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Research Article

Assessing habitat suitability of the Persian Squirrel in the island of Lesvos, Greece

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Abstract

The Persian Squirrel (*Sciurus anomalus*) is a Southwest Asian species of squirrel with a single European Union population on the island of Lesvos in Greece. We evaluated the impact of land cover and tree density habitat variables on squirrel spatial distribution on the island. Our analysis was based on 240 localities of recorded occurrence of the species across the island, as well as 240 pseudo-absence localities, with land cover and tree density habitat variables at each locality. A total of 31 variables were analysed by principal component analysis (PCA). The significant predictors obtained from PCA were then used to obtain a binary logistic regression model to represent relative likelihood of occurrence and habitat suitability for this population. Lesvos Persian Squirrels appear to use all main arboreal vegetation types on the island, including both woodland as well as tree crops, especially olive cultivation. They are also found in rather small and isolated patches of such vegetation. However, although pine trees provide cones as a regular food source, the species is remarkably absent from larger areas of continuous coniferous forest and pine trees appear to be used only when mixed with or close to broad-leaved trees. Even though the Persian Squirrel is quite widespread on Lesvos, this population may still be at risk from habitat changes due to changing agricultural practices or urban expansion.

Introduction

The Persian Squirrel (*Sciurus anomalus*) is a southwest Asian tree squirrel with an isolated population on the Greek island of Lesvos, in the eastern Aegean Sea (Ondrias, 1966). This population, estimated at 500–3000 mature individuals (European Topic Centre on Biological Diversity, 2015), is the only population of the species in the European Union. *Sciurus anomalus* is widely distributed in Turkey, including the Aegean island of Gökçeada (Gavish and Gurnell, 1999), and its global range extends North to the Caucasus, East to Iran, and South to Jordan (Masseti, 2010; Yiğit et al., 2016). The Persian Squirrel's population size at local, national or international level remain uncertain (Yiğit et al., 2016). Population declines have been noted at the edges of its global distribution (e.g. Syria and Lebanon) due to poaching and on-going habitat degradation. Hence, the species should be monitored carefully especially at the edges of its range (Yiğit et al., 2016).

The Persian squirrel is similar to the congeneric Eurasian Red Squirrel (*Sciurus vulgaris*), differing in colour and with a comparatively shorter tail (Kryštufek and Vohralík, 2005). It feeds primarily on tree seeds such as acorns (*Quercus*), walnuts (*Juglans regia*), chestnuts (*Castanea sativa*), hazelnuts (*Corylus* spp.), beech nuts (*Fagus*), apricot seeds and almonds (*Prunus*), as well as pine seeds (*Pinus brutia*) (Abi-Said et al., 2014; Gavish, 1993). However, it may also consume a variety of berries, commercial fruits (e.g. apples, pears, peaches, grapes, and plums) (Ognev, 1966) as well as grass seeds (Aidek et al., 2021), cereal grains, and mushrooms (Gavish, 1993). In the Anatolian region the Persian Squirrel's habitat has been distinguished into five groups (Kryštufek and Vohralík, 2005), including Mediterranean mosaic agriculture areas with scattered trees (olives, pines, evergreen and deciduous broadleaves) and shrubs, and pine forests with patches of broadleaf trees and shrubs, as found on Lesvos (see Study Area below). The species has been described as difficult to trap, and its abundance and density is hard to estimate by direct observations (Abi-Said et al., 2014; Amr et al., 2006; *pers. obs.*).

In Greece, *S. anomalus* is included in the National Red Data Book as Near Threatened (NT) (Legakis and Maragou, 2009). It is mainly threatened by habitat loss due to the expansion of building activity into agricultural areas, the expansion of the road network and wildfires (European Topic Centre on Biological Diversity, 2015). However, there is a shortage of systematic data concerning the species' distribution, habitat usage and overall ecological requirements in Lesvos, essential for the development and implementation of conservation plans (European Topic Centre on Biological Diversity, 2015).

This study aims to determine the habitat features affecting the spatial distribution of the species on the island and to assess the most suitable areas of distribution of this isolated squirrel population. We obtained a habitat suitability model for the species by analysing land cover categories and types, as well as density of arboreal vegetation, in relation to the spatial distribution of observation records of the species. Particularly, we were interested to show whether (a) Persian Squirrels are expected to be found in any type of arboreal vegetation, and (b) whether isolated or semi-isolated patches of arboreal vegetation in treeless areas are occupied by the species.

Material and Methods

Study Area

Lesvos is an island in the north-eastern Aegean Sea, very close to Turkey, with an area of 1632.8 km^2. The island is hilly and rugged with a maximum altitude of 968 m (Mt. Lepetymnos). The island's climate is Mediterranean, hot and dry in summer and cool and wet in winter. The monthly mean temperature ranges from 9.6 °C in January to 27.0 °C in July. The mean annual rainfall varies from 725 mm

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in the East to 415 mm in the West of the island, with little or no rain between May and September (Kosmas et al., 2000). The eastern and southern parts of Lesvos have a mosaic landscape of traditional olive groves (*Olea europaea*), grazing land and other non-intensive agriculture with scattered small patches of pine trees (*Pinus brutia*). Extensive areas of *Pinus brutia* forest, and locally *Pinus nigra*, can be found especially in the central part of the island. Broadleaved forest in the form of sweet chestnut plantations (*Castanea sativa*) is found in one small area at higher elevations. The western and northern parts of the island are starkly different, with low shrubby vegetation, known in Greece as "phrygana", dominated by *Sarcopoterium spinosum*, and smaller areas of denser and taller shrubby vegetation as well as patches of oak trees (*Quercus ithaburensis* spp. *macrolepis* and *Q. pubescens*).

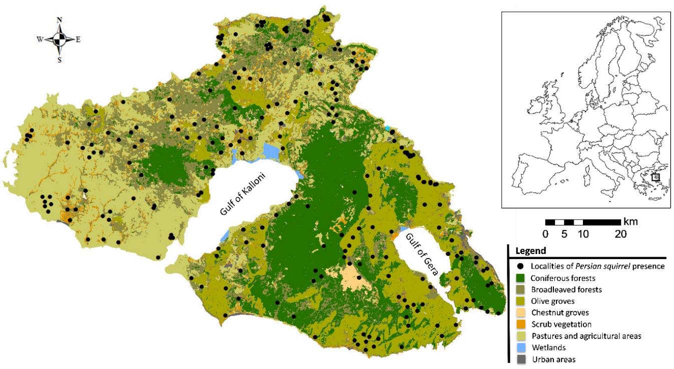

Figure 1 – Observation points of Persian Squirrel on the combined CORINE Land Cover and Copernicus high resolution layers basemap.

Persian squirrel sightings

We collected observations of the Persian squirrel mainly by systematic searching of the whole island from 2014 to 2020. Our searches were based on a 2×2 km grid, covering as much as possible of woody vegetation in each grid cell by walking along tracks and secondary roads traversing areas with trees. Up to three repeat searches were made in cells where squirrels were not observed. We found Persian squirrels quite difficult to observe because of dense foliage at a low height. Nonetheless, sometimes they were easy to locate from a distance due to vocalisations. In addition to systematic searching, we also used records from casual encounters or records by birdwatchers and other naturalists up to 2021. This resulted in a total of 240 observation localities.

Habitat and landscape data extraction and processing

To obtain habitat and landscape feature data for further analysis we used ArcGIS 10.2 software (ESRI Inc., Redlands, CA, USA) to create 50 m and 500 m radius circular plots centred on each observation locality. We chose these distances as approximations to the "core area" actively used by each animal (or group of animals) at the time of observation (50 m radius) and to the wider area ("home range", 500 m radius) in which each animal is likely to spend all or most of the annual cycle, based mainly on published data for the congeneric *S. vulgaris* and *S. carolinensis* (Rima et al., 2010; Wauters and Dhondt, 1992), as well as our knowledge of the species.

Within the 500 m radius of each observation point we extracted the total area of each land cover type from the CORINE Land Cover (CLC) dataset (European Union Copernicus Land Monitoring Service, 2018) and then converted the area of each land cover type into percentage cover within the 500 m radius circle. CLC provides spatial data for European main land cover features such as agricultural areas, forests and semi-natural areas, as well as wetlands and man-made structures, in the form of polygons with a geometric accuracy better than 100 m and a minimum mapping unit of 25 ha (areal) or 100 m wide (linear). For the 50 m radius circle we used tree type and density data available from the Tree Cover Density (TotalTreeCD) subset of the COPERNICUS high resolution layers (European Environment Agency, 2018). We extracted the following information within the 50 m radius of each observation point: (a) TotalTreeCD for all arboreal vegetation (deciduous, evergreen and coniferous), (b) Broadleaved Trees Density (BroadLTD), (c) Broadleaves Density (OtherBroadLTD) that include *Quercus* spp., *Platanus orientalis*, *Populus* spp. and other broad-leaved deciduous and evergreen trees except olives and sweet chestnuts, (d) Coniferous Density (ConiferTD) (*Pinus brutia*, *P. nigra*), (e) Olive Tree Density (OliveTD) and (f) Chestnut Tree Density (ChestnutTD). Olive tree density was extracted by intersecting the Broadleaves data of COPERNICUS with the agricultural areas layer of CLC, given that for Lesvos olive groves are the only crop that is classed as "Broadleaves". Chestnut tree density was similarly extracted from the Broadleaves data of COPERNICUS since chestnut cultivation is strictly delimited in one part of the island. Geomorphological features such as altitude, mean inclination and aspect were derived from a Digital Elevation Model (DEM) of Lesvos with a 30 m cell width, produced and validated in the Biodiversity Conservation Laboratory at the University of the Aegean. Aspect was split into a N-S and an E-W component by using the sine and cosine of the angle from North. We used interaction of aspect with slope as a landscape variable since aspect is meaningful only on sloping rather than level ground. A total of 31 variables resulted for each location: seventeen Corine Land Cover use types, six tree cover density variables and eight geomorphological features. The full list of variables is given in Table S1 in the Supplemental Material.

To reduce the number of variables we used Principal Components Analysis (PCA). The first step was to eliminate variables with communality values of 0.7 or less, keeping only variables with most of their variance (communality value close to 1.0) accounted for in the retained principal components (McGarigal et al., 2000). To ensure that the selected variables are applicable for use we checked that the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was between 0.5 and 1.0, as has been recommended (Budaev, 2010). We finally extracted the components with eigenvalues greater than 1.0 by using Varimax rotation method.

Modelling observation distribution of squirrels

In order to have a comparison between places of known presence and those with no observations, we generated 240 random localities (Barbet-Massin et al., 2012) on the island in addition to the 240 observation points (Fig. 1), at a minimum distance of 1 km from localities of known presence. The above-mentioned variables were extracted from both the 50 m and 500 m radius plots for each random locality. Since searching was quite thorough and most of the island was covered, we believe that few of these localities actually held squirrels (i.e., false negative). We used binary logistic regression to determine habitat and landscape features that affect the suitability of habitat for squirrels. Statistically significant principal components resulting from the PCA were entered as the independent predictor variables and the analysis was run with the bootstrap procedure (10000 iterations). The accuracy of the model was evaluated according to Nagelkerke's R square (Nagelkerke, 1991) and the equation goodness of fit was assessed with the Hosmer-Lemeshow test (Hosmer and Lemeshow, 2000). We evaluated the ability of the model to discriminate between presence and absence localities with a 2×2 classification table of observed and predicted values and the area under the receiving operating characteristic (ROC). An empirical ROC curve (Supplemental Material Figure S2), plotting the proportion of presence localities correctly classified (sensitivity) against the proportion of absence localities incorrectly classified as presence (1-specificity), was used to obtain the cut point (threshold). This cut point optimises prediction accuracy by balancing sensitivity and specificity (Hosmer and Lemeshow, 2000). The area under the curve (AUC) is considered the standard method for assessing the accuracy of predictive distribution models as it avoids the supposed subjectivity in the threshold selection process, when continuous probability-derived scores are converted to a binary presence–absence variable, by summarizing overall model performance over all possible thresholds (Lobo et al., 2008). The use of AUC is known to have some drawbacks, such as assuming equal costs for commission and omission errors or not providing information about where the model per-

Table 1 – PCA loadings and communality values of the four rotated PCs.

Variable	Communality of 4 PCs	Principal Components loadings PC1	PC2	PC3	PC4
OtherBroadLTD	0.916	0.951	-	-	-
BroadLTD	0.924	0.810	-	-	-
TotalTreeCD	0.946	0.746	-	-	-
OliveGroveLC	0.904	-	0.932	-	-
OliveTD	0.910	-	0.922	-	-
ConiferTD	0.917	-	-	0.950	-
ConifLC	0.885	-	-	0.894	-
ChestnutTD	0.929	-	-	-	0.962
BroadLFLC	0.924	-	-	-	0.951

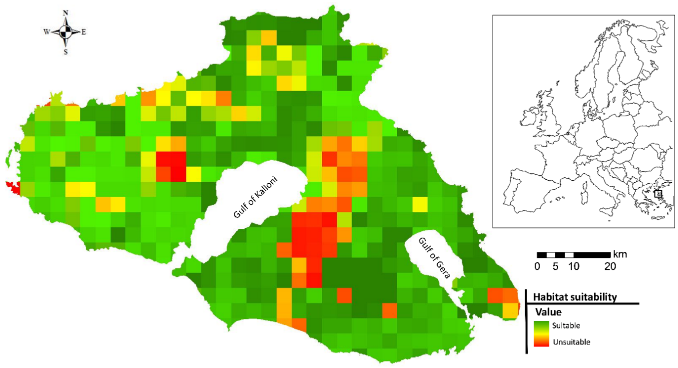

Figure 2 – Map of estimated habitat suitability of Persian Squirrel in Lesvos.

forms well and where it does not (Jiménez-Valverde, 2012; Lobo et al., 2008). Nevertheless, AUC is informative when true absences are available and the goal is to estimate the true distribution (Jiménez-Valverde, 2012; Lobo et al., 2008). Typically, models having an area under the curve (AUC) >0.7 (Hosmer and Lemeshow, 2000) are considered successful and can be trusted for accurate predictions.

Applying the presence/absence model to the study area

To create a habitat suitability map we applied the prediction model to our study area using a 2×2 km grid. For each cell (total of 508 cells), we extracted the habitat and landscape features of CLC and TotalTreeCD with significant loadings in the four principal components of the PCA (Tab. 1). Then, we calculated new factor scores, for each cell, using the expression $NFS_i = \sum(Z_j CS_{ij})$ where NFS_i is the new factor score for cell i, Z_j is the z-score of variable j, and CS_{ij} is the component score for cell i and variable j. We finally calculated the habitat suitability for squirrels for each grid cell by applying these new factor scores to the binary logistic regression model (Eqn. 1):

$$P = \frac{1}{1 + e^{-\text{intercept} + B_1 NFS_1 + B_2 NFS_2 + \ldots + B_i NFS_i}} \quad (1)$$

All the statistical analyses were carried using the SPSS software (v. 25.0. Armonk, NY: IBM Corp.).

Results

The PCA conducted on habitat and landscape feature variables extracted four significant PCs based on eigenvalues which cumulatively explained 91.7% of the total variance. The communalities and loadings of the variables on the four PCs are presented in Tab. 1. Most of the communalities are higher than 0.90 except for one at 0.885. The high communality values strengthen the explanatory power of the four retained components. The first PC (PC1, 36.8% of total variance) was strongly associated with OtherBroadLTD, BroadLTD, and TotalTreeCD. OtherBroadLTD had the highest loading on PC1 (0.951). The second PC explained 22.9% of the total variance and was strongly associated with OliveGroveLC (0.932) and OliveTD (0.922). The third component (20.2% of total variance) was strongly associated with ConifLC and ConiferTD (0.950 and 0.894). BroadLFLC (0.951) and ChestnutTD (0.962) are strongly associated with the fourth component which explained 11.8% of the total variance.

The results of the binary logistic regression are shown in Tab. 2 and 3. The model has a very good fit ($\chi^2_{4,N=480}$=298.38, p<0.001), with an overall classification accuracy of 84.8% (Nagelkerke R^2=0.617; Hosmer=Lemeshow=43.852, p>0.05). It is noteworthy that PC3, related to pine forest, has a negative coefficient. PC2, related to Olive groves has a positive coefficient but PC4 (chestnut tree density and broad-leaf land cover) is not statistically significant. The area under the ROC curve (AUC=0.891; S.E.= 0.015; 95% CI 0.862–0.921; p<0.001) (Figure S2) showed a high discriminatory performance.

The habitat suitability map produced using the result of the above analysis procedure is shown in Fig. 2. A cut point (threshold) of 0.6211 was selected based on the ROC curve. Cells with values greater than 0.6211 represent the ones where squirrels are likely to be present, cells with lower values are where squirrels are likely to be absent.

Discussion

The principal component analysis resulted in four quite distinct factors, all of them related to vegetation cover, including tree density, but none to the topographic or landscape features. The first component (PC1) is mainly influenced by general tree density, with an emphasis on broad-leaved trees (excl. olive and chestnut trees). The remaining three principal components were strongly associated with olive (PC2), conifer trees (PC3), and chestnut and other broad-leaved trees (PC4) respectively. The clear distinction of the four PCs was expected because olive groves, coniferous forest and chestnut plantations are all quite distinct and geographically clearly delimited land cover types of the island (Fig. 1).

The first three principal components, representing seven different tree cover and tree density habitat variables, were found to be important in predicting the relative likelihood of presence Persian squirrels on the island of Lesvos. It appears that it is possible to estimate the habitat suitability for the species with a quite high degree of accuracy on the basis of these seven variables. The model predicts higher habitat suitability in the eastern and southern parts of the island than in western parts, where the treeless phrygana habitat dominates and where trees, when present, are scattered or in small patches. Those cells in western parts which do have a more suitable habitat are those with larger stands of broad-leaved trees (these are especially *Quercus*). Oak trees are of direct importance to squirrels as a food source in autumn and winter

Table 2 – Binary logistic regression model with 10000 bootstrap iterations for the probability of squirrel presence. B = logistic coefficient; Bias = change in B when bootstrap method is applied; S.E. = standard error of estimate; *p*-value = significance; 95% CI = 95% confidence interval.

Predictor	B	Bias	S.E.	*p*-value	95% CI upper	lower
PC1	1.669	0.120	0.263	<0.001	1.211	3.078
PC2	1.258	0.054	0.212	<0.001	0.937	1.910
PC3	−1.543	−0.087	0.310	<0.001	−2.190	−1.216
PC4	1.059	0.738	2.002	0.273	0.231	7.739
Constant	−0.021	0.090	0.329	0.919	−0.732	1.345

Table 3 – Classification table of observed and predicted presence/absence.

Observed	Predicted Presence	Absence	Correct
Absence	220	20	91.3 %
Presence	54	186	78.2 %
Overall Correct			**84.8 %**

(Kryštufek and Vohralík, 2005; Koprowski et al., 2016; *pers. obs.*). The olive groves of Lesvos may also harbour other cultivated trees that serve as food sources. Lesvos's olive groves are mostly of the "traditional" type, frequently with terraces and dry-stone walls, very mild cultivation practices, low pesticide use, a diverse herbaceous vegetation on the ground (Zevgolis et al., 2021), and, what is most important for squirrels, often with other tree species at field edges, streamsides or near settlements (*pers. obs.*). Such tree species as walnuts and almonds are very widely planted in small areas, not sufficiently extensive to appear as distinct types of land cover, but which are of great importance to Persian squirrels as food sources. Oak, olive and other broad-leaved trees, are important to squirrels for a further reason, in providing cavities suitable as nest sites (Kryštufek and Vohralík, 2005; Khaili et al., 2015; Koprowski et al., 2016; Aidek et al., 2021; *pers. obs.*).

Thus, as expected from the literature, our results show that the species uses all habitats with trees, both cultivated and natural or semi-natural (tree crops or woodland). It is noteworthy, however, that natural pine woodland, covering a substantial part of the island (342.9 km^2), appears totally unsuitable in large blocks. The pine forests of Lesvos tend to be single-species forests with very little admixture of other tree species (Palaiologou et al., 2020) and with little other herbaceous or shrubby vegetation in the undergrowth. Although Persian Squirrels do regularly feed on pine cones in Lesvos (*pers. obs.*) as they do in other parts of their range (Abi-Said et al., 2014), pure pine woodlands as found in Lesvos are not suitable habitat. This is likely to be due to the lack, or scarcity, of two main resources necessary for squirrel survival: tree holes and alternative food sources available for the time of year when cones are scarce, i.e., after the cones open in June and until next year's crop has ripened sufficiently (*pers. obs.*). As in other parts of their range (e.g., Aidek et al., 2021), squirrels in Lesvos often feed on the flower and seed heads of Papilionaceae, Asteraceae and other herbaceous plants on the ground (*pers. obs.*). Compared with areas with broad-leaved trees, there is little herbaceous vegetation in pine forests. Thus, this alternative food source is scarce or absent from pure pine forests. Moreover, the use of woven dreys in tree branches has never been documented for Persian Squirrels (Gavish, 1993), and has never been observed on Lesvos (*pers. obs.*); the scarcity of cavities in pure pine forests could be a further limitation, though probably secondary to low food source diversity. Thus, although the species' habitat is often described as including coniferous forest (Abi-Said et al., 2014; Soyumert et al., 2010; Albayrak and Arslan, 2006; Amr et al., 2006), the Lesvos population does not appear to use the major areas of *Pinus brutia* or *P. nigra* forests. Nevertheless, it should be stressed that this does not mean that Persian Squirrels do not use pine trees in Lesvos. On the contrary, they are regularly observed to do so but only at the edges of large patches of forest or in isolated stands or single pine trees in a wider broad-leaved tree setting.

Apart from the avoidance of pure pine woodland and of treeless shrubby habitats, Persian Squirrels in Lesvos appear quite catholic in their habitat preferences, making use of more or less any habitat with broad-leaved trees, whether natural, semi-natural or cultivated. Unlike conclusions from previous work (Matsinos and Papadopoulou, 2004), records of the species even in rather isolated small patches of broad-leaved trees in western Lesvos indicate considerable resilience of this population to fragmentation. This could be due to the much more terrestrial habits of the species compared with, e.g., *Sciurus vulgaris* (Koprowski et al., 2016). Although widespread on the island of Lesvos, this population may still be at risk from a variety of habitat-related threats both because it is isolated and because all of its main habitats are affected by human activities. Olive cultivation, as well as grazing shrubland with scattered oak trees, are currently compatible with squirrel presence. Expansion of urban areas and intensification of agricultural practices, as has been seen in recent decades as a result of changing socio-economic conditions and agricultural policies, could easily lead to serious habitat degradation or loss for this island population.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Full list of variables obtained for each grid cell used in the PCA.
Figure S2 ROC curve of the binary logistic regression model.