

Providing water sources to insectivorous bats for conservation biological control in arid date plantations

Yuval Arzi^a, Michal Segoli^a, Jessica Schäckermann^{b,c}, Carmi Korine^{a,*}

^a Mitrani Department of Desert Ecology, Swiss Institute of Dryland, Environmental and Energy Research, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midreshet Ben-Gurion 8499000, Israel

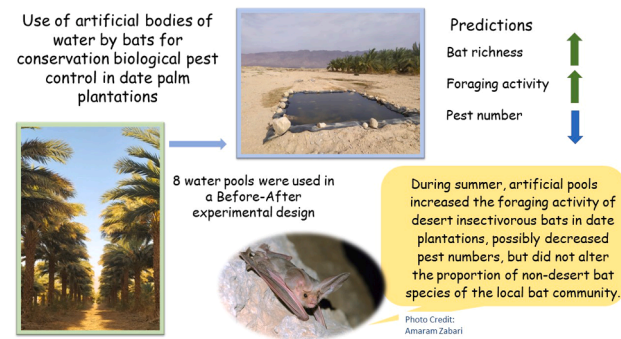
^b Southern Arava R&D, Eilat Regional Council, D.N. Hevel Eilat 8882000, Israel

^c The Arava Institute for Environmental Studies, D.N. Hevel Eilat, Ketura 8884000, Israel

HIGHLIGHTS

- Arid insectivorous bats feed on important pests such as the lesser date moth.
- These bats use bodies of open water, either for drinking and/or as foraging sites.
- We show that placing small bodies of water in date plantations enhanced the activity of the bats during summer.
- The abundance of the lesser date moth was negatively correlated with bat activity.
- Integration of artificial pools may enhance bat biological control services and bat conservation and the method can be easily adopted in other crops.

GRAPHICAL ABSTRACT



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ABSTRACT

Balance between the high demand for agricultural production and the negative environmental impact of intensive agriculture requires the development of sustainable agricultural approaches. One such approach is conservation biological control (CBC), which aims at enhancing pest suppression by using natural enemies, such as predators and parasites. Insectivorous bats are considered as potential natural enemies for CBC of insect agricultural pests. Bats drink from open water sources and forage above them, hence we hypothesized that supplementation of artificial water pools adjacent to desert date plantations might promote the activity and species richness of insectivorous bats in this habitat, thereby contributing to pest suppression. We predicted that bats will be more attracted to the pools during summer, when other water sources are scarce, than during spring. In addition, we explored the effect of water supplements on the desert bat community structure. Eight pools were installed in a date plantation in the hyper-arid Arava valley, Israel. Bats were acoustically monitored during three experimental stages: 1) before filling the pools with water; 2) while the pools held water and 3) after emptying them. The lesser date moth (*Batrachedra amydraula*), a major date pest, was monitored using pheromone traps in parallel with the experimental stages. We found that the pools increased bat activity in summer, but not in spring, while species richness was not affected in either season. The local bat community structure was significantly altered while the pools held water, but not due to increased activity of synanthropic Mediterranean

* Corresponding author.

E-mail address: ckorine@bgu.ac.il (C. Korine).

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species at the expense of local desert species. The number of individuals of the lesser date moth near the pools decreased with the increase in bat activity. Our results support the idea that seasonal water supplementation enhances bat activity in arid farmlands with potential contribution to pest control and the actual contribution to pest suppression should be further quantified. We suggest that the integration of small artificial pools to promote agricultural pest predation by bats may help reduce crop loss and potentially contribute to the conservation of desert bat communities by adding water sources.

1. Introduction

Agricultural animal-pests are a major cause of crop loss worldwide and treated mainly by pesticides (Oerke & Dehne, 2004), which entail considerable risks (Pimentel & Burgess, 2014) and limited efficacy (Oerke & Dehne, 2004). Agroecological knowledge should be enlisted to promote sustainable pest control approaches (Tilman et al., 2001). One such approach is conservation biological control (CBC), which aims at altering the agricultural environment in a way that promotes the effectiveness of pest control by natural enemies (e.g., predators or parasites of the pest) (Barbosa, 1998). Although most CBC practices are designed to enhance the success of natural enemies of arthropods (Zehnder et al., 2007), recently, there is a growing interest in biological control by predatory vertebrates (Lindell et al., 2018), such as insectivorous bats (Russo et al., 2018).

Insectivorous bats have a crucial role in the suppression of agricultural pests (Kunz et al., 2011). Meta-barcoding molecular techniques revealed that bats frequently feed on agricultural pests (Cohen et al., 2020; Charbonnier et al., 2021; Hughes et al., 2021; Tuncu-Corral et al., 2023). Moreover, it has been suggested that bats opportunistically adjust their dietary niche to prey on taxa associated with agricultural crops (Aizpurua et al. 2018), show preference to foraging in agricultural fields compared to adjacent forests and secondary vegetation (Kemp et al. 2019), and increase their foraging activity in response to increased abundance of prey (Charbonnier et al., 2014; Weier et al., 2018; Korine et al., 2020). Maine & Boyles (2015) demonstrated that when the access of bats to cornfields was prevented by enclosures, more pest damage occurred. Based on that, they estimated that the global economic value of pest suppression provided by bats in cornfields is more than 1 billion USD annually. In vineyards, 7% of the damage to grape clusters was prevented due to pest predation by bats (Rodríguez-San Pedro et al., 2020). Thus, bat-friendly farm management can be economically and environmentally beneficial. Such management practices include increasing crop diversity, reducing the use of pesticides (Olimpi & Philpott, 2018), preserving or planting tree lines and woody patches that serve as foraging habitats for bats (Kalda et al., 2015), installing bat roosting boxes (Puig-Montserrat et al., 2015), or attracting the bats by applying sex pheromones of pests (Korine et al., 2022). Another potential practice that has been suggested is providing artificial water sources to bats (Tuttle et al., 2006; Adams & Hayes, 2008; Russo et al., 2012). It was shown that flooding management in rice paddies promotes bat foraging and feeding activity (Toffoli & Rughetti, 2020), although this practice is always applied regardless of its effect on the bats. In arid lands, where natural water sources are rare, water supplementation may attract bats, potentially enhancing pest control and contributing to the conservation of desert bat communities (Korine et al., 2016).

Bats are one of the most successful and diverse mammal groups in deserts (Carpenter, 1969). While some desert bat species can survive for very long periods without drinking (Carpenter, 1969), most species require stable access to water sources to compensate for their water loss (Adams & Hayes, 2021). Moreover, bats rely on open water sources not only for drinking, but also for foraging, because of the high abundance of insects around them (Adams & Hayes, 2008; Toffoli & Rughetti, 2020). Thus, most of the bat activity in arid regions is concentrated over open bodies of water (Adams & Hayes, 2021), which are important for their survival and reproduction (Williams & Dickman, 2004; Korine et al., 2016). In accordance, proximity to water sources is a strong determinant

of species distribution in the deserts of Israel, including the Arava valley (Razgour et al., 2018), which is a regional hotspot for bat diversity, where up to 17 bat species were documented (Hackett et al., 2013, 2017; Schäckermann et al., 2022; Yom-Tov and Kadmon, 1998). Given the substantial loss and degradation of natural water resources due to urbanization and irrigation for agricultural development (Dubois, 2011), artificial water sources are highly important for bat preservation in arid lands (Korine et al., 2016; Adams & Hayes, 2021).

Livestock troughs (Tuttle et al., 2006; Russo et al., 2012), artificial wetlands and sewage ponds (Stahlschmidt et al., 2012; Sirami et al., 2013; Korine et al., 2015) serve bats as drinking and foraging sites. However, in some cases, such artificial water sources may attract certain species more than others and lead to interspecific competitive interactions, thereby altering community composition (Hutchinson, 1978; Adams & Hayes, 2021). For instance, Mediterranean non-desert synanthropic species, such as *Pipistrellus kuhlii* and *Tadarida teniotis*, which are highly dependent on water (Razgour et al., 2010) and exploit human-made water sources (Korine & Pinshow, 2004; Greenfeld et al., 2018), expanded their distribution into the desert of Israel following human settlements and agriculture (Yom-Tov & Kadmon, 1998). Expansion of synanthropic bat populations may potentially lead to the decline of other species (Arlettaz et al., 2000). Thus, when evaluating the contribution of water supplementation for pest control and bat conservation in arid environments, potential negative impacts on bat communities should be considered, and resolved if they occur (Greenfeld et al., 2018).

The date palm (*Phoenix dactylifera* L.) is considered one of the most important and economically relevant fruit crops in the arid regions of North Africa and the Middle East (Zaid, 2002; Cohen & Glasner, 2015). The lesser date moth (LDM) *Batrachedra amydraula* Meyerick, is highly specific to dates and one of the major pests affecting this crop (Perring et al., 2015). The larval stage feeds on the young green fruits and can cause up to 75% yield loss if not treated (Blumberg, 2008). Currently, the main practice used against LDM is insecticides (Perring et al., 2015). The use of pheromone traps is still under development (Levi-Zada et al., 2018; Yuval Arzi, pers. comm.) and some natural enemies of the moth have been identified, the main ones being several parasitoid wasps, but their efficacy as control agents is unclear (Blumberg, 2008). Schäckermann et al. (2022) showed that several species of insectivorous bats feed on date pests in the plantations in the Arava valley. For example, *Eptesicus bottae* and *P. kuhlii* feed on a variety of important date pests such as the LDM, while *Otonycteris hemprichii* feeds on the Rhinoceros beetle (*Oryctes agamemnon*) and the Dubas bug (*Ommatissus lybicus*).

Our main objective was to assess whether the implementation of artificial water pools in desert date plantations can enhance species richness and activity of insectivorous bats, thereby potentially contributing to pest suppression. We predicted that bat activity and richness will increase when filling the pools with water and decrease again when emptying them, and that this effect will be more pronounced in summer, when water sources are scarce. We further hypothesized that local enhancement of bat activity could reduce the local abundance of pests. Accordingly, we predicted a negative association between bat activity and the number of moths monitored near the pools. Finally, we studied the effects of water pool implementation on the local bat community structure, predicting an increase in the proportional activity of the synanthropic species *P. kuhlii* and *T. teniotis*, potentially at the expense of desert species.

2. Material and methods

2.1. Study area

The study was carried out in organic date plantations of Kibbutz Samar in the southern Arava valley, Israel, which is part of the Great Rift Valley (Fig. 1). Samar's date plantation is the only organic plantation of its kind in the Arava valley and its size is > 250 acres. The plantation is a mix of date trees of different age classes and cultivars such as Maghull and Dekel Nour. It is surrounded by sand dunes and loess soil, thus creating a diverse large patch of small plots of date trees. The area is a hyper-arid desert (following classifications in Noy-Meir, 1973), with mean annual temperature of 25.4 °C (January: 15.8°C - July: 33.8°C) and 27.6 mm of yearly rain in average, typically with no precipitation during June-August (Israel Meteorological Service, <https://ims.gov.il/en/ClimateAtlas>). Several settlements are located along the valley cultivating extensive agricultural lands, dominated by date plantations (Cohen & Glasner, 2015). Date farmers, both conventional and organic, treat the date plantations according to an integrated pest management (IPM) approach against LDM in which insecticides are applied according to the actual pest infestation level of LDM, along with alternative sustainable pest control methods, such as light traps and pheromone mass-trapping (Schäckermann et al., 2022). The main differences between Samar's organic date plantation and other conventional plantations are as follow: 1) Samar's farmers cut ground-covering weeds with machinery, leaving a patch of green vegetation around the trunk of the tree which may enhance the abundance of natural enemies, 2) Use high pressure water washers to spray against pests, and 3) do not use herbicides (Cohen & Glasner, 2015; Schäckermann et al., 2022).

2.2. Experimental design

The large size of Samar's plantation allowed us to randomly select eight locations for the artificial pools that were built by us and the farmers (Fig. 1). The pools were dug in the ground and sealed by a plastic sheet. The size of the pools was approximately 2x3 meters, and 30 cm deep, large enough to enable drinking by most of the insectivorous bats in Israel, based on the morphological traits of the local bat fauna (Mendelsohn & Yom-Tov, 1999), and studies that explored bats drinking from comparable water ponds (Tuttle et al., 2006; Greenfeld et al., 2018). All the pools were located on the edge of the date plantations (Fig. 1), in open areas that enable bats to drink while flying. The aerial distance between pools was ~ 350–850 m, aiming to have them as separate from each other as possible under the spatial limitations of the area. For further details on the construction of the pools, see Supplementary material.

We performed an experiment composed of three consecutive stages: **1st stage**) before filling the pools with water; **2nd stage**) while the pools were full of water; **3rd stage**) after emptying the pools from water, according to the classic Before-After design, which is common in conservation studies and aids reduction of problems caused by natural spatial variation between sites (Osenberg & Schmitt, 1996). The 1st experimental stage was shorter (3–4 nights) as there was no need for acclimatization, while the 2nd stage (18 nights) and 3rd stage (8 nights) lasted longer because of the bats' need to locate the water and respond to the lack of the water (Korine, pers. Observations). We repeated this experiment twice during 2020, first in March to mid-April (spring), when the first generation of the LDM is active, and second in July (summer), when the third generation is active (Levi-Zada et al., 2018). To minimize potential drowning of small animals in the pools, plastic nets and stone ladders were attached to the banks of the pools to enable animals to climb out of them (Fig. 1).

2.3. Acoustic monitoring

Passive acoustic bat monitoring was done in each pool site

throughout the three stages of the experiments using a bat detector (AnaBat SD2, Titeley Electronics, Australia) placed 2–10 m from the pool, dictated by the need to avoid damage from agricultural machinery. The detector, whose detection range is on average 40 m (Patriquin et al., 2003), pointed towards the pool at a 30° angle upwards. We used Analoop software to analyze the bat calls recorded by the detectors. We analyzed calls manually to the species level, since call frequencies of the different bat species in this area do not overlap (Supplement, Table S1). Different individual bats cannot be distinguished based on recordings; hence, every call sequence of certain species, approximately 5 ms fragments, was considered as one pass of a bat, rather than as a specific individual (Fenton, 1970). "Bat activity" was defined as the number of passes per night and "species richness" as the number of species recorded and identified at each night. Data included the activity of all the species together, including passes of bats that we could not identify to species, and a species-specific bat activity.

We analyzed recordings of all nights of the 1st experimental stage. For the longer 2nd and 3rd stages, we excluded the first four nights after filling or emptying the pools due to the expected acclimation period of the bats to the environmental change and randomly chose other nights for analysis. Altogether, spring trial data consisted of three nights before filling the pools, five nights while the pools were full, and four nights after emptying the pools. Only the last night of the third stage overlapped with insecticide application against LDM, which is directed to fruit clusters and affects only the larvae rather than potential prey for bats (*i.e.*, adult flying moths). Pool 7 (Fig. 1) was not included in the analysis of the spring experiment, due to large amounts of sand that reduced its depth. Summer trial data consisted of four nights before filling the pools, six nights with full pools and three to four nights after emptying the pool, depending on the pool.

2.4. Moth monitoring

We monitored the LDM abundance during summer, using pheromone traps, following Levi-Zada et al. (2018). We failed to monitor the moths during spring, due to technical problems. Traps were placed in pairs - one trap on the date tree closest to each pool (8–15 m from the pool) and the other trap ~ 200 m away, but within the same plot (*i.e.*, same cultivar, age of the trees and management). The traps were placed 2–2.5 m above the ground. The pheromone attracts male moths in a radius of ~ 27 m (Levi-Zada et al., 2018). The captured moths were counted every second night in most cases. In two cases, we had a gap of three and four nights between moth counts due to technical problems. Hence, the data was normalized to estimate the average number of moths captured per night.

2.5. Statistical analysis

We conducted linear mixed model (LMM) to test the effect of the three experimental stages on bat activity and species richness, using the GAMLj module (Gallucci, 2019) on Jamovi statistical software (The jamovi project, 2021). We included the average night wind speed, average night temperature (derived from: <https://ims.gov.il/en/ClimateAtlas>) and moonlight percentage (derived from: <https://github.com/mourner/suncalc>, but see Kyba et al., 2020) as fixed explanatory variables, as they were previously suggested to affect bat activity (Richards, 1989). Pool ID was defined as a random variable. We used a correlation matrix to assess autocorrelations between explanatory variables. Thereafter, we excluded the average night temperature from summer models due to autocorrelation with the experimental stage ($r_s = 0.814$, $p < 0.001$, $N = 95$). In both models (spring and summer), bat activity was log-transformed to fit the assumptions of normal distribution and homoscedasticity of the residuals. Top models for the LMM were manually selected following the Akaike's Information Criterion (AIC) method (Akaike, 1974; Burnham & Anderson, 2002). We removed from the complete model the explanatory variables (except of the

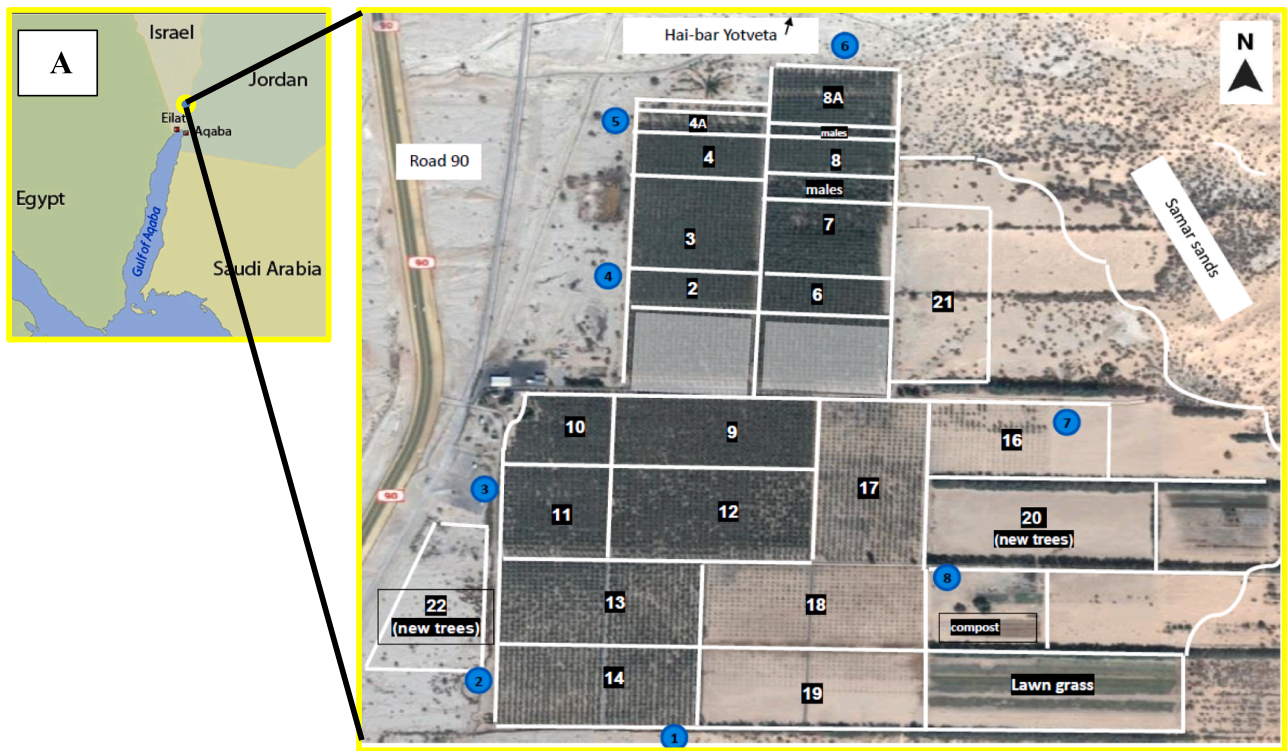


Fig. 1. A: Map of the study area in Kibbutz Samar's date plantations, Arava valley, Israel. Different agricultural plots are separated by white lines and marked with white numbers. The pools are numbered and marked with blue circles. B: A photo of the experimental pool during the second stage of the experiment when it held water. Note the stone ladder that was added to enable animals to climb out of the pool (blue triangle).

“experimental stage” variable, that remained constant) which their elimination resulted with an AIC score of at least two points less than the next best model ($\Delta AIC > 2$). In all models testing the effect of water treatments, we performed the Holm-Bonferroni correction for multiple comparisons post hoc (Holm, 1979).

Changes in local bat community structure during the experiment were tested using R program, version 4.1.2 (R Core Team, 2020). We used the ‘adonis’ function in the ‘Vegan’ package (Oksanen et al., 2016) to perform a permutational multivariate analysis of variance (PERMANOVA) and compare the bat community structure at the three experimental stages, based on Bray-Curtis dissimilarities (Anderson, 2014). We considered wind speed and moonlight percentage as fixed explanatory variables and the pool ID as a random variable. Complementary to the PERMANOVA analysis, we used the function ‘metaMDS’ to create a Non-metric Multidimensional Scaling (NMDS) plot to visualize the community structure dissimilarities between the experimental stages in two dimensions (Matthews, 1978). Furthermore, we employed the similarity percentage breakdown (SIMPER) Analysis (Clarke, 1993) by the ‘Vegan’ R package (Oksanen et al., 2016), to test the relative contribution of each bat species to the overall dissimilarity observed between the community structures in the different experimental stages.

We used Pearson correlations to test the relationship between bat activity and the number of moths captured close to the pools. In addition, we compared the number of moths captured close to the pool and farther from the pool within the same agricultural plot, by a GLMM for negative binomial distributed data, in which the number of moths in the trap was the response variable, distance from the pool (close/far), experimental stage and distance*experimental stage interaction were the explanatory variables, and pool ID was a random variable.

3. Results

A total of 12 bat species were identified (Supplement: Table S1). All species were recorded during both spring and summer. In both seasons, *Rhinolophus hipposideros* and *Asellia tridens* were extremely rare, with a single pass each, while *Hypsugo ariel* was the most common species.

3.1. Bat activity and richness: Spring experiment

Altogether we recorded 12,433 bat passes across 12 nights and 7 pool

Table 1

Results of the top linear mixed models testing the effect of the water manipulation (filling/emptying) and environmental variables on bat activity and on species richness during spring and summer experiments in date plantations, Arava valley, Israel. (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.05$.

Season	Response	R ²	Variable	Estimate ± SE	t	p-Value	
Spring	Bat activity	0.69	Intercept	2.062 ± 0.093	22.06	<0.001***	
			Filling	-0.053 ± 0.130	-0.409	0.68	
			Emptying	-0.266 ± 0.104	-2.563	0.025*	
			Temperature	0.121 ± 0.014	8.503	<0.001***	
			Wind speed	-0.032 ± 0.030	-1.094	0.28	
			Moonlight	0.286 ± 0.156	1.83	0.07	
			Species richness	0.61	Intercept	7.230 ± 0.259	27.9
	Filling	-1.818 ± 0.707	-2.57		0.025*		
	Emptying	-0.565 ± 0.565	1		0.32		
	Temperature	0.661 ± 0.078	8.5		<0.001***		
	Wind speed	-0.418 ± 0.162	-2.58		0.01*		
	Moonlight	-1.148 ± 0.854	-1.34		0.18		
	Summer	Bat activity	0.82		Intercept	2.355 ± 0.107	21.95
				Filling	0.236 ± 0.036	6.49	<0.001***
Emptying				-0.083 ± 0.035	-2.35	0.02*	
Species richness		0.46	Intercept	7.593 ± 0.349	21.771	<0.001***	
			Filling	0.708 ± 0.768	0.923	0.72	
			Emptying	0.063 ± 0.628	0.100	0.92	
			Wind speed	1.161 ± 0.489	2.376	0.02*	
			Moonlight	0.372 ± 1.018	0.365	0.72	

sites. We were able to identify 11,950 of the passes (96%) to the species level. *H. ariel* and *Eptesicus bottae* accounted for ~ 42% and 41% of the total passes, respectively.

Total bat activity decreased throughout the experiment but was only significantly lower after emptying the pools (Table 1; Fig. 2A). Bat activity was positively and significantly associated with the average nightly temperature but was not associated with moonlight percentage or average nightly wind speed (Table 1). Bat species richness showed a similar decreasing trend throughout the experiment as bat activity, with significant decrease after filling up the pools and non-significant decrease after emptying the pools (Table 1; Fig. 2B). In addition, species richness was positively associated with temperature, and negatively associated with wind speed (Table 1).

3.2. Bat activity and richness: Summer experiment

Altogether we recorded 34,333 bat passes across 14 nights and 8 pool sites. We identified 33,501 of the passes (97%) to the species level. *H. ariel* was responsible for 48% of the total passes, followed by *Taphozous nudiventris* with 23% of the passes and *E. bottae* with 21% of the passes.

Bat activity increased significantly by 1.8 times after filling up the pools and decreased by 0.14 times after emptying the pools (Table 1; Fig. 2C). Bat activity was not associated with moonlight percentage and night wind speed and thus were not included in the models. In contrast to bat activity, species richness was not affected by the water manipulation but was positively associated with average wind speed (Table 1; Fig. 2D), which varied between nights from 1.5 to 2.3 ms⁻¹.

3.3. Bat community

The analysis of the structure of the bat community was only done for summer experiment as pools were found to be ineffective in enhancing bat activity or species richness during spring (see above). The Two rare species, *R. hipposideros* and *A. tridens*, each recorded only once during the entire experiment, were not included in community analyses. Excluding them, the bat community during summer was composed of similar species throughout all the experimental stages, dominated by *H. ariel*, *E. bottae*, and *T. nudiventris*. However, the community structure significantly differed between experimental stages (PERMANOVA:

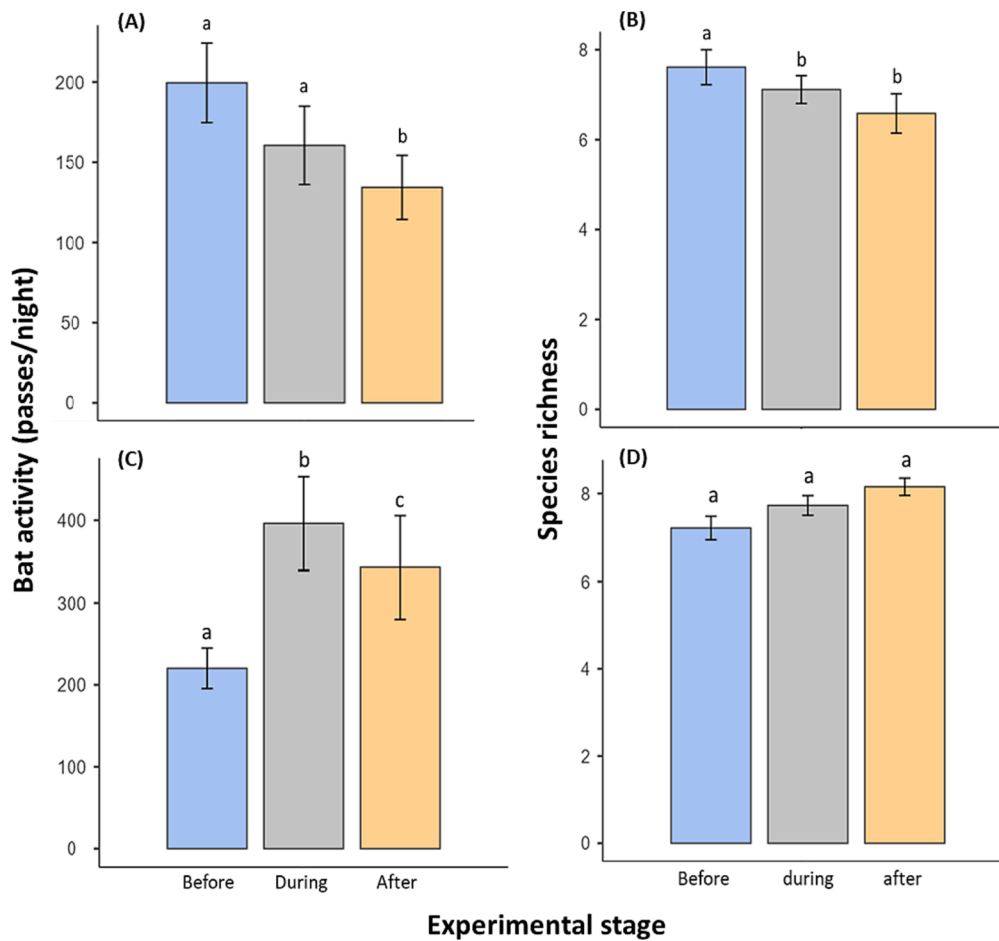


Fig. 2. Average bat activity (passes per night) \pm S.E (A, C) and average species richness per night \pm S.E (B, D), before, during, and after the pools contained water (Experimental stage) in spring experiment (upper panel) and in the summer experiment (lower panel). Different letters denote significant differences between the experimental stages in date plantations, Arava valley, Israel.

Pseudo $F = 8.93$, $p = 0.01$), with noticeable pattern of dissimilarities between them, but also considerable overlap (Fig. 3). The NMDS stress value was 0.104, conveying a good representation of the actual dissimilarities in the two-dimensional space.

The main differences between experimental stages were in the relative activity of each species. Before filling the pools (stage 1), the community was dominated by *H. ariel* (~63% of the bat activity on average) and *E. bottae* (~22%). When the pools held water (stage 2), *T. nudiventris* became the dominant species and its activity increased from ~ 5% to ~ 32% of the total bat activity. These three species dominated the community after the pools were emptied (stage 3) (Fig. 4).

In accordance, *H. ariel*, *T. nudiventris*, and *E. bottae* were the main contributors to the community structure dissimilarity before and during the times that the pools contained water (55% total dissimilarity, SIMPER analysis), when shifts in their activity accounted, respectively, for ~ 47%, ~23% and ~ 19% of the difference (~89% in total). *Pipistrellus kuhlii* accounted for ~ 6% of the difference, while other species had minor effects (<1.25%) (Supplement: Table S2). Similarly, after emptying the pools, ~88% of the community structure dissimilarity (52% total dissimilarity) was attributed to bat activity of the same three species – *T. nudiventris* (~35%), *H. ariel*, (~31%) and *E. bottae* (~22%). Changes in *P. kuhlii* activity contributed only ~ 3% of the dissimilarities (Supplement: Table S3).

3.4. Moth captures

The number of moths caught close to the pool in summer was negatively correlated with bat activity (Pearson correlation: $p = 0.004$, $R = -0.278$; Fig. 5). There was no significant difference in the number of moths caught close and far traps from the pool (GLMM: $X^2(1) = 0.140$, $p = 0.708$), and the effect of the interaction between distance from the pool and the experimental stage was also non-significant (GLMM: $X^2(2) = 0.226$, $p = 0.893$). In both close and far traps, the number of moths decreased throughout the experiment.

4. Discussion

We assessed the role of artificial bodies of water as an ecological-based method to enhance the activity of insectivorous bats, natural enemies of insect pests in date plantations (Schäckerermann et al., 2022). We found that bat activity during summer increased significantly after water supplementation. This might be due to the attraction of more bats to the water pools. Alternatively, as bat activity is not a measure of the number of bat individuals (section 2.3), a similar number of bats might have stayed longer around the pools or returned to them repeatedly to drink and exploit food resources (Krebs, 1978), thereby increasing the number of recorded passes. Most likely, the combination of both effects enhanced bat activity. The smaller decrease in bat activity after emptying the pools in summer, compared to the high increase after filling them, could be explained by the relatively shorter period (seven nights) of the third experimental stage, after the pools were emptied. It is

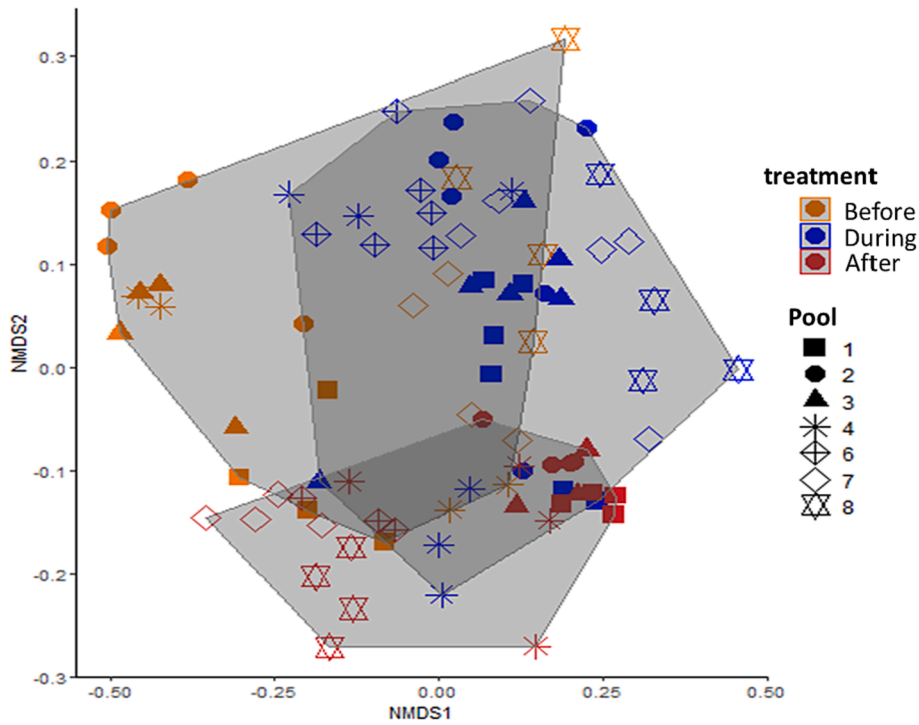


Fig. 3. NMDS plot showing dissimilarities in the bat community structure between different stages of summer experiment in date plantations, Arava valley, Israel. Stress value = 0.104. Each point represents the bat community structure recorded along one night, at a specific pool (shapes), and during a specific stage of the experiment (colors).

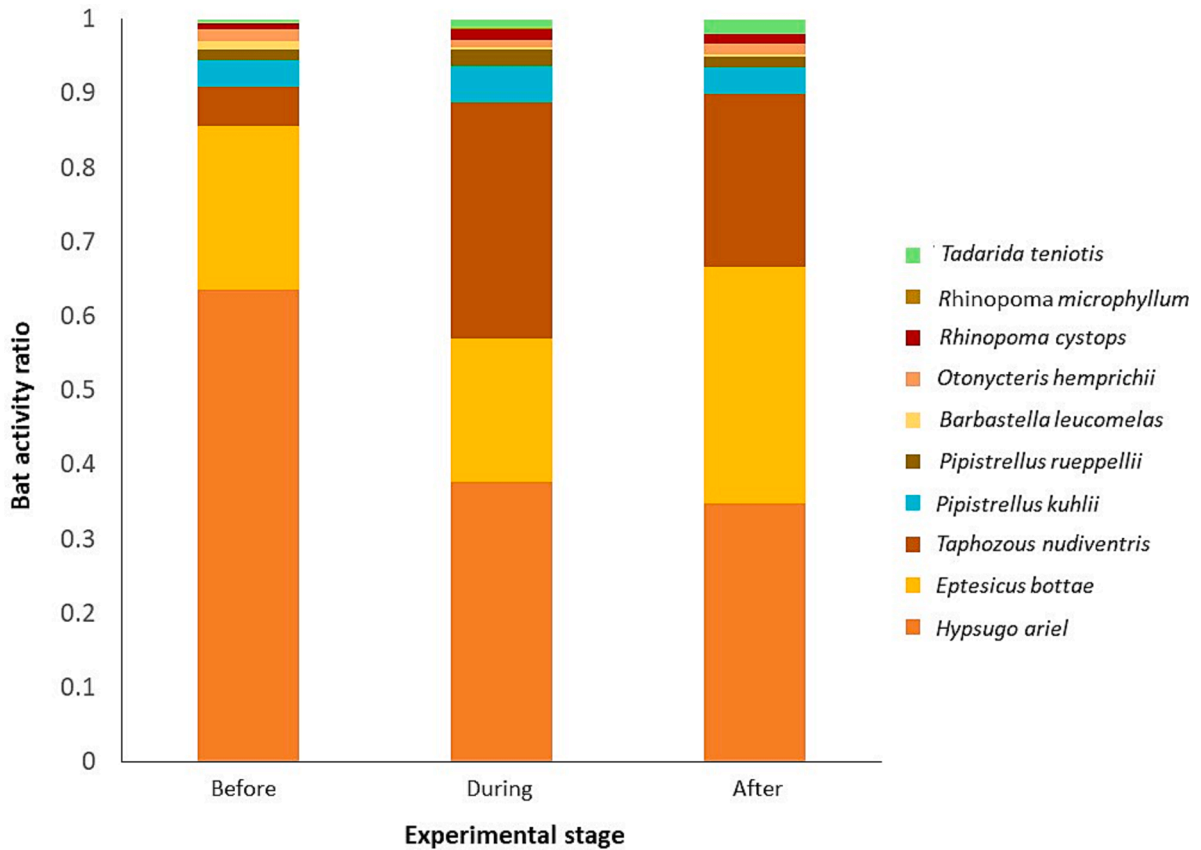


Fig. 4. The proportional activity of species before, during, and after the pools contained water, during summer experiment. All desert species are represented by warm colors and two Mediterranean species (*Pipistrellus kuhlii* and *Tadarida teniotis*) by cold colors.

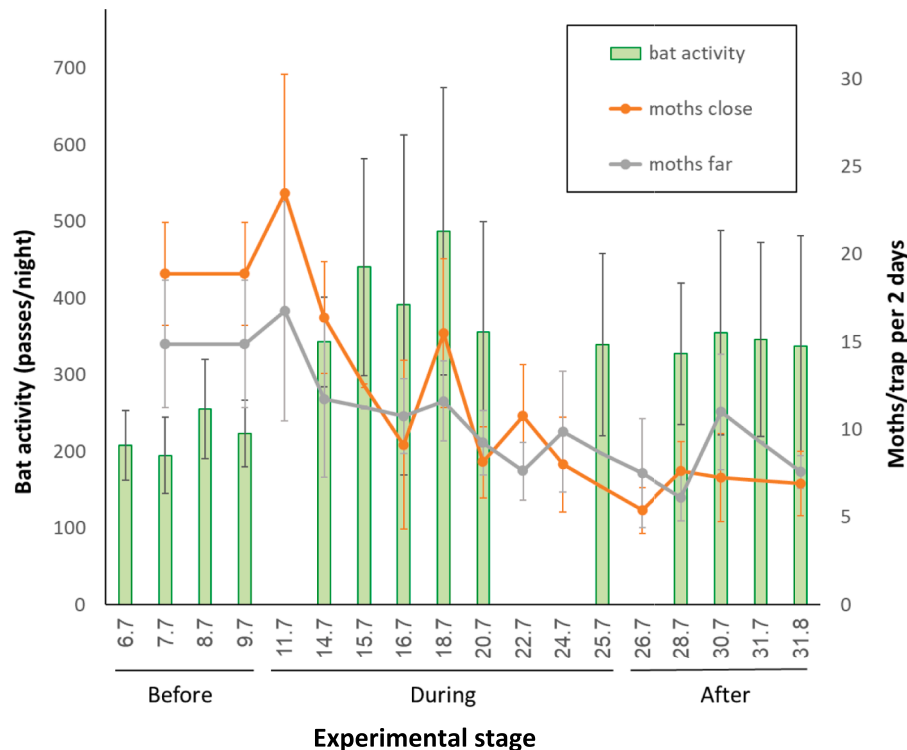


Fig. 5. Average \pm SE bat activity (passes per night; green bars) near the pools and average \pm SE number of moths accumulated in the traps every two days, close (orange line) and far (gray line) from the pools, during summer experiment in date plantations, Arava valley, Israel. The number of moths caught close to the pool was negatively correlated with bat activity ($y = 0.5619x - 0.7817$, $r = -0.278$, $P < 0.004$).

possible that bats returned to the familiar source of water (Marques et al., 2004) for a longer period than expected and as a result, the reduction in their activity was not as pronounced.

The installed water pools were more attractive to bats during summer than during spring. In spring, following winter floods, more natural water sources are available and could make artificial water pools less attractive. Other studies indicated that bodies of open water attract higher bat activity and species richness mainly when water is scarce in the area (Amorim et al., 2018; Toffoli & Rughetti, 2020). In the Negev desert, bat activity and species richness increased in semi-permanent and permanent ponds when the ephemeral ponds dried out at the beginning of summer (Razgour et al., 2010). This suggests that bats track the temporal variation in water distribution, similarly to the way they track temporal variation in food sources (Charbonnier et al., 2014; Cohen et al., 2020). In addition, the need to drink may be more critical during summer due to increased evaporative loss, compared to spring (Korine et al., 2016). Furthermore, bat lactation takes place mostly during summer (Crichton & Krutzsch, 2000) and lactating females may visit water sources more often (Adams & Hayes, 2008) due to increased water requirements (Kurta et al., 1989). Indeed, lactating females of the three most abundant species in this study - *H. ariel*, *E. bottae* and *T. nudiventris*, were captured in Israel only during summer months (Yom-Tov et al., 1992). Finally, the different responses may also partially reflect seasonal variation in the emergence of adult aquatic insects from the pools, which is an important factor affecting bat activity over water sources (Fukui et al., 2006).

4.1. Bat community structure

The significant effect of water supplementation on bat community structure during summer conforms to the known conclusive influence of water on bat communities, especially in arid zones (Korine et al., 2016; Adams & Hayes, 2021). The NMDS ordination plot revealed distinctive

separation between community structure monitored during different experimental stages, but also some overlap. This overlap may reflect variation among the different pool sites regardless of the existence of water in the pool. Variation between pool sites may be explained by spatial aspects of the different locations of pools and their surroundings (Kalda et al., 2015; Weier et al., 2018) that were beyond the objectives of our study.

Our results show that the synanthropic Mediterranean species, *P. kuhlii* and *T. teniotis*, did not displace desert species from pool sites. Throughout the summer experiment, the local bat community was dominated by three desert species- *H. ariel*, *E. bottae*, and *T. nudiventris*, which were also the main contributors to the observed variation in community structure between the experimental stages. The moderate response of Mediterranean species to the pools indicates no immediate consequences of water supplementation for the conservation of desert bat communities. Nevertheless, the activity of *P. kuhlii* did increase slightly when water was available, which could indicate that water supplementation may enhance local populations of this species. Although no displacement by non-desert species was observed following water supplementation, some interspecific competitive interactions, such as shifts in foraging times due to temporal partitioning of food and access to water surface, might take place over the pools (Adams & Thibault, 2006; Razgour et al., 2011), but were beyond the scope of this study. Thus, the potential effect of the pools on non-desert synanthropic species and subsequent effects on community structure and dynamics should be further explored.

Taphozous nudiventris responded to the water supplementation more actively than any other species. As an open space forager which tends to hunt high above the ground (Benda et al., 2012), The bats may have used the pools mainly for drinking, rather than for foraging. Hence, it was less likely to be recorded while the pools were empty, in contrast to bats that forage a few meters above the ground, such as *H. ariel*, *E. bottae*, and *P. kuhlii*. Moreover, *T. nudiventris* is the largest insectivorous bat in

Israel (Mendelssohn & Yom-Tov, 1999), and might have struggled to drink from the small pools due to its low maneuverability (Adams & Hayes, 2021), possibly resulting in repeated drinking attempts and consequently exaggerated bat activity when the pools were full (Razgour et al., 2010). Finally, the high activity of *T. nudiventris* over filled pools might be due to considerable water requirements, since it is not a desert-obligate species (Razgour et al., 2018), and also inhabits Mediterranean zones in Israel (Yom-Tov & Kadmon, 1998).

4.2. Potential contribution to pest control

The negative correlation between bat activity and the number of moths captured close to pools during summer experiment suggests that bats suppressed the LDM to some extent. However, the number of moths captured did not significantly differ between moth traps located close and far from the pool. Future research could include an assessment of bat-moth associations close and far from pools over a larger spatial scale. In addition, the impact of increased bat activity on the abundance of other insect assemblages should be investigated, especially given the high bat species richness that we recorded and the diet variation between different species, as well as the diverse diet of some of the bat species (Feldman et al., 2000; Schäckermann et al., 2022). Comparing bat-pest associations in pool and non-pool sites throughout the pest activity season, and preferably over several consecutive years, could shed further light on the effect of the pools on pest abundance and crop damage.

The observed responses of bat activity to water supplementation highlight the notion that water pools may be an efficient tool to attract insectivorous bats to date plantations, especially during summer. Hence, artificial water pools can be used as a tool to enhance CBC in arid farmlands and particularly in date plantations. Our results raise interesting questions on bat species dynamics over water sources and suggest that no immediate displacement of native desert bat species by synanthropic bats accompanies the introduction of pools. Further research should explore the characteristics and locations that are most favorable, as well as practical, in order to improve the application of this practice and maximize its contribution for pest control, as well as for bat conservation.

CRedit authorship contribution statement

Yuval Arzi: Conceptualization, Methodology, Field work, Data Analysis, Writing – original draft. **Michal Segoli:** Conceptualization, Methodology, Writing – review & editing. **Jessica Schäckermann:** Conceptualization, Methodology, Field work, Writing – review & editing, Funding acquisition. **Carmi Korine:** Conceptualization, Methodology, Field work, Data Analysis Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocontrol.2023.105374>.

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