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Insect visitation rates to wild flowers increase in the presence of arid agriculture in South Sinai, Egypt

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In temperate and tropical environments agricultural intensification has primarily negative consequences for pollinator conservation. However, in arid environments agriculture is often highly dependent on irrigation and farms can offer higher availability of floral resources than the external environment.

This study compares floral visitation rates to wild plants inside and outside 40 agricultural gardens in South Sinai, Egypt. The mean number of flower visitors per plant during a 30 min focal watch was significantly higher inside the gardens than outside, and this was true of orders Diptera, Hymenoptera and Lepidoptera.

In total, 23 insect families were recorded inside the garden and 17 outside. The average family richness per plant was significantly higher inside the gardens, with higher rates of family accumulation across focal plants. Pollinating insects (hoverflies, solitary bees and honeybees) all had higher visitation rates inside the gardens.

Seed set was assessed for two common pollinator-dependent plants, *Stachys aegyptiaca* and *Alkanna orientalis*. Neither species showed a significant difference in the seed set achieved inside and outside of the gardens, but *S. aegyptiaca* produced a higher number of seeds per plant inside the gardens because plants tended to be larger.

In contrast to many other studies, the presence of agriculture appears to increase the abundance and diversity of flower visitors in this under-studied system, with no negative effect on the seed set of two common wild species.

1. Introduction

The effect of agriculture on pollinators is well established in both a temperate and tropical setting. The documented effect of agricultural intensification on bees is primarily negative; in European farms (both crops and livestock) higher land-use intensity is associated with a loss of bee abundance and diversity (Grixti et al., 2009; Holzschuh et al., 2008; Holzshuh et al., 2007; Jha and Vandermeer, 2010; Le Féon et al., 2010); in North America major declines in bumblebee populations have been attributed to wide-scale agricultural intensification (Grixti et al., 2009); and in a tropical setting deforestation and a loss of canopy cover are associated with declines in the abundance and richness of both solitary and social bees (Brosi, 2009; Jha and Vandermeer, 2010). Pollinator communities can be enhanced through less intensive, organic farming practices (Gabriel et al., 2013; Holzschuh et al., 2008), by including higher numbers of hedgerows (Hannon and Sisk, 2009) and by increasing canopy cover and plant diversity in tropical coffee plantations (Jha and Vandermeer, 2010; Perfecto et al., 1996; Vergara and Badano, 2009).

In arid and semi-arid environments the situation is very different. Agriculture is often heavily dependent on irrigation and as a result farms may offer higher availability of floral resources than the natural landscape. Initial impressions may suggest that arid agriculture is beneficial to pollinators, but there may be a risk that attracting unnaturally high densities of insects to farms reduces pollination services to surrounding native plants. Indeed Gotlieb et al. (2011) found that though irrigated Israeli gardens supported a higher abundance of bees than the external habitat, there was an increase in generalism and a loss of rare species. The authors reflect that this impairment of the pollinator community could have negative implications on the pollination of external plants.

This study investigates the effect of irrigated agricultural gardens on flower visitor abundance and diversity in the arid region of

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South Sinai, Egypt. These agricultural gardens are farmed by the local Bedouin who typically cultivate a variety of orchard trees interspersed with vegetables, herbs and crops for subsistence use. Irrigation water comes from wells within each garden that access underground accumulations of rainwater (Zalat and Gilbert, 2008) with water from irregular flash floods sustaining the gardens throughout dry seasons. Wild desert annuals and perennials are allowed to grow in the rocky soil between cultivated beds (Zalat et al., 2001) and the higher availability of water means that gardens support equal densities of wild plants as control plots of natural habitat, with higher plant species richness (Norfolk et al. 2013). The high abundance of resources within these irrigated gardens is likely to influence the behavior of pollinators in the region and this study addresses two main questions relating to the impacts of the gardens on wild plant pollination:

1) Do wild plants within the irrigated gardens receive higher levels of floral-visitation than plants in the natural environment?
2) How does this influence the subsequent pollination success of wild plants in the two habitats?

2. Materials and methods

2.1. Study area

This study was conducted throughout May to June 2010 in the St Katherine Protectorate, South Sinai, Egypt (28°33′37.97″N, 33°56′44.68″E). It is an arid, mountainous region occurring at altitude of 1500–2624 m. The climate is extremely dry, with hot and rainless summers and cool winters. There is an average of 57 mm of rainfall a year (Ayyad et al., 2000), but extreme annual variability means that there are often long periods of drought followed by heavy rains and floods. The landscape is dominated by rugged mountains, interspersed with steep sided valleys (wadis) with river-beds that remain dry for most of the year, only temporarily returning to rivers during flash floods. The study site contains numerous walled gardens, most of which are owned and maintained by the local Gebaliya Bedouin. From satellite imaging we have estimated that there are between 500 and 600 gardens in the St Katherine Protectorate. Gardens are strategically positioned above underground water-sources, resulting in clusters of gardens along the base of the wadis. Fig. 1 shows photographs of typical mountain gardens; orchard trees are under-cropped with vegetables and herbs, but there are often large areas of sparse soil in which wild plants frequently grow.

2.2. Data collection

Focal watches were carried out on pairs of wild plants inside and outside of forty gardens. All gardens in the wadis surrounding St Katherine Town were sampled (Wadi Shraig, Tofaha, Itlah, Telah, Kharass and Abu Fraish), except several omitted because permission could not be obtained. Each plant was observed for 30 min and the identity of all flower visitors recorded. A visit was defined as any contact with the stamens or stigma: landing on the petals was not sufficient. If an insect moved between flowers it was not recorded as a new visit unless it left the plant and returned later during the watch. Individuals were observed on the wing and could not all be identified to species level, so diversity analyses were carried out at family level.

In each garden three native desert plants were chosen according to which species were present both inside and outside of that particular garden. Local plant diversity restricted the choice of species; the three focal species differed among the gardens with

Fig. 1. Photographs depicting typical walled gardens; wild desert plants are frequently found growing amongst the orchard trees and cultivated beds.

the choice of individual plants determined by the availability of a suitable pair in both the garden and natural habitat. All plants were observed between 9 am and 5 pm, with each pair of plants (inside/outside) observed within half an hour of each other. In total 93 pairs of plants from 13 species were observed in the focal watches, all of which were native to region (Table 1). For each plant we recorded the size of the plant (width at widest point) and the number of flowers.

2.3. Seed set

Seed set was examined in the two most common species, *Stachys aegyptiaca* Pers.,1806 (Lamiaceae) and *Alkanna orientalis* (L.) Boiss., 1844 (Boraginaceae). *S. aegyptiaca* is a desert calcicolous chasmophyte, with purple tubular zygomorphic flowers. It is insect-pollinated, reproduces by seed (Danin, 2006) and as with the majority of Lamiaceae it requires outcrossing (Huck, 1992). *A. orientalis* is a sticky, glandular plant that grows to 1 m in diameter. It produces yellow trumpet-shaped, protandrous flowers borne upon a determinate scorpioid cincinnus. It is insect-pollinated, reproduces by seed and is an obligate out-crosser (Gilbert et al., 1996).

Seed set was measured for plants inside and outside of 20 gardens (all of which were included in the flower visitor focal watches). Three plants were randomly selected from inside each garden. External plants were selected along a transect running away from the garden wall (outside) with three of the first ten plants randomly selected for seed counts. For each plant the number of seeds per seedpod was recorded for 10 randomly chosen branches. Small plants sometimes had less than ten branches, in

Table 1
Plant species observed in the paired focal watches (gardens and outside). Average visits are calculated from all plants, gardens and outside. Worldwide distributions are defined by Boulos (2002).

Family	Species	Distribution	*N* pairs	Average visits per 30 min focal watch	
				Gardens	Outside
Boraginaceae	*Alkanna orientalis* (Boiss.)	Sinai, Greece, Turkey, Lebanon, Palestine, Iran	24	6.17 ± 0.8	4.47 ± 0.7
Brassicaceae	*Matthiola arabica* (Boiss.)	Sinai, Palestine, Saudi Arabia	10	1.70 ± 0.8	0.50 ± 0.2
	Zilla spinosa (L.)	North Africa	2	17.50 ± 4.5	1.00 ± 1.0
	Diplotaxis harra (Forssk.)	North Africa	3	8.33 ± 1.5	3.67 ± 2.2
Lamiaceae	*Phlomis aurea* (Decne.)	Sinai	1	37.00 ± 0.0	7.00 ± 0.0
	Stachys aegyptiaca (Pers.)	Egypt, Palestine, Saudi Arabia	21	4.05 ± 0.8	2.00 ± 0.5
Nitrariaceae	*Peganum harmala* (L.)	North Africa, southern Europe	8	6.25 ± 1.6	8.00 ± 1.7
Resedaceae	*Reseda alba* (L.)	Sinai, Europe, Mediterranean,	2	5.50 ± 1.7	1.25 ± 0.8
	Caylusea hexagyna (Forssk.)	North Africa	1	0.00	0.00
Rubiaceae	*Galium sinaicum* (Boiss.)	Egypt, Palestine	2	3.00 ± 1.0	8.5 ± 1.5
Scrophulariaceae	*Scrophularia xanthoglossa* (Boiss.)	Egypt	3	2.5 ± 0.5	9.5 ± 1.5
Zygophyllaceae	*Fagonia mollis* (Delile.)	Egypt, Palestine, Syria, Arabia	12	2.85 ± 0.8	1.08 ± 0.4
	Fagonia arabica (L.)	Egypt, Algeria, Libya, Palestine, Arabia	5	2.8 ± 1.1	1.8 ± 1.1

which case all available branches were recorded. Both species were able to produce a maximum of four seeds per seedpod. Seed set was then calculated as the number of produced seeds divided by the maximum seed potential. The number of seeds per plant was estimated as the average seed set multiplied by the total number of seedpods. There was no effect of distance from the garden on the visitation rates (*Linear regression*: *S. aegyptiaca* $F_{1,130} = 0.20$, $P = 0.652$; *A. orientalis* $F_{1,44} = 0.04$, $P = 0.834$) or seed set (*S. aegyptiaca* $F_{1,130} = 0.20$, $P = 0.652$; *A. orientalis* $F_{1,77} = 0.06$, $P = 0.815$) so it was not included in subsequent analyses.

2.4. Statistical analyses

Visitation rates and the diversity of flower visitors were compared between the gardens and outside using linear mixed-effect models using *lme4* (Bates, 2005) in R.15.1 (R Development Core Team, 2010). Plant visitors that were less relevant for cross-pollination (spiders and ants) were excluded from the analysis. Diversity analyses were based upon family-level identification, so family richness was used in the place of species richness. The average visitation rates differed between the plant species (Table 1), but our paired experimental design ensured that each species was observed inside and outside of each garden, so differences between plant species should not affect our analyses. Even so we included *plant species* as a random factor within the linear mixed effect model in order to disentangle the effect of the garden from that of plant species. *Wadi* and *garden* were also included as random factors to account for the spatial variation between plants. Model simplifications followed Zuur et al. (2009). *Location* (garden/outside), plant *size* and number of *flowers* were all included as fixed factors, but only *location* remained in the minimum sufficient model. Plant size and the number of flowers were also compared between gardens and the natural habitat using a linear mixed effect model that included *plant species*, *wadi* and *garden* as random factors Sample-based accumulation curves were calculated using the *vegan* analysis package (Oksanen et al., 2012) and were based upon sampling without replacement, using a family-matrix with focal plant as the sampling unit. Seed set and the number of seeds per plant were compared inside and outside using linear mixed effect models with *wadi* and *garden* as random factors.

3. Results

Insect visitation rates were significantly higher within the gardens (*Linear mixed-effect model:* $\chi^2{}_1 = 21.88$, $P < 0.001$), with an average of 4.9 (±0.59) visits per focal watch inside and 3.5 (±0.42) outside, despite there being no difference in the average plant size ($\chi^2{}_1 = 1.95$, $P = 0.377$) or the number of flowers ($\chi^2{}_1 = 0.44$, $P = 0.804$). The flower visitors belonged to 24 families from eight orders, 23 of which were observed inside the gardens and 17 outside. Table 2 shows that the visitation rates of orders Diptera, Hymenoptera and Lepidoptera were all significantly higher within the gardens than outside. The family richness of flower visitors was significantly higher inside the gardens ($\chi^2{}_1 = 16.34$, $P < 0.001$) with an average of 2.0 (±0.15) families per focal watch inside the gardens and 1.6 (±0.16) outside. Fig. 2 shows that the flower visitor family-accumulation curve was steeper for plants inside the gardens, suggesting a more diverse community of flower visitors.

Fig. 3 shows the breakdown of visitation rates between the main groups commonly regarded as pollinators (bees, wasps, hoverflies and butterflies). The total visitation rate across these groups was significantly higher inside the gardens ($\chi^2{}_1 = 29.4$, $P < 0.001$) with all groups occurring in higher numbers within the gardens. Hoverflies were the most frequent flower visitors and made up 65% of the visits inside the gardens and 75% outside. The hoverflies that were most commonly observed visiting flowers were *Eupeodes (Metasyrphus) corollae* Fabr., 1794 (60 inside, 38 outside), *Syritta orientalis* Macq., 1842 (58 inside, 13 outside) and *Ischiodon aegyptius* Wied., 1830 (12 inside and 1 outside). Wild solitary bees and honeybees occurred in similar numbers inside and outside of the gardens. 60% of these solitary bees were from the genus *Anthophora*.

Percentage seed set of the two most common plant species, *S. aegyptiaca* and *A. orientalis*, showed no significant difference

Table 2
Average visitation rates (per half hour focal watch) in the gardens and outside. Significant results are highlighted in bold. SEM represents the standard error of the mean.

	Average number of visits per plant (±SEM)		Test of the difference	
	Gardens	Outside	χ^2	*P*
Coleoptera	1.4 (±0.2)	1.3 (±0.2)	0.04	0.853
Diptera	**2.3 (±0.3)**	**1.2 (±0.2)**	**32.27**	**<0.001**
Hemiptera	0.01 (±0.01)	0	1.38	0.240
Hymenoptera	**0.89 (±0.2)**	**0.40 (±0.1)**	**17.30**	**<0.001**
Lepidoptera	**0.09 (±0.03)**	**0**	**11.06**	**<0.001**
Neuroptera	0.04 (±0.04)	0	3.00	0.083

Linear mixed effect models with *location* as the fixed factor and *wadi, garden* and *plant species* as random factors.

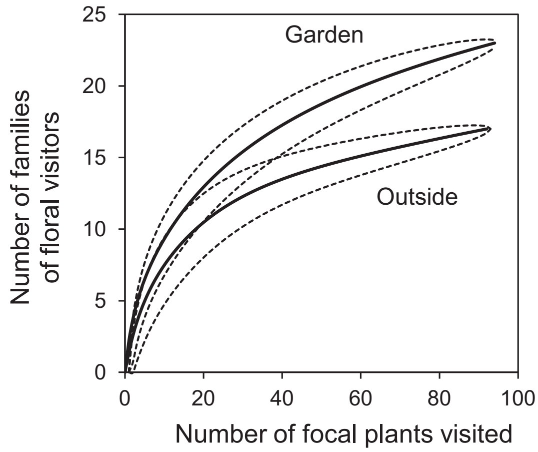

Fig. 2. Sample-based accumulation curves of floral-visitors to the focal plants inside and outside the gardens. Solid curves represent the accumulation of families visiting the focal plants as they are successively pooled. Dotted lines represent the 95% confidence intervals.

Table 3
Seed set and visitation rates of the two most common wild plant species inside and outside of the gardens. Grey bars represent gardens, white bars represent outside. Significant results are highlighted in bold.

	Stachys aegyptiaca		*Alkanna orientalis*	
Seed set (%)	86 / 84	$\chi^2_1 = 0.86$, $P = 0.355$	160 / 131	$\chi^2_1 = 0.01$, $P = 0.942$
Number of seeds per plant	11 / 11	$\chi^2_1 = 7.35$, $\mathbf{P = 0.007}$	2.5 / 1.1	$\chi^2_1 = 0.02$, $P = 0.893$
Pollinator visitation rate	151 / 43	$\chi^2_1 = 9.7$, $\mathbf{P = 0.002}$	1.8 / 1.3	$\chi^2_1 = 2.48$, $P = 0.115$

Gardens / Outside

P values obtained from linear mixed effect models with *location* as the fixed factor and *wadi* as a random factor.

inside and outside of the gardens (Table 3). *S. aegyptiaca* produced significantly more seeds per plant inside the gardens (because plants produced more seedpods) and had significantly higher pollinator visitation rates. *A. orientalis* also had higher number of seeds per plant and higher pollinator visitation rates inside the gardens, but the differences were not significant.

4. Discussion

Wild plants received significantly higher floral visitation rates inside the agricultural gardens than in the surrounding natural habitat. In tropical and temperate systems, the presence of agriculture typically has a negative influence on the abundance and richness of pollinating insects (Grixti et al., 2009; Kremen, 2002; Le Féon et al., 2010), but in this arid environment the irrigated gardens actively increase the rate of pollinator visits to wild flowers. Despite lower visitation rates outside of the gardens there was no reduction in the seed set of two common pollinator-dependent plants suggesting that wild plants outside the gardens do not suffer a decrease in pollination success.

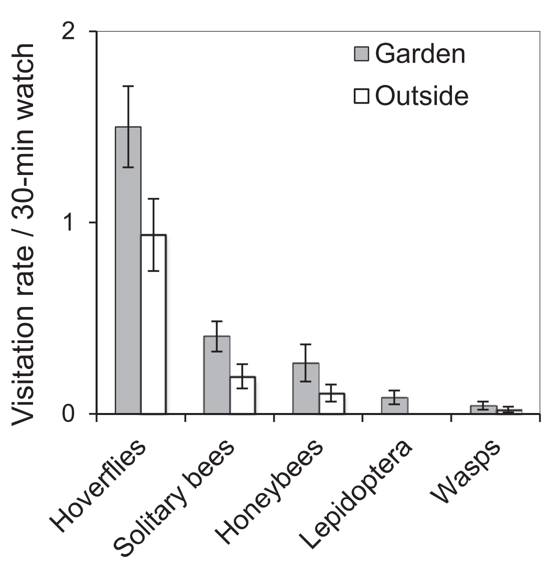

Fig. 3. Average floral visitation rates to focal plants inside and outside of 40 gardens.

Agriculture is not always a negative presence for pollinating insects and in many agricultural landscapes flower visitors are known to exploit resources from weeds growing in floral verges and field margins (Hopwood, 2008; Norfolk et al., 2012b; Pywell et al., 2005). The situation is unusual here because these gardens increase visitation rates to native desert plants with high conservation importance (Ayyad et al., 2000) and not to exotic agricultural weeds. The rainwater harvesting used to irrigate these gardens seems to provide benefits for a range of wild organisms (not just flower visitors): it also increases the abundance of beetles and ants (Norfolk et al., 2012a) and the diversity of wild plants (Norfolk et al., 2013). Maintaining such diversity of wild organisms within an agro-ecosystem is often regarded as essential for maintaining valuable ecosystem services such as pollination and soil formation (Altieria, 1999; Jose, 2009).

In Israel, irrigated gardens have also been shown to support a higher abundance of bees than the external habitat (Gotlieb et al., 2011), but authors reported an increase in generalism and a loss of rare species. They reflect that this impairment of the pollinator community could have negative implications on the pollination of external plants. In this system the diversity of flower visitors increased at a family level inside the gardens, though it is not possible to comment on species level diversity or abundances. There was no evidence of reduced pollination success in the two most common species of wild plant, with equal seed set achieved in plants inside and outside of the gardens. However *S. aegyptiaca* did produce lower numbers of seeds per plant outside the gardens, because plants tended to be smaller and produced fewer flowers per plant.

In a temperate setting, unmanaged pollinators frequently exploit mass-flowering events associated with agriculture (Rader et al., 2012), but this can be at the expense of wild plants. Seed set of wild *Primula veris* has been shown to decrease with proximity to oil-seed rape fields due to dilution effects, whereby pollinators spend more time foraging on the crop (and less on wild plants), leading to a reduction of pollen transfer between wild plants (Holzschuh et al., 2011). Seed set was equal in plants inside and outside of the gardens, but it is still possible that dilution effects are at play in this system if visitation to cultivated species is surpassing that to wild plants. *S. aegyptiaca* achieved high levels of seed set (>80%) so is unlikely to be suffering from dilution effects, but

A. orientalis had a low seed set of 11% which is half that reported in previous studies (Gilbert et al., 1996). Although *A. orientalis* can certainly be pollen limited (see Gilbert et al. 1996 for bagging experiments), here it is not possible to determine whether pollen limitation or some other environmental factor such as drought is responsible for the low seed set.

5. Conclusion

In temperate and tropical environments agricultural intensification has primarily negative consequences for pollinator conservation. The effect of agriculture in arid regions is less well established, but in this particular arid system rainwater harvesting has created agricultural gardens that actively increase levels of pollinator visitation above those in the surrounding environment. Initial results suggest that seed set of two common species of wild plants is not affected by the presence of the gardens, but further work could reveal interactions or dilution effects involving cultivated flowering plants. This study highlights the fact that arid agriculture can dramatically shape and influence pollinator distributions and draws attention to a largely under-studied system.

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