitats with regard to the small mammal species distribution, using the modified Morista's similarity index and nearest neighbor amalgamation.

was clearly different in its rodent composition from all other plots.

Discussion

While the findings of our extensive study of rodent species in four different large plots in the Ashdod-Nizzanim sands are indicative of that area, they can plausibly suggest a similar occurrence in other sandy areas as well. A more statistically valid inference can be made only after more studies are performed also in other such areas. The species composition of rodents in this study was found to differ according to the degree of stabilization of the sands, with decreased numbers of psammophile rodents and increased presence of species commensal with humans in the more stable plots (including acacia). The most unique habitat was the mobile dune, as this was the only one in which the strict psammophiles, *Gerbillus pyramidum* and *Jaculus jaculus*, were caught in relative abundance. In fact, *Jaculus jaculus* was trapped only in this habitat, as expected for a bipedal species (Randall 1993; Shenbrot et al. 1999). The most abundant rodent caught, *Gerbillus andersoni allenbyi*, was trapped in low numbers in the mobile dune, as would be expected for a more generalist species. Hence, *Gerbillus pyramidum* and *Jaculus jaculus* have a narrower niche and can be considered more “strict” or specialist psammophiles than *Gerbillus andersoni allenbyi*. The disappearance of the mobile sands due to stabilization of the dunes would thus create a real threat to the existence of *Gerbillus pyramidum* and *Jaculus jaculus* in the coastal plain. Our results are similar to those of Manor et al. (2008) who found that man-made environmental changes which bring biotic homogenization, can promote the geographic expansion of some cosmopolitan, generalist nonnative species and the geographic reduction of regional and endemic native species.

In the semi-stabilized dune, *Gerbillus andersoni allenbyi* was the dominant species trapped, while *Gerbillus pyramidum* was captured in low numbers. No species commensal with humans were found in this habitat.

Most captures per ha were obtained in the inter-dune depression, and consequently the biomass of this plot was the highest.

In the acacia plot, the two species commensal with humans – *Mus musculus* (58 individuals) and *Rattus rattus* (3 individuals), as well as a generalist species – *Crocidura suaveolens* (16 individuals), composed most of the 129 captures. The presence of species commensal with humans in the acacia and the inter-dune depression plots may be attributed to the fact that these habitats are less unique in vegetation and soil characteristics and thus require less adaptation compared to the open sand habitats. In these habitats psammophile species have no advantage over the generalist species that are considered to be "Jack of all trades" (Shenbrot et al. 1999). The lack of competition from psammophile granivores may open up this habitat to generalists such as *Mus musculus*, which are omnivorous and do not rely only on the soil seed bank (Mendelssohn and Yom-Tov 1999). The study also revealed that among all the sample plots, the lowest capture rate of small mammals and the lowest biomass were in the acacia plot. Thus, the acacia habitat may have a low carrying capacity for rodents, as also seen in other disturbed habitats (Lehmann and Perevolotsky 1992; French and Majors 2001).

Our findings support Rosenzweig's (2001) conclusion that the main problems caused by invasive species are not necessarily a reduction in the diversity level (note the high species diversity indices in the acacia habitat) or a reduction in species richness (note the high number of species in the acacia and in the inter-dune depression habitats), but that endemic species may vanish and be replaced by immigrants (the replacement of *Gerbillus pyramidum* and *Jaculus jaculus* by mice and other species in the more stable habitats). It is not only a question of how many species exist in the invaded habitat, but which of those species are able to occupy these new habitats successfully, and which cannot. Our conclusion is that the invasive *Acacia saligna* in the sands has rendered the dunes unsuitable for psammophile rodents. It enforces Cohen and Bar (Kutiel) (2017) botanical conclusion that “the presence of *A. saligna*, whether planted or invasive, is detrimental to nature conservation, in terms of the indigenous vegetation cover, diversity, and composition”.

If we wish to protect psammophilic species such as *Jaculus jaculus* and *Gerbillus pyramidum,* which are already under great threat, measures should be taken to halt the spread of *Acacia saligna* and prevent any further stabilization of the dunes. The effect of *Acacia saligna* on soil characteristics (such as levels of pH, carbon, nitrogen, available phosphorus, ammonium, nitrate and electrical conductivity) can persist even ten years after clearing (Nsikani et al. 2017), an unfortunate state that should be taken into account in habitat restoration.

The Mediterranean biota of the Levant is a product of co-evolutionary processes involving human disturbances (Naveh 1985; Shmida 1985), and this applies to the coastal sand dunes as well (Tsoar 2005). Diminished human pressure on the coastal dunes of Israel during the last 70 years, contributed to the stabilization of the dunes due to increased perennial vegetation, and to a decreased presence of psamophilic species. Thus, to revert the environment to its former equilibrium state, a reduction in vegetation cover is necessary – either by mechanical removal or by enhanced grazing activity.

Several studies on the effect of shrub cover removal were conducted in the coastal sand dunes of Israel. Working on semi-stabilized dunes in the Nahal Alexander Nature Reserve (ca. 80 km north of Ashdod-Nizzanim), Kutiel et al. (2000) found that while richness and diversity of small mammals decreased in the opened areas, the most abundant were those species that are specific to semi-stabilized sand dunes. Studying the reptile population of Ashdod-Nizzanim dunes, Shacham (2010) found that the stabilized dunes feature the greatest species richness – a conclusion similar to our findings – due to an increased presence of generalist species. While partial removal of perennial vegetation cover by mechanical means did produce some changes in reptile assemblages, reaching the desired mobile dune assemblage did not happen – maybe because a single removal is not enough. Bird et al. (2017) demonstrated the effect of vegetation removal in Ashdod-Nizzanim dunes on beetle diversity. They concluded that since landscape heterogeneity contributes to high γ-diversity, continued shrub encroachment and the associated fixation of mobile dunes would lead to habitat homogenization and a decline in γ-diversity. However, they recommend a restorative intervention that promotes disturbance and heterogeneity at the landscape level by conserving all three dune states.

We again emphasize the need for additional similar studies in other sandy areas to confirm the validity of our conclusions beyond the Ashdod-Nizzanim area.

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