



Factors contributing to the biodiversity value of an archaeological landscape in Jordan

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Archaeological landscapes are important places because they protect areas of historical importance, shape cultural and national identity, are recreational spaces, and vital sources of tourism revenue. Archaeological landscapes have the potential to assist in reptile conservation. The objective of this study was to compare the diurnal reptile richness of an archaeological site to the reptile richness of a nature reserve (treatment control for biodiversity value) and a modern olive grove (treatment control for poor biodiversity value). Our results suggest that archaeological landscapes provide valuable reptile habitat, as our archaeological site supported similar reptile richness as the natural site, with both sites having higher species richness than the modern olive tree farm. The high reptile richness and densities were the result of high potential food availability and habitat mosaic of relatively low tree density and open areas with exposed, tall, rocky ruins. Reptile richness had a negative relationship with tree density. The ruins and high food availability of the archaeological site supported higher densities of saxophilic lizard species as the density of these species increased as mean maximum rock height and percentage of green ground vegetation cover increased. Promoting the reptile richness of archaeological sites provides another justification for the protection and visitor appreciation for archaeological sites as places of historical, cultural and biodiversity importance.

Keywords: *Stellagama stellio*, *Ptyodactylus puiseuxi*, reptile richness, rock outcroppings, vegetation greenness indices

INTRODUCTION

Archaeological landscapes have the potential to be valuable spaces of wildlife conservation. Historical human activity sometimes increases environmental or habitat heterogeneity that increases flora and wildlife biodiversity (Celesti-Grapow et al., 2006; Dambrine et al., 2007; Vanderplank et al., 2014). For example, remains of historic human disturbance, such as shell middens from hunters, was found to change soil composition and increase microsite habitat structural heterogeneity, which in turn resulted in increased plant diversity (Vanderplank et al., 2014). Species richness and coexistence is often related to the availability and diversity of habitat and food (Schoener, 1974). Heterogeneous and structurally diverse habitats often favour a greater number of species as a result of the greater availability of refuge, nesting, and foraging niches (Pianka, 1966).

Archaeological sites can be viewed as a landscape of rock outcrops, a habitat recognised as having high biodiversity value because of their habitat heterogeneity. Archaeological ruins often consist of structures with different states of preservation creating a mosaic of irregular remains of walls, buildings, and rock piles that can be used for basking, perching and refuge by different wildlife (Celesti-Grapow et al., 2006; Dambrine et al.,

2007; Fitzsimons & Micheal, 2017). These anthropogenic rock piles have a long history of abandonment, which would allow species from neighbouring natural habitats to colonise and utilise the semi-modified landscape (Celesti-Grapow et al., 2006; Dambrine et al., 2007).

Biologists often quantify food availability to examine the relationship between food availability and biodiversity. However, trapping and quantifying insects as a measure of food availability for reptiles can be time consuming and may require some entomological taxonomic specialisation (Newbold & Macmahon, 2014). In arid environments, vegetation availability is sometimes used as a proxy to quantify food availability for higher trophic levels (Hunter & Price, 1992). Vegetation greenness indices are often used to assess precipitation quantity and resultant vegetation quality at a large scale, which is used to correlate greener and presumably higher nutritional vegetation with wildlife populations (Creech et al., 2016). Therefore, an indirect measurement of percent green vegetation cover measured on the microhabitat scale would be useful to represent the availability of potential food for reptiles at the immediate site (Patrignani & Ochsner, 2015).

Despite the potential for archaeological landscapes to contain high biodiversity or rare species, this aspect is often not studied or appreciated (Ruben & Disi, 2006;

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Celesti-Grapow et al., 2006; Damhoureyeh et al., 2011). The objective of this study was to compare the diurnal reptile richness between an archaeological site, a nature reserve (treatment control for biodiversity value) and a modern olive grove (treatment control for poorer biodiversity value) in northern Jordan. Jordan is an ideal field site because of its high reptile diversity and numerous large archaeological sites, which are habitat to a variety of reptile species (Disi et al., 2001). We then examined which habitat factors had a significant relationship with reptile richness and the abundance of the two most common rock dwelling lizards in order to understand why some species may have high densities at archaeological sites.

METHODS

Study site

We surveyed three sites between 22 May 2018 and 8 June 2018 in northern Jordan. The three sites were Umm Qais Archaeological Park, Yarmouk Protected Area, and a modern olive tree farm (Fig. 1). The three sites are part of the Mediterranean biogeographic zone characterised by warm summers and relatively cold winters, with mean precipitation of 400 mm / year. The area consists of plateaus, hills, and mountains with deeply dissected valleys that feed into the Yarmouk river. The Umm Qais town is the closest urban center to all three study habitats. The Umm Qais archaeological park (45 ha) consists of a partially excavated Greco-Roman site on a plateau covered by newer Byzantine and Ottoman village and cemetery. The archeological structures consist of columns, buildings, walls, and rubble outcroppings in different states of preservation. The site also contains a historic olive grove, which contains olive trees as old as several hundred years, with old growth olive trees being the most abundant and widespread tree in the archaeological park. The olives are harvested using traditional farming by hand and are not sprayed with pesticides. Native trees such as deciduous oak *Quercus aegilops* and Atlantic pistachio *Pistacia atlantica* are also found in the archeological site, while native shrubs, grasses, and other flowering plants occur. Grazing mostly occurs in the periphery of the park by a small herd of cows and sheep throughout the spring and early summer. The entire park is enclosed by a wired fence.

Yarmouk Nature Preserve (2000 ha²), borders the Umm Qais archaeological site, overlooks Yarmouk river, and consists of deciduous oak forest (roughly 85 percent of Jordan's surviving oak cover) on mountains (500 m), deep valleys (seasonally flowing riverbeds), limestone rocky outcroppings, and open grassland habitats. The tree community is dominated by deciduous oak with other prominent species including carob *Ceratonia siliqua*, Atlantic pistachio, white willow *Salix alba*, and Aleppo pine *Pinus halepensis*. The Yarmouk Nature Preserve served as our control treatment for high species richness.

The modern olive tree farm (roughly 100 ha) consisted of an olive tree farm on a plateau that is less than twenty years old and was considered the treatment control for poor species richness. In order to accommodate vehicles

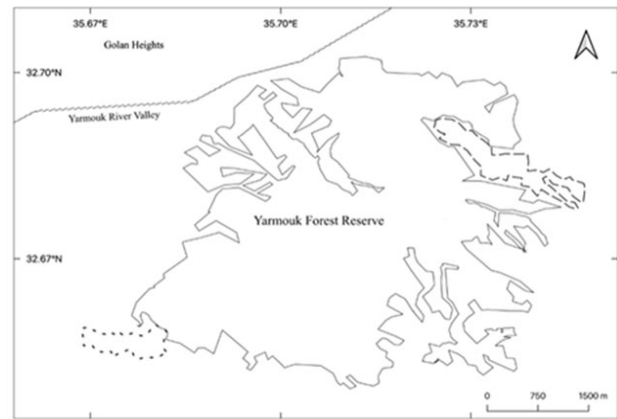


Figure 1. Map of the study site. The smaller dashed lines represent the border of Umm Qais archaeological park. The solid lines represent the border of Yarmouk protected area, and the longer lined dash represents the border of the modern olive tree farm.

such as tractors, most of the large rocks have been removed, while some native trees and vegetation remain. Herbicides and pesticides are also applied to remove herbaceous ground cover and reduce insect populations. The modern olive tree farm is adjacent to Yarmouk protected area and the archaeological site.

The purpose of the surveys was not to comprehensively document species richness, but instead to obtain values for comparison between sites. We thus surveyed six, GIS randomly selected 300 m transects, with a minimum distance of 200 m apart, in each habitat. In order to standardise topography, all the transects were located on plateaus, given that the archaeological site only occurs on a plateau. Habitat data was collected at 30 m intervals, for a total of 10 points for each transect. For each sampling point, we recorded measurements of available tree and rock microhabitat and percent of green, ground vegetation cover.

The tree microhabitat measurements included diameter at breast height (DBH), maximum tree height, and maximum canopy diameter of the nearest tree to the sampling point. Regarding rock structure, we recorded the percent of exposed rock substrate along a 6 m length using a flexible tape measure, the maximum height of the nearest stone with a height greater than 15 cm, and a vertical heterogeneity index within a three-metre radius of the survey point. The vertical heterogeneity index was measured by recording the actual 6 m distance by laying a flexible tape measure along the substrate (bare ground, rocks, ruins, etc.) and then dividing the actual distance by the straight-line distance between the start and end point of the actual distance (actual 6 m distance / straight line distance), with higher values indicating higher vertical habitat heterogeneity. Vertical habitat heterogeneity can be influenced by topography from hills or large vertical rocks. The percent of green vegetation cover was measured on the microhabitat scale and represents availability of green vegetation at the immediate site. We recorded percent green, ground vegetation cover using

the smart phone application, Canapeo (Patrignani & Ochsner, 2015), by extending our arm to the side and placing the camera parallel to the ground at a height of roughly 1.45 m above the ground. The percent green ground cover would consist of photosynthetically active annual and perennial herbaceous plants and small, low lying shrubs. Yellow, dormant or dying plants, and bare ground were excluded from the measurement of percent green, ground cover (Patrignani & Ochsner, 2015). We measured tree density post-hoc by counting the number of trees within 15 m of each side of our transects using the satellite imagery from Google Earth. Reptile surveys occurred roughly two to three hours after sunrise and by walking along the length of each transect at an intentionally slow pace of roughly 15 m / minute. For each observation, we recorded the number of each species.

Statistical analysis

We compared mean reptile richness and abundance between the three sites through the use of multiple ANOVAs. Whenever the ANOVA detected a significant difference between the three habitats, we proceeded with follow-up simple contrasts in which the archaeological habitat was the reference and compared to the natural site and olive tree farm. We then used backward stepwise linear regressions to identify which microhabitat variables had a significant relationship with reptile richness and abundance. The microhabitat variables included in the regressions were maximum canopy diameter, percent of exposed rock substrate, maximum rock height of the nearest stone, vertical heterogeneity, percent green, ground vegetation cover, and tree density. We did not include diameter at breast height (DBH) and maximum tree height in the analysis because these variables were highly correlated with maximum tree canopy.

RESULTS

Five tree species were recorded in the archaeological site, four species recorded in the natural site, and three species in the agricultural site. The natural site ($n = 60$ trees) was dominated by deciduous oak *Quercus aegilops* (77 %, $n = 46$), spiny hawthorn *Crataegus aronia* (17 %, $n = 10$), carob tree *Ceratonia siliqua* (5 %, $n = 3$), and Palestine buckthorn, *Rhamnus palaestina* (2 %, $n = 1$), whereas the archaeological site ($n = 58$ trees) was dominated by old olive trees, *Olea europaea* (67 %, $n = 39$), Atlantic pistachio *Pistacia atlantica* (19 %, $n = 11$), Syrian Christ-thorn *Ziziphus spina-christi* (10 %, $n = 6$), and fig *Ficus carica* (3 %, $n = 2$). The modern olive tree farm ($n = 60$ trees) was dominated by olive (90 %, $n = 50$), oak (8 %, $n = 5$) and Palestine buckthorn *Rhamnus palaestina* (2 %, $n = 2$). We could not compare the sizes of specific trees between the three habitats because of the different species composition across sites. We therefore combined the measurements of all tree species and compared the tree microhabitat structures (tree height, etc.) between habitats and when examining the relationship between tree structure and species richness or lizard abundance.

The three habitats had similar tree structure as

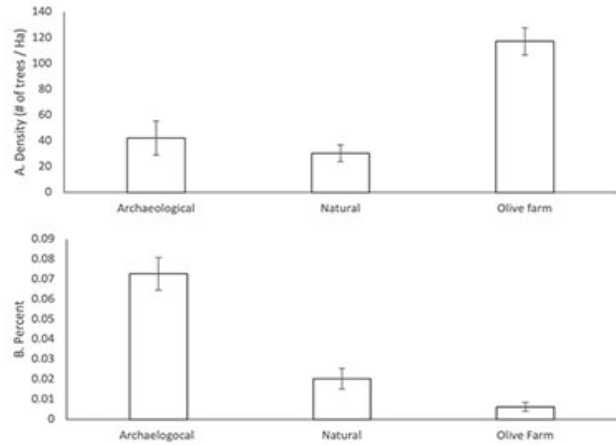


Figure 2. A comparison of mean \pm SE of tree density and percent green vegetation cover from the three different habitats, an archaeological site, natural site, and modern olive tree farm. **A)** tree density (number of trees / ha). **B)** percent green ground vegetation cover, which was used as an index of food availability.

there was no significant difference between mean dbh (ANOVA: $F_{2,170} = 1.18$, $P = 0.31$) and height (ANOVA: $F_{2,170} = 0.46$, $P = 0.63$) of the three habitats. However, there was a significant difference between the three habitats regarding their mean maximum tree canopy (ANOVA: $F_{2,170} = 3.56$, $P = 0.031$), percent of green ground vegetation cover (ANOVA: $F_{2,170} = 6.13$, $P = 0.003$), and tree density (ANOVA: $F_{2,15} = 20.18$, $P < 0.0001$). Follow-up contrasts showed that the mean maximum tree canopy (Fig. 2) was not significantly different between the archaeological and natural habitat ($P = 0.60$) and olive tree farm ($P = 0.056$) but the archaeological habitat did have significantly more green ground vegetation cover than the natural ($P = 0.029$) and olive tree farm ($P = 0.001$; Fig. 2). In addition, the archaeological site had similar tree density as the natural site ($P = 0.44$), but significantly less tree density than the modern olive tree farm ($P < 0.0001$; Fig. 2).

The overall rock structure (Fig. 3), percent of exposed rock substrate (ANOVA: $F_{2,170} = 39.76$, $P < 0.0001$), maximum rock height (ANOVA: $F_{2,170} = 14.86$, $P < 0.0001$), and microhabitat rugosity (ANOVA: $F_{2,170} = 16.26$, $P < 0.0001$) were significantly different between the three sites. The simple contrasts showed that archaeological site had significantly taller rocks and greater microhabitat rugosity than the natural site ($P < 0.0001$, $P < 0.0001$), and olive tree farm ($P < 0.0001$, $P < 0.0001$), respectively. The natural site did have significantly more exposed rock substrate than the archaeological site ($P < 0.0001$) and olive tree farm ($P < 0.0001$).

The three most common diurnal reptiles in the archaeological and natural sites were the starred agama *Stellagama stellio*, Levant fan footed gecko *Ptyodactylus puiseuxi* and snake eyed lizard *Ophisops elegans*. However, we were not able to compare abundance of *O. elegans* or other reptile species between the three habitats because of the small sample size. A total of six reptile species

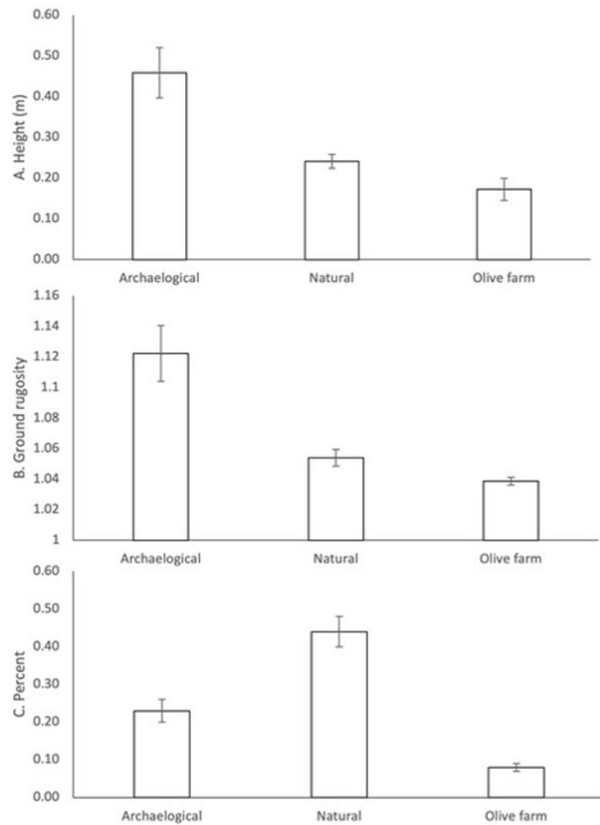


Figure 3. A comparison of mean \pm SE rock habitat structure of the three habitats, an archaeological site, natural site, and modern olive tree farm. **A)** maximum rock height (m), **B)** ground rugosity. Values closer to one are flatter with less micro-topographical heterogeneity, while larger values represent greater micro-topographical heterogeneity. **C)** percent of exposed rock substrate.

(including the Forskal's sandsnake *Psammophis schokari*, Mediterranean chameleon *Chamaeleo chamaeleon*, and the nationally endangered and globally threatened Spur-thighed tortoises *Testudo graeca*) were observed at the archaeological site and four species (including the Collared dwarf racer *Platyceps collaris*) were observed at the natural site and zero species of reptiles were observed at the agricultural site. Reptile (ANOVA: $F_{2,18} = 19.92$, $P < 0.0001$) richness was significantly different between the three sites. There was no significant difference in mean reptile richness ($P = 0.11$) between the archaeological and natural sites but the modern olive tree farm had significantly lower reptile ($P < 0.0001$) richness than the archaeological site (Fig. 3). There was a significant relationship between microhabitat structure with reptile richness ($F_{1,17} = 12.44$, $p = 0.001$), with the final model only containing percent green ground vegetation cover and tree density, explaining 62 % ($r^2 = 0.62$) of the variation of reptile richness. There was no significant relationship between reptile richness and percent green ground vegetation cover ($t = 1.83$, $B = 12.11 \pm 6.61$, $P = 0.087$; Fig. 3) but reptile richness significantly decreased as tree density increased ($t = -3.74$, $B = -0.021 \pm 0.006$, $P = 0.002$; Fig. 4).

There were significant differences in the number of *S.*

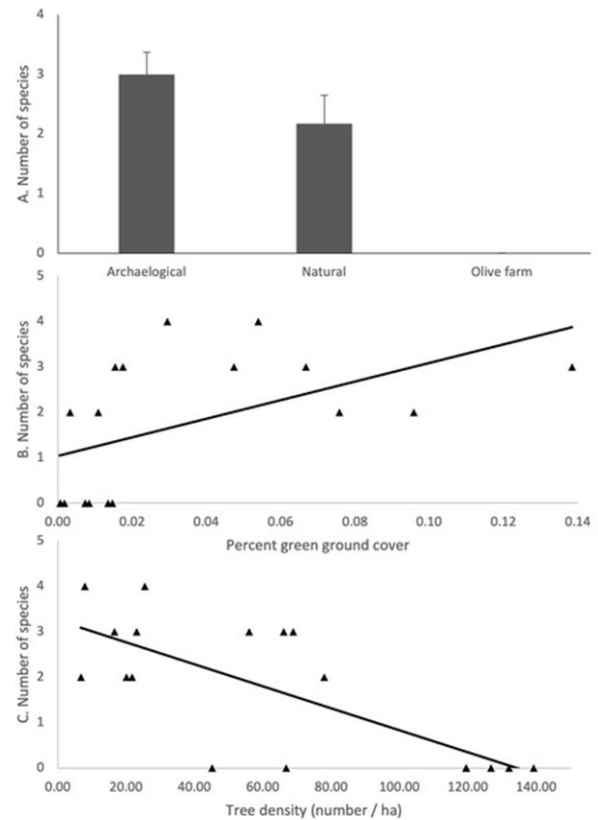


Figure 4. A comparison and relationship of species richness. **A)** Comparison of reptile richness in the three habitats. Olive farm = modern olive tree farm. **B)** Relationship between percent green vegetation cover with reptile richness. **C)** Relationship between tree density (number / ha) and reptile richness.

stellio (ANOVA: $F_{2,18} = 44.52$, $P < 0.0001$) and *P. puiseuxi* (ANOVA: $F_{2,118} = 4.86$, $P = 0.024$) observed in the three sites (Fig. 5). Simple contrasts showed that significantly more *S. stellio* and *P. puiseuxi* were observed in the archaeological site than the natural ($P < 0.0001$, $P = 0.025$) and the modern olive tree farm ($P < 0.0001$, $P < 0.0001$), respectively (Fig. 5). Microhabitat was a significant predictor of the number of *S. stellio* ($F_{1,17} = 26.95$, $P < 0.0001$) and *P. puiseuxi* ($F_{1,17} = 51.09$, $P < 0.0001$) observed. Percent green ground cover and maximum rock height were the two variables that remained in the final model, explaining 78 % ($r^2 = 0.78$) and 87 % ($r^2 = 0.87$) of the variation in the number of *S. stellio* and *P. puiseuxi* observed, respectively. The number of *S. stellio* and *P. puiseuxi* observed increased as the percent of green ground cover ($t = 3.89$, $B = 0.57 \pm 0.35$, $P = 0.001$, $t = 2.63$, $B = 0.17 \pm 0.066$, $P = 0.019$) and maximum rock height increased ($t = 2.68$, $B = 7.42 \pm 2.79$, $P = 0.017$, $t = 6.23$, $B = 7.79 \pm 1.24$, $P < 0.0001$), respectively (Fig. 5).

DISCUSSION

The higher reptile richness and densities of starred agama and Levant fan footed gecko at the archaeological site was a result of the habitat mosaic consisting of open

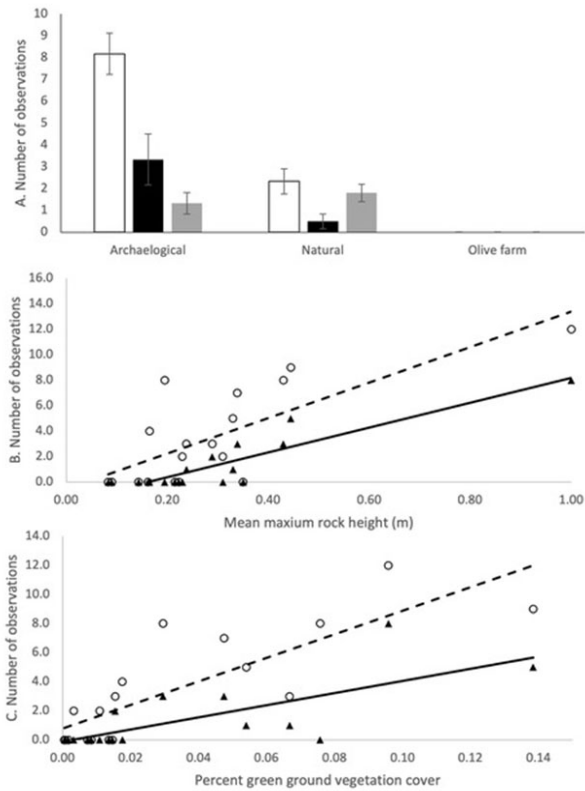


Figure 5. A comparison of the number lizard observations and their relationship with mean maximum rock height and percent green ground vegetation cover. **A)** A comparison of the number of lizard species observations across three different habitats. The hollow bars represent *Stellagama stellio*, the black bars represent *Ptyodactylus puiseuxi*, and the grey bars represent *Ophisops elegans*. **B)** The relationship between the number of observations with the mean maximum rock height (m). The hollow circles represent *S. stellio* and the black triangles represent *P. puiseuxi*. **C)** The relationship between the number of observations with percent green ground vegetation cover. The hollow circles represent *S. stellio* and the black triangles represent *P. puiseuxi*.

areas with relatively low tree density and exposed, tall, rocky ruins that had high potential food availability (Santos & Poquet, 2010). Diurnal reptile richness was negatively associated with tree density (Fig. 3). Artificially high tree density, especially of planted trees used in agriculture or afforestation programs, can lead to a decrease in richness or change the community composition in more arid environments (Shochat et al., 2001; Hawlena & Bouskila, 2006; Schreuder & Clusella-Trullas, 2016; Carpio et al., 2017). The modern olive farm contained an artificially high tree density that was much higher than the natural and archaeological sites, although lower than olive groves in Europe (Metzidakis et al., 2008). Reptiles naturally found in open habitat with low tree densities are likely selected against when the habitat has changed from an open space to a habitat characterised by high tree or vegetation density (Jellinek et al., 2004). The high tree density reduces thermoregulation basking sites for reptiles (Schreuder

& Clusella-Trullas, 2016), while potentially increasing predation from avian predators utilising the high availability of once rare perching sites (Shochat et al., 2001; Goode et al., 2005; Hawlena & Bouskila, 2006; Hawlena et al., 2010). The modern olive farm, which had the highest density of trees, had more bird of prey species observations than the other sites (Attum et al., unpublished data).

Although we did not find a relationship between maximum rock height and reptile richness, we believe that the ruins provided rock outcropping habitat to the saxaphilic *S. stellio* and *P. puiseuxi*, as their density increased as mean maximum rock height increased (Jellinek et al., 2004; Fitzsimons & Micheal, 2017). Taller and the greater availability of rock habitat would allow more saxaphilic lizards to utilise the archaeological ruins for thermoregulation and display (Michael et al., 2008, 2010; Monasterio et al., 2010; Norfolk et al., 2010; Croak et al., 2013), while minimising predation risk from the avian predators, such as shrike species that occurred in the archaeological site (Hawlena et al., 2010; Monasterio et al., 2010). In contrast no reptiles were observed in the modern olive tree farm because farmers removed the large rocks in order to facilitate tractor movement which resulted in the modern olive tree farms having the shortest rocks, least habitat rugosity and percent exposed rock substrate (Fig. 2). Saxaphilic reptiles can be negatively impacted by the removal of larger rocks and resultant habitat simplification (Goode et al., 2005; Pike et al., 2010).

Green, herbaceous vegetation was not common in our study sites as the percent of green cover ranged from zero to fourteen (Fig. 4), suggesting that primary productivity that supports higher trophic levels could be a limiting resource. It is believed that in vegetation limited environments, greater percent of green vegetation cover would support more species and higher abundances as result of increased carrying capacity (Carpio et al., 2017). For example, there is often a positive relationship between increased vegetation cover and the number of invertebrates, suggesting that areas with higher vegetation cover provide increased food availability for insectivorous birds and lizards (Robinson, 1981; Sanchez & Parmenter, 2002). Our results supported the assumption that food availability may increase carrying capacity, as both *S. stellio* and *P. puiseuxi* increased in density as percent green, ground vegetation cover increased (White, 1978). In contrast, the modern olive farm had the lowest percent of herbaceous green vegetation cover (Fig. 1) as this site was intentionally heavily grazed to remove herbaceous ground cover that farmers view as competing with young olive trees for water. In addition, the modern olive grove sprayed pesticides to reduce insect populations, which further reduced food availability for insectivores (Cotes et al., 2010).

The archaeological site had the highest percent of green ground vegetation cover, which is likely a result of the lower levels of grazing and the rockiness or heterogeneity of the terrain, which may slow grazing rates or make some areas less accessible (Fitzsimons & Micheal, 2017). Our results suggest that historic olive groves, like those in the archaeological site, are often

categorised by relatively low tree density that could potentially be similar in density to natural forests of the region. In addition, historic olive groves likely have more biodiversity value than modern olive tree farms because historic olive groves have lower tree density, more diverse community of native and fruit trees, and older olive trees have a greater number of niches, such as tree cavities, greater branching extent and branch size heterogeneity, all of which contributes to biodiversity potential (Awad & Attum, 2017; Pinto et al., 2018). We observed *S. stello* basking and escaping into the trunk openings in older olive trees. The archaeological site also contained a species of interest, the Greek tortoise, which is endangered within Jordan. Presumably, high food availability and the mixture of old growth olive trees and open areas for thermoregulation in the archaeological site provided suitable Greek tortoise habitat (Attum et al., 2011).

We believe that archaeological landscapes can be important areas for reptile conservation in Jordan and the region. Rare reptile species and high reptile richness have been recorded in other archaeological parks in Jordan (Disi et al. 2001; 2014). For example, 40 % of the wildlife species found in Jordan have been recorded in the Petra region that includes Petra Archaeological Park, Jordan's largest archaeological park. (Ruben & Disi, 2006). The Petra region is believed to be biologically rich due to its large size, diverse habitats, availability of springs and waterholes, and diverse plant community (Ruben & Disi 2006; Damhoureyeh et al. 2011). Although the preservation of archaeological sites and biodiversity do not always overlap and in a few instances may have competing priorities, we believe that biodiversity and archaeological conservation are mutually beneficial because archaeological sites provide habitat heterogeneity as a result of excavations, herbaceous ground cover, and some level of protection to wildlife (Damhoureyeh et al., 2011; Vanderplank et al., 2014). Promoting the reptile richness of archaeological sites provides another justification for the protection and visitor appreciation of archaeological sites as places of historical, cultural and biodiversity importance (Celesti-Grapow et al., 2006).

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Authors contribution

OA devised the project, conducted field work, analysed data, and contributed to the manuscript. SM conducted field work and contributed to the manuscript. NH

provided logistical support and contributed to the manuscript.

Ethical statement

This study abided by all local legislation and standard ethical practices.

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