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Effects of Vineyards and Olive Plantations on Reptiles in a Mediterranean Agroecosystem

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Abstract: Agriculture poses a threat upon wildlife worldwide and particularly to reptiles. However, the effects of many crop types on reptile diversity remain unknown. In this field study, we examined the local effects of two understudied common crop types in Mediterranean regions, intensively cultivated vineyards and intensified-traditional olive plantations, on reptile diversity patterns. We compared measurements of diversity among an array of study plots representing each crop as well as plots in adjacent patches of natural habitat. We developed a new index, the Average Specialization Index, in order to compare the degree of habitat-specialization of the species in the different habitats. Among the habitat types examined, the natural patches were the most structurally heterogeneous and contained the greatest species richness and diversity. In contrast, the intensive vineyards were structurally homogeneous and were uninhabitable areas for reptiles. The more-traditionally cultivated olive plantations were intermediately heterogeneous and provided a unique habitat occupied by a community with a high proportion of reptile species considered to be habitat specialists. Despite showing high abundance and eveness, the reptile community within the olive plantations still contained a lower species richness and diversity compared to natural patches. In light of our results, we recommend implementing a more wildlife-friendly management strategy in landscapes converted to agricultural cultivation.

Key words: Agricultural landscape; Habitat heterogeneity; Habitat specialization; Reptile communities; Species diversity

The rapid expansion and intensification of agriculture worldwide contributes to the biodiversity crisis (Norris 2008), inflicting habitat loss and contaminating habitats with agrochemicals (Saunders and Hobbs 1991; Benton et al. 2003; Green et al. 2005). This issue is prominent in the Mediterranean basin, a leading biodiversity hotspot (Myers et al. 2000), which has been impacted by agriculture practices for thousands of years (Ben-Yosef 1980). Reptiles constitute one of the taxa that are most severely affected by habitat change (White et al. 1997), and by agriculture in particular (Norris 2008), on account of their physiological and ecological constraints (i.e., being ectothermic, with poor dispersal abilities and small home ranges; Huey 1982). Nonetheless, they are rarely studied in the Mediterranean, and the status of many species remains unknown (Porat 2011; Carpio et al. 2015).

Olive plantations and vineyards are two of the main crops in the Mediterranean region (Gómez et al. 2011). Both crops have a long history of cultivation in the area (Loumou and Giourga 2003; Terral et al. 2010), and both are subjected to increasing intensification (Gómez et al. 2011). Olive plantations and vineyards managed with varying levels of intensity are presently found across the Mediterranean (e.g., Biaggini and Corti 2015), and practices can include different intensities of chemical inputs, mechanization, tillage, irrigation, and the removal of natural vegetation (Biaggini and Corti 2015; Carpio et al. 2016; Buchholz et al. 2017). The trend toward intensified management has led to diversity loss in numerous taxa, yet the effects on reptiles are still poorly studied (Biaggini and Corti 2015; Carpio et al. 2017).

One mechanism responsible for the declines in farmland biodiversity at the local scale is the loss of heterogeneity in habitat structure (Benton et al. 2003; Porat 2011). Structurally complex habitats can increase species diversity by providing more niches and, therefore, more opportunities for coexistence among the different species therein (Hutchinson 1959; Kadmon and Allouche 2007). Unfortunately, agricultural intensification usually involves monoculture crops that promote habitat homogeneity as well as the use of chemicals and additional processes (Benton et al. 2003). Porat (2011) has shown that a decrease in habitat heterogeneity has a negative effect on reptiles in a Mediterranean agroecosystem in Israel.

In addition to the intensity of management and its effects on heterogeneity, the plant characteristics themselves might contribute to the influence of these crops on biodiversity. Being a large, evergreen tree with a complex morphology, olive trees (*Olea europaea* L.) might serve as a high-quality habitat for arthropods and small vertebrates (Loumou and Giourga 2003; Graziani et al. 2006), provide shelters (Biaggini et al. 2009), and affect the microclimate (e.g., lower soil temperature; Belsky et al. 1989). In fact, olive plantations might support diverse fauna and native Mediterranean flora (Loumou and Giourga 2003; Davy et al. 2007). In contrast, the grapevine (*Vitis vinifera* L.) is a deciduous liana that produces foliage for only a few months a year. Thus, the soil of the vineyard can be quite bare and the plantation offers a lower density of shelter microhabitat (Biaggini et al. 2009). Nevertheless, fruits produced by the grapevine can attract wildlife (Somers and Morris 2002), including reptiles and their prey.

The alteration of habitat properties as a result of agricultural cultivation might affect the structure of the communities that inhabit the modified areas. Understanding the responses of species assemblages to land-use is critical for the improvement of conservation strategies (Thompson et al. 2016). A related conservation concern is the expected shift in species composition from specialist to generalist species in modified habitats (Attum et al. 2006; Hawlena and Bouskila 2006). When compared to specialists, generalist species have more-flexible habitat requirements and less-specific adaptations, with the potential benefit of having a higher fitness in a greater variety of environments (Attum et al. 2006). Therefore, landscape alterations might favor generalists. In turn, this might affect species composition

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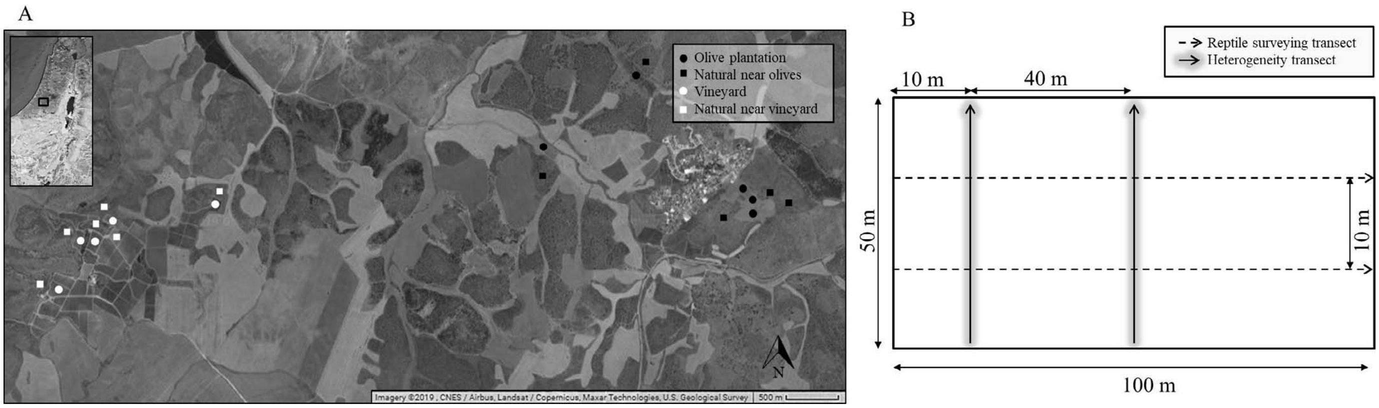

Fig. 1.—Study design within vineyards, olive plantations, and natural patches in the Southern Judea Lowlands area of Israel: (A) The array of sampling plots for the impact of vineyards and olive plantations on reptile communities in the Southern Judea Lowlands area of Israel (Google Maps 2019). Each crop was represented by five revisited sampling plots, each paired with a plot in an adjacent natural patch (total $n = 20$). (B) A schematic diagram of a sampling plot. Reptile surveying included two line transects along the long axis of the plot, while heterogeneity assessment was based on the relative coverage of seven structural elements recorded along two, 50-m transects per plot.

and cause changes in the relative abundances of species and can induce species replacement (Hawlena and Bouskila 2006; Carpio et al. 2016).

Considering the knowledge gaps regarding the effects of vineyards and olive plantations on reptiles, the main objective of this study was to examine the effects of these crops on reptile diversity patterns in the Mediterranean region of Israel. A better understanding of the links between habitat structure in agricultural areas and the corresponding reptile assemblages will promote the establishment of a more efficient conservation management for reptiles in Mediterranean agroecosystems. We hypothesized that habitat structure would have an impact on reptile diversity in our study system and, therefore, expected to find a positive relationship between reptile diversity and habitat heterogeneity. Based on this hypothesis, we also anticipated a difference in the species assemblage between stands of the different crops, including a higher proportion of generalist species in areas where the crop is more intensively cultivated.

Materials and Methods

Study Area and Plot Arrangement

We conducted our study in the Southern Judea Lowlands, central Israel (31.668275°N, 34.879696°E; datum = WGS84; Fig. 1A). The area is included in the dry Mediterranean region (350–550 mm annual rainfall; Skutelsky 2011) and constitutes a contact zone among different biogeographical regions: Mediterranean, Saharo-Arabian, and Irano-Turanian. Therefore, the landscape is characterized by a particularly high biodiversity (including high reptile diversity; Rotem 2014). The area is a habitat mosaic consisting of natural patches and agricultural fields. The vegetation in the area has been impacted by anthropogenic activity for thousands of years (Ben-Yosef 1980), including agricultural cultivation and grazing. Today, the natural patches consist of Mediterranean garrigue, scrub-steppes, and Maquis. This agroecosystem has been studied in the past in relation to various taxa including beetles (e.g., Yaacobi et al. 2007), spiders (Gavish et al. 2012), and reptiles (e.g., Rotem et al. 2013, 2016).

In the context of our study, olive plantations and vineyards were managed with cultivation regimens, which are typical in the region. The olive plantations were classified as intensified-traditional plantations: The trees are annually pruned but are not irrigated or fertilized. The soil is tilled twice a year, herbicides are applied approximately three times annually, and pesticides are applied separately, on a monthly basis, for 5 mo a year. Nevertheless, their management seldom requires the utilization of heavy machinery, and some native vegetation usually persists within the cultivated areas. The vineyards were more intensively farmed, with management practices that include irrigation, frequent use of a variety of pesticides and herbicides (twice a month and more during Spring), biannual pruning, more prevalent use of heavy machinery (at least 1×/yr), and the constant removal of most of the ground cover.

Each type of focal crop was represented by five plots of identical size (100 × 50 m). As a control, each plot was paired with a plot of the same size in an adjacent patch of natural habitat, for a total of 20 study plots. The study plots were distributed within a range of approximately 7 km^2, with a maximum distance of 241.07 m separating an agricultural patch and its paired natural plot (Fig. 1A).

Reptile Surveying

We conducted seven reptile surveys in the study plots during the main activity season of reptiles in Israel (March to October) in 2015 and 2016. The surveys were conducted on days with favorable climatic conditions (sunny days with temperatures ranging from ~22–31°C; Carpio et al. 2015, 2017). We used two complementary methods to record observations of reptiles. The first method, line transects, was conducted by walking at a moderate pace along the long axis of the study plot. Two transects were surveyed at each plot during a single sampling event, with 10 m separating the transects so as to minimize the probability of observing the same individual twice within the sampling period. The transects were sited at the interior of each plot in order to minimize edge effects (Fig. 1B).

The second method was an active search, performed under a time limitation (an hour of searching effort for one person or divided evenly among the number of surveyors when >1 participant was present). During the survey period, we actively searched for reptiles by turning over shelters (e.g., stones, tree bark, piles of leaves, etc.) that were present in each plot. All shelter objects returned to their original position in order to minimize habitat disturbance. If any reptile was captured for closer inspection, it was released back to its habitat immediately thereafter. The combination of these survey methods provides the greatest likelihood of encountering all species occurring in these types of agricultural habitats (Porat 2011) and, in particular, is the most efficient method when surveying for reptiles in olive plantations (Carpio et al. 2015).

Heterogeneity Assessment

We recorded the percent cover of seven structural elements along 50-m transects in each study plot. We included any element that occurred with a 20-cm buffer along each side of the transect. The quantified elements were chosen based on their biological importance for reptiles (e.g., common shelters, ovipostion sites, and elements with importance for thermoregulation; adapted from Tews et al. 2004) and their occurrence within the landscape. Specifically, percentages quantified were the primary woody plant species in the habitat (olive trees, grape vines, or *Sarcopoterium spinosum* shrubs in the natural patches), woody vegetation other than the primary plant species, herbaceous vegetation, large rocks (>20 cm in at least one axis), stones, bare soil, and dead plant material. Two transects were surveyed within each plot, along its wide axis, and were separated by 40 m (Fig. 1B). From the values for percent cover, we calculated habitat heterogeneity using Shannon's index of diversity (Shannon 1948; following Tews et al. 2004; Porat 2011) and averaged values from the two transects to provide an index for each plot.

Data Processing and Statistical Analysis

We summed the total number of observations for each study plot throughout the study in order to calculate total reptile abundance and species richness per plot. Only observed reptiles identified to species level were included in the count. We referred to the total number of observations in the plot as total abundance because, in this study area (Rotem et al. 2013) and in a similar ecosystem (Porat 2011), the number of recaptures between surveys was negligible. When possible, we also calculated species diversity using Fisher's alpha index of diversity (Fisher et al. 1943). Unless otherwise stated, response values are reported as means ± 1 standard error (SE).

Because of the relationship between the communities representing the agricultural fields and the adjacent natural patches, the diversity measurements of these two habitats were compared using Wilcoxon's matched pairs test. This nonparametric test was appropriate given the small sample sizes, although the data did violate the assumption of homogeneity of variance when comparing the vineyards to adjacent natural patches. The statistical analyses were performed using Statistica v12.5.192.7 (StatSoft/TIBCO Software Inc., Palo Alto, CA).

We used nonmetric multidimensional scaling (NMDS) to visualize the degree of similarity between the species composition of the study plots. The resulting configuration

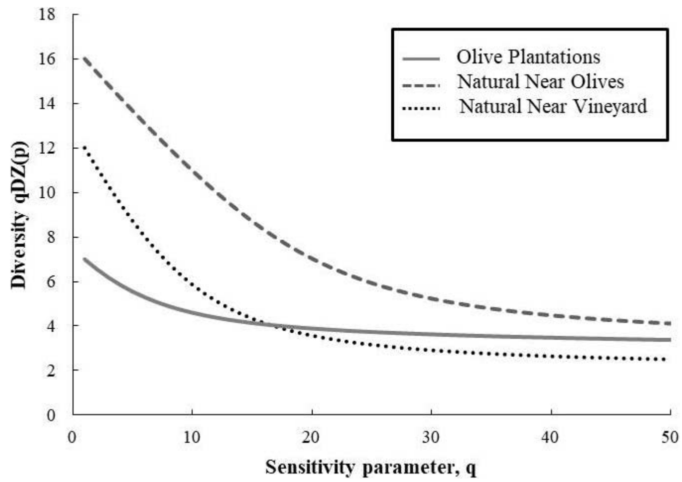

Fig. 2.—Diversity profiles of the reptile communities observed in olive plantations, the natural patches adjacent to them, and the natural patches adjacent to vineyards in the Southern Judea Lowlands of Israel (following Leinster and Cobbold 2009). The vineyard's profile is not depicted because observations of reptiles were absent in that habitat.

portrays the relative values of similarity between the samples (relative to one another) as a distance between data points in a graph. As such, the axes of the NMDS plots have no meaningful absolute scales (absent in Fig. 2). A nonparametric analysis of similarities (ANOSIM) allowed a statistical comparison of the similarity between the different habitats (Clarke and Warwick 2001). All diversity measurements and analyses were produced using PRIMER-e v6.1.6 (Clarke and Gorley 2006).

We produced diversity profiles for the reptile communities within each habitat following Leinster and Cobbold (2009) and using their naïve model in R; we implemented that code in RStudio v0.99.491 (RStudio Team 2015). The diversity profile produced is a graph in which the x-axis represents the sensitivity parameter, q, which quantifies the relative emphasis on common and rare species in the community: its value reflects the community's insensitivity to rare species. The y-axis represents the diversity measurement, ${}^{q}D^{Z}(p)$, which embodies various familiar diversity indices for particular values of q. Hence, this method is a helpful tool that enables visualizing several diversity indices of a community on a single graph, and it also visually compares these indices in different communities. For instance, whereas the left-hand end of a diversity profile gives information about species richness and the relative impact of rare species, the right-hand tail gives information about species dominance (low emphasis on rare species).

To address the issue of shift in composition from specialist to generalist species, we developed the Average Specialization Index (SI), following Bar Kutiel and Cohen (2002). The index represents the average level of habitat-specialization of the species observed, and is calculated for each study plot (p):

$$SI_p = \frac{\sum_{i=1}^{n} SR_I E_{ip}}{N_p},$$

where SR_I is the general habitat specialization rank (SR) attributed to species i and E_{ip} is the existence (1) or absence

Table 1.—The ranking system for calculating the specialization rank (SR) score for reptiles observed in vineyards, olive plantations, and natural patches in the Southern Judea Lowlands area of Israel. The SR is the sum of ranks in three scales for a specific species and represents the degree of habitat-specialization for this species.

Rank	Scale I: distribution pattern[a]	Scale II: affinity to biomes[b]	Scale III: affinity to certain structural elements[b]
4	Endemic mainly to a particular region in Israel	Affinity mainly to one of the following: arid, shrub-steppe, garrigue, maquis/forest	High affinity
3	Single distribution pattern type (e.g., Mediterranean)	Affinity mainly to two of the above-mentioned	Medium affinity
2	One main distribution pattern type and penetration to another region, or several subspecies with different distribution patterns	Affinity mainly to three of the above-mentioned	Low affinity
1	Wide distribution which includes most of Israel	Exists in all of the above-mentioned	Negligible affinity

[a] Following Dolev and Perevolotsky (2002).

[b] Structural elements (e.g., trees, rocks); B. Shacham, personal communication.

(0) of species i in plot p. The sum of their products for the *n* species observed in the plot is divided by N_p, the total species richness in plot p.

The species-specific SR score is an additive rank composed of three scales, each ranked 1–4, with an increasing rank indicating an increase in specificity (Table 1). We calculated the SI score for each plot, with high SI scores indicating a high degree of specialization among the observed species. We compared the SI scores representing different habitats using a Kruskal–Wallis test. This nonparametric test was again used because of the small sample size, although the data violated the assumption of homogeneity of variance, and transformations did not yield any improvement in this regard. We then tested the differences between each pair of habitats using Tukey's honest significant difference (HSD) test.

In order to examine whether the observed diversity patterns might be attributed to the structural properties of the habitats, we used principal component analysis (PCA) based on the structural variables measured in the study plots (PRIMER-e, v6.1.6, PRIMER-E Ltd, Plymouth, UK). The plots, regarded as points in a multi-dimensional variable space, are projected onto a best-fitting plane composed of principal components (PCs) that capture a maximal amount of variation in the environmental data (Clarke and Gorley 2006). We then examined the ecology of the three most common species in each habitat in relation to the PCA results. We chose the three most common species to avoid habitat-specific bias because three species accounted for 83% of the total abundance in the olive plantations. Additionally, we tested the relationships between the reptile diversity measurements and structural heterogeneity, as commonly applied in reptile diversity studies (e.g., Pianka 1973; Porat 2011). In these regressions, values for species richness and total abundance were square-root transformed to improve distribution normality and homogeneity of variance.

Results

We recorded a total of 359 observations of reptiles in the study plots during the surveys. Observed individuals belonged to 21 species and 10 families, including two species categorized as vulnerable to extinction (International Union for Conservation of Nature [IUCN] 2016). These two species were found in the natural patches, and one of them was also found within the surveyed olive plantations. No threatened species were found within vineyard habitat. Juveniles and eggs of several reptile species were observed in the natural patches and the olive plantations, but not in the vineyards. Only three reptiles were observed in the vineyards throughout the study (one of which was dead). Therefore, data from surveys of vineyard habitat were omitted from most of the species diversity analyses.

Reptile abundance in the olive plantations (15.2 ± 3.4 individuals per plot) was similar to that in the adjacent natural patches (19.0 ± 4.7; Wilcoxon's matched pairs test, $Z = 0.67$, $P = 0.50$). In contrast, species richness in the olive plantations (4.4 ± 0.5) was lower in comparison to adjacent natural patches (8.4 ± 1.0; $Z = 2.02$, $P = 0.04$). Consequently, species diversity (Fisher's alpha index) was lower in the plantations (2.6 ± 0.4) when compared to values from nearby natural patches (7.2 ± 1.2; Wilcoxon's matched pairs test, $Z = 2.02$, $P = 0.04$). The diversity profiles of the communities (Fig. 2) confirm that the natural patches were richer in species in comparison to the olive plantations, as evidenced by their higher values of ${}^{q}D^{Z}(p)$ at $q = 0$ (Leinster and Cobbold 2009). The vineyard habitat contained a lower reptile abundance (0.6 ± 0.2 individuals per plot) in comparison to adjacent natural patches (11.0 ± 2.4; Wilcoxon's matched pairs test, $Z = 2.02$, $P = 0.04$). Similarly, species richness was lower in the vineyards (0.6 ± 0.2) when compared to values from adjacent natural patches (4.6 ± 1.1; Wilcoxon's matched pairs test, $Z = 2.02$, $P = 0.04$). Because all of the observations in the vineyards were single observations of each of three species, Fisher's alpha index (as with most species diversity indices) could not be calculated.

The NMDS ordination of species composition in the study plots showed that the assemblage of species in the olive plantations was distinct, similar to the other communities by only 20%, whereas the communities of the two groups of natural patches were clustered together (Fig. 3). Values from plantation plots differed from the species composition in adjacent natural patches (ANOSIM, $R = 0.92$, $P = 0.008$) and from the species composition in the natural patches near the vineyards ($R = 0.82$, $P = 0.008$). Three species prominently dominated the reptile community occurring within the olive plantations: the skink *Ablepharus rueppellii* (35.06% of the observations), the gecko *Mediodactylus kotschyi* (24.67%), and the lacertid lizard *Phoenicolacerta laevis* (23.37%). Surveys within any of the natural plots did not yield any *M. kotschyi*. On the other hand, the three most common species in the natural patches were the gecko *Ptyodactylus guttatus* (37.58% of the observations), the skink *Heremites vittatus* (9.39%), and the tortoise *Testudo graeca*

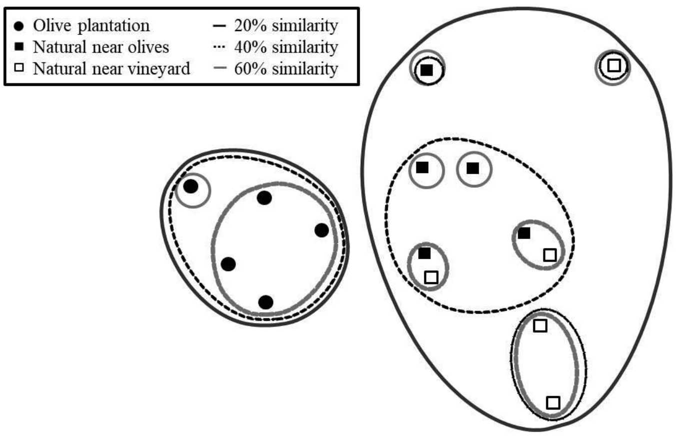

FIG. 3.—The nonmetric multidimensional scaling ordination based on Bray–Curtis similarities (calculates for root-transformed abundances) presenting the species composition of reptile communities in 15 study plots ($n = 5$ for each habitat) with olive plantations, the natural patches adjacent to them, and the natural patches adjacent to vineyards in the Southern Judea Lowlands of Israel. Stress = 0.12. The overlaid circles denote the level of similarity between clusters. Plots in the vineyards are not shown because observations of reptiles were absent in that habitat.

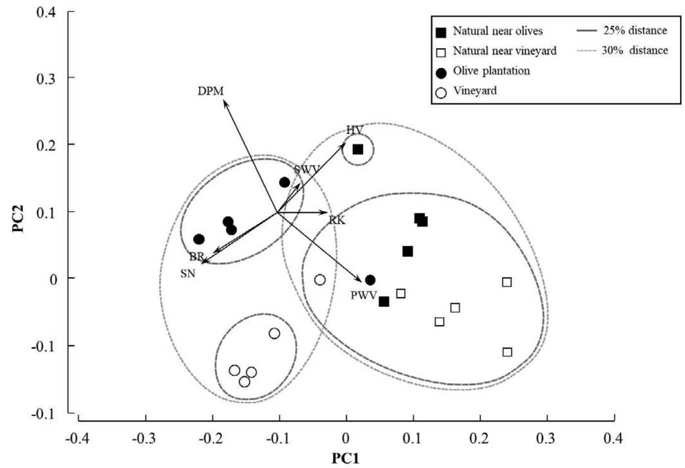

FIG. 4.—Projection of the 20 study plots on the first two principal components, PC1 and PC2 ($n = 5$ for each habitat), based on the relative covers of seven prominent structural elements in these habitats. The overlaid circles denote the level of dissimilarity (Euclidean distance) between clusters. PC1 explains 50.4% and PC2 explains 22.3% of the total variance. The length and direction of each vector portray the contribution of each structural element to the PCs in terms of magnitude and sign, respectively. Abbreviations are as follows: PMV = primary woody vegetation; SWV = secondary woody vegetation; HV = herbaceous vegetation; DPM = dead plant matter; RK = rock cover; SN = stone cover; BR = bare soil.

(8.05%). The patches of natural habitat hosted larger proportions of rare species in comparison to the olive plantations, as evidenced in the steeper drops in the diversity profiles of the natural patches close to the left-hand tail (Fig. 2). Nonetheless, the reptile community within the olive plantations demonstrated a high level of evenness, as the value of ${}^{q}D^{Z}(p)$ at the right-tail hand of the graph even exceeded its equivalent in the natural patches near the vineyards (Leinster and Cobbold 2009).

A comparison of SI values between the habitats, based on the calculated SR (Table 2), revealed an overall difference between the average specialization level of the species in different habitats (Kruskal–Wallis test, $H_{(2,15)} = 9.41$, $P = 0.009$). The specialization level in olive plantations (7.56 ± 0.23) was higher in comparison to adjacent natural patches

TABLE 2.—Species-specific specialization rank (SR) for the reptiles observed in vineyards, olive plantations, and natural patches in the Southern Judea Lowlands area of Israel (based on values in Table 1). A high SR indicates a high degree of habitat specialization.

Family	Species	Specialization rank
Agamidae	*Stellagama stellio*	6
Anguidae	*Pseudopus apodus*	5
Chamaeleonidae	*Chamaeleo chamaeleon*	8
Colubridae	*Dolichophis jugularis*	5
Colubridae	*Eirenis lineomaculatus*	5
Colubridae	*Eirenis rothii*	5
Colubridae	*Platyceps collaris*	6
Colubridae	*Rhynchocalamus melanocephalus*	4
Colubridae	*Telescopus fallax*	6
Gekkonidae	*Mediodactylus kotschyi*	10
Lacertidae	*Ophisops elegans*	6
Lacertidae	*Phoenicolacerta laevis*	9
Phyllodactylidae	*Ptyodactylus guttatus*	6
Scincidae	*Ablepharus ruppellii*	7
Scincidae	*Chalcides guentheri*	8
Scincidae	*Chalcides ocellatus*	3
Scincidae	*Eumeces schneideri*	5
Scincidae	*Heremites vittatus*	7
Testudinidae	*Testudo graeca*	4
Viperidae	*Daboia palaestinae*	5

(5.96 ± 0.19; Tukey's HSD test, $P = 0.001$). Moreover, it was higher in comparison to natural patches near the vineyards (5.84 ± 0.26; $P < 0.001$). The vineyards were omitted from this analysis, yet, based on the few reptiles found in them, the mean SI was low (5.33 ± 1.20).

The different habitats we studied differed in their physical structures. While the primary woody vegetation in each type of agricultural habitat was olive trees or vines, in the natural patches it was the thorny shrub *S. spinosum*. A PCA of the measured structural elements summarizes the physical differences between the habitats (Fig. 4). The first two principal components accounted for 72.7% of the environmental variation. Most of the study plots produced two distinct clusters: one containing the agricultural plots and one containing the plots representing adjacent natural patches. With a larger similarity between them, the olive plantations and the vineyards also differentiated into two clusters, but not the two types of natural habitats. The PC1 was most strongly associated with an increase in the percent cover from primary woody vegetation and herbaceous vegetation and with a decrease in the percent cover of stones. Generally, PC1 scores corresponded positively with elements of live vegetation and large rocks and negatively to ground which was bare, covered with stones, or with dead plant matter. The distinction between the agricultural and natural plots corresponded primarily to this axis because the natural plots tended to have higher scores on PC1 (–0.12 ± 0.07 vs. 0.12 ± 0.07 respectively; see Appendix). On the other hand, PC2 most strongly scaled with an increase in dead plant matter and herbaceous vegetation and to a decrease in the primary woody vegetation. In general, PC2 scores corresponded positively with vegetation elements other than the primary woody vegetation and negatively to bare soil and small stones. The separation between the two types of agricultural plots corresponded mainly to this axis, with the vineyard plots mainly corresponding with high proportions of bare ground and gravel. The patches of natural habitat adjacent to vineyards tended to have higher scores on PC1 (0.17 ± 0.06) and lower scores on PC2 (–0.04 ± 0.04) in comparison to the ones adjacent to olive plantations (0.07 ± 0.04 and 0.07 ± 0.08, respectively). Nevertheless, the two types of plots did not form distinct clusters.

Patches of natural habitat near olive plantations and vineyards were found to be the most structurally heterogeneous habitats (Shannon's index = 1.88 ± 0.03 and 1.85 ± 0.03, respectively). Habitat heterogeneity was lower in the vineyards (1.66 ± 0.04) in comparison to the natural patches adjacent to them ($P = 0.005$). The heterogeneity of the olive plantations (1.76 ± 0.04) did not differ from that of the vineyards ($P = 0.21$), however, nor from that of the adjacent natural patches ($P = 0.11$). We detected a positive relationship between species richness and structural heterogeneity (linear regression, $F_{1,18} = 11.77$, adjusted $R^2 = 0.36$, $P = 0.002$). Total reptile abundance also increased with increasing heterogeneity, though less sharply ($F_{1,18} = 5.77$, adjusted $R^2 = 0.2$, $P = 0.02$).

Discussion

The management practices employed at intensive vineyards and intensified-traditional olive plantations have clear and different impacts on local reptile diversity that distinguish them from patches of natural Mediterranean habitat. Vineyard habitats constitute inhospitable areas for reptiles, reflected both in low abundance and species richness when compared to adjacent natural patches. Previous studies have shown similar patterns, with a decrease in reptile diversity in intensive land-uses which do not preserve original land cover (Porat 2011; Biaggini and Corti 2015). Our results also indicate that intensive vineyards constitute a barrier in the landscape for reptiles, similar to what has been identified for certain groups of beetles (Skutelsky 2011). Therefore, this agricultural practice might induce habitat fragmentation and thereby promote a regional decline in the diversity of those reptile species that are particularly susceptible to habitat changes (cf. Gibbons et al. 2000). Our findings should be considered in light of the rapid increase in wine production in Israel (Rosenfeld and Avisar 2012).

Unlike the vineyards, the more traditionally cultivated olive plantations supported an abundant reptile community. Their community was characterized by high evenness (Fig. 2), which might contribute to its stability (Wittebolle et al. 2009). Nevertheless, species richness and species diversity in the olive plantations were lower in comparison to adjacent patches of natural habitat. Atauri and De Lucio (2001) and Carpio et al. (2016) have reported negative relationships between reptile species diversity and the presence of olive groves in Spain at the landscape scale. A decrease in local species richness in olive plantations was reported by Biaggini and Corti (2015), who also noted a low number of individuals in comparison to other crop types and natural vegetation strips. However, we found that reptile abundance in the olive plantations was similar to that found in adjacent natural patches. This unexpected result indicates that, based on reptile presence, olive plantations in our study system might serve as a high-quality habitat for some species. Further support for this interpretation comes from the fact that we found evidence for reptile reproduction in the olive plantations. As such, cultivation intensity appears to have consequences on levels of reptile diversity (cf. Biaggini and Corti 2015).

The species composition also differed between habitats in association with their physical structure. The intensified-traditional olive plantations host a unique assemblage of species (Fig. 3), including a threatened species. Their species composition was entirely separated from the communities in the two groups of natural patches that clustered together. Similar results were obtained regarding the habitat's structure in PCA (Fig. 4). In terms of structure, the separation between the agricultural and natural plots mainly corresponded to PC1. This axis was negatively related to typical characteristics of agricultural soils where the rocks are cleared off, the herbaceous vegetation is eliminated or controlled, and therefore the ground is mostly bare or covered with small stones that typically do not provide adequate shelter for reptiles. However, a decrease in PC1 and an increase in PC2 were also related to an increase in dead plant matter on the ground—an important characteristic of the olive plantations in particular. The ground in these patches was constantly covered by a thick layer of dead leaves, a preferred habitat of the skink, *A. rueppellii* (Bouskila and Amitai 2003). This lizard species was the most abundant reptile in this habitat. Healthy populations of *A. rueppellii* were found in almond plantations in a similar ecosystem (Porat 2011), and it is one of the only species inhabiting dense, planted pine forests in Israel (Bouskila and Amitai 2003; Maza 2008), apparently for the same reason.

The other two most dominant reptile species in olive plantations emphasize the influence of the olive trees themselves on the composition of the reptile community. For example, the gecko *M. kotschyi* inhabits (in Israel) mainly large trees that offer it (and its prey—invertebrates) various shelters, in or beneath the bark. Such trees are quite rare in the Mediterranean scrubland patches, and accordingly this species was not observed in the patches of natural habitat during the study. The patches of olive trees, on which the gecko is well-camouflaged, might therefore contribute to persistence of this species at the landscape scale. The third most abundant species, *P. laevis*, is a common species in gardens and inhabits habitats with plenty of vegetation and vertical elements such as rocks, trees, and walls. It also feeds on arthropods and is an adept climber that uses such microhabitats to escape predators (Bouskila and Amitai 2003). These species were very abundant in the olive plantations, although they had lower PC1 scores in comparison to the natural patches and lower PC2 scores in comparison to the vineyards—indicating a lower cover of the primary woody vegetation. In the more intensively cultivated vineyards, the vines are planted more densely than are the olive trees, yet, similarly to the dense, low *S. spinosum* shrubs in the natural patches, they are apparently less suitable for these species. The contribution of olive plantations to arboreal species (Hódar et al. 2000) might distinguish olive plantations from other tree crops in which the communities are composited by open, bare-habitat species (Gardner et al. 2007). Because two of the dominant reptile species were the most highly specialized species observed throughout the study (Table 2), the average specialization degree in the community was higher in comparison to the natural patches. This finding might indicate that, for some reptile species, the olive tree's unique structure might compensate for the negative impacts of cultivation.

The natural patches had higher PC1 scores, corresponding with their higher rock cover. Noticeably, the dominant reptile species in this habitat was *P. guttatus*, which favors such rocks as activity and oviposition sites (Bouskila and Amitai 2003). The second most abundant species in the natural patches, *H. vittatus*, inhabits various types of habitats including rocky areas of scrublands, areas with plenty of stones and high grass, agricultural soils, and gardens (Bouskila and Amitai 2003). Therefore, its abundance in the natural patches is not as clearly associated with specific structural elements as is the case for *P. guttatus*. Nevertheless, *H. vittatus* primarily inhabits areas with moderate vegetation cover, where it occasionally basks on exposed rocks (Werner 2016) and regularly utilizes rocks, shrubs, and thick patches of grass as shelters (Bouskila and Amitai 2003). The natural patches, as opposed to the crops we studied, offer a variety of shelters and activity sites for this insectivorous species. Interestingly, Rotem et al. (2013) reported that *H. vittatus* prefers natural patches over agricultural ones (wheat fields) for reproduction, even though the natural patches might offer higher arthropod abundance. The third most abundant species in the natural patches was the tortoise *T. graeca*, which is mostly herbivorous and thus associates more in the plots which were located higher on PC1 (i.e., higher live vegetation cover). The natural patches adjacent to the vineyards tended to have higher PC1 scores and lower PC2 scores in comparison to the natural patches near the olive plantations—corresponding with a higher coverage of *S. spinosum*. This is a common shrub occurring in disturbed habitats, and the difference thus derives from the higher grazing pressure (of cattle) in the area of the vineyards. Nonetheless, the two types of natural plots did not form distinct clusters in terms of structure (Fig. 4) nor species composition (Fig. 3).

The patches of natural habitat supported relatively abundant communities, which were richer and more diverse in comparison to the agricultural patches and included two species that are vulnerable to extinction. Although being less even, they support some species that were not observed within the agricultural habitats, and they also host high proportions of uncommon species (Fig. 2). These findings emphasize the importance of protecting these natural patches in Mediterranean scrubland areas for the conservation of the local herpetofauna (e.g., Maza 2008; Porat 2011). Vegetated buffer strips and connectivity between natural patches also support reptile diversity (Biaggini and Corti 2015). Unfortunately, the availability of this habitat type continues to decline in Israel (Sorek and Perevolotsky 2016).

Our results point to a positive relationship between reptile diversity and habitat heterogeneity. Structural heterogeneity was high in patches of natural habitat, low in the vineyards, and intermediate in the olive plantations. It is possible that the relationship between reptile diversity and structural heterogeneity is only an artifact of untested differences between the habitats (e.g., toxicity of pesticides, soil quality). Nonetheless, we suggest that the degree of structural heterogeneity can serve reliably to predict reptile diversity in agricultural landscapes. Similarly, Carpio et al. (2017) reported an increase in the abundance of squamate reptiles in olive plantations having a monoculture ground cover and a further improvement in species diversity in plantations with heterogeneous ground cover. Therefore, negative impacts of vineyards and olive plantations on reptiles might be mitigated by conserving the original cover, where possible. However, this conservation practice should be used in conjunction with reduced cultivation intensity (e.g., the use of heavy machinery and pesticides) to avoid creating an ecological trap (Rotem et al. 2013). Unquestionably, there is a need for the implementation of a more holistic, wildlife-friendly management in our study area.

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Appendix.—Eigenvectors of environmental variables and principal components scores of the study plots.

	Principal component	
	PC1	PC2
(a) Variable		
Primary woody vegetation	0.508	−0.42
Secondary woody vegetation	0.139	0.179
Herbaceous vegetation	0.412	0.421
Rock	0.303	−0.001
Stone	−0.456	−0.309
Dead plant matter	−0.324	0.678
Bare soil	−0.385	−0.243
(b) Plot[a]		
NO1	0.109	0.092
NO2	0.055	−0.033
NO3	0.113	0.086
NO4	0.091	0.042
NO5	0.017	0.194
NV1	0.239	−0.004
NV2	0.138	−0.063
NV3	0.161	−0.042
NV4	0.239	−0.108
NV5	0.080	−0.021
O1	−0.178	0.087

[a] Abbreviations are as follows: NO = natural plot near an olive plantation; NV = natural plot near a vineyard; O = olive plantation; V = vineyard.