Research Article

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Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: experimental set-up and preliminary results

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Abstract

BACKGROUND: Ecologically based rodent pest management using biological control has never been evaluated for vole plagues in Europe, although it has been successfully tested in other systems. The authors report on the first large-scale replicated experiment to study the usefulness of nest-box installation for increasing the breeding density of common kestrels (*Falco tinnunculus*) and barn owls (*Tyto alba*) as a potential biological control of common vole (*Microtus arvalis*) abundance in agricultural habitats in north-western Spain.

RESULTS: The results show that: (1) population density of both predator species increased in response to both nest-site availability and vole density; (2) voles are a major prey for the common kestrels during the breeding period; (3) vole density during the increase phase of a population cycle may be reduced in crop fields near nest boxes.

CONCLUSION: The installation of nest boxes provides nesting sites for barn owls and kestrels. Kestrel populations increased faster than in areas without artificial nests, and the common vole was one of their main prey during the breeding season. The results suggest that local (field) effects could be found in terms of reduced vole density. If so, this could be an environmentally friendly and cheap vole control technique to be considered on a larger scale.

Keywords: *Microtus arvalis*; rodent outbreaks; biological pest control; *Falco tinnunculus*; *Tyto alba*; agriculture

1 INTRODUCTION

The common vole (*Microtus arvalis*) is a major agricultural pest in Europe that can cause significant crop damage during population outbreaks,[1] as well as sanitary problems.[2] In the Iberian Peninsula, before 1980, the common vole was mainly restricted to northern and central mountainous locations,[3] where conflict between this species and farmers was practically non-existent. However, in recent decades the common vole has colonised agricultural lands of Castilla y León (north-western Spain). Shortly after the first records of the presence of the species in these agricultural areas, population outbreaks were reported,[4] a large population outbreak was reported in 1983[5] and subsequent regular outbreaks have been reported up to the last important plague during 2006–2007.[1,6,7] All common vole population outbreaks in agricultural areas have been associated with economic losses due to crop damage, although scientific studies quantifying losses are lacking.[8]

In order to reduce crop damage, this rodent pest has usually been controlled in the region by campaigns based mostly on large-scale rodenticide use, particularly anticoagulants such as chlorophacinone and bromadiolone.[8,9] The use of chemical rodenticides can cause secondary poisoning on non-target predatory species, such as the red kite (*Milvus milvus*),[10] but may also impact on many other species, including game of economic value and eaten by man, such as pigeons or hares,[8] or endangered species such as great bustards (*Otis tarda*).[11] Chemical control campaigns could also increase sanitary risks associated with rodent

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outbreaks.[2] In addition to pollution risk at the ecosystem level, rodenticides have to be reapplied frequently, so chemical control of agricultural rodent pests, especially during a period of maximum density population, may have a negative impact over the economic production of the croplands.[12] During the last peak registered in north-western Spain in 2007, the regional government estimated the cost of control campaigns at €15 million, and compensations paid to farmers at €9 million.[1]

The development of alternative environmentally friendly control strategies with low economic cost is thus essential. Artificially increased populations of barn owls have been tested in some areas as a biological control method for rodent pests within an ecologically based rodent management framework. These can have an efficacy similar to that of rodenticides, and at a lower cost.[13–15] In Castilla-y-Leon, an area of Spain recently colonised by the common vole, the latter has become one of the most important prey species for many predators, as reported elsewhere in the world.[5,16–18] The use of predators as a biological control agent has been discussed during the last decades by scientists all over the world,[19] with some data showing that avian predators are a major cause of density-dependent mortality in voles,[20] rats and mice.[21] A central point of discussion about this technique is what happens when the prey population increases faster than predation rate,[21] as could be the case in cyclic vole populations. Artificially increased predation could be a promising control technique but has never been tested in this kind of situation,[1,22] particularly in agrarian deforested areas that may have a low availability of nesting sites for raptors and where nest site provisioning could be used artificially to increase predator density. In the case of using raptors as a biological control system, these predators should have the ability to aggregate as a response to changes in prey densities over short periods of time, where the availability of nesting sites or perches for hunting can be the main limiting factor of population density for a raptor community enjoying abundant food resources.[23–26] In the case of kestrels, the use of nest boxes in deforested areas can notably increase population density, and kestrel populations may regulate common vole density in grassland areas.[27] For the barn owl, several studies developed in Israel have shown that the population has grown quickly after the introduction of artificial nests,[28,29] with similar results in other parts of the world, for example in Malaysia.[30]

This paper reports on the preliminary results of the application of ecological principles in a Mediterranean agroecosystem, based on the use of nest boxes for the barn owl and common kestrel on croplands, as an experimental pest control programme of common vole plagues. The focus was on these two species because the populations of both can be managed easily by providing nest boxes, and they are major rodent predators in agricultural environments.

2 MATERIALS AND METHODS

2.1 Study areas

Data were collected in three study areas of Castilla y León (north-western Spain) (Fig. 1) in the provinces of Valladolid (study area A), Zamora (study area B) and Palencia (study area C), where common vole populations reached high densities during the last vole outbreak of 2007. In each area (replicate), a control plot and a nest-box plot, each of 2000 ha, were selected (Fig. 2), so three control plots and three nest-box plots were analysed. A total of 300 nest boxes were erected in the three experimental plots (nest-box plots). In 2009, 120 nest boxes were provisioned in February (nest-box plot A), April (nest-box plot B) and May (nest-box plot C). The remaining 180 nest boxes were installed in January 2010. For the control plots, areas at least 4 km away from the experimental plots (and thus away from the influence of nest boxes) but with similar habitats were selected. Kestrels and barn owls rarely forage farther than 4 km from nest sites.[31,32]

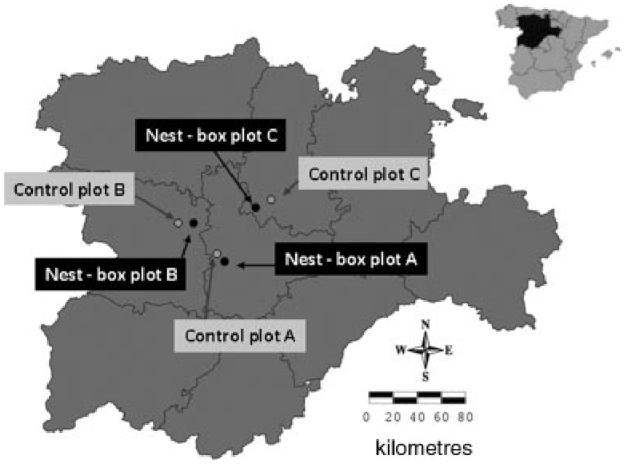

Figure 1. Map of the location of study areas in Castilla y León (north-western Spain), showing the distribution of the three nest-box plots and the three control plots.

2.2 Breeding success

Nest-box occupation was detected by nest inspections during the 2009–2011 breeding seasons (between March and July). Each nest box was revised at least 3 times during the breeding season in every nest-box plot. The occupation rate was defined as the proportion of breeding pairs nesting in installed boxes for each area in each year.

2.3 Census methods

Kestrel abundance in study areas was estimated using a kilometric index of abundance (KIA) from eight road transects in each study area (four in each control and four in each experimental plot, with a total of 16 km of transects within each 2000 ha plot). The abundance of rodents was measured in two ways. On every study plot (experimental and control), use was made of Sherman LFAHD traps, 3 times per year (March, July and November), on twelve trapping plots stratified by habitat (alfalfa, cereal and uncultivated), with 35 traps in each trapping plot. In addition, a previously validated indirect abundance index (IAI) of the presence of *M. arvalis* was used, based on recording the presence of fresh droppings and/or vegetation clippings.[33] In the experimental plot of study area 1, the IAI was used at points located at distances of 25, 100, 200, 300, 400 and 500 m from 18 nest boxes, seven of them occupied, in a cross-pattern oriented in the cardinal directions. These data were gathered in February, April and July 2010.

2.4 Vole consumption by kestrels

This was evaluated by analysing fresh pellets collected at nests and nest surroundings during the breeding seasons. Tawny hairs of common voles are easily identifiable in kestrel pellets. The proportion of pellets containing only vole hair (i.e. including vole as the only prey) was used as an index of vole consumption at a population level.

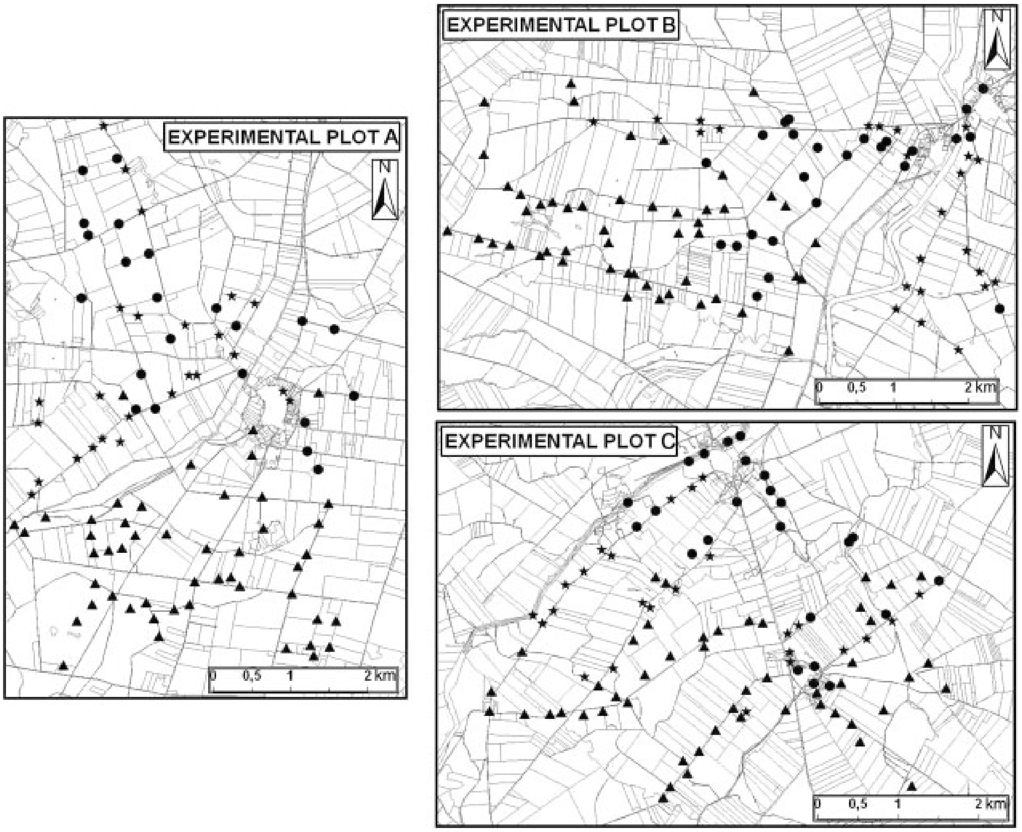

Figure 2. Distribution of nest boxes in the experimental plots. Plot A is located in the municipality of Villalar de los Comuneros in the province of Valladolid. Plot B is located in the municipality of San Martin de Valderaduey in the province of Zamora. Experimental plot C is located in the villages of Boada de Campos and Capillas, both of them in the province of Palencia. ● barn owl nest box with interior wall; ▲ kestrel nest box; △ barn owl nest box without interior wall.

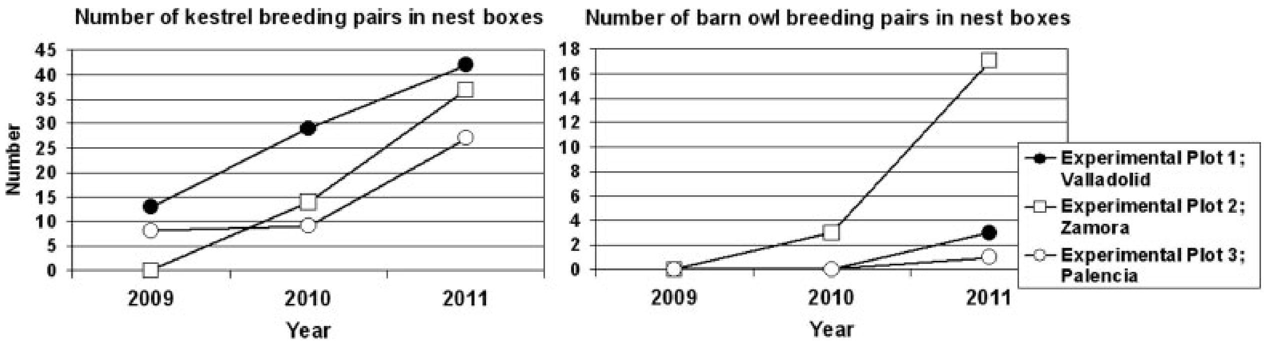

Figure 3. Number of kestrel and barn owl breeding pairs in nest boxes during the 2009–2011 breeding seasons in the three experimental plots. 120 boxes were installed in 2009, and 180 more in 2010, reaching the final number of 100 boxes in each experimental plot.

2.5 Data analysis

General linear mixed models (GLMMs) with identity link and a normal distribution of errors, where the dependent variables were number of common voles and kestrel abundance, were used to explore the differences between areas (provinces), years and treatments as independent variables. Analysis started with saturated models, removing sequentially non-significant interactions and variables, as indicated by lowest *F*-values, until a final model retaining only significant variables or interactions was reached. Variation in the IAI was analysed using GLMMs with a Poisson distribution, and using ANOVAs to compare means. The vole consumption by kestrels was analysed as the percentage of kestrel pellets with common voles as the only prey. A binomial proportion test was used to evaluate whether the consumption of voles had increased in 2011 compared with 2010, coinciding with an increase in the abundance of voles in the study areas, although, in the case of area 3 in 2010, the sample was relatively small ($n = 46$).

3 RESULTS

3.1 Nest-box occupation

From 2009 to 2011, 179 kestrel breeding attempts in the three experimental plots were monitored (Fig. 3). The provision of artificial nests had clearly increased the number of breeding pairs since the beginning of the research in the three treatment plots. The number of artificial nests occupied by barn owl pairs was much lower than for kestrels (only 24 barn owl breeding attempts monitored), especially during the first two study years. The barn owl population showed a high occupation rate only on experimental plot B, especially in 2011, but barn owls also started to occupy nest boxes in the other areas in 2011. No nest box was used by barn owls in 2009, and three breeding attempts were detected on experimental plot B in 2010.

Kestrel and barn owl nesting populations out of boxes (natural nests) were very small in the study plots (in the experimental plots as well as in the control plots), probably because adequate nesting sites were scarce in these highly deforested and flat croplands (all natural nests were found in buildings and old corvid nests). In the same year, maximum numbers of six pairs of kestrels and four pairs of barn owls in the experimental plots, together with two pairs of kestrels and four pairs of barn owls in control plots, were found. In the case of the kestrels, the number of pairs out of boxes remained constant since 2009. For the barn owl, these maximum results were recorded exclusively during 2011. At the beginning of the project, in 2009, two pairs were located in study area A, no pairs in study area B and only one pair in study area C.

3.2 Abundance of the common vole and common kestrel

Comparison of the kestrel KIAs in the three study areas shows that the nest-box installation increased kestrel population densities, especially during the summer of the final year (2011) when kestrel abundance was markedly higher in nest-box plots than in control plots in the three study areas (Fig. 4). There was a statistically significant effect of nest-box presence (nest-box plot: control plot, $F_{1,38} = 13.42$, $P = 0.001$, with a large size effect: partial $\eta^2 = 0.261$) on kestrel KIAs. A statistically significant effect of year ($F_{2,34} = 4.41$, $P = 0.018$, with a large size effect: partial $\eta^2 = 0.191$) was also found. There was no significant effect of study area (provinces), nor a significant interaction effect between the independent variables.

In the case of abundance of common voles, a significant effect of interaction between year and study area was found ($F_{4,33} = 3.16$, $P = 0.015$, with a large size effect: partial $\eta^2 = 0.365$). There was also a statistically significant effect of year ($F_{2,33} = 3.91$, $P = 0.030$, with a large size effect: partial $\eta^2 = 0.192$). The main effects for the nest-box plots did not reach statistical significance. Although these are preliminary results during what seems to be the increase phase of a vole cycle, the abundance of common voles seems to have grown more in the plots without artificial nest boxes in study areas B and C (Fig. 4) in 2011, although differences in vole

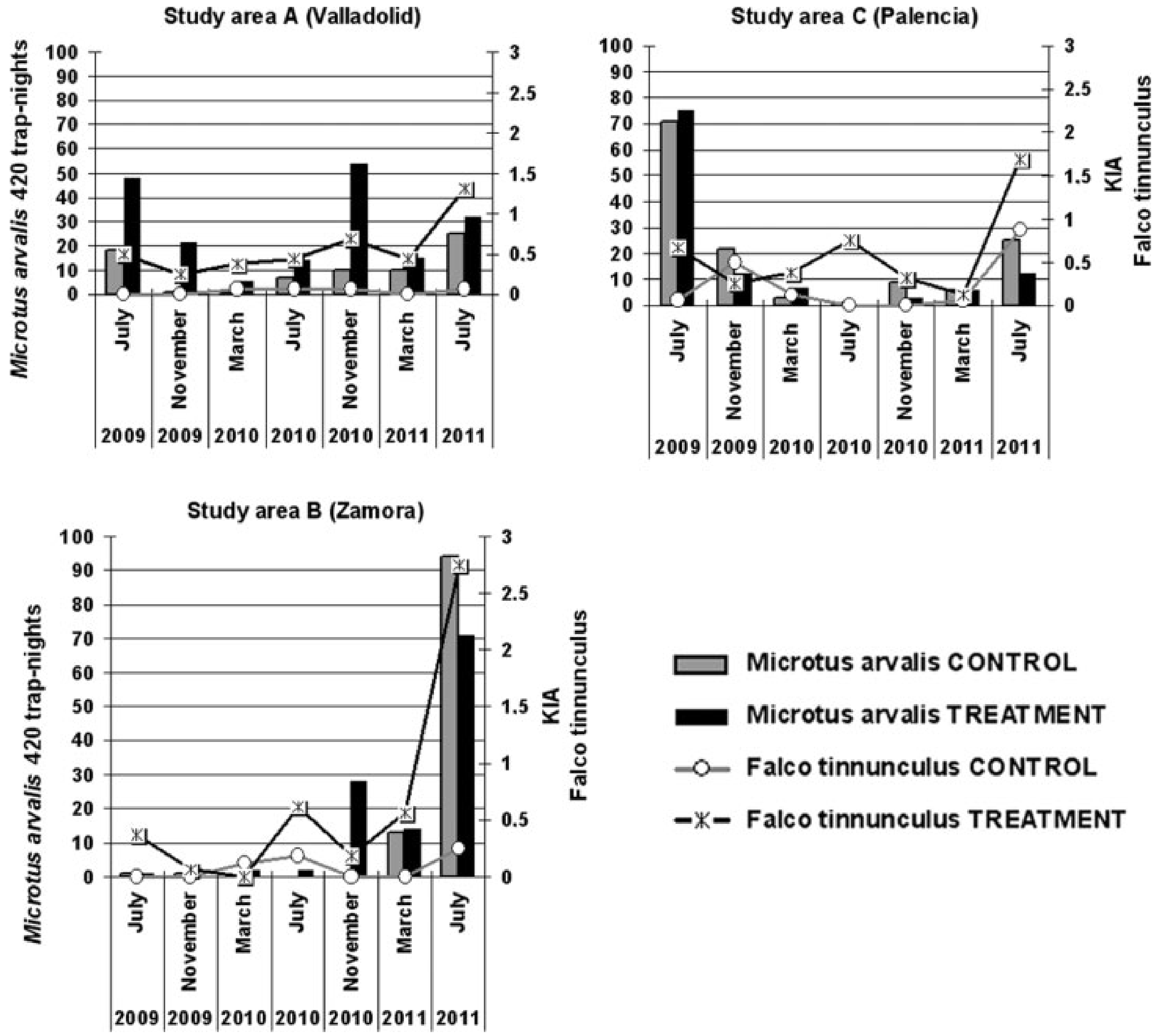

Figure 4. Temporal variations in the abundance of *Microtus arvalis* (number of captures per 420 trap-nights) and *Falco tinnunculus* (kilometric index of abundance, falcons per km) in the control and experimental plots in each of the three study areas.

Table 1. Monthly differences in the mean (± SE) abundance of common vole [as estimated using an indirect abundance index (IAI)] in study area 1 (Valladolid) near nest boxes that were occupied by kestrels (n = 7 each month) or unoccupied (n = 11 each month)

	February IAI		April IAI		July IAI	
Nest box	Mean	SE	Mean	SE	Mean	SE
Occupied	2.857	2.854	0.286	0.488	0.143	0.378
Unocccupied	1.364	1.912	0.091	0.302	0.909	0.944

density were not statistically significant between treatment and control plots ($P > 0.10$). The highest common vole abundance was recorded in study area B during the summer of 2011 (71 voles in the experimental plot and 94 in the control plot for 420 trap-nights in each plot) and in the summer of 2009 in area C (75 voles in the experimental plot and 71 voles in the control plot for 420 trap-nights) (Fig. 4). In the case of area B in 2011, the increase in vole population was paralleled by an increase in the abundance of the common kestrel (Fig. 4). In area C, no increase in kestrel abundance was observed in 2009, but this was the study area where nest boxes were probably installed too late in the breeding season (May).

3.3 Common vole indirect abundance index (IAI) and nest boxes

During the early spring of 2010, vole abundance, as measured with the IAI, tended to be higher near nest boxes that were subsequently occupied by kestrels, as opposed to those that were not subsequently occupied (Table 1), but differences were not statistically significant ($F = 1.788$, df $= 1$, $P = 0.2$). Conversely, by the end of the breeding period, an opposite pattern was found (Table 1), with lower vole abundances near occupied nest boxes as compared with unoccupied ones ($F = 4.115$, df $= 1$, $P = 0.059$). When modelling the IAI in relation to next-box occupancy, month and distance to the nearest nest box, significant differences were found between months (Wald $\chi^2 = 23.177$, df $= 2$, $P < 0.0001$). The occupation of a nest box was not significant (Wald $\chi^2 = 0.038$, df $= 1$, $P = 0.845$), but the interaction between month and nest-box occupancy was near statistical significance (Wald $\chi^2 = 5.781$, df $= 2$, $P = 0.056$) (Table 1). Furthermore, a highly significant positive relationship was found between distance to the nearest nest box, occupied or not, and the abundance of common voles (slope $= +0.003 \pm$ SE $= 0.001$, Wald $\chi^2 = 9.717$, df $= 1$, $P = 0.002$).

3.4 Kestrel diet

An analysis was made of 1003 kestrel pellets collected from the nest boxes in the three experimental plots during the 2010 and 2011 breeding seasons (except from experimental plot B in 2010). *Microtus arvalis* was the most important prey for breeding kestrel pairs (Table 2). The proportion of pellets with common voles as the only prey was significantly larger in 2011 than in 2010 (Table 2), when it reached on average 80%.

4 DISCUSSION

The present study shows that nest-box provisioning in Spanish cropland areas clearly increased local barn owl and common kestrel breeding population densities, as generally observed in cavity-nesting bird species, including kestrels,[26,27,34] indicating that nest site availability in this kind of flat and strongly deforested area is a main limiting factor for both species. Interannual density increases and nest-box occupation rates seemed to be lower in barn owls compared with common kestrels, but, in the final study year, when vole populations greatly increased, barn owls started to settle in next boxes too, particularly in the area with the highest growth in vole abundance. These contrasting results may be due to ecological differences between species. The barn owl is considered to be a sedentary species, while the common kestrel tends to be nomadic,[35] which means that the ability of the barn owl to access new areas may be lower than that of common kestrels. In addition, barn owls need larger territories for breeding than common kestrels,[36] and thus lower densities (lower occupation rates in the present case) are expected in barn owls than in common kestrels, as observed in the present study.

Vole abundance was different between areas, depending on the year, but no statistically significant differences were found between control and nest-box plots. In the case of study area A, vole abundance even tended to be larger in the nest-box plots, although differences were not significant. Differences in soil type between study areas, a factor not considered *a priori*, could also have a major influence on vole abundance or dynamics.[37] In study area A, the plot selected for nest boxes had more sandy soils, which may be more favourable for the settlement of vole populations. It will take more years of study to assess the real impact of predators over the local abundance of the arvicoline, particularly at times of peak densities.

The analysis of kestrel pellets during the breeding season indicates that the common vole is one of the most important prey for this raptor in the given study area, and that breeding pairs increase the consumption of this prey when vole abundance is higher. Other studies on raptor diet and prey density show how the abundance of the primary prey is related to the number of breedings pairs and the productivity of the raptor population,[38] a pattern also found in a nearby mountain population of kestrels.[27]

In 2010, estimated vole density (IAI) in summer was lower nearer nest boxes, irrespective of their occupancy status. The absence of differences in the vole abundance index between occupied and unoccupied nest boxes may be explained by a similar predation pressure around occupied and unoccupied nest boxes if the latter are used as perches by foraging kestrels and barn owls or other raptors, especially common buzzards (*Buteo buteo*). In fact, common buzzard abundance, measured by a KIA index equivalent to that of kestrels (individuals per km), was significantly higher in experimental plots (0.17 ± 0.11, $n = 7$) than in control plots (0.05 ± 0.04, $n = 7$; $F_{2,34} = 7.922$, $P = 0.008$, with a large size effect: partial $\eta^2 = 0.173$). Thus, poles holding nest boxes were probably attracting other rodent-eating raptor species that typically hunt from perches, which would be an additional advantage of this kind of programme.

Overall, the preliminary results suggest that avian predators could be at least partially limiting vole populations, keeping them at an intermediate fluctuating density in the study area where predator population settled sooner (study area A), limiting vole densities during the increase phase of the cycle in comparison with control plots in study areas where predators settled later (study areas B and C) and/or limiting vole densities near poles holding nest boxes, which would be consistent with results obtained in a nearby mountain area.[27] However, no conclusive results will be obtained until a full vole cycle in the study area is completed, because a stage of population outbreak, like those registered

Table 2. Differences between years in the percentage of *Falco tinnunculus* pellets with *Microtus arvalis* as the only prey. Pellets were collected during the breeding season from April until August

			Number of pellets			
	2010 (%)	2011 (%)	2010	2011	*Z*	*P*
Experimental plot A (Valladolid)	68.72	87.84	243	255	−5.19	0.0000
Experimental plot B (Zamora)	*No data*	86.86	*No data*	274	*No data*	
Experimental plot C (Palencia)	43.48	57.30	46	185	−1.68	0.046
Total	64.70	79.50	289	714		

in the study area during previous outbreak years, has yet to be reached.

On the other hand, long-term effects that might appear in the community of predators as the kestrels and barn owls increase, and their impact on the dynamics of rodents or other alternative prey, are yet to be seen. It is possible that the increase in the abundance of kestrels may reduce the density of other natural vole predators such as buzzards (*Buteo buteo*) or Montagu's harriers (*Circus pygargus*) by habitat competition, or that the densities of other vole predators such as weasels (*Mustela nivalis*) may be reduced if they are consumed by raptors.[39]

5 CONCLUSIONS

Overall, the present results suggest that increasing an avian predator population artificially may affect vole population density. It is possible that similar trends on a larger scale may be found, but more years of monitoring will be necessary to investigate how the raptors affect the vole population dynamics. Furthermore, these preliminary results must be considered cautiously until vole populations reach a high-density phase, as it is possible that effects may be observed in the amplitude of oscillations or in the growth and decline rates of the vole populations. If such local effects are found, this could provide a basis for developing an environmentally friendly and cheap vole control technique that could be applied on a larger scale.

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