Migratory bird species benefit from traditional agricultural gardens in arid South Sinai

Olivia Norfolk*, Andrew Power, Markus P. Eichhorn and Francis Gilbert

School of Life Sciences, University of Nottingham, University Park, Nottingham, NG7 2RD

* corresponding author: olivia_norfolk@hotmail.com

Abstract

In temperate and tropical regions agricultural conversion of natural habitat typically has negative impacts upon the diversity and functional complexity of bird communities. In arid environments however, the irrigation associated with agricultural can lead to an increase in local abundances of plant and insect resources, so has the potential to benefit bird communities. South Sinai is a key migratory corridor for many birds making the annual journey from wintering sites in Africa to breeding sites in Europe. We assess the importance of traditional Bedouin agricultural gardens for both resident and migratory species by comparing the density and functional composition of birds within the irrigated gardens to those in the unmanaged desert habitat. Estimated bird densities were significantly higher within the gardens than the unmanaged habitat, with a higher estimated species richness within the gardens. Functional composition of bird communities differed between the two habitats, with gardens supporting a higher proportion of insectivorous and migratory birds in addition to the resident desert species that were associated with the unmanaged habitat. Migratory species were almost entirely absent from the unmanaged habitat, suggesting that this region may not be used as a migratory stop-off if not for the presence of traditional agricultural gardens.

Keywords: birds; desert; functional richness; migration; oases

1. Introduction

The impact of anthropogenic land-use on bird communities has received limited attention in arid regions. In temperate and tropical regions, land-use change such as agricultural conversion of natural habitat typically lead to the disruption of bird assemblages and a loss of functional diversity (Tscharntke et al., 2008; Flynn et al., 2009), but initial research suggests that the irrigation associated with agricultural systems and gardens in arid regions can actively increase the functional diversity of plants (Norfolk et al., 2013) and increase the abundance of pollinators (Gotlieb et al., 2011) and birds (Selmi & Boulinier, 2003; Khoury & Al-Shamlih, 2006). Human population growth and land-use change in arid environments are likely to have direct impact upon local bird communities, but may also have implications for the estimated 4 billion birds that make the bi-annual migration across the Saharan-Arabia desert belt, passing between wintering sites in Africa and summering sites in Europe (Frumkin et al., 1995). In order conserve the migratory routes of these species it is important to understand how birds and humans are interacting in the en route arid environments.

Crossing the inhospitable expanse of the Sahara desert can pose a major ecological challenge for birds, one which imposes an exceptional energy demand (Zduniak et al., 2013). Strategies for desert crossing differ between bird groups, with raptors tending to use soaring flight and small passerines flapping flight which allows them to fly through the night and avoid high temperatures (Bruderer, 1994; Chernetsov, 2006). Many passerines make the entire 40-50 hour journey across the Sahara in one stretch, but others take an intermittent strategy and stop along the way for refuelling either in the desert or in well-vegetated man-made oases (Biebach, 1990; Biebach et al., 2000; Khoury, 2004; Salewski et al., 2010).

South Sinai forms a key migratory corridor at the latter end of this migration and numerous species of passage migrant have been observed in oases and traditional gardens across the region; most individuals rest for just a day, but some remain for lengthier refuelling periods (Lavee et al., 1991; Bairlein, 1992). South Sinai is also known to support many species of over-wintering migrant that remain throughout the entire winter and make a shorter migration to Europe in the spring (Svensson et al., 2010). The region is hyper-arid and is typified by rocky valleys and low-growing shrubs (Grainger & Gilbert, 2008), but the local Bedouin harvest rainwater from intermittent flash floods in order to create oasis-like gardens along the base of the valleys (Perevoltosky, 1981; Zalat & Gilbert, 2008).

The irrigated gardens contain a wide variety of vegetables and herbs grown underneath a canopy of orchard trees. As a consequence they support a more diverse and functionally complex plant community than the unmanaged desert habitat (Norfolk et al., 2013) and have been shown to support more insects (Norfolk et al., 2012). The higher availability of water, shelter and food resources within these gardens is likely to have a strong influence on the distribution and functional composition of bird communities in the area. Specifically we predicted that: a) the presence of the gardens would have a positive influence upon bird densities and b) that the modification of the vegetation and insect resources would influence the functional composition of these bird communities. We utilised species-based and functional trait-based analyses to test these hypotheses, paying specific attention to the gardens' relative importance for resident versus migratory species.

2. Methods

Study Site

The St Katherine Protectorate (28°33′N, 33°56′E) in South Sinai, Egypt is an arid, mountainous region with altitudes of 1200-2624 m a.s.l.. The region has a hyper-arid climate, experiencing extremely dry, hot summers and cold winters (Grainger & Gilbert, 2008). Average annual rainfall ranges from 10 mm per year in low coastal areas to 50 mm per year in the high mountains, but this entire annual rainfall can fall within the space of a single day as unpredictable flash floods (Cools et al., 2012). The habitat is strongly defined by the presence of Bedouin orchard gardens that are clustered along the bases of the mountain valleys. These traditional gardens depend on runoff rainwater, which facilitates the growth of a variety of orchard products as well as vegetables and herbs (Zalat & Gilbert, 2008). The gardens are primarily used for subsistence, but also contain ornamental flowers and have been shown to provide important habitat for rare wild native plants (Zalat et al., 2001; Norfolk et al., 2013). The unmanaged habitat consists of rocky slopes and sandy wadis, with the vegetation is typified by low growing desert shrubs. Plants experience low levels of grazing from goats and sheep, but livestock are primarily fed on imported grain (Gilbert, 2013) and wild desert shrubs occur at a similar abundance in the unmanaged habitat as they do within the gardens (Norfolk et al., 2013).

Site selection

The aim of the study was to compare the bird communities within the gardens to those that would be present in the absence of agriculture so we used a paired design of gardens and associated unmanaged habitat. In total we conducted surveys in 12 gardens and associated areas of unmanaged habitat; four from St Katherine town, four from Wadi Itlah and four from Wadi Gebel. Gardens were selected at random from the gardens available in each wadi. Unmanaged transects were a minimum of 50 m from their associated garden, and were 200 m in length. In the mountains it was often only feasible to survey along the base of the steep sided valleys, so transect locations were determined by geographic feasibility. Though complete randomization of the transects would have been ideal, the gardens are also constrained to the wadi bases so our design allows for a reasonable comparison with the habitat that would be presence in the absence of agriculture. For the exact locations of gardens and their associated transects see Appendix 1.

Data collection

The study was conducted between February and March 2014, allowing us to observe over-wintering migrants and the first wave of the migratory birds. Each garden and associated unmanaged habitat was repeatedly surveyed five times throughout the course of the study period. All surveys were conducted between 07:00 and 11:00 hours, with gardens and their unmanaged habitat surveyed on the same day to ensure similar weather conditions.

Within the gardens, densities were estimated from a slow walk which covered the whole area of the garden, with all birds detected visually within the boundary recorded. Searches typically took between ten and twenty minutes depending on garden size. Areas of denser vegetation (trees and shrubs) were studied carefully to make sure that secretive passerine species were not missed. Due to high visibility in this sparse arid habitat, we are confident that this method allowed high detection rates. When multiple individuals of the same species were present within one garden, conservative estimates of abundance were always made to avoid duplicate counts of the same individuals. The area of each garden was recorded using a Garmin eTrex GPS device and average garden size was 2700 (± 200) m^2.

Bird densities in the unmanaged habitat were extremely low, meaning that it was not feasible to use an equivalent point count method. Point-counts were trialled, but nearly always resulted in no sightings. In order to make a more accurate density estimate in the unmanaged habitat we used line transects and a distance approach to estimate bird densities. All birds detected visually along the transect were recorded, as was their distance from the transect and the angle at which they were observed. A digital rangefinder was used to measure and estimate distances, with all observations beyond 50 m discarded. Out of 407 individuals recorded, just one remained unidentified.

Functional groups

In order to establish how the gardens influence the functional composition of the bird communities, we classified each species according feeding guild, habitat preference and migratory status, with data extracted from Svensson et al. (2010) and Hollom et al. (1988).

Feeding guilds included insectivore, granivore, frugivore, nectarivore and carnivore, but for analyses we only compared the two most frequent guilds, insectivores and granvirores. Habitat preference was divided into two categories; birds that preferred 1) sparse habitats (such as rocky desert, mountains, wadis, low scrub) and those that preferred 2) well-vegetated habitats (such as woodlands, gardens, parks and oases). Migratory status was also split into two categories for analyses; 1) residents and 2) migrants. The latter category included both passage migrants and over-wintering migrants, with feral species (feral pigeons) excluded from both categories.

Data analyses

Statistical analyses were computed in R.3.0.2 (R Core Team 2013). Distance 6.0 (Thomas et al., 2010) was used to estimate the densities of birds in the unmanaged habitat, with data from all five sampling rounds combined for each transect. The detection models were selected according to AIC value and were fitted with a half-normal curve. Density estimates within each gardens was the average number of birds per garden (across the five survey rounds) divided by the area of the garden. For comparison densities were both standardised to the number of individuals per 1000m^2.

The sampling methods used within the gardens and the unmanaged habitat did differ, which means that interpretation of the density estimates must be taken with some care. However the accuracy of the two methods appears to be fairly comparable with both displaying similar confidence levels; in the unmanaged habitat density estimates along transects had an average standard error of 0.30 per 1000m^2 and in the gardens density estimates had an average standard error of 0.49 per 1000m^2 (S.E.M across the five survey rounds). A linear mixed-effect model was used to compare the densities in the gardens and unmanaged habitats, with average density as the response variable, habitat (gardens/unmanaged) as the fixed effect and wadi (Town, Itlah, Gebel) as a random effect to account for spatial variation. Model fit was based upon AIC and followed Zuur et al. (2009), with the significance of fixed effects and their interactions tested by comparing models with a likelihood ratio test (distributed as Chi-squared).

To establish the completeness of our sample we created species accumulation curves for the gardens and the unmanaged habitat. Curves were created using the *specaccum* function in package vegan (Oksanen *et al.*, 2012), and were estimated from 100 random draws from the data, sampling without replacement. Estimated species richness was calculated using Chao bias-corrected form. The similarity of all species found within the gardens and the unmanaged habitat was compared using the incidence-based Sørenson similarity index, calculated in SPADE with 200 iterations (Chao & Shen, 2010). A model-based approach was used to assess how community structure changed between the two habitat types. Presence/absence community data were analysed using the *manyglm* function in R package *mvabund* (Wang et al, 2012). We fit a *manyglm* with a binomial distribution to the data, with garden/unmanaged as the treatment effect. The significance of the treatment effect was tested using *anova.manyglm*, with the Wald test statistic and 999 resampling iterations.

The relative abundance of functional traits (feeding guild, habitat preference and migratory status) were compared between gardens and unmanaged habitat using Chi-squared tests which compared the observed frequencies of birds in each functional category to the expected frequencies.

3. Results

In total we recorded 407 birds of 34 species belonging to 17 families (Table 1). Twenty-six of these species were observed in the gardens and 16 in the unmanaged habitat. Estimated bird densities were significantly higher within the agricultural gardens than in the unmanaged habitat (Wald chi-square: $\chi^2 = 14.66$, df=1, $P < 0.001$), with an average density (per 1000 m^2) of 1.8 ± 0.3 within the gardens and 0.29 ± 0.12 in the unmanaged habitat.

Species accumulation rates were higher in the gardens than the unmanaged habitat, with a higher overall species richness (Fig. 1). Estimated species richness estimates (Chao bc) within the gardens (34 ± 16) was almost twice that in the unmanaged habitat (13 ± 7). Within the gardens the most abundant species were Laughing Dove (14 % of all garden sightings), Chiffchaff (12 %), Tristram’s Starling (12 %), Rock Martin (11 %), and White-spectacled Bulbul (9 %). In the unmanaged habitat the most abundant species were Desert Lark (22 %), Rock Martin (15 %), Laughing Dove (10%), Sinai Rose Finch (10 %) and Tristram’s Starling (7 %). Though three of the top five species were shared between the two habitats, the overall species similarity was 0.49 ± 0.04 (Sørenson Index) and the composition of bird species differed significantly between the two habitats (Wald statistic: W= 4.80, df=22, P=0.006).

Comparison of the feeding guilds revealed a significant difference between the relative abundance of granivorous and insectivorous species between the two habitats ($\chi^2 = 18.00$, df=1, $P < 0.001$), with gardens containing a higher proportion of insectivorous species than the unmanaged habitat (Fig. 2a). Comparison of habitat preference also revealed a significant difference between the gardens and unmanaged habitat (Fig. 2b; $\chi^2 = 40.04$, df=1, $P < 0.001$). In the unmanaged habitat the majority of individuals (80%) were species that prefer rocky, desert habitats, but in the gardens the majority of individuals (60%) were species that prefer well-vegetated habitats, such as gardens, oases and woods.

There was a significant difference between the relative abundance of migratory and resident species in the two habitats (Fig. 2c; $\chi^2 = 46.70$, df=1, $P < 0.001$). Resident bird species were abundant within the gardens and accounted for approximately 60% of all observed individuals, but the gardens additionally contained high numbers of migratory species that were almost entirely absent from the unmanaged habitat. In total, 17 migratory species were observed within the gardens, five of which were over-wintering within the gardens (Table 1). The most common migratory species was the over-wintering Chiffchaff (*Phylloscopus collybita*), which made up 11% of all bird sightings, followed by the passage migrant Lesser Whitethroat (*Sylvia curruca*) (7% of sightings).

4. Discussion

Estimated bird densities were higher within the gardens than the unmanaged mountain habitat. Species richness was twice as high within the gardens and the distinct community of species found within the gardens suggests that they supporting species that would not otherwise be present in the unmanaged habitat. There were clear differences in the composition of bird communities in the two habitats, with gardens supporting a higher proportion of migratory and insectivorous birds in addition to the desert species that were associated with the unmanaged habitat. Traditional oases in southern Tunisia have been shown to provide important habitat for breeding birds (Selmi & Boulinier, 2003) and our study confirms that traditional desert agriculture can provide important habitat for resident breeding birds, while additionally demonstrating its importance for migratory species.

The majority of resident species were observed in both the gardens and the unmanaged habitat, but in contrast, the 17 migratory species were found almost exclusively within the gardens, with just one sighting outside. The majority of these migrants were insectivorous passerines, with a preference for well-vegetated and wooded habitats. They were frequently observed foraging for insects in and around the flowering fruit trees and were undoubtedly benefiting from the active cultivation of the gardens. Fokidis (2011) stressed the importance of providing birds with native desert plants within ornamental gardens in the North American

Sonoran desert, but in this Middle Eastern ecosystem migratory birds seem to actively benefit from the inclusion of non-native fruit trees within these agricultural gardens. The absence of migratory birds from the unmanaged desert habitat further suggests that many of these birds would not overwinter or stop off in this region were it not for the abundant resources within the cultivated gardens.

There were clear differences in the functional guilds within the two habitats, with gardens supporting a higher proportion of insectivores than the unmanaged habitat. As previously mentioned, many of these were migratory species, but gardens also supported several resident insectivores such as White spectacled bulbul (*P. xanthopygos*), Tristram's starling (*O. tristamii*) and Scrub warbler (*S.inquieta*), which were observed in more frequently within the gardens than they were in the unmanaged habitat. In tropical habitats, the conversion of natural forest habitat into agricultural land tends to lead to decrease in insectivorous birds and a reduction in the pest control that is associated with the feeding guild (Tscharntke et al., 2008). In this arid system we find a contrasting pattern, with actively farmed agricultural gardens supporting a higher proportion of insectivores than the natural desert habitat. In another arid system in Mexico, more complex agricultural systems have been shown experience an increase in bird mediated pest control (Mellink, 1991) and it is possible that the high abundance of insectivores may have similar ecological benefits in this diverse agricultural system.

This study was conducted between February and April and while our results clearly demonstrate the importance of the gardens for a variety of over-wintering and passage migrants, the patterns observed here cannot be directly extrapolated throughout the year. In fact the strong seasonal variation in food availability is likely to influence the functional composition of bird communities and in later months when orchard trees begin to fruit, one may predict an increase in frugivorous species within the gardens. A number of migratory species such as Blackcap, Golden Oriole (*Oriolus oriolus*), Garden Warbler (*Sylvia boring*) and Eastern Olivaceous Warbler (*Iduna pallida*) (Power, 2013) have been observed foraging upon apricot fruit within the gardens during May and June in previous years. Resident birds may also vary their usage of the gardens seasonally either in response to food availability or breeding and nesting behaviours. Further surveys across a longer timeframe would help to clarify how and when these gardens are utilised by birds in the region.

These Bedouin gardens have persisted for over one thousand years (Zalat & Gilbert, 2008), though recently their future has come under threat. Increasing urbanisation and a dependence on the tourism industry for income had led to many families abandoning gardens to live in cities (Gilbert, 2011). Current political instabilities in Egypt have devastated the local tourist industry, which has actually led to a resurgence of gardening with many Bedouin resuming the maintenance of gardens in the hope of supplementing dwindling incomes. Local charities have also been investing heavily in the future of these gardens, by providing garden owners with the money needed for improvements of wells and garden walls. The loss of these gardens would have profound negative social and ecological implications within the region; not only are they deeply ingrained in the local culture, but they are shown here to enhance densities of local birds and provide important habitat for migratory birds en route to Europe.

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Table 1. List of all bird species observed in the gardens and unmanaged habitat.

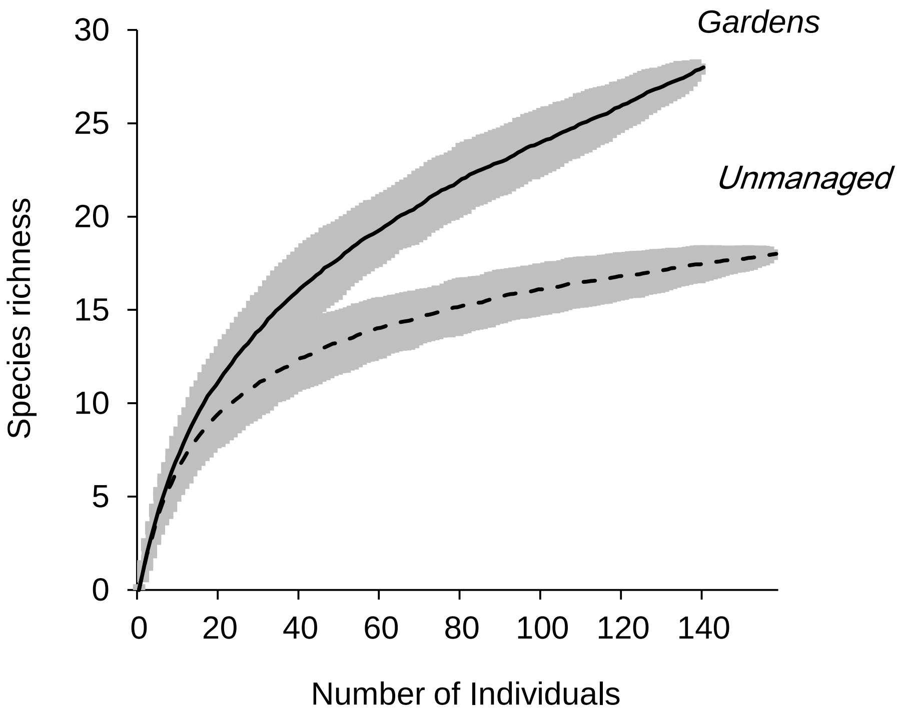
Family	*Species*	Common name	Migratory status	Feeding guild	Habitat	Present in: Gardens	Present in: Unmanaged habitat
Accipitridae	*Accipiter nisus*	Eurasian Sparrowhawk	Passage migrant	Carnivore	Woods	Y	
Alaudidae	*Ammomanes deserti*	Desert Lark	Resident	Granivore	Arid ground	Y	Y
Apodidae	*Apus apus*	Swift	Passage migrant	Insectivore	Mixed habitats		Y
Columbidae	*Streptopelia decaocto*	Collared dove	Resident	Granivore	Towns		Y
	Columba livia (domest.)	Feral pigeon	Feral	Granivore	Towns	Y	Y
	Streptopelia senegalensis	Laughing dove	Resident	Granivore	Gardens	Y	Y
	Columba livia	Rock dove	Resident	Granivore	Rocky upland	Y	Y
Fringillidae	*Carpodacus synoicus*	Sinai rose finch	Resident	Granivore	Wadis	Y	Y
	Bucanetes githagineus	Trumpeter finch	Resident	Granivore	Wadis		Y
Hirundinidae	*Ptyonoprogne fuligula*	Rock martin	Resident	Insectivore	Desert	Y	Y
Motacillidae	*Motacilla alba*	White wagtail	Wintering migrant	Insectivore	Scrub	Y	
Muscicapidae	*Phoenicurus ochruros*	Black redstart	Wintering migrant	Insectivore	Mountains	Y	
	Phoenicurus phoenicurus	Common Redstart	Passage migrant	Insectivore	Woodlands	Y	
	Erithacus rubecula	European Robin	Wintering migrant	Insectivore	Gardens	Y	
	Monticola saxatilis	Rock thrush	Passage migrant	Insectivorous	Rocky desert	Y	
	Ficedula semitorquata	Semi-collared flycatcher	Passage migrant	Insectivorous	Orchards	Y	
	Saxicola torquatus	Stonechat	Migratory	Omnivore	Scrub	Y	
	Oenanthe leucopyga	White-crowned wheatear	Resident	Insectivore	Rocky desert	Y	Y
Nectariniidae	*Cinnyris osea*	Palestine sunbird	Resident	Nectarivore	Gardens		Y
Phasianidae	*Alectoris chukar*	Chukar partridge	Resident	Granivore	Rocky desert		Y
	Coturnix coturnix	Common quail	Passage migrant	Granivore	Farm crops	Y	
	Ammoperdix heyi	Sand partridge	Resident	Granivore	Rocky desert		Y
Phylloscopidae	*Phylloscopus collybita*	Chiffchaff	Wintering migrant	Insectivore	Woodland	Y	
	Phylloscopus orientalis	Eastern Bonelli's	Passage migrant	Insectivore	Trees	Y	

		warbler					
Picidae	*Jynx torquilla*	Wryneck	Passage migrant	Insectivore	Gardens	Y	
Pycnonotidae	*Pycnonotus xanthopygos*	White-spectacled bulbul	Resident	Insectivore + Frugivore	Gardens	Y	Y
Scotocercidae	*Scotocerca inquieta*	Scrub warbler	Resident	Insectivore	Desert	Y	Y
Sturnidae	*Onychognathus tristamii*	Tristram's starling	Resident	Insectivore + Frugivore	Gardens	Y	Y
Sylviidae	*Sylvia atricapilla*	Eurasian blackcap	Passage migrant	Insectivore	Woodland		Y
	Sylvia curruca	Lesser whitethroat	Passage migrant	Insectivore	Trees	Y	
	Sylvia rueppelli	Rüppell's warbler	Passage migrant	Insectivore	Scrub	Y	
	Sylvia melanocephala	Sardinian warbler	Wintering migrant	Insectivore	Wadis	Y	
Upupidae	*Upupa epops*	Hoopoe	Resident	Insectivore	Orchards	Y	

Figure 1. Species accumulation curves for the gardens and the unmanaged habitat. The curves represent the average of 100 random draws, sampling without replacement. The grey shaded envelopes represent the standard deviation from the random permutations of the data.

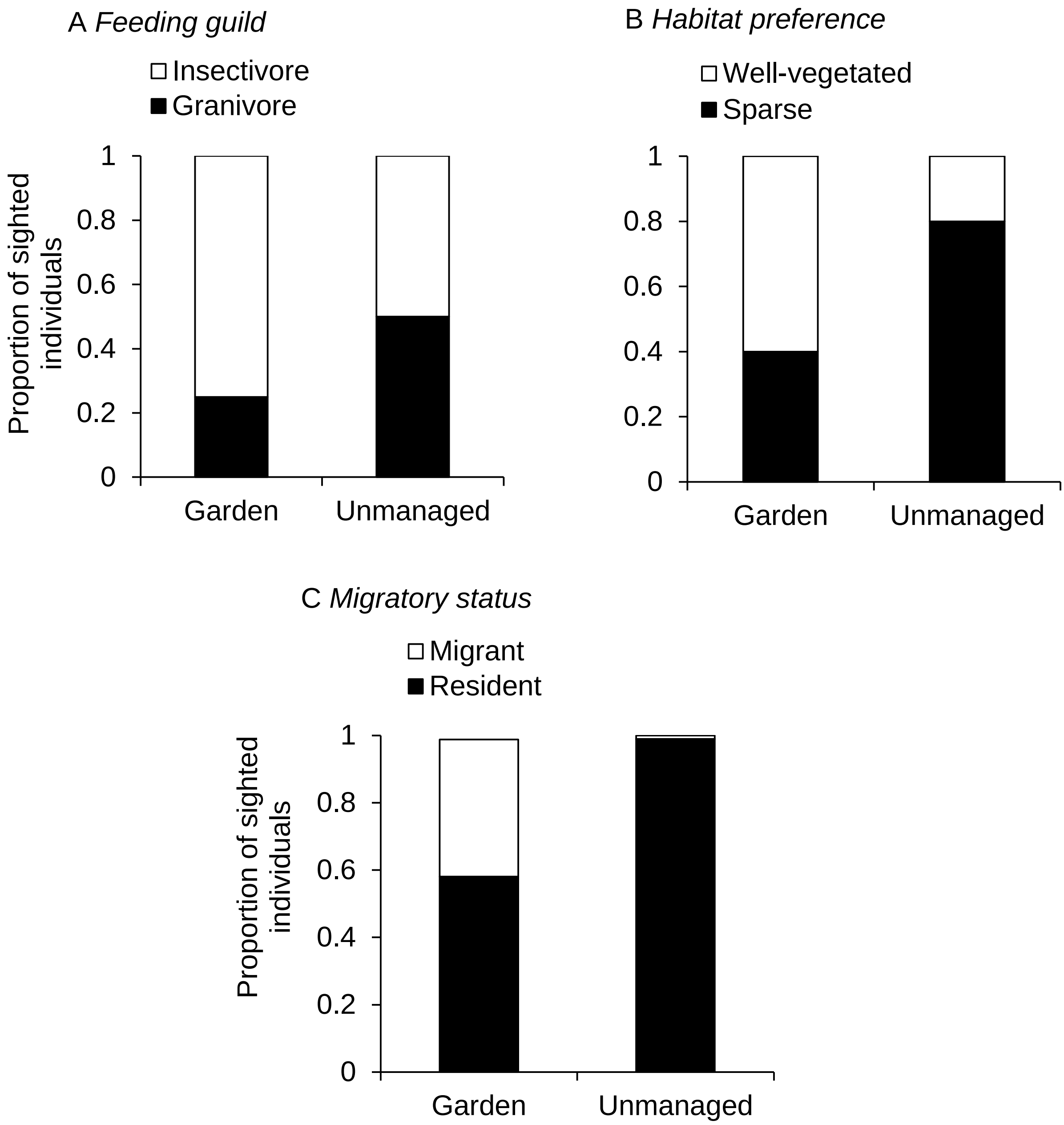
Figure 2. Comparison of the functional groups in gardens and unmanaged habitat, for a) feeding guilds, b) habitat preference and c) migratory status. Bars represent the proportion of individuals observed in each habitat respectively.

Fig 1



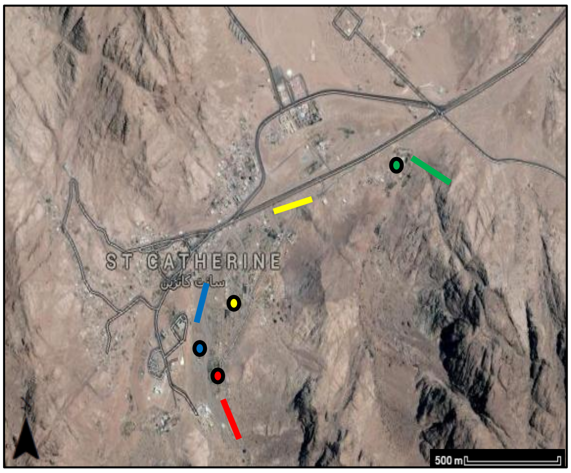
Gardens
Unmanaged
30
25
20
15
10
5
0
Species richness
0
20
40
60
80
100
120
140
Number of Individuals

Fig 2

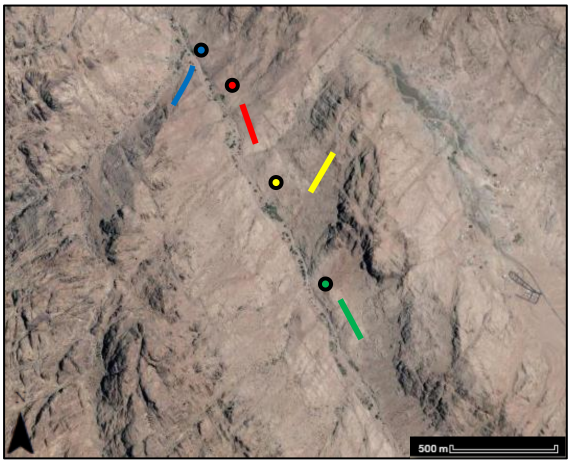

A Feeding guild
Insectivore
Granivore
Proportion of sighted individuals
0
0.2
0.4
0.6
0.8
1
Garden
Unmanaged
B Habitat preference
Well-vegetated
Sparse
0
0.2
0.4
0.6
0.8
1
Garden
Unmanaged
C Migratory status
Migrant
Resident
Proportion of sighted individuals
0
0.2
0.4
0.6
0.8
1
Garden
Unmanaged

Appendix 1. Maps of gardens and their associated transects in A) St Katherine Town, B) Wadi Itlah and C) Wadi Gebel. Circles represent the gardens, lines their paired transect.

(A) Town



(B) Wadi Itlah



(C) Wadi Gebel