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Crop diversity and rotation may increase dispersal opportunities of reptiles in a heterogeneous agroecosystem

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ABSTRACT

Land sharing strategies in agricultural landscapes need to allow for organisms to move between natural areas and different crops within an agro-ecological landscape in order to reduce extinction probability and the negative effects of small isolated populations. In this study, we tested whether legume or wheat fields differed in their effects on reptiles' movement patterns. We conducted our study in an agro-ecosystem consisting of small isolated natural habitat patches nested within agricultural fields. We trapped reptiles in sampling arrays before and after harvest in both wheat and legume fields, and in adjacent natural habitat patches. For both crops, prior to harvest, we found an increase in movements of *Trachylepis vittata*, the most common reptile in our study, from the natural habitat patches into fields, but negligible movement in the opposite direction. In both crops before harvest, the individuals that moved into the fields were adults of better body condition than those remaining in the natural habitat patch, suggesting that long-distance movements were only possible for individuals with high prospective fitness. After harvest, no movements were documented between wheat fields and natural habitat patches. However, in legume fields, a high symmetrical movement (i.e. in both directions) of individuals of similar body condition between fields and natural habitat patches took place. Importantly, newborn lizards were only found in the natural habitat patches and in post-harvest legume fields. Our results suggest that agricultural heterogeneity, through a mixture of crop types may mitigate some of the negative effects of particular crops on biodiversity. As crop rotation between wheat and legume fields is common worldwide, our findings highlight the importance of creating an agricultural mosaic to enhance biodiversity permeability within the agricultural matrix.

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1. Introduction

The current need to increase food supply is being tackled by an expansion of farming area and an intensification of agricultural practices, both of which cause biodiversity loss (Bommarco et al., 2013; Green et al., 2005). Consequently, methods which ensure food production while maximizing biodiversity conservation within the agricultural systems ('Wildlife Friendly Agriculture'; WFA) have become one of the major challenges for modern agriculture (Matson et al., 1997; Mendenhall et al., 2014; Tscharntke et al., 2012a,b; West et al., 2014). A key approach of WFA is 'land sharing' (Fischer et al., 2011, 2008; Phalan et al., 2011) which strives to promote a balance between food production and conservation by leaving natural habitat patches within the agricultural matrix (Benton et al., 2003; Duelli and Obrist, 2003; Fahrig et al., 2011; Green et al., 2005; Troupin and Carmel, 2014; Tscharntke et al., 2012a,b; West et al., 2014).

However, keeping fragmented natural patches within an agricultural landscape is only effective if those patches can support ecological processes for long-term persistence of populations (Tscharntke et al., 2012b). One of these ecological processes that are vital for the long-term survival of populations are dispersal of organisms between the fragmented natural habitat patches. Fully isolated patches, especially small ones, which are common within many agricultural landscapes, may result in reduced population sizes and lower species diversity, due to stochastic effects as well as amplified antagonistic interactions. Hence, the ability of native species to move between patches throughout the agricultural matrix is a crucial requirement for any WFA implementation.

Agricultural heterogeneity can provide diverse opportunities for native species to survive within the agricultural matrix (Blitzer et al., 2012; Tscharntke et al., 2012b). These opportunities result from different crop dynamics (e.g., time of seeding and crop

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development), crop structure (e.g., plant formation and architecture) and agricultural practices (e.g., chemicals' distribution and machinery use). Consequently, it is essential to explore how different crop dynamics affect movement patterns within a given agricultural landscape.

We study agroecological issues in the Southern Judea Lowlands (SJL; Fig. 1a) (Giladi et al., 2014, 2011; May et al., 2013a,b; Rotem et al., 2016, 2013; Yaacobi et al., 2007a,b). Thousands of years of human inhabitance and recent intensive agricultural use has formed a landscape consisting of natural habitat patches at different degrees of isolation, surrounded by agricultural fields. The natural habitat patches' main vegetation types are characterized by semi-steppe batha (Mediterranean scrubland) and grassland (Giladi et al., 2011). Overall, 342 plant species have been identified in this area, belonging to three phytogeographic zones – Mediterranean, Irano-Turanian and Saharo-Arabian (Giladi et al., 2011, 2014; May et al., 2013a,b). The most dominant perennial species are the dwarf shrub *Sarcopoterium spinosum* in the batha vegetation and the tussock grasses *Hyparrhenia hirta* and *Hordeum bulbosum* in the grassland. The most common annual species are *Avena sterilis*, *Anagallis arvensis*, *Linum strictum*, *Urospermum picriodes*, and *Plantago afra* (Giladi et al., 2011).

The natural habitat patches in this landscape host a high diversity of reptiles. In previous censuses, this landscape has been shown to host 20 reptile species (approximately 20% of all known reptile species in Israel) (Rotem et al., 2016, 2013).

The agricultural fields within this landscape are usually planted with either wheat or legumes (mainly pea or clover). While the planting of both crops takes place in November, legumes and wheat differ in harvest time – legumes in April and wheat in June. In wheat fields, after harvest, the hay is collected immediately into stacks and removed from the field. As a result, the wheat field turns into an exposed and poor habitat for many organisms, especially vertebrates. In contrast, after legume harvest, the pulled plants are piled in long lines, usually stretching from one natural habitat patch to another. These piles of greenery remain in the field to dry in the sun for several weeks until removal.

This paper aims to analyze the movement patterns of reptiles between natural habitat patches and the surrounding wheat and legume fields in order to investigate whether these crops provide different dispersal opportunities. In wheat fields, using the model species *Trachylepis vittata* [Scincidae], we (Rotem et al., 2013) have already shown that individuals asymmetrically move from natural habitat patches to the fields during the crop's growing season, creating a dense population within the wheat fields. However, harvest activities cause a sharp decline in population size in the wheat fields (acting as an ecological trap; Rotem et al., 2013). Thereafter, no movement between the natural habitat patches and the wheat fields takes place resulting in complete functional isolation of the natural habitat patches surrounded by wheat fields. Here we ask whether legume cropping allows for different movement opportunities for reptiles trapped in natural habitat patches, and whether agricultural spatial heterogeneity enhances dispersal within the landscape. Given that wheat and legume are grown in rotation worldwide, identifying differences in animal dispersal ability between legume and wheat can inform WFA approaches to agricultural spatial crop planning.

Our current study intends to emphasize three main points: First, because the agricultural practice in legume fields differs from that of wheat fields, and hence providing different opportunities for wildlife, it is important to review agricultural protocols when dealing with wildlife-friendly agriculture. Second, because different crops differ between each other in affecting native populations, agricultural heterogeneity at large scales may enhance

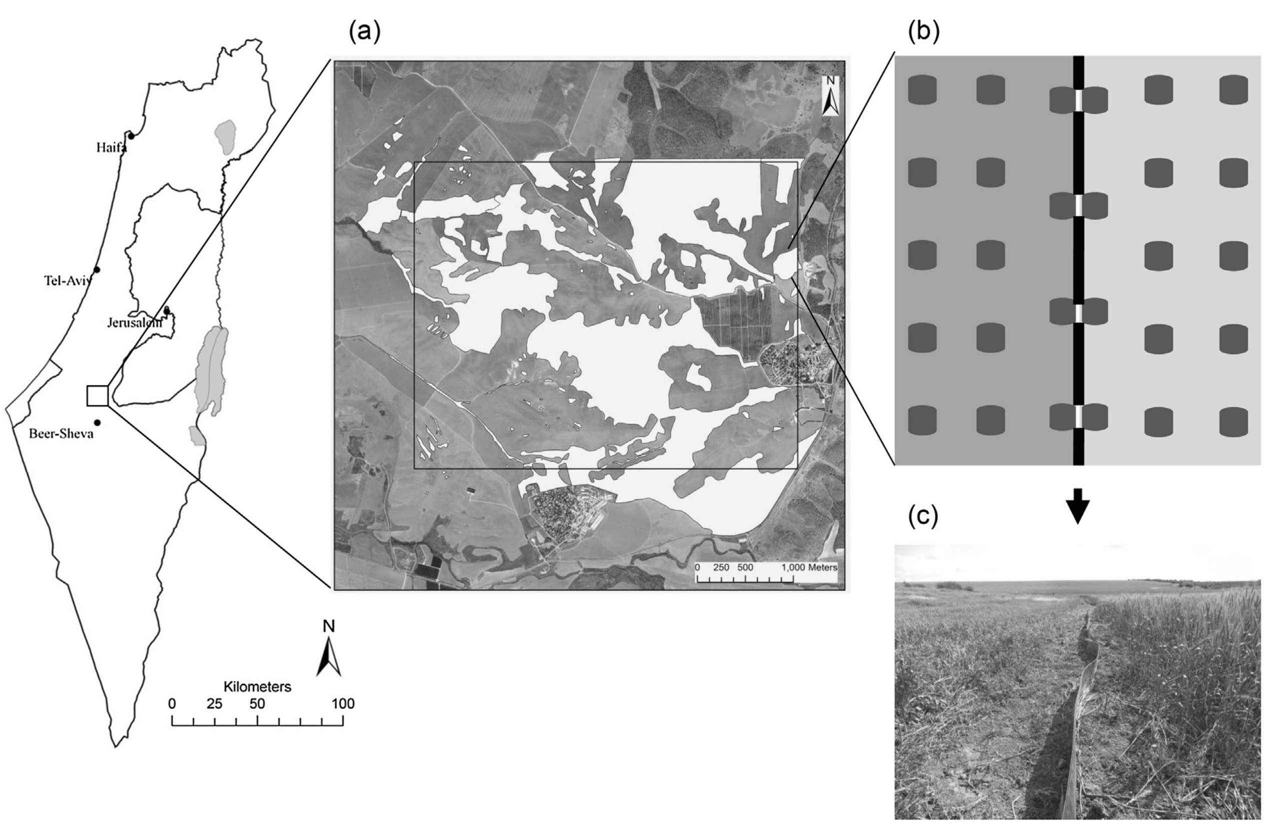

Fig. 1. Map of the research area and the study site (a), where white polygons represent natural patches surrounded by agricultural fields. A diagram of a trapping array (b) shows the fence (black line) and the trapping array in each habitat and along the separating fence. A picture of the patch-field edge and the separating fence is given in (c).

biodiversity. Third, as already known for natural ecosystems, the spatial context, e.g., landscape configuration and physiognomy, of an agroecosystem should not be ignored.

According to Bouskila and Amitai (2001), Israel is home to seven amphibian species, 11 turtle species and 86 species of the *Squamata* order. However, 47 species of the Israeli herpetofauna are at risk, according to the International Union for Conservation of Nature (IUCN) criteria (Bouskila, 2002). One of the major threats to reptiles in Israel (and worldwide) is agricultural activity. Therefore, developing methods to ensure sustainable reptile communities within the agricultural systems is very important to protect those threatened species.

2. Methods

During the spring of 2013 and 2014, we surveyed reptiles in 12 sampling sites – six each in wheat and legume fields. The field sizes ranged from 78 to 110 ha, and the natural habitat patches within these fields ranged in size from six to 130 ha. Each site included a natural habitat patch, an adjacent cultivated field (either wheat or legume), and the patch-field edge (Fig. 1b). At each site we installed 40 one-liter dry pitfall traps, positioned in two arrays, each consisting of 20 traps. The traps were arranged in two 100 m long parallel lines at 10 and ~15 m on either side of the patch-field edge (Fig. 1b), while distances between two traps in each line was 10 m. On the patch-field edge, a polypropylene multiwall sheet fence 100 m-long and 40 cm-high directed all reptiles' movement between the natural habitat patches and the agricultural field to passageways located every 20 m along the fence (Rotem et al., 2013). At these passageways, we placed two one-liter dry pitfall traps, one at each side (total of 10 one-liter dry pitfall traps along each fence). This sampling setup enabled us to simultaneously asses the reptile populations' size in the natural habitat patch and in the field, and to distinguish direction of movement (Rotem et al., 2013).

Crop rotation in this agroecosystem occurs by growing wheat for 2–3 years in a row and then changing to legume for one year for nitrogen enrichment. We explicitly chose our sites to avoid site-specific effects – wheat fields changed to legume fields and legumes fields changed to wheat fields in 2013 and 2014, respectively. This provided us with a unique opportunity to measure the effect of different agricultural crops on the movement ability of reptiles in the same location within a particular agricultural configuration.

Each year we trapped reptiles during six sessions throughout the spring (March to June). Although we kept sampling times constant for both wheat and legume, the phenological state of the field was different in accordance with each crop's agricultural cycle and practice. In the wheat fields, we sampled four times before harvest, immediately after the harvest, and one week post-harvest. In the legume fields, we sampled once before harvest, once immediately after harvest, and four times post-harvest. In each session, traps were left open for 72 h. Trapped animals were measured (e.g., mass, snout-vent-length (SVL)) and individuals' physical condition were assessed by a body condition index (IC; Andrews and Wright, 1994), which takes into account the body state of the animal reflected by its overall weight relative to its snout-to-vent-length (i.e. $IC = (Mass^{0.3}/SVL)*100$). Due to a very low capture-recapture success in our previous research (Rotem et al., 2013), we avoided individual marking in the current study. We immediately released all captured individuals back to the habitat where they were captured or to the habitat they were travelling towards. Given our previous studies and experience from using capture-recapture methodology, the probability of resampling the same individuals is very small (Rotem et al., 2013). We averaged all the observations from each combination of 'habitat' × 'session' × 'site' prior to any statistical analysis and used these summarized data as our replicates, thus avoiding pseudo-replication.

3. Results

We obtained very similar results for both 2013 and 2014. Throughout the study, we trapped 617 reptiles belonging to eight species. Only two species were trapped in the agricultural fields (*Trachylepis vittata* and *Ablepharus rueppellii*; 188 and 24 individuals, respectively), while all eight species were trapped in the natural habitat patches (*Ptyodactylus guttatus*, *Ophisops elegans*, *Phoenicolacerta laevis*, *Chalcides ocellatus*, *Chalcides guentheri*, *Trachylepis vittata*, *Ablepharus rueppellii*, *Testudo graeca*; 4, 13, 3, 9, 5, 307, 62, and 2, respectively). Four-hundred and ninety-five of the trapped individuals belonged to our model species, *T. vittata*. The vast majority (396) of *T. vittata* individuals were adults, 42 were sub-adults and 56 were newborns (this species is ovoviviparous). All the newborns were captured in the natural patches and in the legume fields during the post-harvest session. Because we could not reliably distinguish males from females, our analysis was not stratified by sex.

In both the wheat and legume fields, we found a significant effect of time and habitat, as well as their interaction, on *T. vittata*'s abundance (Table 1; Fig. 2). *T. vittata* abundance in the natural patches remained relatively constant throughout the study period (Fig. 2a and c). However, its abundance in the wheat fields (Fig. 2a) increased from the beginning of the season until the harvest and dropped to zero immediately afterwards. In these fields, before the harvest, we found an asymmetric movement (Fig. 2b) between the natural habitat patches and the fields; most of the individuals moved from the natural habitat patches to the fields, while only a few moved in the other direction. No movement was found in the wheat fields after the harvest.

As in the wheat fields, the abundance of *T. vittata* in the legume fields (Fig. 2c and d) increased from the beginning of the season until harvest and dropped to zero immediately afterwards, with an asymmetrical movement, i.e. a higher movement from the natural habitat patches to the fields compared with the other direction. However, in contrast to the absence of movement between the wheat fields and natural habitat patches after harvest, in the legume fields, movement continued. Individuals of *T. vittata* recolonized the legume fields and then moved between the fields and the natural patches in both directions, with a relatively high movement on both sides. The body condition of *T. vittata*'s individuals before harvest was significantly lower in the natural habitat patches compared with the wheat fields or the patch-to-wheat field fence side (Fig. 3a; Two-way ANOVA, $F_{(2,49)} = 4.173$, $p = 0.02$) and compared with the legume fields or the patch-to-legume field fence side (Fig. 3b; two-way ANOVA, $F_{(2,40)} = 4.094$, $p = 0.025$). However, after harvest in the legume fields, no

Table 1
Repeated-measures ANOVA testing differences in reptile presence at different times during the season (Time) and between wheat and legume (Habitat).

	Time	Habitat	Interaction
Legumes 2013	$F_{(5,81)} = 7.775$ $p < 0.001$	$F_{(3,18)} = 54.611$ $p < 0.001$	$F_{(15,81)} = 2.015$ $p = 0.013$
Legumes 2014	$F_{(5,78)} = 5.629$ $p = 0.001$	$F_{(3,23)} = 68.260$ $p < 0.001$	$F_{(15,78)} = 1.927$ $p = 0.028$
Wheat 2013	$F_{(5,92)} = 17.043$ $p < 0.001$	$F_{(3,21)} = 124.71$ $p < 0.001$	$F_{(15,92)} = 6.108$ $p < 0.001$
Wheat 2014	$F_{(5,86)} = 13.186$ $p < 0.001$	$F_{(3,18)} = 80.793$ $p < 0.001$	$F_{(15,86)} = 4.836$ $p < 0.001$

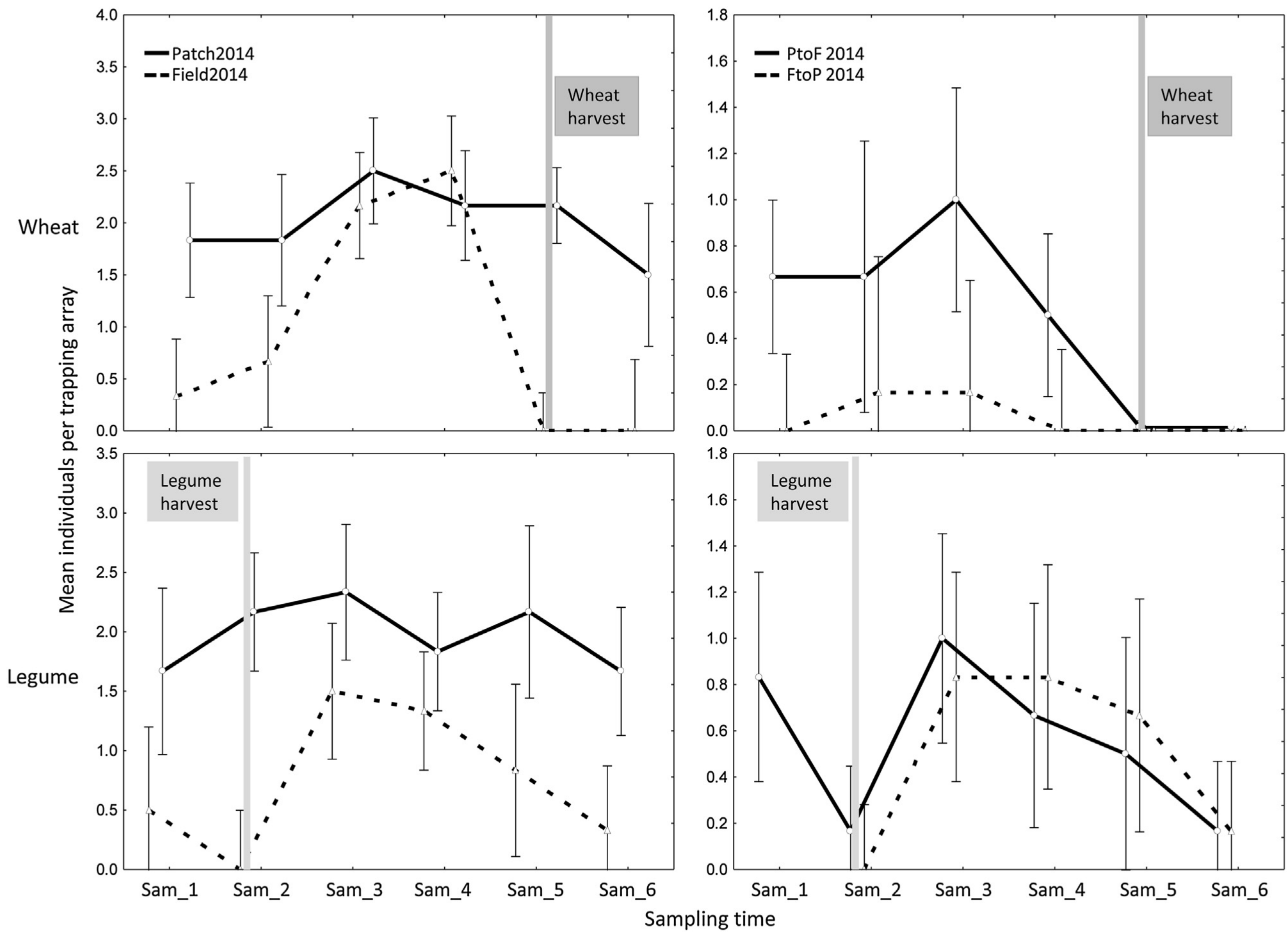

Fig. 2. Mean number of *T. vittata* individuals per trapping array that was captured in natural patches, wheat or legume fields and while crossing between these habitats at different times along the wheat growing season (here, the graph shows the 2014's results, which are similar to those of 2013). In wheat fields, *T. vittata* was captured in four occasions prior to the wheat harvest, immediately after the harvest and one week later (see text). In legume fields, *T. vittata* was captured in two occasions prior to the legume harvest, immediately after the harvest and after the harvest (see text). Within a year, the wheat and the legume have been sampled at the same time.

significant difference in body condition was found between individuals in the legume fields, natural patches and fence sides (Fig. 3c; two-way ANOVA, $F_{(3,34)} = 0.682$, $p = 0.569$).

Importantly, all individuals in the wheat fields, and those crossing from the natural habitat patches to the fields were adults. In the natural habitat patches, and in particular in the legume fields, newborns were found in addition to adult individuals. Therefore, newborns were found only in the legume fields during the time when individuals were able to move symmetrically between the natural habitat patches and the legume fields.

4. Discussion

In line with the WFA approach towards the integration of agriculture and biodiversity practices, land sharing has been suggested as a means to provide ways for native species to persist and maintain viable populations (Fischer et al., 2011; Tscharntke et al., 2012a). On a different scale, agricultural heterogeneity has been shown to support richer communities of native species (Benton et al., 2003). Movement between natural areas and different crops within an agroecosystem may play a major role in species conservation through reducing extinction probability and negative effects acting on small isolated populations. However, very few studies have looked at movement patterns between natural habitat patches and different agricultural crops. Since one of the major threats to reptiles in Israel (and worldwide; Norris, 2008) is agricultural activity, and because agricultural fields increase in proportion in open areas, protecting reptile communities within the agricultural system becomes crucial. Furthermore, as reptiles may serve as bioindicators, studying their community structure and dynamics may reflect changes in the overall ecological system. In addition, due to their potential role for biological control (Gibbons et al., 2000), protecting reptiles may enhance the contribution of ecosystem services for farmers.

Our results present a clear example of how crop diversity may increase survival in an agro-ecological landscape by allowing different movement opportunities between natural habitat patches and different crop types. With respect to wheat fields, our results support our previous finding that wheat fields do not provide opportunity for individuals of *T. vittata* to move through fields after harvest nor to reproduce in the bare ground after haystack collection (Rotem et al., 2013). As a result, in addition to being an ecological trap, post-harvest wheat fields create a barrier to movement of individuals in the landscape. In our case, this meant that young individuals of *T. vittata* could not move between natural habitat patches and, presumably, were preyed upon if they attempted such a movement.

Our results also indicate that before harvest, like in wheat fields, legume fields adjacent to natural patches attract individuals of *T. vittata*, causing an almost uni-directional patch-to-field movement pattern. Harvest reduces the number of individuals to almost zero presumably due to harvest machinery action and birds of prey that follow the harvester. However, the relative early harvest of legumes, and the leaving of cut and piled legume plants in the

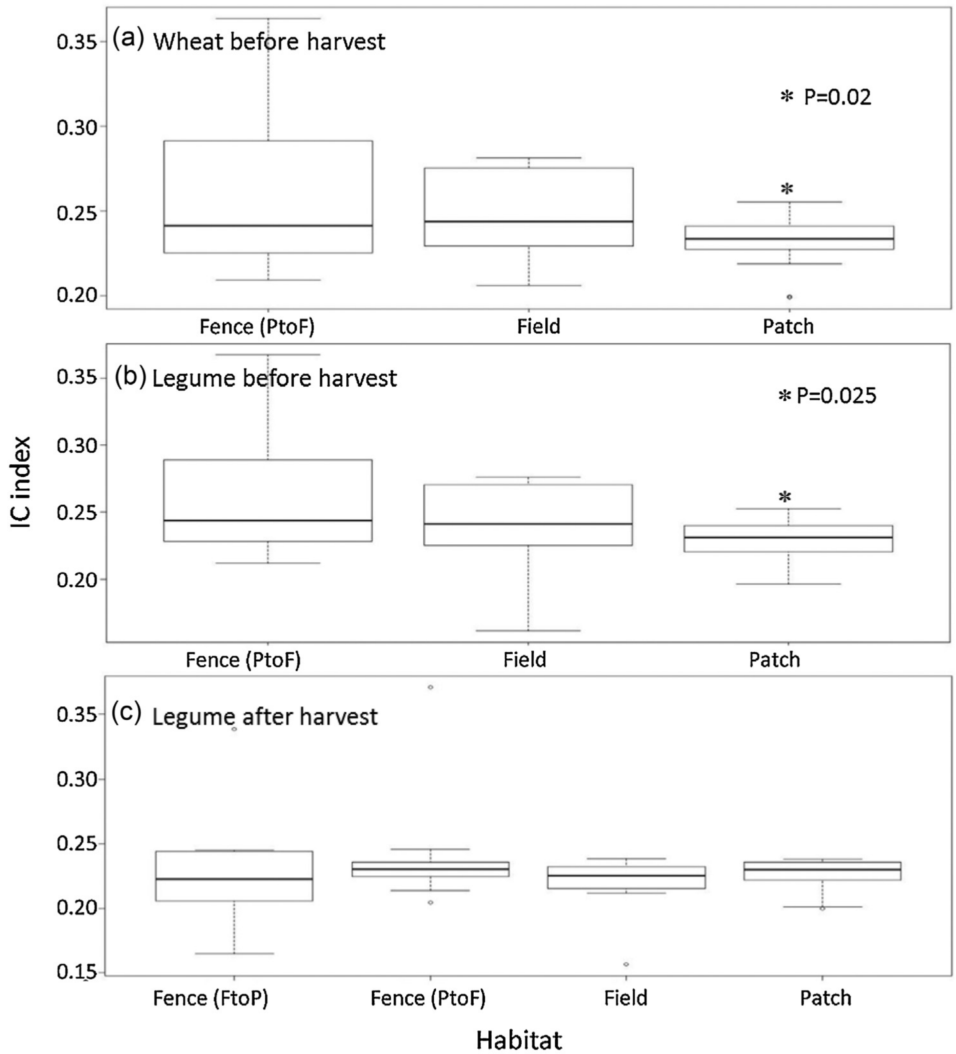

Fig. 3. Index of body condition (IC index) of individuals in the fence, field and natural patch before the harvest in the wheat fields (a) and legume fields (b), and after the harvest in legume fields (c). PtoF and FtoP indicate the tendency to move from patch to field and from field to patch, respectively. Note that before the harvest almost no movement from field to patch occurred, hence FtoP in (a) and (c) is unavailable. The symmetrical movement of individuals after the harvest in the legume fields did provide information on both PtoF and FtoP.

fields to dry in the sun, promote an entirely different movement dynamic – a symmetrical movement from the patches to the fields and vice versa is apparent in the post-harvest period. Furthermore, we show that not only are adults moving, but newborns are also moving between natural habitat patches and legume fields. Contrast this finding with the fact that newborns have never been observed in the wheat fields. The presence of newborns in legume fields can be a result of movement of newborns and/or reproductive females from the natural habitat patches to the legume fields after harvest. Regardless of the specific mechanism, the presence of newborns, especially deep in these fields, suggests that the post-harvest period in the legume fields provides an opportunity for individuals to move freely. It is likely that this movement potential is achieved by the long lines of the cut legumes, which usually stretch from one natural habitat patch to another, creating long tunnel-like structures that may improve refuge from predators and create better microhabitat conditions for individuals to move throughout the agricultural fields.

The differences found in individuals body condition between the natural habitat patches and the wheat or legume fields, (see also Rotem et al., 2013), show that both wheat and legume fields serve as an ecological trap. In this trap, better (heavier) individuals are attracted to the new “emerging habitats” of the fields before harvest. However, the lack of differences in body condition of individuals after harvest in legume fields and their adjacent natural patches strongly indicates that the entire population is now mixed, providing support or the idea that high symmetrical movement between the natural patches and legume fields indeed exists.

Our study indicates that different crop practices provide different opportunities within the agro-ecological landscape. Different opportunities may mitigate the overall negative effect of one crop by the presence of another, a potentially more wildlife-friendly, crop. Additionally, our continuous communication with the farmers in the current study shed light on the importance of the specific agricultural practices of an area. The creation of long, patch-to-patch pile lines in the legume fields has the unintentional benefit of allowing small reptile movements between natural habitat patches, and may have other far-reaching consequences for the mobility of other organisms in this landscape. This suggests that it is beneficial to review carefully the specific practices used by farmers in each agro-ecological landscape. Adequate communication at this level will allow the evaluation of specific agricultural practices with the aim towards benefiting both the famer and biodiversity. Possibly, a small change in a particular practice, such as linking piles of hay between natural habitat practices, or ensuring that these piles are in a certain direction or a certain depth could provide the correct microhabitats for a whole range of species resulting in a tremendous impact for populations and community viability.

In many other regions throughout the world, agricultural heterogeneity is also the product of the crop rotation between wheat and legume. As has already been shown, crop rotation is one of the keystones to protect biodiversity within agricultural fields (Dicks et al., 2014), having also positive effects on soil micro-organisms and naturel enemies. However, our study also emphasizes the importance of spatial mosaic at the landscape scale, given that farmers in large agricultural areas grow both wheat and legume and that legume fields allow higher movements of reptiles during their reproductive season. Consider two scenarios within the same agricultural landscape: the first scenario involves a continuous wheat field that encompasses a large area and then another continuous legume field next to it. In the second scenario, different medium-sized fields of wheat and legume are mixed together, producing a mosaic of agricultural fields. Based on our findings, the second scenario will probably provide higher native species permeability within the agroecosystem, potentially allowing a higher survival probability for some populations. Possibly, reaching the second scenario may require negotiations with the farmers as well as governmental support. However, given that reptiles, as main predators of arthropods, may also contribute to pest control, such a scenario may also present a necessary ecosystem service to the farmer.

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