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Three Decades of Satisfied Israeli Farmers: Barn Owls (*Tyto alba*) as Biological Pest Control of Rodents

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ABSTRACT: Compared to the use of invertebrate as biological pest control of agents of invertebrate pests, the use of vertebrates as biological pest control agents against other vertebrates is less common due to difficulties in manipulating and increasing their populations. Barn owls have been used as biological control agents in different countries, including Israel, which initiated the project in 1982 and as of 2017 has a total of 3,250 nest boxes deployed in the country. Our aim here was to determine whether farmer satisfaction/dissatisfaction response to a survey on the effectiveness of the barn owl project is related to the number of nest boxes and breeding barn owl pairs that the farmers have in their fields; and whether farmers deploy nest boxes as a result of previous rodent damage in their fields. We found that farmers that had incurred rodent damage both used more rodenticides and also installed more nest-boxes (and consequently had more breeding barn owls) than those who reported a lack of damage. Farmers who were satisfied using barn owls had more nest boxes and hence more breeding barn owls, and reported that rodent damage had decreased during the project, as compared to farmers who were not satisfied with the project. The number of nest boxes added to agricultural fields is growing yearly, both due to scientific and national projects and because farmers in Israel purchase nest boxes independently, indicating their belief in the project.

KEY WORDS: barn owls, biological rodent control, crop damage, integrated pest management, rodent damage, rodents, *Tyto alba*

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INTRODUCTION

Even though the use of cats as biological pest control agents of rodents can be traced back to ancient Egypt, such an approach has been studied and used predominantly in modern times for invertebrate pests rather than vertebrate ones (Hajek 2004). In most cases, introduced or domesticated/feral vertebrate predators have been used to control rodents of various species, while the use of natural enemies has been applied less often (Hajek 2004), probably due to the difficulty inherent in increasing larger predator numbers to a level that will negatively impact pest species, while also avoiding too great an increase in predators causing damage to natural systems. Large top predators have the potential not only to function by direct predation, but also through the ecology of fear (Clinchy et al. 2013) by causing their prey to alter their behavior and reduce their activity, as found in the natural experiment of reintroducing wolves (*Canis lupus*) in Yellowstone National Park (Ripple and Beschta 2003, 2004).

In many places in the world, nest boxes for birds of prey are used as a conservation tool to increase populations in areas where natural nest sites are limited (Petty et al. 1994). In particular, nest boxes for barn owls (*Tyto alba*) were first used in Malaysia as biological pest control agents of rodents in agriculture in the 1970s (Duckett 1976), and later also in Israel, with the first nest box being deployed in 1981 in the Hula Valley. Nowadays, barn owls are widely used in biological control projects of rodents in Chile (Munoz and Murua 1990), Israel (Meyrom et al. 2009), Malaysia (Duckett 1976, Hafidzi et al. 1997, Hafidzi and Mohd N 2003, Wood and Fee 2003), India (Neelanarayanan and Kanakasabai 2003), Spain (Paz et al. 2013), USA (Moore et al. 1998, Martin 2009, Richard 2012, Kross et al. 2016, Wendt and Johnson 2017), Uruguay (Mikkola 2017), and Venezuela (Poleo et al. 2001).

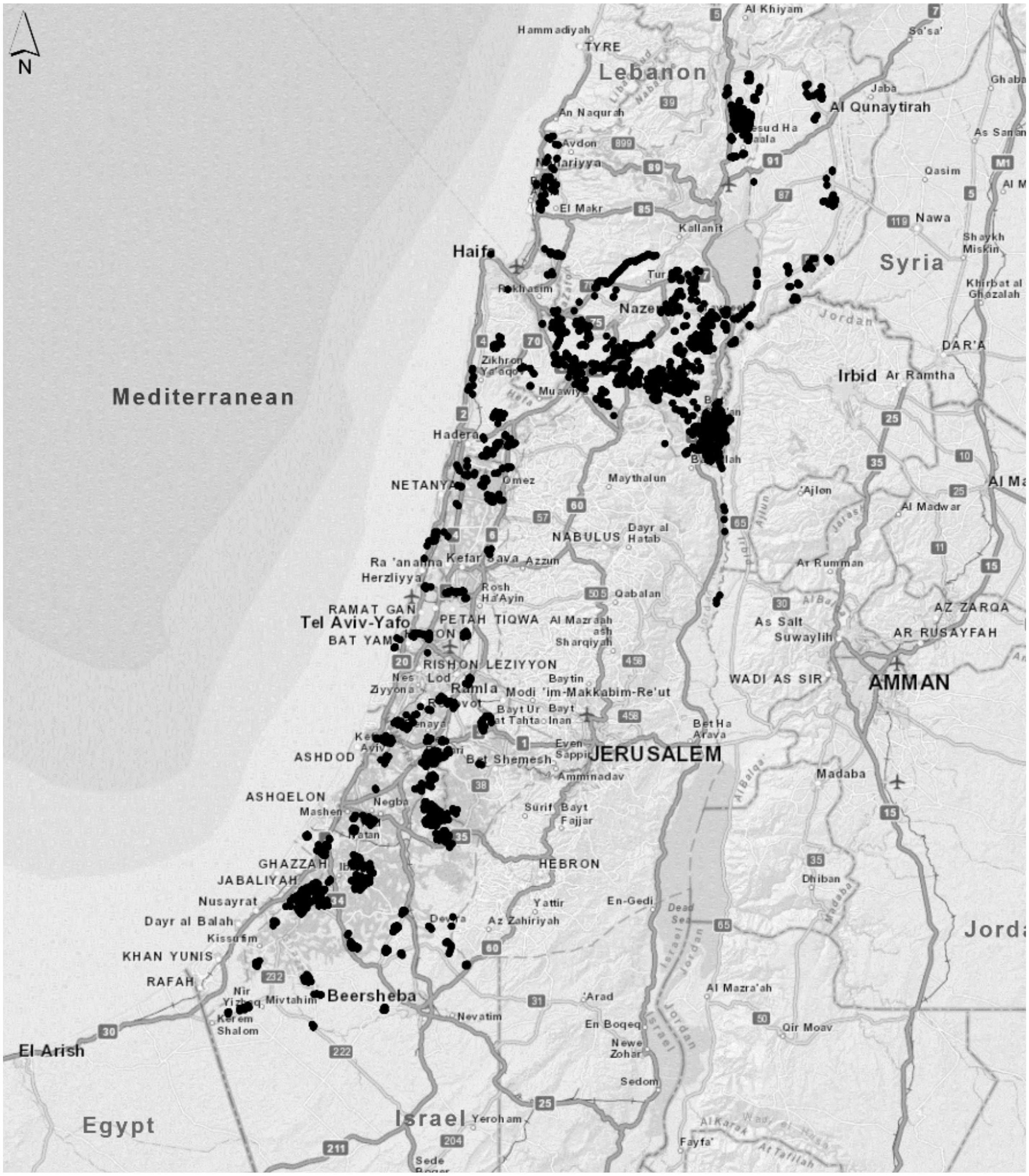

Figure 1. Map of Israel with the locations of the 3,200 barn owl nest boxes (filled dots) used for the biological pest control of rodents. The three valleys used to monitor barn owl populations are indicated with large open circles.

In Israel, farmers who initially deployed nest boxes independently without the assistance of academic studies (Kahila 1992, Tores et al. 2006) or conservationists, made mistakes that reduced the nest efficiency, such as locating the boxes too low, in inappropriate locations, or constructing them from unsuitable materials (Meyrom et al. 2009). To mitigate these initial problems, an applied project called the "Israel National Project of Using Barn Owls as Biological Pest Control Agents of Rodents" (hereafter "National Project") was established in 2008, managed by the Society for the Protection of Nature in Israel (a non-governmental organization), in collaboration

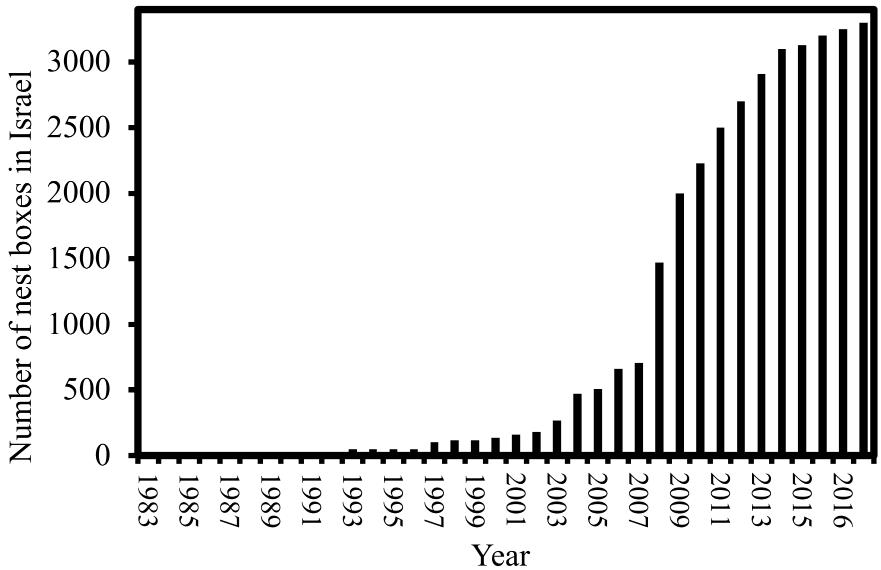

Figure 2. The number of barn owl boxes in Israel from 1983 to 2017.

with governmental organizations (Ministry of Agriculture and Rural Development, and Ministry of Environmental Protection) and academic institutes (University of Haifa, Tel Aviv University) in order to instruct farmers in the applied use of barn owls in their fields, and began a monitoring scheme of nest boxes. Concomitantly, independent scientific studies led by academic institutes (Shamir Research Institute, University of Haifa, Tel Aviv University, Hebrew University, and University of Lausanne) provided professional assistance, researched barn owl biology, and sought to improve the project's efficiency in controlling agricultural pests.

Even before the artificial nest boxes deployed, barn owls were resident breeders in Israel, mainly in abandoned human structures (Meyrom et al. 2008) and natural cavities in cliffs and caves. The initial project was established in the Hula Valley, but due to the Lebanese War in 1982 it was halted and moved to the Beit Shean Valley. After a decade, installation of the nest boxes was extended to include other agricultural fields and increased from 14 boxes per 3 km^2 in 1983 to about 300 boxes per 90 km^2 throughout the Beit Shean Valley in 2007 (Kahila 1992, Meyrom et al. 2009). There was a continuous increase in the number of nest boxes deployed in the country from 1993 to 2007 (Figure 1) and after the National Project was established in 2008, this number doubled to reach 3,200 units in 2017, located from Beer Sheva in the south to the very northernmost borders with Lebanon and Syria (Figure 2), excluding the Negev Desert in the south. From 2002 onwards, there was an ongoing effort to use barn owls in Jordan and the Palestinian Authority, also in collaboration with Israeli conservationists and academics and funded mainly by European, USA, and Israeli governments/non-governmental organizations, but the focus on these much smaller projects were "People to People" (getting people together) (Roulin et al. 2017) and not applied pest control (the farmers did not work independently) and no scientific studies were performed.

The majority of scientific studies on using barn owls as biological pest control agents of rodents in agriculture in Israel have concentrated on the owl's breeding biology as related to nest box design (Meyrom et al. 2009, Charter et al. 2010b, Charter et al. 201*2,* Charter et al. 2015a), the effect of weather (Charter et al. 2017), the owl's diet (Tores et al. 2006, Charter et al. 2009, Charter et al. 2012a, Charter et al. 2015b), competition between owls and other birds (Charter et al. 2010a), behavioral and evolutionary ecology (Charter et al. 2012c, Charter et al. 2014, Peleg et al. 2014), and economic analysis of using owls as biological pest control agents (Kan et al. 2013). One question that had remained unanswered was that of whether farmers are satisfied with barn owls as biological pest control agents of rodents. This is a key question pertaining to the project in the long term. To this end, we surveyed 67 farmers by means of a questionnaire related to the barn owl project in Israel. We hypothesized that compared to farmers who were not satisfied with the project, satisfied farmers would have more barn owls. Other important questions were whether the farmers who had installed nest boxes in their fields had suffered more or less rodent damage than those who had not installed nest boxes, and whether the addition of nest boxes had increased the number of breeding pairs of barn owls. We hypothesized that farmers would not have deployed nest boxes randomly, but rather added more nest boxes in specific fields that had encountered rodent problems in the past.

MATERIALS AND METHODS

Farmer Survey

From March 4 to April 24, 2012, 67 male Israeli farmers who used barn owls as biological pest control agents were asked 4 questions by one of the authors (Ori

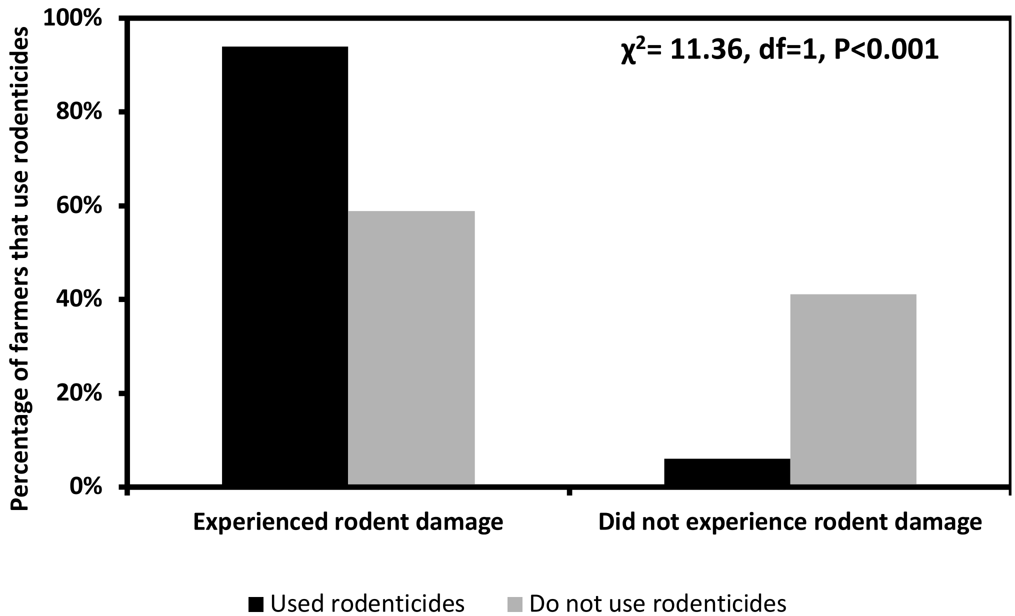

Figure 3. Comparison between farmers that use and do not use rodenticides in farms that have rodent damage compared to those that do not.

Peleg): 1) whether they had suffered rodent damage (yes, no); 2) whether they were satisfied with the barn owl project (yes, no, unsure); 3) whether they continued to use rodenticides after having implemented the barn owl program (yes, no); and 4) whether they considered rodent damage to have decreased after having added barn owl boxes (yes, no, unsure).

In order to determine whether the breeding parameters of the barn owls were associated with the farmers' answers, we analyzed the answers in relation to the number of nest boxes in their farms, the percentage of nest boxes occupied by barn owls, and the number of barn owl pairs in those farms for which the nest boxes have been monitored two to five times during the 2011 breeding season.

Did Farmers Add Nest Boxes According to Rodent Hot Spots?

In the above survey, farmers did not assess rodent damage using a standardized approach, but rather answered from memory regarding visible rodent activity (rodent burrows) and damage (areas with visible damage by rodents). In order to determine whether farmers had deployed the nest boxes according to previous rodent damage, we determined whether the number of nest boxes had varied in alfalfa fields (n = 50) cultivated for two to four consecutive years in the Beit Shean Valley from 2002 to 2013. Alfalfa is one of the most difficult crops for farmers to grow in Israel because rodents prefer it even in the presence of rodenticides, it is not grown annually (once a year), but rather for two to four years and is harvested by cutting the alfalfa, similar to grass, almost monthly from April until November. One of the main differences between alfalfa and annual crops is that the fields of annual crops are plowed after the crops are harvested, thereby destroying all rodent burrows, whereas the alfalfa fields are just trimmed and the rodent burrows remain intact. Alfalfa fields are also irrigated according to need throughout the year, providing the rodents with ample food, whereas annual crop fields are sometime left barren between crops until the following year and are not always irrigated. Alfalfa cultivation is a good indicator of rodent presence, with alfalfa crops usually not grown for longer than two years due to the damage done by rodents once their population reaches a certain size with a consequent decrease in crop yield thereby making it less profitable to grow. When this occurs the farmers plow the field prematurely (the alfalfa does not reach four years) and grow another type of crop in it the following year. Thus, the earlier the field is plowed, the more rodent damage it has suffered. Thus, if there were more nest boxes deployed in fields with crops that were grown for only two years rather than four years, we could conclude that the farmers had installed more boxes in fields where they expected greater rodent damage.

During 2002 - 2013 (12 years) we monitored on average 200.1 barn owl nest boxes (SE = 7.4, range = 140 - 233 boxes) two to five times a year in an area of 90 km^2 in the Beit Shean Valley (32º30´N, 35º30´E; mean elevation is -221 m) to determine the percentage of nest boxes occupied and the number of nestlings per successful barn owl pair (pairs that fledged at least one young). On average, during the 2002 - 2013 breeding seasons we monitored 114.0 breeding pairs (SE = 7.8, range: 78 - 159 pairs), that occupied 57.1 of the nest boxes (SE = 0.03, range= 38.2 - 78.7%) and raised on average 3.5 nestlings per pair (SE = 0.3, range = 1.7 - 5.1 nestlings). All fields were measured using ArcMap GIS software, and the

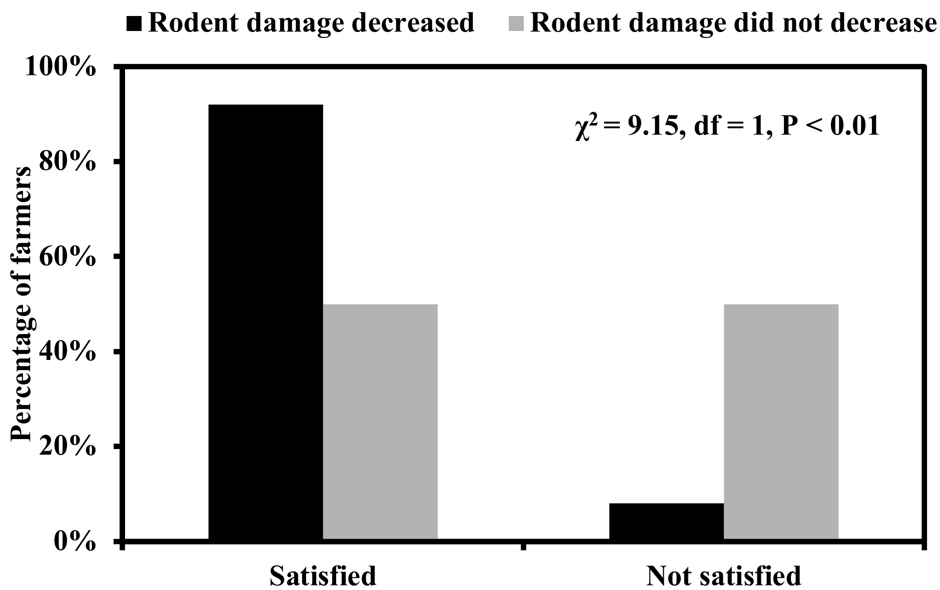

Figure 4. Comparison whether farmers that where satisfied vs. those that were not satisfied with the barn owl project thought that said rodent damage has decreased or did not decrease since the establishment of the barn owl project.

density of breeding barn owls (number of barn owl pairs/ha) was calculated. We determined whether there were more nest boxes, and in turn more barn owl breeding pairs, in farms where alfalfa fields had been grown for two, three, or four years in a row, under the assumption (according to the information provided by the farmers) that fields with crops grown for only two years had experienced more rodent damage than fields with crops grown for a longer period of time. We also compared the number of barn owl pairs per hectare and the number of fledglings per hectare during three periods: one year before the alfalfa fields were planted; and during the first and last years that the alfalfa crops were grown.

Statistical Procedure

In preliminary analyses, it was noted that the age of the farmers (mean age 62.6, SE = 1.3 years old, n = 67 farmers, range = 27 - 72 years old) did not influence their answers regarding whether: incurred rodent damage (t_{65} = -1.64, P = 0.87); they had used rodenticides (t_{65} = -0.32, P = 0.75); rodent damage had decreased ($F_{2,55}$ = 0.29, P = 0.75); they were satisfied with the pest control project ($F_{2,64}$ = 2.14, P = 0.13). Therefore, this variable was not used in further analyses. All statistical tests were 2-tailed and P-values < 0.05 are considered significant. Prior to statistical analyses, the data were checked for normal distribution and log-transformations were used to normalize datasets when possible. We performed a linear model to determine whether the number of nest boxes was related to the size of the fields and the number of years the alfalfa crops were grown. An ANCOVA was used to compare the number of nest boxes in alfalfa fields grown for different numbers of years. Linear mixed-models with year and field identity entered as random factors were performed to compare whether number of breeding pairs and nestlings per hectare were related to the number of nest boxes, periods of growing alfalfa (the year before the alfalfa fields were planted; and during the first and last years that the alfalfa crops were grown), and the number of years the alfalfa field was grown. Means are quoted ± SE. Statistical analyses were performed with the software SPSS version 22.

RESULTS

Farmer Survey

Sixty-seven farmers were interviewed, with a mean farm size of 3.5 ± 0.6 km^2 (range: 0.02 - 23 km^2) and 9.3 ± 1.1 barn owl nest boxes (range: 1 - 61 nest boxes) per farm. 76.1% (n = 67) of the farmers reported that they had experienced rodent damage to their crops and 49.3% (n = 67) said they occasionally still use rodenticides. Farmers who said they had experienced rodent damage used rodenticides more than those who said they had not experienced damage (Figure 3). 62.2% of the farmers reported they were satisfied, 25.4% not satisfied, and 13.4% unsure of the effectiveness of the barn owls as biological pest control agents of rodents. The nest boxes of 12 of the 17 farmers (71%) who were not satisfied with the barn owl project had never been occupied by barn owls. Compared to farmers who were not satisfied with the barn owl project, those who were satisfied reported that rodent damage had decreased to a lower level than before the project (Figure 4), and they had a higher percentage of nest box occupation by barn owls (Figure 5a) and more barn owl pairs (Figure 5b). Whereas there was no difference between whether farmers were satisfied with the pest control project and the number of nest boxes on their farm (t_{56} = -0.47, P = 0.64), farmers who considered rodent damage to have decreased since deploying the barn owl nest boxes possessed more nest boxes than those who

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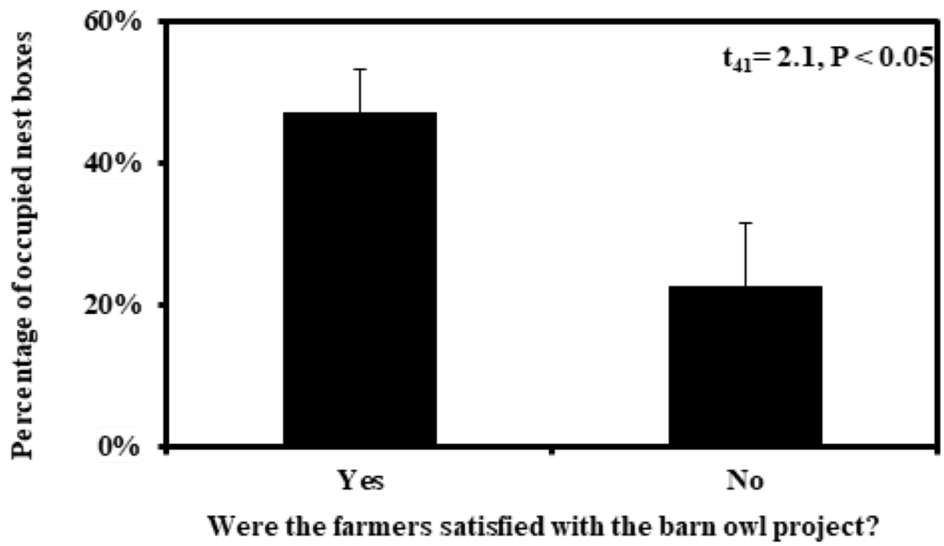

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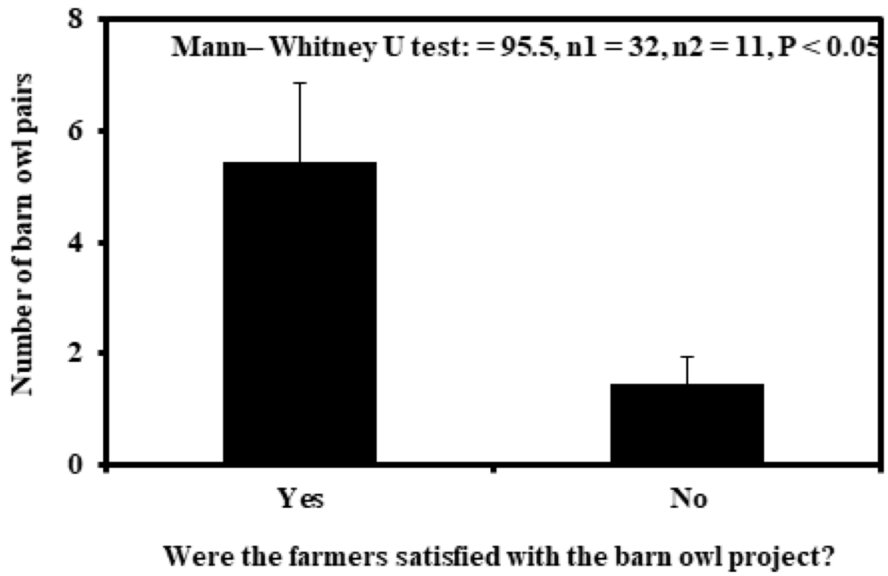

Figure 5 a-b. Comparison between the percentage of nest boxes occupied by barn owls (Figure 5a) and the number of barn owl pairs breeding (Figure 5b) between farmers that where satisfied vs those that were not satisfied with the pest control project.

contended that rodent damage had not decreased (Figure 6). In both cases there was no difference in the proportion of nest boxes that were occupied by barn owls (t_{32} = -1.3, P = 0.22) nor in the number of barn owl pairs (Mann-Whitney U test: 128.5, n1 = 31, n2 = 78, P < 0.90).

Did Farmers Deploy Nest Boxes According to Rodent Hot Spots?

Using a one-way ANCOVA whilst controlling for field size ($F_{1,46}$ = 0.57, P = 0.46) revealed that there were more nest boxes located in alfalfa field that were grown for two years than in those grown for 3 or 4 years ($F_{1,46}$ = 5.2, P = 0.009) (Figure 7). In a linear mixed model with year and field identity as random variables, the number of barn owl pairs per hectare was related to the number of nest boxes per hectare ($F_{1,144}$ = 2,521.6, P < 0.001) but not to the period of growing the crop (the year before alfalfa was planted, 1st year of alfalfa growth, and last year of alfalfa growth; $F_{2,144}$ = 0.1, P = 0.90), nor the number of years alfalfa was grown ($F_{2,144}$ = 2.0, P = 0.14). Furthermore, in another linear mixed model with year and field identity as random variables, the number of nestlings per hectare was related to the number of nest boxes per hectare ($F_{2,1134}$ = 570.69, P < 0.001) but not to the period of growing the crop ($F_{2,134}$ = 0.02, P = 0.99), nor to the number of years alfalfa was grown ($F_{2,134}$ = 0.91, P = 0.40).

DISCUSSION

The findings from the survey indicate that the majority of farmers were satisfied with the effectiveness of the barn

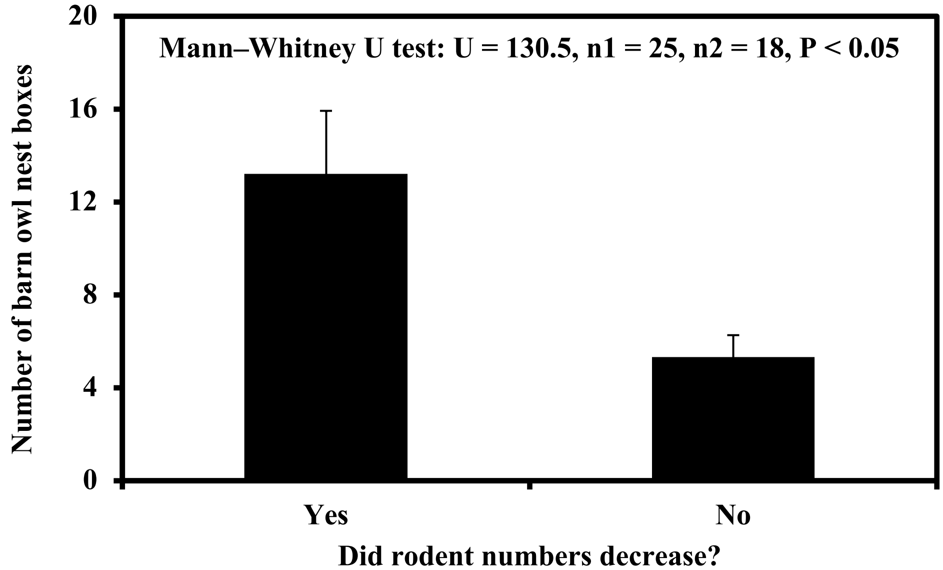

Figure 6. Comparison between the number of barn owl nest boxes owned by farmers that thought rodent damage did and did not decrease during the project.

owls as biological pest control agents of rodents. Specifically, more farmers who were satisfied with the project considered that rodent damage had decreased since the establishment of the biological pest control project than those who were not satisfied. Since we did not monitor rodent populations, the farmers' idea of satisfaction may have been psychological or it may have reflected a genuine reduction in pests. There were two factors that predicted satisfaction: how many nest boxes had the farmers deployed, and how many nest boxes were occupied by barn owls (farmers with more barn owls consider that this works better). It is highly probable that the farmers' satisfaction as found in this study is not emotional but, rather, legitimate, because the majority of farmers who were not satisfied with the project did not have any owls breeding in their nest boxes, while those who were satisfied had more nest boxes occupied, and in turn more barn owl pairs. That said, since the satisfied farmers were probably aware that their nest boxes were occupied, it is also possible that their responses were psychological.

The only two studies to date that have surveyed farmers regarding the effectiveness of barn owls as biological pest control agents were in California and reported contrasting findings (Moore et al. 1998, Wendt and Johnson 2017). In Moore et al. (1998) only 23% of farmers thought owls were effective in controlling the main pest, Botta's pocket gophers (*Thomomys botta*), whereas in Wendt and Johnson (2017) most vineyard owners answered that barn owls provide a viable method for rodent control as part of an integrated pest management plan. The number of nest boxes per farm was lower in Moore et al. (1998) than in the present study (9.3 vs. 4.1 nest boxes). In comparison to both the present study (100% of people surveyed) and Wendt and Johnson (2017) (82% of people surveyed), fewer people in Moore et al. (1998) had deployed nest boxes specifically for rodent control (48% of people surveyed). A major difference between the studies in the US and Israel lies in that pocket gophers are significantly larger than the rodent pests in Israel and even though the subspecies of barn owls (*T. alba furcata*) in the US is larger than that in Israel (*T. alba erlangeri*), owls typically prefer prey that are easier to capture and handle and therefore avoid large prey species (Trejo and Guthmann 2003). That said, another study in the US (Browning et al. 2017) demonstrated that barn owls hunt primarily pocket gophers, and that the use of barn owls in this case is more cost effective than trapping ($0.34 per rodent per barn owl vs. $8.11 per rodent trapping). In comparison to the present study, the two studies in the US did not present data on whether the farmers answers were related to the number of nest boxes deployed and the number of barn owl pairs occupying them.

There are conflicting reports on whether barn owls are able to control rodents in farmlands (Labuschagne et al. 2016). In Israel, alfalfa fields with barn owl nest boxes were more profitable ($235.8/ha more per year) than those without (Kan et al. 2013), but rodents were not trapped and the findings were based on radio telemetry of a small sample of owls. This was later found to underestimate the distance that barn owls hunt from the nest (Charter, unpubl. data). In Spain, using barn owls and kestrels as biological control agents was suggested to reduce vole populations near nest boxes (Paz et al. 2013). In another study in Malaysia, rodent damage decreased from 12% to less than 2% within a year of deploying barn owl nest boxes (Hafidzi et al. 1997). In comparison, in Florida (Martin 2009) it was suggested that barn owls were not capable to reduce rodent abundance in sugarcane fields because, according to the author, the predation by owls was less than the rodent reproductive capacity. Calculating

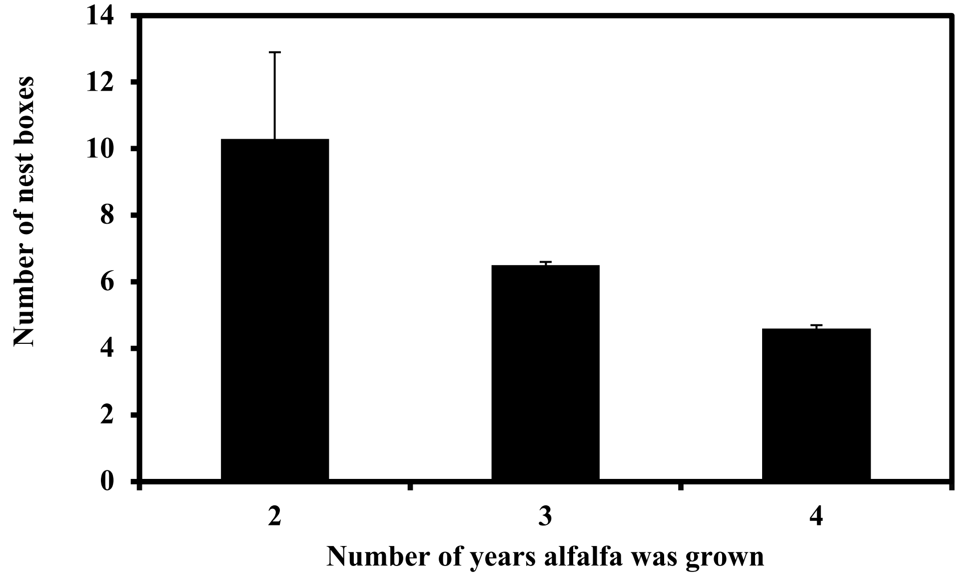

Figure 7. Relationship between the number of nest boxes and the number of years during which alfalfa crops were grown. Bars= SE.

the effect of direct predation alone is not enough to determine the overall predatory pressure, however, because predator density and perception of predation risk can also impact and reduce prey reproduction (Creel et al. 2011, Zanette et al. 2011).

Because barn owl breeding (Charter et al. 2012c) and diet (Charter et al. 2009) vary (Charter et al. 2015b) when nest boxes are located near different crop types and regions, the owls' effectiveness as biological control agents of rodents may also vary. Barn owl populations may be limited during different seasons in different parts of the world because rodent populations may decrease due to onset of rainfall in arid environments (Charter et al. 2017) and harsh winter weather (e.g., snow; Altwegg et al. 2006); while in other areas rodents may be present but inaccessible such as when the vegetation is too high (Arlettaz et al. 2010). In areas where barn owl populations are unstable and/or rodent population numbers are low, the use of barn owls may not be feasible. We therefore suggest that new projects should take into account the stability of both rodent populations and weather.

Farmers deployed more barn owl nest boxes in alfalfa fields that were grown for a shorter amount of time because they knew that rodents were problematic in those specific fields. They therefore distributed nest boxes according the extent of previous rodent damage and were able to accurately determine rodent numbers in their fields. The number of nest boxes was positively related to the density of breeding barn owl pairs and the number of nestlings fledged in those fields, implying that by deploying more nest boxes in specific fields, the farmers are also effectively attracting more barn owls that fledged more nestlings in the area in which they needed them most. We conclude that the more nest boxes that farmers will deploy the more barn owl will likely be bred.

Most nest boxes in barn owl projects were deployed by researchers for scientific purposes (Munoz and Murua 1990, Martin 2009, Paz et al. 2013, Chausson et al. 2014) and not by farmers for pest control (Duckett 1991, Kross et al. 2016, Wendt and Johnson 2017). Unlike the projects in which farmers purchase the nest boxes independently, in many projects that are led by conservationists or researchers, the boxes are either given to the farmers or deployed on farms independently of the farmers themselves. In the latter case, nest boxes are often taken for granted by the farmers and do not receive the proper upkeep compared to those boxes that the farmers purchase themselves. Even though nest boxes cost $250 a unit in Israel, they last at least 10 years and farmers continue to add new nest boxes, not because they specifically like barn owls, but rather for rodent control.

There are 4,300 km^2 of cultivated land in Israel, which could hold between 800 to 1,500 breeding barn owl pairs in nest boxes alone. Since a barn owl laying pair with an average of 4.6 nestlings (Charter et al. 2015b) consume between 2,000-6,000 rodents annually (depending on the number of nestlings and rodent species, which vary in size), the overall owl predation could reach 1.6 to 9 million rodents annually. In addition to their direct predation by barn owls, the behavior of rodents may also undergo change due to their fear of predators (Clinchy et al. 2013), which could further decrease rodent damage from foraging (Kotler et al. 1991, St. Juliana et al. 2011).

Most farmers were not only initially willing to give the biological pest control project a try after conventional rodenticides had proven unsuccessful in controlling rodent numbers, but also to continue to maintain the boxes and add new ones. Furthermore, due to the increased awareness disseminated by the National Project, scientific studies, and positive feedback by other farmers, the project continues to spread throughout Israel. There is nevertheless still a need for quantitative experimental studies in order to determine whether combined biological and mechanical techniques can reduce pest damage and increase crop yield.

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