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Reptile diversity and rodent community structure across a political border

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ABSTRACT

The peace treaty between Israel and Jordan found the Arava desert ecosystem, shared by the two countries, in a state of developmental dichotomy. On the Israeli side, vast lands have been settled and transformed into agricultural fields, while the Jordanian side has remained relatively intact and inhabited by only a few traditional and pastoral societies. This study examined the effect of different landscape units and proximity to agriculture on reptile diversity and rodent community structure on both sides of the border. It appears that in addition to the effect of proximity to agricultural fields and landscape habitat, the border between the two countries may play a role in determining diversity on the respective sides. While reptile abundance was generally higher on the Israeli side of the border, diversity was found to be significantly higher on the Jordanian side. Rodent community structure also revealed significant differences between the two sides of the border, mainly due to the more favorable conditions for psammophilic gerbils in Jordan. When comparing Western society with pastoral traditional society, it appears that development activities of the former have altered diversity and community structure of the taxa studied in the Arava. We suggest that in addition to the effects of habitats and human disturbances, such as modern agricultural practices, cultural differences between societies should be considered when conservation plans are developed for cross-border ecosystems.

1. Introduction

Human societies that emerge from a state of war or a long-term conflict into a peaceful environment may gain many benefits, among them economic growth (Blomberg and Hess, 2002). However, while economic growth may often satisfy short-term needs, it may also imply an increase in the amount of resources used (Primack, 1998), consequently leading to habitat destruction and loss. In 1994, Israel and Jordan signed a peace treaty ending 45 years of hostility. The treaty

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found the Arava region, shared by the two countries, in a state of developmental dichotomy, with vast lands settled and transformed into agricultural fields on the Israeli side, while the Jordanian side remained relatively intact and inhabited by only a few traditional and pastoral societies. This temporal and spatial contrast provides an unique opportunity to study the effects of agricultural practices on local biodiversity and community structure and to use this information to plan a sustainable development strategy for a region that might be severely affected by the expected future prosperity.

One of the major factors in habitat destruction that leads to loss of diversity is transformation of natural lands into agricultural fields. Large parts of the world's arable lands already have been transformed into agricultural lands (FAO, 2001). Yet, beyond loss of diversity on the degraded land itself, farming has far-reaching effects that extend to nearby ecosystems (Matson et al., 1997; Tilman, 1999; Vandermeer and Perfecto, 2005). The effect of agriculture on the environment varies from vast habitats change, leading to large-scale biodiversity loss (e.g., the clearing of rain forests; Skole and Tucker, 1993; Roy and Tomar, 2000), to dramatic changes in species diversity and abundance (e.g., use of land for livestock grazing grounds; Anderson and Inouye, 2001). It has been recently recognized that farming poses the greatest extinction threat for birds, especially in the developing world (Green et al., 2005).

At every level, agricultural activity alters the natural environment over both the short and the long-terms (Sotherton, 1998; Darkoh, 2003; Tscharntke et al., 2005). By examining the effects of agricultural practices on desert fauna and the sensitivity of different landscape units to anthropogenic effects, we offer a multi-scale approach to the study of the diversity of an area that is under accelerated development. Moreover, we offer an additional dimension by considering the cultures of societies on both sides of the same border as a factor shaping diversity. As Homewood et al. (2001) demonstrated in their study of the Serengeti-Mara region, shared by Kenya and Tanzania, different societies on the two sides of the border can have quite different impacts on existing wildlife. As such, the spatial and temporal characteristics of the Arava provide us with a natural field laboratory in which to further explore this "border impact" of human cultures on diversity of a single geographic region.

2. Materials and methods

2.1. Study site

We conducted our study in the southern Arava Valley, a part of the Great Rift Valley, located between Nahal Shita in Israel and Wadi Arandal in Jordan (030°07′10″ N) in the north; the Red Sea (029°32′57″ N) in the south; the mountains of the Israeli Negev in the west; and the Sharrah Mountains of Jordan in the east. Temperatures in this region vary from 23 to 45 °C during summer and 0–23 °C during winter. Average annual precipitation is 28.7 mm (1971–2000 mean, Israel Central Bureau of Statistics). During the two-year period of our study, precipitation levels were 12 mm and 22.5 mm for 2002–2003 and 2003–2004, respectively. The valley is comprised of different habitats, of which the major ones are alluvial fans, sand dunes, semi-stable sands, salt marshes, and wadi beds. It is politically divided between Israel and Jordan; the physical division is only a loose fence along the border.

2.2. Landscape units

We selected four types of landscape units (LU) where we expected to find most biological diversity of the region, based on literature and on a preliminary study: **HD** – alluvial fans with a relatively high density of acacia trees (*Acacia tortilis* and *A. raddiana*) and bushes (10–20 acacia trees per hectare, *Salsola tetrandra* and *Lycium shawii* as major bushes); **SM** – salt marsh edges typified by silty soil, where the most common bush was *Nitraria retusa* (18–160 individuals per hectare), in some places joined by *Alhagi graecorum* and *Zygophyllum* spp. bushes; **SD** – sand dunes, typified by shifting sands with approximately 30 *Haloxylon persicum* bushes per hectare; and **MX** – semi-stable sands occasionally mixed with gravel, with approximately 25 *Haloxylon persicum* bushes per hectare and sporadic occurrence of *Calligonum comosum* bushes.

2.3. Proximity to agriculture and "border effect"

In order to examine the effect of agricultural land on the LUs, we chose three plots from each LU close to (50–200 m) and three plots far from (>2 km) agricultural land. As a function of the imbalance in agricultural activity on the two sides of the border, most of the "close" sites were on the Israeli side and most of the "far" sites were on the Jordanian side. Because we also suspected that the border itself, dividing two societies with distinct impacts on the land, would affect biodiversity, we chose additional plots in each country to enable an exclusive comparison of the effect of agricultural land and an exclusive comparison of the "border effect" (Table 1). In this way, we were able to compare the four LUs within each country; then use the SM plots close and far from agricultural lands within Israel, and the SD plots close and far from agricultural lands within Jordan to perform separate comparisons on the effect of agriculture. The SM far plots and the SD close plots were used to compare the "border effect." The agricultural fields were comprised mainly of date palms, seasonal onions, melons, and tomatoes. Each plot size was 150 × 150 m (2.25 ha).

2.4. Timeframe and replications

Each of the 30 plots was sampled four times a year, during mid-winter, spring, mid-summer, and autumn. Sampling times were chosen based on temperature, with mid-winter (January–February) and mid-summer (July–August) sampling sessions taking place during the extreme cold and hot seasons, respectively. Sampling dates during the season were chosen according to lunar phase. All sites were sampled either immediately before or after the new moon. In each season, plots were sampled for three consecutive nights and days. Every night, four plots were sampled in parallel (two in Israel and two in Jordan) in a fixed order to ensure that the same LUs were sampled at the same time on both sides of the border. Thus, sampling started in four plots six nights before the new moon and progressively moved to the next

Table 1 – Reptile species richness (S) in the four landscape units, and the number of sites sampled within each country

	HD	SM	SD	MX
Close to agriculture	9	7	5	6
Number of sites within a country	3 sites in Israel	3 sites in Israel	3 sites in Israel and 3 in Jordan	3 sites in Israel
Far from agriculture	6	6	3	5
Number of sites within a country	3 sites in Jordan	3 sites in Jordan and 3 in Israel	3 sites in Jordan	3 sites in Jordan

HD – high density of Acacia trees; SM – edge of salt marshes; SD – sand dunes; MX – mixed stable sands; C – close to agricultural land; F – far from agricultural land.

plots, until sampling was completed in the last plots on the sixth night after the new moon.

2.5. Animals sampled

2.5.1. Reptiles

In order to trap reptiles, we constructed 20 pitfalls in each plot by burying 18L buckets ($r = 14$ cm). Every set of four pitfalls was connected by three sets of 18 m (l) × 20 cm (h) plastic drift fences (Fig. 1). The buckets had a double bottom to ease the collection of the animals. Toilet paper rolls served as hiding places at the bottom of the buckets. We shaded the pitfalls with a rectangular wooden cover, raised 10 cm above ground level. Between trapping sessions, we sealed the buckets with lids and dismounted the drift fences. Drift fences were remounted and pitfalls were opened before sunset of the first night in each trapping session. They were emptied the next three mornings before sunrise and the two following afternoons. Each reptile caught was identified, sexed, weighed, measured, photographed, and marked by toe clipping. Toes were stored for future DNA analysis. Immediately after recording data, reptiles were released back into the bush nearest to the trapping site. All invertebrates that fell into the pitfalls were preserved in alcohol for future analysis.

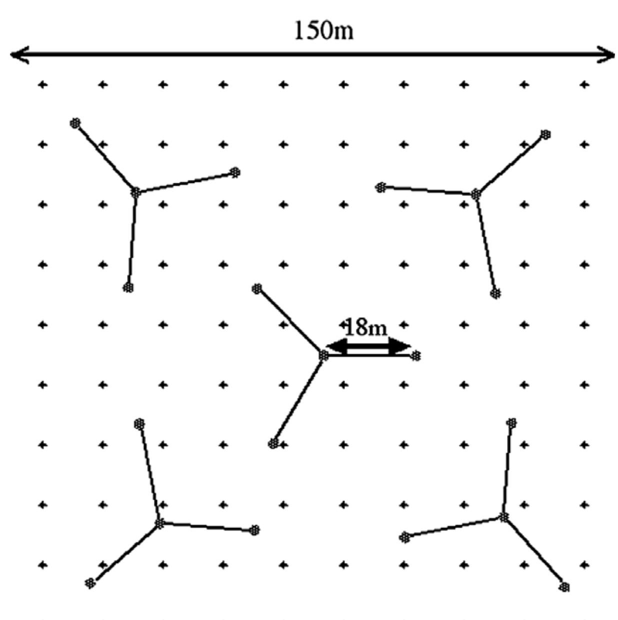

Fig. 1 – A single plot experimental design. Lines represent drift fences, circles represent pitfalls, and stars represent Sherman rodent traps.

Pitfalls and drift fences were covered by sand during sand storms. This occurred more frequently in Jordan than in Israel. We discarded any pitfall sample that had its bottom covered to a depth of more than 1cm of sand. However, since the total number of discarded pitfalls for each plot was always less than 5% of the total sampled pitfalls per plot, we ignored this information in the final analysis.

2.5.2. Rodents

Rodents were sampled with 100 Sherman traps in a grid (15 m apart) in each plot (Fig. 1). We baited the traps with two pieces of a commercial peanut-butter snack, and during winter sessions we added synthetic cotton bedding. We opened the traps every afternoon before sunset and collected them in the early morning to prevent overheating during the day. Each rodent caught was identified, sexed, weighed, measured, photographed, and marked by toe clipping. Toes were stored for future DNA analysis. Immediately after recording the data, rodents were released at the trapping site.

2.6. Data analysis and statistics

2.6.1. Reptiles

We calculated abundance, species richness (S), Morisita-Horn index, and diversity (Simpson and Fisher alpha) in each LU, with the EstimateS software (Colwell, 2004), in order to compare the effect of a LU kind, the proximity to agriculture, and the "border effect." After testing for normality and homogeneity (Bartlett's test) using StatView 5.0, we conducted ANOVA tests to examine differences in abundance and diversity among LUs. We then combined comparable LUs, SDs, and SMs on each side of the border in order to test the differences of between countries in abundance and diversity of reptiles. Thus, three plots of SDC and three plots of SMF on one side of the border were compared to the same kinds of plots on the other side of the border. We paired plots from the same LUs that were sampled simultaneously on two sides of the border on the same days. After testing them for normality and homogeneity, we computed a paired t-test ($n = 6$). Because it was impossible to pair the plots, as they were not sampled simultaneously, we used an unpaired t-test to examine effects of proximity to agriculture on abundance and diversity.

2.6.2. Rodents

We trapped only five rodent species throughout the entire study. Therefore, we did not attempt to calculate rodent richness or diversity. In order to compare differences among LUs and proximity to agriculture, we used rodent species composition and abundance. We analyzed the "border effect" using a two-way ANOVA of abundance, comparing species composition and countries.

3. Results

3.1. Reptiles

3.1.1. Number of species

During the two-year research period, a total of 545 reptiles from 13 different species was captured (*Acanthodactylus boskianus*, *Bunopus tuberculatus*, *Chalcides ocellatus*, *Cyrtopodion scaber*, *Eumeces schneideri schneideri*, *Hemidactylus turcicus*, *Malpolon moilensis*, *Mesalina olivieri*, *Sphenops sepsoides*, *Stenodactylus doriae*, *Stenodactylus sthenodactylus*, *Trapelus pallidus*, *Tropiocolotes nattereri*). This represents 36% of the reptile species previously reported from this area (Disi et al., 2001). Because we were using only pitfall traps, we expected to capture only small surface-walking species. Our species list represents 68% of those known species (excluding species living on cliffs, trees, or having large body size).

3.1.2. Landscape unit effect

We found a significant difference among LUs in the number of reptiles caught (ANOVA: $F = 6.6$, $p < 0.05$; and $F = 21.9$, $p < 0.001$ for LUs close and far from agriculture, respectively, Fig. 2). Among the LUs close to agriculture, the largest number of reptiles was found in HD sites (59 ± 22.3) and the smallest number in SD sites (15 ± 15.6). Among LUs far from agriculture, the largest number of reptiles was found in SM sites (12.6 ± 2.1 animals), while the smallest number was in SD and MX sites (4.7 ± 0.6 for both sites).

The HD and the SM LUs had the largest number of species, whereas SD and MX LUs had the smallest number of species (Table 1). The Morisita-Horn index for species composition complementarities between each pair of LUs (Table 2) suggests the highest similarity between SD and MX LUs, and between HD and SM LUs. The HD and the SD LUs were least similar. However, both Simpson and Fisher's alpha indices suggest that the four landscape units did not differ in species diversity (Simpson, ANOVA: $F = 1.5$, $p > 0.05$; and $F = 2.1$, $p > 0.05$ for LUs close and far from agriculture, respectively, Fig. 3; Fisher's Alpha, ANOVA: $F = 0.233$, $p > 0.05$; and $F = 3.096$, $p > 0.05$ for LUs close and far from agriculture, respectively).

Table 2 – Morisita-Horn index of similarity between landscape units based on reptile data

	HD	MX	SD
Close to agriculture			
SM	0.719	0.381	0.364
SD	0.163	0.984	
MX	0.194		
Far from agriculture			
SM	0.788	0.297	0.225
SD	0.068	0.945	
MX	0.145		

3.1.3. Border effect

We found no significant difference in the number of reptiles caught between Israel and Jordan (Israel: 17.7 ± 11.1; Jordan: 10.7 ± 3.8; paired *t*-test, $t = 1.8$, $p > 0.05$). However, the diversity of reptiles was significantly higher in Jordan than in Israel (Simpson: paired *t*-test, $t = 2.0$, $p < 0.05$; Fisher's Alpha: paired *t*-test, $t = 2.5$, $p < 0.05$; Fig. 4).

3.1.4. Proximity to agriculture effect

We tested the effect of agricultural fields on nearby natural lands by focusing on two different LUs: SD (in Jordan) and SM (in Israel). The abundance of reptiles caught was not affected by the proximity to agriculture (SD: 8.7 ± 4.5 and

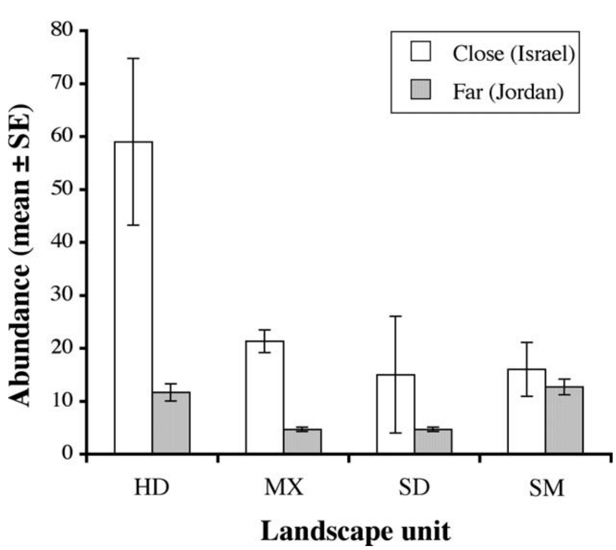

Fig. 2 – Effect of proximity to agricultural fields on abundance of reptiles caught during four sampling seasons at four different landscape units. HD – high density of Acacia trees; SM – edge of salt marshes; SD – sand dunes; and MX – mixed stable sands.

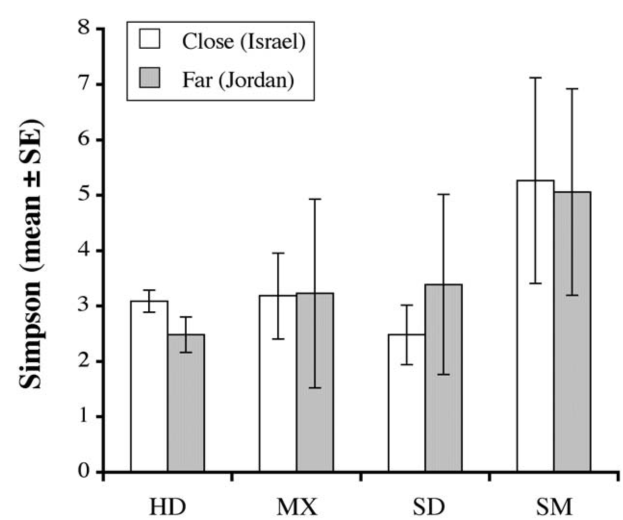

Fig. 3 – Comparison of reptile species diversity index (Simpson) in different landscape units. HD – high density of Acacia trees; SM – edge of salt marshes; SD – sand dunes; and MX – mixed stable sands.

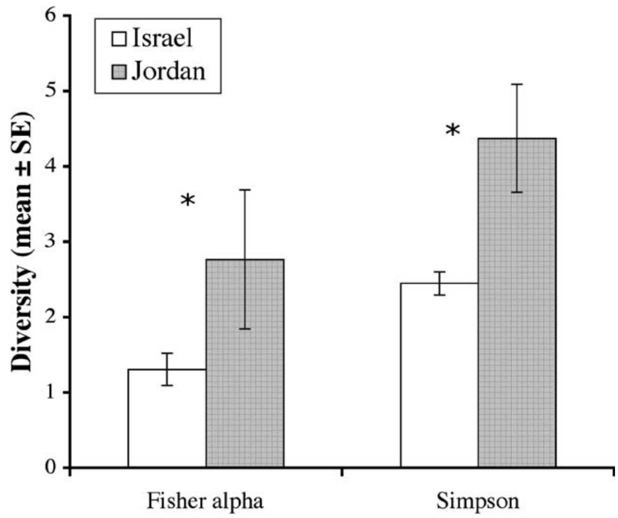

Fig. 4 – Reptile species diversity (Simpson and Fisher Alpha) of comparable landscape units in Israel and Jordan ($^*p < 0.05$, paired *t*-test).

4.7 ± 0.6 for LUs close and far, respectively, unpaired *t*-test, $t = 1.5$, $p > 0.05$; SM: 16.0 ± 7.2 and 20.3 ± 6.7 for LUs close and far, respectively, unpaired *t*-test, $t = 0.8$, $p > 0.05$). In both LUs, sites close to agriculture had more species than sites far from agriculture (six vs. four species in SD and seven vs. four species in the SM). The values of the Morisita-Horn similarity index (comparing close and far sites) were relatively high (0.93) for SD, but lower (0.62) for SM.

In general, species diversity was found to be higher close to than far from agriculture. However, the difference was significant only when comparing SM close and far from agriculture in Israel, using the Fisher's Alpha index (3.007 ± 0.713 and 1.142 ± 0.119, respectively, unpaired *t*-test, $t = 3.8$, $p < 0.05$).

3.1.5. *Rodents*

A total of 246 rodents were caught during the 2 years of study. *Gerbillus gerbillus* was the most abundant rodent (118) followed by *Gerbillus nanus* (81), *Acomys cahirinus* (39), *Gerbillus dasyurus* (7), and *Mus musculus* (1). Many of the same rodents were recaptured either in the same session or in subsequent sessions (total of 193 recaptures).

3.1.6. *Landscape unit effect*

Of the five rodent species caught, the Cairo spiny mouse (*A. cahirinus*) was found exclusively in the HD landscape units. The lesser Egyptian gerbil (*G. gerbillus*) was abundant in sandy habitat LUs (SD and MX), and the Baluchistan gerbil (*G. nanus*) replaced it when moving to more stable sands, such as SM LUs (Fig. 5).

3.1.7. *Border effect*

The effect of border was examined in the SD LUs close to agriculture. A two-way ANOVA (Table 3) revealed differences in rodent composition across the border. Sand dunes held more *G. gerbillus* than *G. nanus*, and in general, *G. gerbillus* was more dominant in Jordan than in Israel (Fig. 6). *G. nanus* was more abundant in the SM LUs far from agriculture, and a higher number was caught on the Israeli side than on the Jordanian side (5.0 ± 2.0 vs. 1.8 ± 0.6).

3.1.8. *Proximity to agriculture effect*

In both the SM LUs close and far from agriculture, *G. nanus* was the dominant or sole rodent that was trapped. Proximity to agricultural fields had no detectable effect on its abundance (5 ± 5.3 vs. 5 ± 2.0). In the SD LUs, both *G. gerbillus* and *G. nanus* were found, and there was no difference in species composition between plots that were close and plots that were far from agriculture (two-way ANOVA: $F = 0.135$, $p > 0.05$).

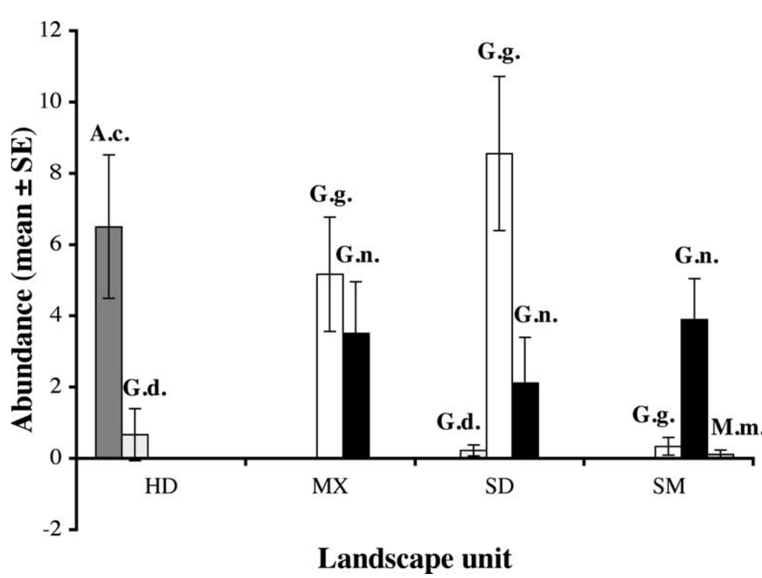

Fig. 5 – Abundance of rodent species in all landscape units (combined close and far, Israel and Jordan). HD – high density of Acacia trees; SM – edge of salt marshes; SD – sand dunes; and MX – mixed stable sands. ▩ *Acomys cahirinus* (A.c.), □ *Gerbillus dasyurus* (G.d.), □ *Gerbillus gerbillus* (G.g.), ■ *Gerbillus nanus* (G.n.), and ▨ *Mus musculus* (M.m.).

Table 3 – ANOVA of the effect of country on rodent community structure

	DF	Sum of squares	Mean square	F-value	P-value
Rodent	1	126.750	126.750	9.108	0.0166
Country	1	80.083	80.083	5.754	0.0433
Rodent × Country	1	52.083	52.083	3.743	0.0891
Residual	8	111.333	13.917		

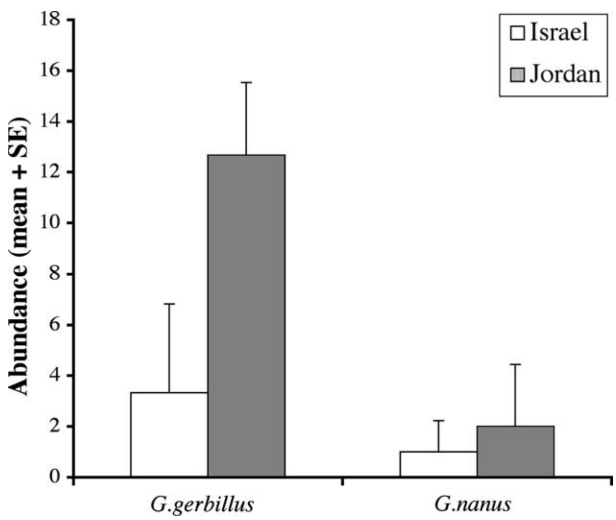

Fig. 6 – Border effect on species composition. Gerbil abundance in sand dunes close to agriculture in Israel and Jordan (See ANOVA table for statistics).

4. Discussion

Differences in reptile diversity and in rodent population structure across the Israeli–Jordanian border reflect differences in human pressure on the two sides of the border. The Israeli–Jordanian border, which consists in places of an imaginary line on the ground or a loose fence, poses no barrier for most animals and certainly not for the studied species. However, it does limit the passage of humans and thus divides the two societies, creating a dichotomy in human cultures and human impacts on nature. Although we found a similar abundance of reptiles in comparable habitats on both sides of the border, diversity was significantly higher on the Jordanian side compared to the Israeli side (Fig. 4). This dichotomy is most likely attributable to the few species dominating the Israeli fauna, in contrast to the more evenly represented reptiles on the Jordanian side that contribute to its higher diversity. The border apparently also has an effect on rodent population structure. We found significant differences in gerbil occurrence on both sides of the border, caused by the relatively higher abundance of the psammophilic *G. gerbilus* on the Jordanian side (Fig. 6, Table 3).

This cross-boundary study provides a better understanding of the differences in land use and the effect of culture on the two sides of a border. The Israeli side of the Israeli–Jordanian border is heavily settled with Western-style agricultural communities that have transformed large portions of the land into irrigated agricultural fields. In contrast, the Jordanian side of the Arava valley has remained largely intact and is inhabited by pastoral Bedouin villages that practice only low-level agriculture, with hunting and wood collecting relatively common.

The reason for the observed difference in diversity between the two sides of the border may be found in the higher connectivity of the natural lands in Jordan, which are less interrupted by settlements, roads, and agricultural fields. It may also be found in the high commensal predator population present around the agricultural fields on the Israeli side (Shapira, 2006).

We found that while the HD sites close to agriculture (in Israel) had by far a higher abundance of reptiles than any other LUs, the same LU sites far from agriculture (in Jordan) did not differ much from other LU sites in reptile abundance. We suggest that the relatively high grazing level practiced in Jordan (mainly herds of goats), in contrast to the low level of grazing in Israel (naturally occurring gazelles), may cause a decrease in the abundance of reptiles. This negative effect of grazing on reptile abundance has been demonstrated in other studies as well (Woinarski and Ash, 2002; James, 2003). An examination of SM LUs provides support for the effect of pastoralism on reptile abundance. This was the only type of landscape unit that exhibited a similar abundance of reptiles in both close (Israel) and far (Jordan) plots (Fig. 2). Interestingly, the far SM sites on the Jordanian side are located in an area that is restricted for pastoralism by the Jordanian army, resulting in reduced density of grazers.

However, grazing is not always a factor in limiting the diversity of reptiles (Read, 2002; Smart et al., 2005). In fact, an intermediate level of grazing as disturbance (Connell, 1978) can actually support reptile diversity by breaking the sand crust and thus assisting burrow construction as well as food gathering (Zaady and Bouskila, 2002). Therefore, the effect of grazing on the diversity of reptiles in the southern Arava should be further studied.

Wood collecting is another factor that was found to distinguish the Jordanian sites from the Israeli ones. Collecting woody elements for fuel has acute effects in reduced biomass, especially in dry lands (Darkoh, 2003), and might explain the relatively low abundance of reptiles found in some of the Jordanian sites.

Contrary to our predictions, agriculture did not affect significantly the abundance of reptiles. It is possible that two opposing factors affect reptile abundance near agricultural fields: higher primary production of the agricultural fields, and use of insecticides that affect the reptiles' prey (Alexander et al., 2002; Peveling et al., 2003). Moreover, numerous perching spots for birds near agricultural fields might put additional pressure on reptiles (Hawlena and Bouskila, in press). Contrary to reptile abundance, however, reptile richness and diversity seem to be higher at sites closer to agricultural lands, suggesting that the positive effects of higher productivity may outweigh the negative effects of proximity to agricultural lands, and that this proximity provides an advantage for certain species. For example, commensal species, such as the *Hemidactylus turcicus* gecko, or the generalist gecko, *Stenodactylus sthenodactylus*, were found almost solely near agricultural farms.

The results for both reptiles and rodents highlight the uniqueness of the LUs in the Arava Valley ecosystem. As expected, in water-limited ecosystems, sites that are rich in plant cover (i.e., HD and SM) hold more reptiles. This was found to be the case despite the fact that indices of diversity demonstrated no differences between these LUs. However, it is likely that the small sample sizes obtained from the overall low density in this region do not allow statistical differences to emerge.

The LUs exhibit uniqueness in their species composition (Table 2), implying that although some LUs are species richer, they may be missing certain important species. For example, we found that the endemic and endangered gecko *Stenodadctylus doriae*, as well as the rodent *G. gerbillus*, can be found only in the sandy habitats that usually correlate with low richness and diversity of both plants and animals. Lyons and Scwartz (2001) suggested that often the less abundant species have major importance for the ecosystem, such as resistance to invaders. The similarity between the SD and MX LUs demonstrates the importance of the non-dune sandy habitats (i.e., MX), which are often regarded by local decision makers as low quality in comparison with sand dune habitats. Hence, if the two LUs hold similar species, they should be treated by local developers as being equally important.

In conclusion, the current study suggests that in addition to the effects of habitats and obvious human disturbances, such as modern agricultural practices, cultural differences between societies should be considered when conservation plans are developed for cross-border ecosystems. When comparing the impact of Western society (Israel) to that of a pastoral traditional society (Jordan), it appears that development actions on the Israeli side have altered diversity and community structure of the taxa we studied in the Arava valley. This is an important lesson for the whole region, but especially for those areas on the Jordanian side that may undergo increased development in the coming years in order to keep up with the agricultural practices in other parts of Jordan and on the Israeli side of the border. For example, corridors of natural landscape, and active regulation of commensal predators may be required to sustain the current level of species diversity in future areas of development.

The recent era of peace in the region provides Israel and Jordan new opportunities to collaborate on cross-border conservation programs. However, it is also paving the way for adverse developmental projects along the border of the two countries by enabling resource and land exploitation to occur without appropriate controls (McNeely, 2003). Regions that experience a reduction in political tension often see enhanced land transformation and habitat loss, thus requiring immediate action to ameliorate the negative impacts of peace. The Arava valley might require just such an intervention in the near future.

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