The effect of prey availability and habitat characteristics on the site selection of little owls (*Athene noctua*) in the southern Algarve, Portugal

Abstract

- **Justification:** Land-use changes and intensification are the primary drivers of biodiversity loss in Europe. One of the species seemingly affected by these changes is Little Owl (*Athene noctua*), which is experiencing population declines across the continent. It is however not well understood which variables are responsible for this.
- **Aims:** To study the effect of prey availability and habitat characteristics on the site selection of Little Owls in the southern Algarve, Portugal.
- **Methods:** I estimated the population size and mapped the presence of little owls around the Ria de Alvor peninsula, using play-back tracks. Also, I used Helsinga live-traps to sample small mammal availability for five different habitat types around the same area. I compared these data with data collected in 2005 and 2022 with Manly ratios and a generalized linear model (GLM).
- **Results and Discussion:** Prey availability was significantly higher in the orchard and vineyard than in the other habitat types. Ruins were found to be a significantly preferred habitat for little owls. Furthermore, little owl presence probability increased with decreased distance from nearest orchard. This indicates a preference for orchards, which is likely related to the higher abundance of small mammals in the orchard.
- **Conclusion:** Little owls preferred to be in/near ruins and orchard habitats, as these habitats provide prey, as well as roosting- and perching opportunities. These two habitats should be prioritized in future conservation measures.
- **Synthesis:** As regional economies are shifting away from small-scale agricultural practices, important little owl habitat, as well as the habitat of their small mammal prey is being lost, and with that little owl populations will continue to decrease throughout Europe. Knowing which habitat types to conserve will help with future conservation measures.

Introduction

Currently, agricultural intensification is the primary driver for biodiversity loss in Europe (Emerson et al., 2016), resulting in a major loss of farmland bird populations across the continent (Donald et al., 2006; Traba & Morales, 2019). The little owl (*Athene noctua*), a small nocturnal predator that nests mostly in tree cavities is one such farmland bird (Goutner & Alivizatos, 2003). The species prefers open country, grasslands, pastures, and old orchards with vertical elements such as trees, bushes, rocks, or man-made structures like ruins or telephone poles (Van Nieuwenhuyse et al., 2008). Although sedentary, the Little Owl can undergo significant displacements (Hagemeijer & Blair, 1997). Studies have shown that its diet primarily consists of small mammals and large invertebrates, with mammals contributing the most to the overall prey biomass. Invertebrates make up a significant portion of the consumed food items but account for a lower proportion of the total prey biomass (Goutner & Alivizatos, 2003; Chenchouni, 2014).

Although the species is listed as 'Least Concern' on the IUCN red list (Birdlife, 2022), for the last 60 years, the little owl has suffered a marked decline in numbers across Europe (Tucker & Heath, 1994; Van Nieuwenhuyse et al., 2008; Andersen et al., 2017). In different countries throughout the continent, the species population decreased in numbers ranging from 50- to as high as 90 percent (Van Nieuwenhuyse et al., 2008; Thorup et al., 2010; Chrenková et al., 2017; Sálek et al., 2019).

The decline in population size observed is in line with the ongoing trend of agricultural abandonment and intensification. Consequently, an increasing number of vertical elements (like e.g. ruins) are being lost, as stated by Donald et al. (2006) and Onrubia & Andrés (2005). Furthermore, there is a shift towards larger grassland patches instead of the preferred smaller ones, as reported by Schönn et al. (2001), Šálek & Schröpfer (2008), and Sálek & Lövy (2012). These smaller grasslands and pastures, which serve as the primary foraging habitat for little owls (Sálek & Lövy, 2012), are also crucial for their hunting activities, using poles and trees as elevated perches (Dalbeck et al., 1999; Newton, 2004; Zmihorski et al., 2009).

Similar studies conducted in central Europe have highlighted the relationship between habitat selection, range use, farming practices, and prey availability (Zmihorski et al., 2009; Apolloni et al., 2018). Although these studies contribute significantly to the conservation of little owls, it is important to note that Europe encompasses diverse climates and habitats, with varying little owl populations. Southern Europe, particularly, exhibits some of the highest densities of little owls (Tomé et al., 2008). Despite studies conducted on little owl populations in southern Europe (Tomé et al., 2008; Framis et al., 2011), the number of studies conducted in central and northwestern Europe outweighs them.

Nonetheless, certain regions in southern Europe, like the Algarve in Portugal, serve as significant study areas due to their relatively high little owl population sizes. However, these populations face the challenge of rapid agricultural abandonment occurring at a significant pace (Martins, 2010). The shift in regional economies from small-scale agriculture to tourism further reduces the availability of little owl habitats (Andino, 2005).

Not only are the little owls affected by land abandonment, but their prey as well. Land abandonment can have profound implications for small mammal populations, as supported by studies conducted by Plieninger et al. (2014), Moreira and Russo (2007), and Plieninger et al. (2013). These studies collectively indicate that land abandonment leads to changes in vegetation structure, resulting in the loss of suitable habitat and reduced food resources for small mammals (Peco et al., 2012). Consequently, there is a decline in the diversity, abundance, and distribution of small mammal species within abandoned areas. While certain species, such as the common vole, may thrive in these altered landscapes, others with specialized habitat requirements or feeding habits experience population declines or even local extinctions. Although there is potential for some species to recolonize abandoned lands over the long term, successful colonization depends on factors such as landscape context, proximity to source populations, and dispersal capabilities. These findings underscore the urgent need for effective management strategies that consider the ecological needs of small mammals and promote habitat connectivity in landscapes affected by land abandonment (Plieninger et al., 2014; Moreira & Russo, 2007; Plieninger et al., 2013).

The little owl population on the Ria de Alvor has been studies several times over the past 2 decades (Tron, 2003; Hof, 2005; Reinartz, 2022). These studies found that this area had one of the highest densities of little owls throughout Europe (Salek et al., 2013; Tomé et al., 2008; Thorup et al., 2010). Lately however, Reinartz (2022) found that the density of owls had decreased significantly. This decrease might be attributed to the reduction in open landscape features within the region (Reinartz, 2022).

Although multiple variables (e.g. perching opportunity and vegetation height) have been identified as a possible explanation for the decline of little owl populations in Europe, little quantitative research has been conducted into prey availability as a possible explanatory factor for the site selection of little owls. This study, will, therefore, focus on this topic. Using prey availability and associated habitat type, and their interaction as predictors for the site selection of little owls, I assessed the effect of food availability and habitat characteristics in the site selection of little owls.

Research objective

The research objective of this thesis is to study the effect of prey availability and habitat characteristics on the site selection of little owls (*Athene noctua*) in the southern Algarve, Portugal.

This research objective will be achieved by answering the following questions:

1. What are the habitat preferences of little owls in the study area?
2. What is the prey abundance of the different habitat types present in the study area?
3. What is the effect of prey availability on the site selection of little owls?

Hypotheses

1. I expect that little owls will occur more in habitat types with ample perching opportunity and lower vegetation heights, like ruins, orchards & vineyards, and long-term fallow and low-density mixed orchards on arable or short-term fallow. The Little Owls will occur less in habitat types that do not have these characteristics e.g. long-term fallow or pastures, plantations, and building or industrial areas.
2. I expect that habitat types with plentiful food resources (seeds, fruits, and small invertebrates) and shelter (lots of burrowing opportunities for the small mammals) like ruins, long-term fallow and old orchards, mixed trees, and shrubs, will yield a higher number of prey compared to habitat types without these characteristics (Santos et al., 2011).
3. I expect prey availability to be an important explaining variable in the site selection of little owls. Habitat types with higher prey abundance will yield more little owl occurrences compared to habitat types with lower prey abundance.

Materials & methods

Study area

The main study site (Figure 1), the Central Peninsula of Ria de Alvor, has been extensively studied in the past for presence of little owl (Hof, 2005; Reinartz, 2022). In this study, I chose to extend the study area was extended with two new sites for censusing, one north of the village Mexilhoeira Grande and the other in the eastern marsh called Abicada (Figure 1). The two new areas were visited beforehand with my supervised and were determined by creating a transect that was accessible by road and from there, we based the area boundaries on the farthest heard little owl calls/songs. Other areas between the used study areas were excluded based on them being either inaccessible by foot or bike, or because of there being no suitable little owl habitat (only building and roads). The study sites are roughly located in the south-western Algarve, West of the city of Portimão (37.1°N, 8.6°W). The Algarve region has a warm Mediterranean climate, with the coastal region being considered semi-arid (Hugman et al., 2017). Rainfall is irregular, characterized by long dry summers and heavy rainfall during winter (Stigter et al., 2009). The total study area encompassed 2033ha, and is located within the Ria de Alvor municipality. The most common land-use types are pastures and arable land, as well as orchards with orange (*Citrus sinensis*), almond (*Prunus dulcis*), fig (*Ficus carica*), and carob trees (*Ceratonia siliqua*). Also, there are several ruins present, which are known to be prime nesting/perching habitats for Little Owls (Reinartz, 2022).

Censusing techniques

To study the current population size and territories of little owls in the study area, I continued using the transects used by Hof (2005) and Reinartz (2022) in addition to adding two new transects in the Abicada and Northern Mexilhoeira Grande area. The eight transects with a total of 20 observation points are different in length, transect 1 being 1250m, transect 2 being 2750m, transect 3 being 2000m, transect 4 being 1550m, transect 5 being 850m, transect 6 being 950m, transect 7 being 1000m, and transect 8 being 850m. The observation points are placed so that they are within the maximum (500m) detection range, and are therefore minimally separated by 500m (Centili, 2001). Each transect has been traversed a minimum of three times during the fieldwork period from February – April 2023. The observations were carried out after dusk, roughly between 20:00 and 22:00, as activity was highest at that time (Navarro et al., 2005). If weather conditions were unfavourable (rain or strong winds), the transects were traversed at a later date.

For this study, I used the play-back method, which is commonly used for bird censusing and relies on the reaction of an individual bird to a conspecific vocalization (Sutherland, 2006). I used a standardized play-back protocol. The protocol starts with two minutes of listening for spontaneous calls, after this, the conspecific vocalization is played. The sequence consists of 29 sec of singing, followed by 26 sec of calling, followed again by 29 sec of singing. The sounds were taken from the Ebird online library (Ebird, 2023). The sequence was played from a (Rapoo A500) speaker that was handheld and kept at the same volume throughout the fieldwork period. The sequence was stopped when an individual responded. After the response, the observer determined the location and type of call (alarm or territorial) of the response and noted it down on the ObsMapp mobile app (waarneming.nl). The data were imported and further analysed using QGIS 3.22.5 (QGIS, 2023).

Food availability

In 2022, Reinartz (2022) classified all habitat types on the Ria de Alvor peninsula based on the classification used by Hof (2005) (Figure 1). For 2023, the same classification was used, but now also for the two new areas (N. Mexilhoeira & Abicada marsh). I sampled the abundance and species composition of small mammals, the dominant prey of little owls in the area (Tomé, 2009), for habitat types that were preferred by little owls in the study by Reinartz (2022). I used 35 Helsinga live traps, which were supplied with carrots, apples, mealworms, and oatmeal and were checked daily. The traps were placed without bait for two days, to create as little disturbance as possible. After this, the traps were active for three straight days. The traps were checked every morning, and when caught, the animals were handled carefully with gloves to minimise stress, then the species was determined, and lastly the animals were weighed with a small scale. Using the 35 traps, I was able to sample a maximum of four habitat types each week, placing 8/9 traps per habitat type. A lot of the land on the peninsula is privately owned, which meant I could only sample a total of five different habitat types throughout the fieldwork period (Figure 2). The five chosen habitat types are one the most common throughout the study area. The sampling spots were selected based on their accessibility by foot, and on them being a 'typical' representation of the chosen habitat type (Table 1).

The sampling spots were primarily on the peninsula itself, only for the orchard (OV) habitat type I was forced to sample outside the study area. In total I sampled three different orchards. Also, due to unforeseen factors, like e.g. mowing or cattle replacement, I was not able to sample each habitat type equally and in the same week.

To analyse the habitat selection of little owls in the study area, a habitat classification map was created in QGIS 3.22.5 (QGIS, 2023). Using map together with the observations from 2005, 2022, and 2023, a distance matrix was created using the 'Distance Matrix' function under 'Analysis Tools'. This matrix is necessary for analysing the interaction effect of habitat type x prey availability. For the data analysis, all observations were loaded into RStudio Team (2023). To test for differences in mammal catch rate, I used a Fisher's Exact test for count dat.

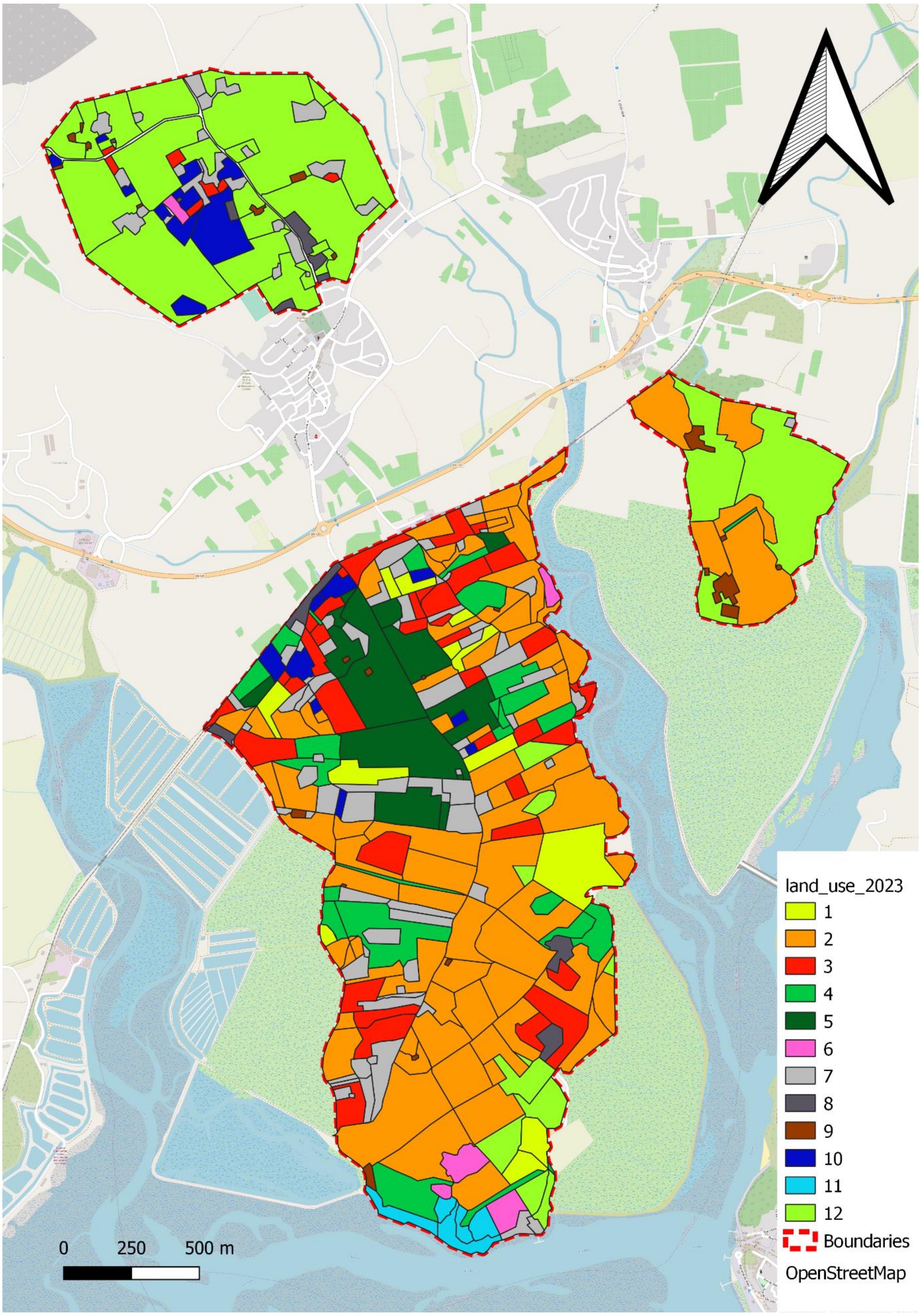

Figure 1: Habitat types present in study area in the year 2023. The study sites from north to south: northern Mexilhoeira Grande, Abicada marsh, and Ria de Alvor peninsula. 1= 'arable or short term fallow', 2= 'long-term fallow or pasture', 3= 'orchards and vineyards', 4= 'old orchard, mixed trees and shrubs', 5= 'low density mixed orchard on arable or short-term fallow', 6= 'plantations', 7= 'house and garden', 8= 'other buildings or industrial area', 9= 'ruins', 10= 'market gardens', 11= 'coastal matos', and 12= 'limestone outcrop shrubland' (Reinartz, 2022).

Habitat selection

All observations were loaded into QGIS 3.22.5 (QGIS, 2023). A square layer of the extend of the 'Land_use2023' layer was created using the 'Extract layer extend' function under 'Research Tools'. This extend was used in combination with the 'Land_use2023' layer to make a new clipped layer without data using the function 'Clip' under 'Geoprocessing Tools'. This new clipped layer was then used to generate a 1:5 ratio, in total 1060 so-called 'absence points' using the 'Random Points Inside Polygons' function under 'Research Tools'. These 'absence points' are needed to analyse habitat selection, where they are compared with the real presence points. The absence points were then joined to the presence points using the 'Join Attributes by Location' function under 'Data Management Tools'. All points were then buffered with a 50m radius, using the 'Buffer' function, so as to compensate for any observation biases. These joined layers were then also combined with the land use layer using the 'Join Attributed by Location' function.

To identify which habitat types were preferred in the site selection of the little owls, I followed the methodology previously used by Reinartz (2022) to be able to compare results directly. I performed a habitat selection analysis using Manly selection ratios (Manly et al., 2007), and used binomial generalized linear modelling (GLM). The Manly selection ratio (w_i) is calculated by dividing the total used area by the total available area for each habitat type (equation 1). The Manly selection ratios were calculated in RStudio (R Core Team, 2023) using the 'WidesI' function of the 'adehabitat' package (Calenge, 2006). The resulting ratios are then compared with the ratios found in 2005 & 2022, using a Friedman rank sum test.

$$w_i = \frac{Total\ used\ area}{Total\ available\ area}$$

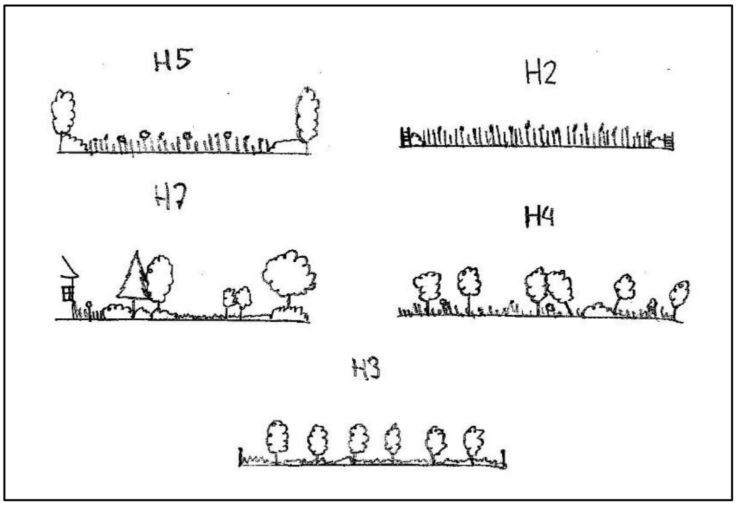

Figure 2 Structional overview of the five sampled habitat types

In addition to using the Manly selection ratios, generalized linear modelling (GLM) was used to test for the effect of different habitat types, period, and distance to nearest orchard on the presence/absence of little owls in the study area for the years: 2005, 2022, and 2023 together in one model. These presence/absence points are the explanatory variable, and the response variables are the areas of each of the habitat types per buffered presence/absence point, as well as the period and distance to nearest orchard. The variables were fitted through a GLM with a binomial distribution and logistical 'cloglog' link. A 1 in the binomial distribution represents a presence point, whilst a 0 represents a randomly created absence point. The GLM's were fitted using the 'glm2' package (Marschner et al., 2018) in R (R Core Team, 2023). The explanatory variables were tested for correlation, and visualised in a correlation matrix with the package ‘PerformanceAnalytics’ (Peterson et al., 2018). No variables in the correlation matrix were found to be highly correlated, however, all explanatory variables were also tested for collinearity, using variation inflation factors (VIF). When this resulted in a variable having a VIF higher than 5, the variable was removed from the model (Akinwande et al., 2015). This meant that the following four variables had to be removed from the model: ‘long-term fallow or pasture’, ‘orchards and vineyards’, ‘low-density mixed orchard on arable or short-term fallow’, and ‘house and garden’.

Following the methodology used by Reinartz (2022), I used a multi-model selection approach in selecting a model (Burnham & Anderson, 1998). This approach compares all possible combinations of the model, using the ‘dredge’ function in the R package ‘MuMln’ (Barton & Barton, 2015). This ‘dredge' function resulted in a specific ordering of models based on the Akaike’s Information Criterion (AIC) value of the models. All models with a ΔAIC < 4, are considered the best fitting models (Burnham & Anderson, 1998). These models were averages using the model averaging function of the same ‘MuMln’ package. From this average model, the relative importance of all included variables, as well as the pseudo R^2 value (using the ‘nagelkerke’ function from the ‘rcompanion’ package was then calculated (Mangiafico & Mangiafico, 2017). Lastly, the average model was tested for overdispersion (Reinartz, 2022).

Results

Little owl territories

The population census in 2023 using the playback method resulted in 85 observations of Little Owls. I estimated there to be 20/15 (progressive/conservative) overall territories (Figure 3), which equates to between 5.42 and 3.87 territorial males/km^2. This is roughly the same as in 2022, the progressive estimate being somewhat higher, as it was 5.27 calling males/km^2, whilst the conservative estimate was somewhat lower than the 4.14 calling males/km^2 in 2022 (Reinartz, 2022). In both 2022 and 2023 the population size estimates were lower than in 2005, when Hof (2005) found a population density of 6.44 calling males/km^2 (Appendix A, Figure 6).

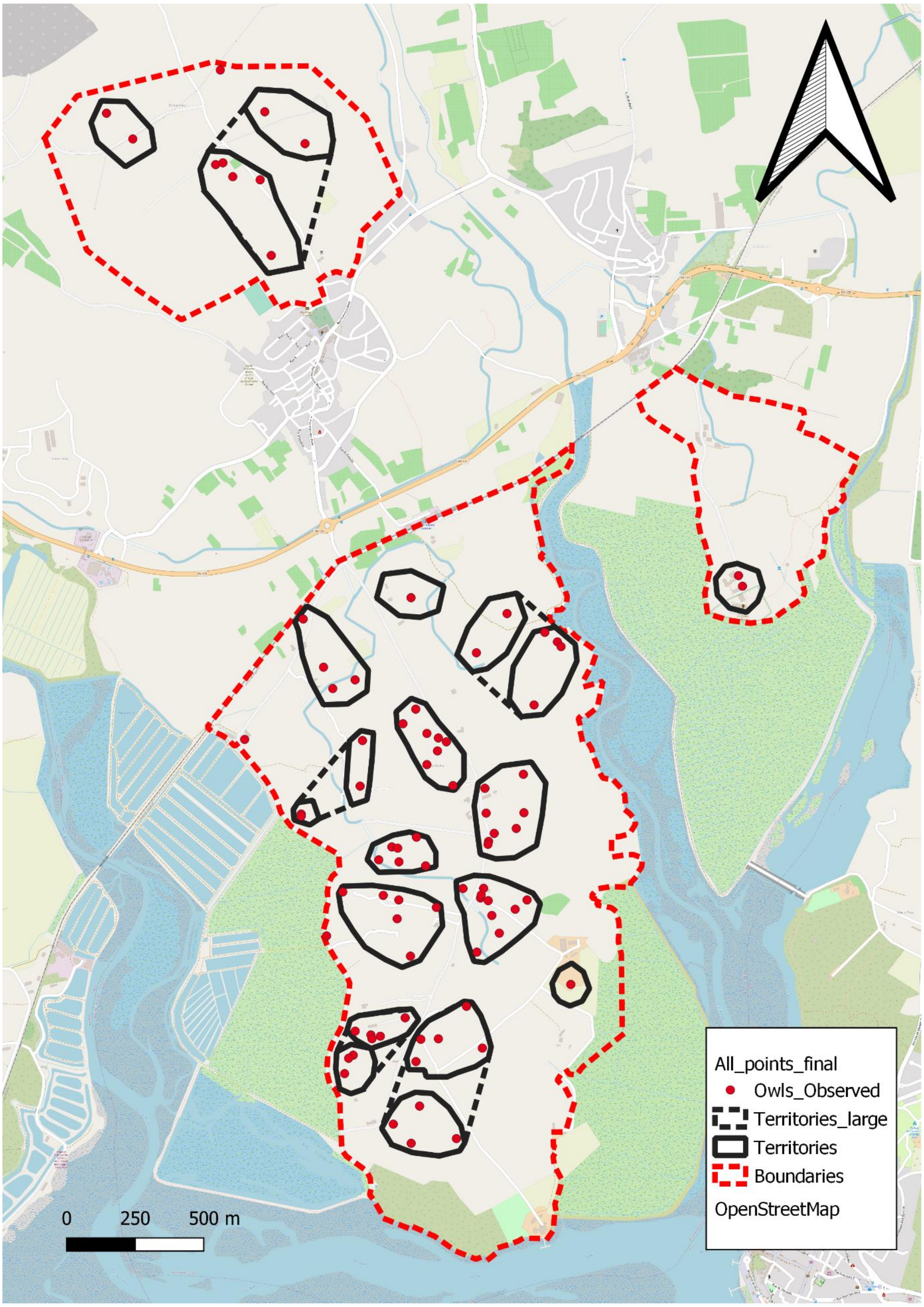

Figure 3: Study area with all Little Owl observations from the year 2023. The conservative estimate of territories is shown by the dashed line, whilst the progressive estimate is shown by the unbroken line, which is respectively 15 or 20 territories. The study sites from north to south: northern Mexilhoeira Grande, Abicada marsh, and Ria de Alvor peninsula.

Food availability

In total 26 small mammals, 24 wood mice (*Apodemus sylvaticus*), one house mouse (*Mus musculus*), and one greater white-toothed shrew (*Crocidura russula*), were caught in five different habitat types (Figure 2 & Table 1) during the fieldwork period. Capture rates differed significantly between habitat types (Fisher's exact test: p < 0.001) with the highest catch rate in 'orchards and vineyards' (table 1).

Table 1 Mammal catch table for the fieldwork period in 2023. Showing amount of catches, non-catches and effort, which is the amount of traps times the amount of open trap days.

Habitat type	Catches	Non-catches	Effort (traps x days)	Rate
Long term fallow or pasture	1	105	106	0.01
Orchards and vineyards	24	214	238	0.10
Old orchard, mixed trees and shrubs	1	69	70	0.01
Low-density mixed orchard on arable or short-term fallow	2	139	141	0.01
House and garden	1	121	122	0.01

Habitat selection

In 2023, the owls were observed in 'long term fallow or pasture' (n=33), 'orchards and vineyards' (n=16), and 'house and garden' (n=12). The other observations were in 'arable or short-term fallow' (n=1), 'old orchard, mixed trees and shrubs' (n=2), 'low density mixed orchard on arable or short-term fallow (n=9), 'other building or industrial area' (n=1), 'ruins' (n=4), and 'limestone outcrop shrubland' (n=7). No owls were observed in 'plantations', 'market gardens', and 'coastal matos'.

A significant difference in habitat selection based on Manly selection ratios between the different years was found (Friedman rank sum test, Chi = 22.013, p = 0.024). In general, the Manly selection ratios found by Hof (2005) show a more even use of the study area by the little owls than the Manly selection ratios found by Reinartz (2022) and me in 2023. In 2005 and 2023, only 3 of the 12 land use types have a wi value below 0.5 (Figure 4). In 2022 and 2023, however, 7/12 and 6/12 habitat types respectively have a wi value below 0.5 This translates into a higher selectivity or avoidance by little owls for certain land use types in 2022 and 2023 than in 2005 (Hof, 2005; Reinartz, 2022).

In 2005, Hof (2005) observed that Little Owls showed a higher presence in 'orchards and vineyards', 'low density mixed orchards on arable or short-term fallow', and 'houses and gardens'. They strongly avoided 'coastal matos', and 'limestone outcrop scrubland', as well as 'ruins', 'other buildings or industrial areas', 'arable or short-term fallow', and 'plantations' (Figure 4). However, in 2022 and 2023, Reinartz (2022) and I found that Little Owls actually preferred 'ruins' and 'long-term fallow or pasture', while avoiding 'coastal matos', and 'old orchard, mixed trees, and shrubs' more in those years (Reinartz, 2022). Most other habitat types in 2005 were used in line with their expected availability (Hof, 2005). In 2022, Reinartz (2022) found that the 'house and garden' habitat type was used as expected, while in 2023, I discovered that this habitat was actually preferred by the Little Owls. Additionally, in 2023, I observed a stronger preference for 'orchards and vineyards' compared to 2005 and 2022 (Hof, 2005; Reinartz, 2022). Unfortunately, in 2023, I did not observe any owls in ‘coastal matos’ and ‘plantations’, so I cannot provide an accurate estimate of their preference or avoidance in that year (Figure 4).

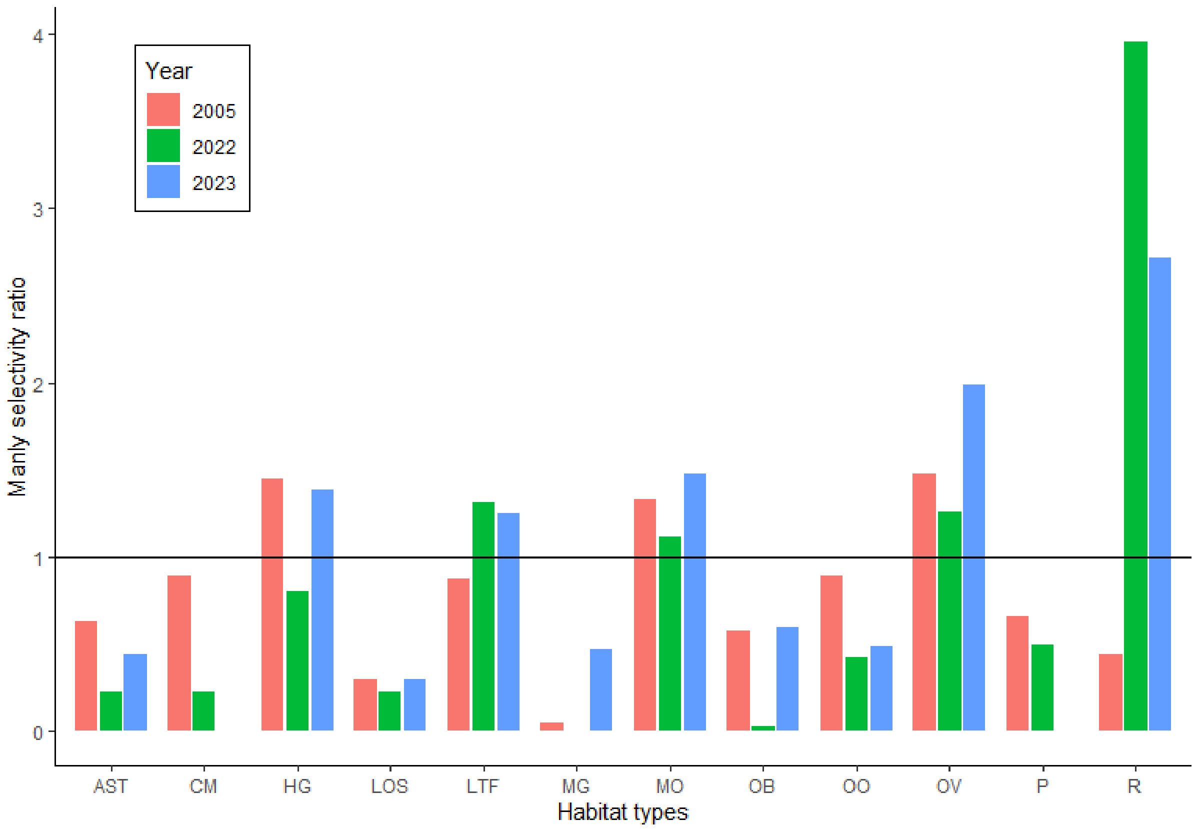

Figure 4 Manly selection ratios for 2005, 2022, and 2023. AST = arable or short term fallow; CM = coastal matos; HG = house and garden; LOS = limestone outcrop vineyards; LTF = long term fallow or pasture; MG = market garden; MO = low density mixed orchard on arable or short term fallow; OB = other buildings or industrial area; OO = old orchard, mixed trees and shrubs; OV = orchards and vineyards; P = plantations; R = ruins.

The average generalized linear model (GLM) used for the habitat selection analysis had a poor fit (pseudo $R^2 < 0.1$, Appendix B). However, the following independent variables were found to have a significant effect on the site selection of little owls: arable or short-term fallow ($p = 0.015$), old orchard, mixed trees and shrubs ($p = 0.012$), ruins ($p < 0.001$), limestone outcrop shrubland ($p = 0.007$), and period ($p < 0.001$). The variable ‘distance to nearest orchard’ is almost significant ($p = 0.050$). All habitat variables except ‘ruins’ had a negative relationship with little owl site selection (Figure 5A). The variables ‘limestone outcrop shrubland’ and ‘period’ explained the most variance in the presence/absence of owls in the study area (Appendix B, Table 3).

The variables ‘arable or short-term fallow’, ‘limestone outcrop shrubland’, ‘old orchard, mixed trees and shrubs’, ‘other building or residential area’, ‘ruins’, ‘distance to nearest orchard’, and ‘period’ were included in all top ($\Delta AIC \leq 2$) models (Appendix C, Table 4). There were 3 models with a $\Delta AIC \leq 2$, and 5 with a $\Delta AIC \leq 4$.

Plotting the four habitat variables with the highest relative importance from the average models, shows that an increase in the variables ‘ruins’ leads to a higher probability of little owl presence, whilst an increase in the variables 'arable or short-term fallow', 'limestone outcrop shrubland', and 'old orchard, mixed trees and shrubs' leads to a lower probability of little owl presence (Figure 5A).

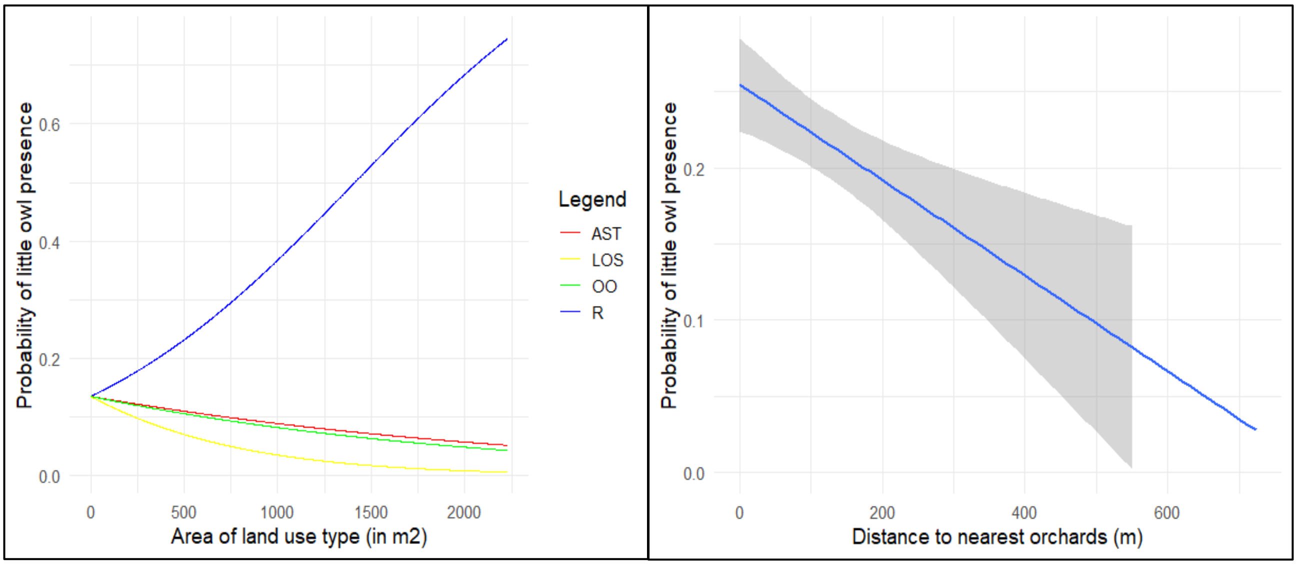

Figure 5. A). The relationship between the area of a land use type and the probability of little owl presence for the four most important variables of the average model. AST = arable or short term fallow, LOS = limestone outcrop shrubland, OO = old orchard, mixed trees and shrubs, R = ruins. B). The relationship between the distance to the nearest orchard (m) and the probability of little owl presence.

The average model from the generalized linear model (GLM) also shows that the likelihood of little owl presence decreases with increased distance from the nearest orchard (Figure 5A).

Discussion

The ongoing trends of agricultural intensification and land abandonment are putting significant pressure on little owl populations across Europe. These changes also affect the populations of small mammal prey, leading to potential alterations or declines (e.g., Plieninger et al., 2014). This study aims to identify habitat types with high food abundance, understanding which habitats are preferred or avoided by little owls.

In my hypothesis, I anticipated that habitats rich in food resources, such as seeds, fruits, and small invertebrates, along with ample shelter and burrowing opportunities like ruins, long-term fallow areas, and old orchards with mixed trees and shrubs, would support higher populations of small mammals compared to habitats lacking these characteristics. Through my research, I discovered that the habitat type categorized as "orchards and vineyards" exhibited a catch rate of small mammals ten times higher than other habitat types (Table 1). Interestingly, our findings align with a study conducted by Apolloni et al. (2018), which supports the idea that orchards provide favorable conditions for small mammal populations. However, our results contradict the majority of studies that focused on small mammal abundance in various linear agricultural landscapes, were they actually found that small mammal populations were negatively related to the presence of orchards (e.g., Jánová & Heroldová, 2016; Sullivan & Sullivan, 2006; Sullivan et al., 2012).

The disparity between our study and others could potentially be attributed to regional differences in climates. Our research was conducted in a semi-arid Mediterranean region where factors like agricultural abandonment, intensification, and tourism development are known to contribute to the decline of little owl populations (Donald et al., 2006; Onrubia & Andrés, 2005; Vogiatzakis et al., 2006). Whilst the other studies were done throughout Western- and Central Europe (Jánová & Heroldová, 2016; Sullivan & Sullivan, 2006; Sullivan et al., 2012).

The unique environmental conditions in our study area may have contributed to the observed variations in small mammal abundance. The semi-arid Mediterranean climate, coupled with agricultural practices and tourism-related changes, likely created a distinct habitat mosaic that favored the proliferation of small mammals within orchards.

These findings highlight the importance of considering regional and local factors when assessing habitat preferences and population dynamics of species like the little owl. Understanding how specific habitats and environmental variables influence species abundance is crucial for effective conservation and management efforts, particularly in regions experiencing rapid land-use changes.

The study conducted by Apolloni et al. (2017) shed light on the complex interplay between habitat characteristics, small mammal abundance, and the decline of little owl populations in the context of agricultural abandonment, intensification, and tourism development. Further research in diverse geographic regions will contribute to a more comprehensive understanding of the factors influencing species distributions and population trends.

It is worth noting that the mammal catch rate, which was in total 0,04, is considerably lower compared to similar studies in Portugal (Galantinho et al., 2017; Teixeira et al., 2017). Multiple factors contribute to this low rate, with the sampling method itself playing a significant role.

Most of our sampling locations, except one, were situated on the Ria de Alvor peninsula. However, limited access to suitable locations posed a challenge as the peninsula is mostly privately owned by farmers, making it difficult to establish sampling points. Furthermore, even when accessible locations were found, external factors such as vegetation mowing or the installation of fencing in previously open areas necessitated trap relocation.

I sampled three different orchards, each managed differently. It is worth noting that the orchard with the highest mouse capture rate had moderate management practices and fruit-bearing trees. Future studies should explore variations in small mammal abundance across different types of orchards.

In summary, the small number of captured individuals does not indicate a lack of sampling effort. Challenges in accessing suitable locations and variations in orchard management practices likely contribute to the low numbers. Future studies should investigate differences in small mammal abundance among various types of orchards. Additionally, the availability of mice and voles may have been low throughout the fieldwork season due to large-scale synchronous population cycles, which can greatly influence the population size and distribution of small mammals (Lambin et al., 2000).

In my initial hypothesis, I predicted that Little Owls would occur more frequently in habitat types with ample perching opportunities and lower vegetation heights, such as ruins, orchards and vineyards, and low-density mixed orchards on arable or short-term fallow. Conversely, I hypothesized that Little Owls would occur less frequently in habitat types lacking these characteristics, such as long-term fallow or pastures, plantations, and building or industrial areas.

The habitat analysis using Manly selection ratios revealed a strong preference of little owls for ruins, orchards and vineyards, and, to a lesser extent, low-density mixed orchards on arable or short-term fallow, house and gardens, and long-term fallow or pasture (Figure 4). Other habitat types were generally avoided. These findings are consistent with the hypothesis, as the preferred habitats provide ample perching opportunities and lower vegetation heights, with the exception of long-term fallow or pasture. This aligns with earlier studies conducted by Hof (2005) and Reinartz (2022), which show a general agreement.

It is worth noting that this study included the Abicada and northern Mexilhoeira areas, but their inclusion did not significantly impact the results. Additionally, the preference for ruins was lower in our study compared to Reinartz (2022), which could be attributed to the inclusion of these two areas, as they offered relatively less orchards than the main Ria de Alvor peninsula. Orchards and vineyards were more preferred this year compared to Reinartz's study, possibly due to increased fragmentation of suitable habitat for small mammal species (Diffendorfer et al., 1995).

Interestingly, similar to Reinartz (2022), a slight preference for long-term fallow or pastures was observed, contrary to the initial hypothesis. Despite the expectation of avoidance due to low vegetation height and limited perching opportunities, previous studies (Apolloni et al., 2018; Calvi & Munzio, 2019; Salek & Lövy, 2012) indicate a negative correlation between little owl presence and these factors. Additionally, prey availability does not seem to be the reason for this preference, as the mammal trapping experiment did not yield a high abundance of small mammals in long-term fallow or pastures (Table 1).

The results of the generalized linear model (GLM) showed a significant relationship between owl presence and several independent variables: 'arable or short-term fallow', 'old orchard, mixed trees and shrubs', 'ruins', 'limestone outcrop shrubland', and 'period'. All significant habitat variables were negatively related to little owl site selection, except for 'ruins', which had a clear positive effect (Figure 5A). This positive effect of ruins is consistent with the Manly ratios and other research on this topic, as ruins are known to provide perching and roosting opportunities (Martínez & Zuberogoitia, 2004; Chrenková et al., 2017). Ideally, I would have also examined food availability in ruins, but this was not feasible as the ruins were mostly located on private properties and too small to gather sufficient data. The GLM also demonstrates that the probability of owl presence decreases with increased 'arable or short-term fallow', 'limestone outcrop shrubland', and 'old orchard, mixed trees and shrubs' (Figure 5A). These habitat types appear to be avoided, which was also observed using the Manly selection ratios (Figure 2). Šálek & Lövy (2010) also support this idea, attributing the avoidance to the high vegetation heights, which make it difficult for the owls to spot their prey (Šálek et al., 2010; Żmihorski et al., 2009).

In my hypothesis, I considered prey availability as an important factor in the site selection of little owls. I expected that habitat types with higher prey abundance would result in a higher likelihood of owl presence compared to habitat types with lower prey abundance. Although the results from the generalized linear models (GLM) were not statistically significant by a narrow margin, there is a clear trend indicating that the likelihood of owl presence increases with decreasing distance to the nearest orchard (Figure 5B). This finding is consistent with other studies on the effect of food availability on the selective behavior of birds (Holmes & Schultz, 1988; Ferger et al., 2014; Apolloni et al., 2017). Apolloni et al. (2017) also found that orchards were the most preferred habitat structure, as they provide rich food resources as well as perching and nesting opportunities (Aebischer & Robertson, 1994; Martınez & Zuberogoitia, 2004; Tome et al., 2004; Zmihorski et al., 2012).

In conclusion, previous studies have extensively explored the relationship between food availability and factors such as bird species richness and foraging selection. However, my study specifically investigated the role of food availability in determining the spatial distribution of little owls. The collective evidence from these studies highlights the significant influence of food availability on site selection of animal species.

To further advance our understanding, future research should delve deeper into the intricate dynamics between orchards and the broader ecosystem. Orchards are prevalent throughout the Algarve region and exhibit diverse management practices. Therefore, conducting more comprehensive investigations into the role of orchards within the larger ecological context would be highly beneficial. By doing so, we can gain valuable insights into the intricate relationships between habitat, food availability, and the conservation of avian populations in agricultural landscapes.

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Appendix A: All little owl observations

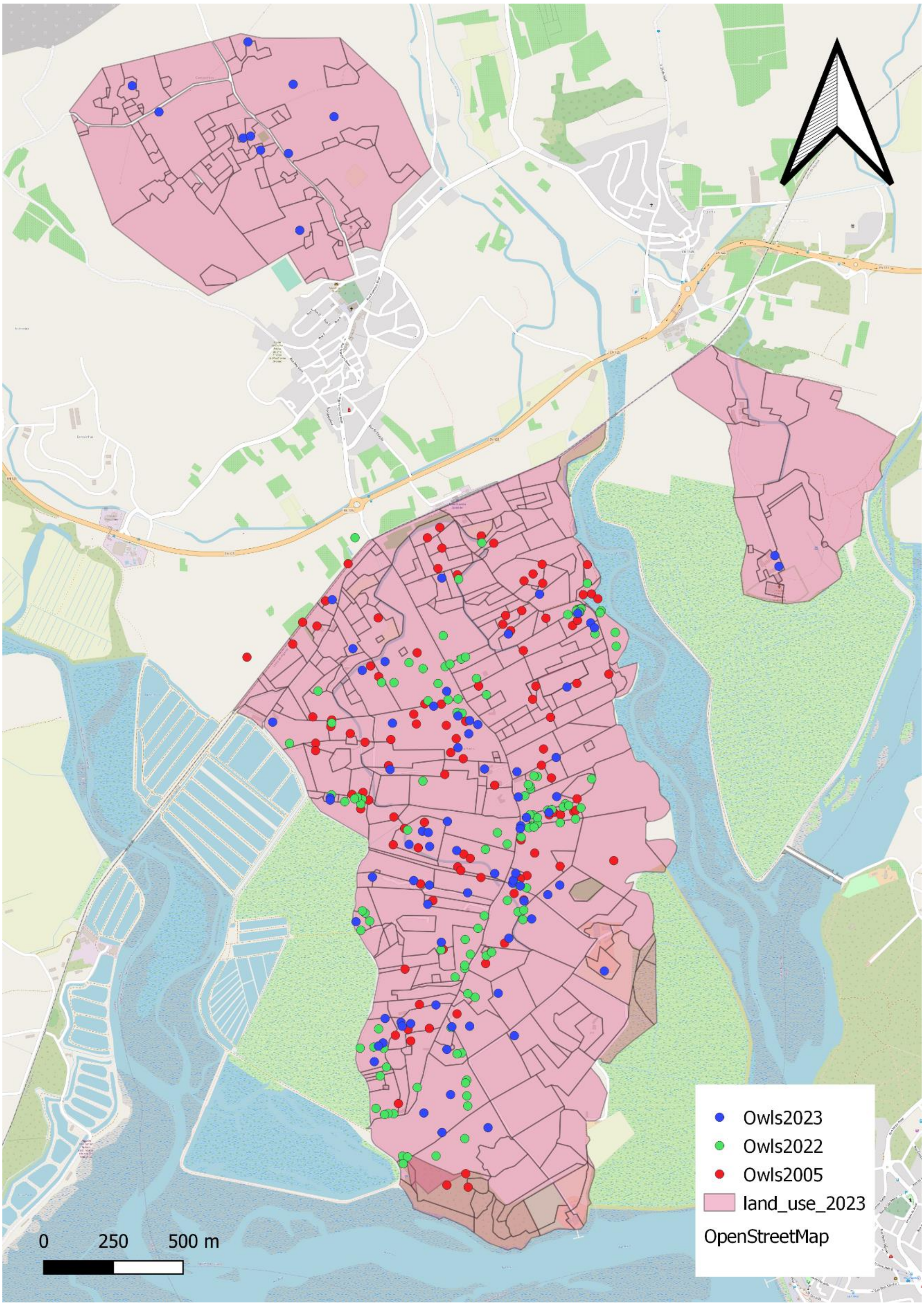

Figure 6 Land use map of the study area with the little owl territorial calls heard during the study period. Territorial calls heard in 2005 in red (n = 106), territorial calls heard in 2022 in green (n = 118), territorial calls heard in 2023 in blue (n = 86) (Reinartz, 2022).

Appendix B: Average model from GLM

Table 2 Average model resulting from the multi-model selection process with generalised linear modelling (GLM) explaining the presence/absence of little owls for different variables. The model is based on a presence to absence points proportion of 1:5. SE = standard error and p = p-value.

Variable	Estimate	SE	p	Importance
(intercept)	-1.855	0.230	**< 0.001**	x
Arable or short term fallow	< 0.001	< 0.001	**0.015**	0.980
Market gardens	< 0.001	< 0.001	0.320	0.690
Limestone outcrup shrubland	< 0.001	< 0.001	**0.007**	1.000
Old orchard, mixed trees and shrubs	< 0.001	< 0.001	**0.012**	0.980
Other building or industrial area	< 0.001	< 0.001	0.125	0.890
Ruins	0.001	< 0.001	**< 0.001**	0.990
Distance to nearest orchard	< 0.001	0.001	0.050	0.920
Period	0.495	0.127	**< 0.001**	1.000
Plantations	< 0.001	< 0.001	0.647	0.380

Appendix C: Best performing models from the multi-model selection

Table 3. Models with ΔAIC ≤ 4 from a multi-model selection consisting of all possible explanatory variables with a VIF <5 for 2023. Shaded areas indicate that the variable was included in the model. AST is arable or short term fallow, MG is market gardens, LOS is limestone outcrop shrubland, OO is old orchard, mixed trees and shrubs, P is plantations, OB is other buildings or industrial area, R is ruins.

ΔAIC	AST	MG	LOS	OO	P	OB	R	distance	period
0.00	■	■	■	■		■	■	■	■
1.21	■	■	■	■	■	■	■	■	■
1.60	■		■	■		■	■	■	■
2.78	■		■		■	■	■	■	■
4.25	■	■	■	■			■	■	■

AIC = 1345.70