The Influence of Vegetation and Anthropogenic Factors on the Distribution and Vocal Activity of Eurasian Scops Owls in Mytilene, Greece

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Abbreviations

GLM	Generalised Linear Model
LMM	Linear Mixed Model
NDSI	Normalised Difference Soundscape Index
SD	Standard Deviation
SE	Standard Error

Abstract

Many studies have demonstrated how urbanisation can impact the distribution and behaviour of animals. However, this has largely focused on diurnal species, resulting in a limited understanding of how nocturnal species are impacted. The Eurasian Scops Owl is a nocturnal insectivore that vocalises at night and often relies on vegetation for nesting and foraging. They are abundant in Southern Europe and commonly sighted in Mytilene, Greece. This study aims to understand the factors that influence Scops Owl distribution and behaviour in Mytilene with reference to vegetation characteristics and anthropogenic noise. Owl presence was estimated by quantifying average call probability over 5 nights at 15 sample sites. The vegetation characteristics of these sites were recorded, including diversity and density. Anthropogenic noise levels were calculated using the Normalised Difference Soundscape Index (NDSI). The results show no significant effect of vegetation diversity or density on Scops Owl presence. Anthropogenic noise levels significantly decreased overnight; however, this did not significantly affect the presence or vocal activity of Scops Owls. The effects of vegetation could be explained by a high food availability, abundance of nest building resources or decreased predation risk in the study area, reducing the need for individuals to distribute near areas of diverse or dense vegetation. Low levels of anthropogenic noise in the area may explain why vocal activity was not affected overnight, as the Scops Owls have not experienced the level or duration of exposure to noise pollution to measurably impact their presence or alter their vocal activity. These results suggest that in Mytilene, the distribution and vocal activity of Scops Owls are not significantly influenced by these vegetation characteristics or anthropogenic noise, implying that they do not need to prioritise these factors in selecting a habitat that optimises their fitness.

Introduction

The distribution of animals within an environment broadly describes where they are present and where they are absent. Habitat selection implies that an animal is distributed in areas that maximise its fitness and survival, suggesting a level of understanding of ecosystem functions and services (Jones, 2001). Animal distribution and habitat selection are heavily influenced by biotic and abiotic factors. Biotic factors relate to the ecological interactions within an area, such as competition, predation and food availability, while abiotic factors relate to the physical characteristics of the environment, such as climate, topography, and vegetation structure. Another contributing factor to animal distribution is anthropogenic, or human, factors, such as urbanisation. The influence of anthropogenic and vegetation factors on animal distribution has been widely studied in many animal groups, particularly birds (Weaving et al., 2011, Lamanna et al., 2015, Connelly et al., 2020).

Urbanisation has increased exponentially since the early 1900s, with large cities expanding and small cities emerging rapidly. Current projections estimate that 6.68 billion people will live in urban areas by 2050 (Kundu and Pandey, 2020). The negative effects of urbanisation on the environment include habitat loss through degradation and fragmentation, increased pollution, and the knock-on effects on animal groups (Theodorou, 2022). Among the many changes that urbanisation brings, greater levels of noise pollution can be found in both urban and rural areas. Anthropogenic noise arises from traffic, transport, construction, and other recreational human activities, such as loud music or sports. Noise pollution is particularly impactful on animals that rely on vocal communication to optimise their overall fitness, such as birds. Noise can mask communication (Halfwerk et al., 2011), preventing conspecifics from hearing calls, affecting breeding success and territory defence, or act as a distraction, impacting vigilance and foraging (Bahía et al., 2024, Passarotto et al., 2025). Research shows that forest birds in semi-urban sites can alter aspects of their calls to maximise communication when anthropogenic noise levels increase. How calls change varies between species but usually involves acoustic parameters such as amplitude and frequency. It is thought that these changes could be passed down generations, resulting in an adaptive evolutionary response (Bahía et al., 2024). However, if species are not able to successfully adapt to these conditions, it can create an unsuitable habitat for them. For example, one study found that the area of suitable habitat for the owl species *Ninox strenua* decreased by 55%

in urban sites compared to rural sites (Isaac et al., 2013). This may force individuals to redistribute and find new habitats (Halfwerk et al., 2011), which can be very costly.

On top of the effects of habitat selection and distribution, anthropogenic noise can also alter animals' daily behavioural patterns and disrupt their biological rhythms. Changes in the onset of calling are widely documented responses in birds to anthropogenic noise, with many species showing earlier calling (Foppen et al., 2024, Dominoni et al., 2016). This allows individuals to send and receive calls successfully before anthropogenic noise reaches a level that would mask or interrupt calls. Anthropogenic noise has the ability to not only alter the timings of activity but also decrease overall activity, which could have serious consequences. Research has demonstrated that in response to anthropogenic noise, the overall activity of urban living Great Tits decreased significantly, but there was no significant response in rural living Great Tits. This suggests that an individual's original habitat could play a part in their response to anthropogenic influences (Dominoni et al., 2020). If an individual's calling behaviour decreased, it could lower their reproductive and foraging success. For example, exposure to traffic noise significantly decreased clutch size and number of fledglings in Great Tits (Halfwerk et al., 2011). If continued over a long period of time, these negative effects could impact an individual's overall fitness, decreasing the suitability of a habitat and triggering redistribution. These examples demonstrate the influence of anthropogenic factors on animal distribution and behaviour, the study of which has heavily focused on diurnal birds. The same ecological principle could apply to nocturnal species too; however, because they are less well understood, this cannot be assumed.

Urban influences have also led to major landscape changes. In Europe, widespread agricultural practices have led to the homogenisation of landscapes and the decline of naturally productive areas. Such changes in landscape and land-use can affect biodiversity and population structures (Martínez et al., 2007). Many studies have found a trend between landscape features and the presence of birds. For example, one study conducted in Brazil found that the presence of open areas and vegetation characteristics, such as a high canopy, were strong predictors of owl distribution. This was explained by these areas likely having a greater diversity of food options, as well as better nest-building resources (Menq and Anjos, 2015). Another study found that *Otus flammeolus* built nests with an open area at the entrance to accommodate them flying in at low heights (McCallum and Gehlbach, 1988). A habitat suitability model developed around Eurasian Scops Owls in Switzerland found that habitat suitability correlated negatively with vegetation cover, potentially explained by a higher abundance of predators in dense forest, such as the Tawny Owl. The model also revealed that suitability correlated positively with the abundance of orthopteran prey (Theux et al., 2022) and it has been suggested that vegetation and habitat diversity are linked to orthopteran richness (Marini et al., 2010). Another study conducted in Spain found that a significant proportion of Eurasian Scops Owl territories were located near areas between tree plantations and seasonal rivers, explained by the high insect diversity in these areas (Martínez et al., 2007). These examples highlight the influence that vegetation diversity and density have on owl distribution, primarily due to the diversity of food options and the presence of open areas.

The Eurasian Scops Owl, *Otus scops* (hereafter referred to as Scops Owl), is a small, nocturnal raptor (Dragonetti, 2007, Martínez et al., 2007, Mori et al., 2014). They are insectivores, eating insects and other invertebrates, as well as some vertebrates, such as small birds and mammals (Theux et al., 2022). Scops Owls have an extensive global range, with individuals distributed across the Palearctic region. However, Europe accounts for over half of its global range, with a particular emphasis on Southern and Mediterranean Europe (BirdLife International, 2021). The Scops Owl call is characterised by a short, repetitive hoot. These calls occur frequently, at a rate of approximately 1 call per 2-3 seconds, which can be repeated for up to several minutes (Dragonetti, 2007). Vocal activity is usually greatest between sunset and midnight, with small fluctuations occurring afterwards (Ganey, 1990, Sevcik et al., 2019). They use calls to defend their territories, attract mates, and alert conspecifics to threats, such as nearby predators (Dragonetti, 2007, Mori et al., 2014, Grieco, 2022). As a result, calling activity and territorial behaviour are increased during the breeding season, particularly among males and nesting females (Mori et al., 2014). Therefore, areas that are Scops Owl territories are likely to exhibit higher calling activity compared to areas that are not Scops Owl territories. Research suggests that Scops Owls can modify their calls in response to threats. For example, one study found that during male-to-male conflicts, individuals would lower the frequency of their calls as the distance between them and their opponent decreased. This may be because a low frequency call correlates with a larger body mass, hence suggesting a more dominant male (Grieco, 2022). This suggests that Scops Owls can modify their call frequency in response to threats.

Scops Owl populations are decreasing. However, due to the rate at which this decline is occurring and their large range, they are not currently regarded as vulnerable, and rank ‘Least Concerned’ on the IUCN red list (BirdLife International, 2021). However, this does not mean that they are not at risk of becoming vulnerable, and in many European countries, they were regarded as endangered for a long period of time following dramatic population reductions approximately 50 years ago (Theux et al., 2022, Denac, 2009). Scops owls may act as indicators of high biodiversity, suggested by research showing that bird richness is higher at Scops Owl breeding sites (Sergio et al., 2005). Therefore, understanding the factors that influence their distribution and habitat selection is not only relevant for their own management, but could also be applicable to other, more vulnerable species that require rapid conservation action.

This study aims to gain a better understanding of the factors that influence the distribution and behaviour of Scops Owls on the Mediterranean island of Lesvos, with specific emphasis on the influence of vegetation and anthropogenic characteristics of the capital, Mytilene, and its surrounding suburban area. This could help inform what factors they prioritise in habitat selection and thus their conservation. To achieve this, the following hypotheses were tested: (i) areas of high vegetation diversity are more likely to have Scops Owls present in them, (ii) areas of high vegetation density are less likely to have Scops Owls present in them, (iii) as anthropogenic noise levels decrease before increasing overnight, Scops Owl presence will increase before decreasing, and (iv) when anthropogenic noise levels increase, the frequency of Scops Owl calls will decrease.

Methods

Study Area and Site Selection

This study was conducted on the East coast of Lesvos, Greece, around the city of Mytilene and the surrounding suburban area. Lesvos is a large Greek island located in the East of the Aegean Sea, where there have been many sightings of Scops Owls (iNaturalist, 2025). Although many individuals migrate to Sub-Saharan Africa during winter (Mori et al., 2014), it is thought that they are year-round residents here (Arnott, 2007, BirdLife International, 2021). Mytilene has a resident human population of 59,034 (ELSTAT, 2021), classifying it as an urban area. The area is characterised by a Mediterranean climate, with hot, dry summers (Koutsovili et al., 2021). The study period ran from July 3rd to July 15th, 2025, during which the mean temperature was 30˚C, with daily temperatures ranging from 23˚C to 37˚C, and nightly temperatures from 22˚C to 32˚C. Sunrise occurred at approximately 06:30, and sunset at 20:30. A total of 15 sites were sampled (Figure 1). This maximised the number of replicates while remaining reasonable given the time and resources available, and the topography of the area. A site assessment study was conducted to finalise potential sites by assessing their accessibility before data collection began. Accessibility involved being reachable by car and being able to access the vegetation on foot from the car while minimising injury risk. In conjunction with this, a survey was carried out on two separate nights to assess Scops Owl presence in the study area. This involved listening for spontaneous calls at sites between 21:30 and 00:30. If nothing was heard within 5 minutes, a recording of a Scops Owl call was played through a speaker to stimulate any individuals in the area. This was carried out for a further 5 minutes. This data was not recorded, but it confirmed that Scops Owls were within the study area, which was essential to assess this project as feasible.

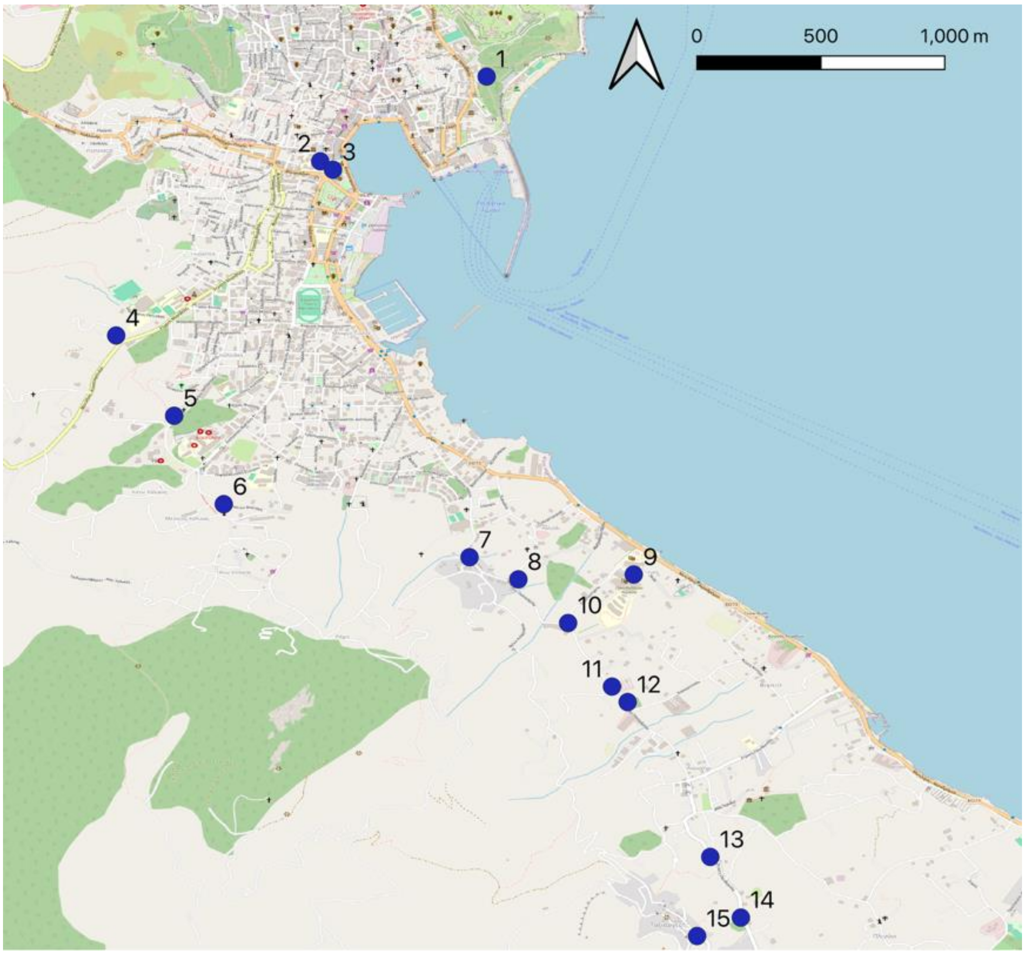

Figure 1: The study area and sample sites. A map of Mytilene (sites 1 to 10) and the surrounding suburban area (sites 11 to 15). Blue points and number labels represent the 15 sample sites used. This figure was created using QGIS (QGIS Development Team, 2021). The coordinates of each site are as follows: 1(39.086098, 26.561474), 2(39.085069, 26.563753), 3(39.083033, 26.566070), 4(39.080069, 26.568116), 5(39.079346, 26.568847), 6(39.085294, 26.569130), 7(39.108514, 26.562272), 8(39.096440, 26.544997), 9(39.104563, 26.554510), 10(39.104169, 26.555106), 11(39.092697, 26.547701), 12(39.088575, 26.550012), 13(39.072125, 26.572700), 14(39.069296, 26.574124), 15(39.068437, 26.572084).

Data Collection

Audio data was collected using AudioMoth devices in order to estimate owl presence and anthropogenic noise levels. AudioMoths were shared with another student collecting the audio data of a different animal; therefore, they were programmed with both of our study species in mind. These recorded 15-second-long audio clips every 15 minutes between 20:30 and 06:30. These intervals were chosen to maximise the likelihood of capturing an accurate representation of noise throughout the night, while preserving battery life, allowing the devices to record and store footage over multiple days. During the study period, each site obtained five days of footage, apart from site 14, which obtained four days of footage due to issues with the AudioMoth activity. Overall, this method generated 3,034 audio recordings for analysis. The average frequency of a Scops Owl call ranges between 1,000 and 2,000 Hz (Dragonetti, 2007, Grieco, 2022); therefore, the AudioMoths were set to record sound up to 16,000 Hz to ensure all calls were picked up. One AudioMoth was deployed at each site on a suitable structure, such as a small branch or pole, and secured with zip ties. The exact height at which it was placed was site-dependent and unable to be fully controlled. However, a single AudioMoth can capture sound across large distances (Manzano-Rubio et al., 2022), so the height at which they were placed was unlikely to affect the results.

To collect data for quantifying the vegetation diversity and density of each site, a laser rangefinder was used to estimate a sample circle around the AudioMoth with a 20m radius. This distance was chosen as it was large enough to provide a reasonable understanding of the vegetation in the immediate area while accounting for logistical constraints, such as time availability and site topography. In particular, some sites were situated on steep slopes or adjacent to roads; therefore, going beyond 20m from the AudioMoth was not safe. Within this area, all vegetation, including trees and shrubs, was identified using PlantNet (Pl@ntNet) (CIRAD et al., 2025), a rapid and accurate plant identification app (Hart et al., 2023). This involved taking detailed photos of each plant, including the bark, leaves, and flowers or fruit (if present), and once uploaded, the app provided the species by comparing the photos with a library of known species. Sampler judgment was used to determine whether the photos accurately matched, and a tally of individuals from each species per site was recorded, as well as the total abundance of trees per site.

Call Probability

Owl call probability was used to estimate owl presence per site. Chirpity (Kirkland, 2025), an automated bird call identifying software, was used to extract recordings that contained Scops Owl calls. The software was programmed to detect recordings containing calls from birds local to the area, with 5% confidence, which highlighted all the recordings with Scops Owls in them. Though this confidence is low, this process merely served to filter out any recordings that definitely didn't contain a call. All flagged recordings were then listened to individually to confirm or deny a Scops Owl call. If a recording contained at least one call, it was marked with 1 in the dataset, and recordings with no call were marked with 0. An average of these values was taken per site.

Call Frequency

The frequency (Hz) of an owl call was determined using the recording's spectrogram in RavenPro (Cornell Lab of Ornithology, 2025), an audio analysis software. The audio file was uploaded, and after listening to the recording and visualising the spectrogram, all Scops owl calls were highlighted using the selection tool. The peak frequency (Hz) of the call(s) was recorded in the selection measurements table. If the recording contained multiple calls, the average peak frequency was calculated. This was repeated for every recording at half past the hour (i.e. 20:30, 21:30, 22:30…06:30) known to contain an owl call.

Vegetation Variables

The vegetation characteristics, including diversity and density, of each site were estimated. This involved calculating species richness, relative abundance and total abundance using the vegetation tally data. For vegetation diversity per site, these values were entered into the Shannon-Weiner Index formula (see Appendix A), where a higher value of H' indicates greater diversity. To quantify vegetation density per site, the total abundance per site was used to estimate the number of trees per $100m^2$ (see Appendix A). $100m^2$ was chosen for the units, as it is less than the area of the sample site, which was $1256.67m^2$. Any unit of measurement greater than the area of the site, such as per hectare, would imply that the density of vegetation was similar beyond the sample site, which could not be assumed.

Anthropogenic Noise

To extract the level of anthropogenic noise in the recordings, the *soundecology* package in R (Villanueva-Rivera et al., 2018, PositTeam, 2026) was used to quantify the Normalised Difference Soundscape Index (NDSI). NDSI estimates the ratio of anthropogenic noise (anthrophony) to biological, or natural, noise (biophony)(Kasten et al., 2012). Values range from -1 to 1, where -1 indicates complete anthrophony, 0 indicates an equal mix of anthrophony and biophony (a mixed soundscape), and 1 indicates complete biophony (Kasten et al., 2012). NDSI values were calculated at half past the hour (i.e. 20:30, 21:30, 22:30…06:30) each night per site.

For comparison against owl call frequency and time after sunset, an average of all NDSI values at each hour was taken and left as a continuous variable. To visualise NDSI trends across sites, mean NDSI values were classified into 3 categories: anthrophony dominated (mean NDSI<-0.1), mixed soundscape (-0.1≤mean NDSI≤0.1), and biophony dominated (mean NDSI>0.1). While a mixed soundscape is usually defined by an

NDSI of 0, a buffer zone of ± 0.1 was applied to account for slight variation around 0 while still indicating roughly equal parts anthrophony and biophony.

Statistical Analysis

All graphs and statistical analyses were carried out using R v.4.5.1 (PositTeam, 2026). To test the hypotheses that owl presence significantly increases in areas of high vegetation diversity and significantly decreases in areas of high vegetation density, a Generalised Linear Model (GLM) for binary data was fitted with owl call probability as the response variable, and vegetation diversity and density as the explanatory variables. A Spearman's correlation test was carried out between vegetation diversity and density. This revealed a non-significant, weak correlation (rho = -0.34, $p > 0.05$); therefore, they could both be included in the same model.

To test the hypothesis that as anthropogenic noise levels decrease before increasing overnight, Scops Owl presence will increase before decreasing, two GLMs were fitted. The first tested whether NDSI significantly changed overnight, with time after sunset as the explanatory variable and NDSI as the response variable. The second tested whether owl call probability significantly changed overnight, and in response to NDSI levels. Here, time after sunset and NDSI were the explanatory variables, and owl call probability was the response variable. This was done as a linear and a quadratic function.

To assess the hypothesis that as anthropogenic noise levels increase, the frequency of Scops Owl calls decreases, a Linear Mixed Model (LMM) was fitted with the frequency of call as the response variable and NDSI as the explanatory variable. Site was controlled by including it as a random effect within the mixed model. This was done as site is an explanatory categorical variable; however, the effect that each level has on the response variable is not the aim of this study, therefore, it only needs to be controlled. This LMM was tested as a linear and a quadratic function.

Results

Vegetation and Scops Owl Call Probability

Mean owl call probability across the entire study period was 7.74%. Call probabilities at each site ranged from 0.00% (at site 13) to 23.42% (at site 4). A total of 45 species of vegetation were found across all 15 sites (see Appendix C). The most abundant species were *Pinus brutia* (Turkish Pine Tree), which accounted for 35.25% of trees, *Olea europaea* (Common Olive Tree), which accounted for 21.07% of trees, and *Pinus halepensis* (Aleppo Pine Tree), which accounted for 9.20% of trees.

The Shannon-Weiner Index values ranged from 0.23 to 2.04 (mean = 0.98, SD = 0.57). The relationship between vegetation diversity and owl call probability can be seen in Figure 2, and it appears that there is no discernible trend between these variables. The results of the GLM confirm that vegetation diversity does not significantly affect the probability of an owl call (Estimate = -0.59 ± 1.97 SE, $p > 0.05$).

The density of vegetation at each site ranged from 0.24 to 5.25 trees/100m^2 (mean = 1.38, SD = 1.22). The relationship between vegetation density and owl call probability can be seen in Figure 3. The results of the GLM reveal that vegetation density does not significantly affect the probability of an owl call (Estimate = -0.36 ± 1.21 SE, $p > 0.05$).

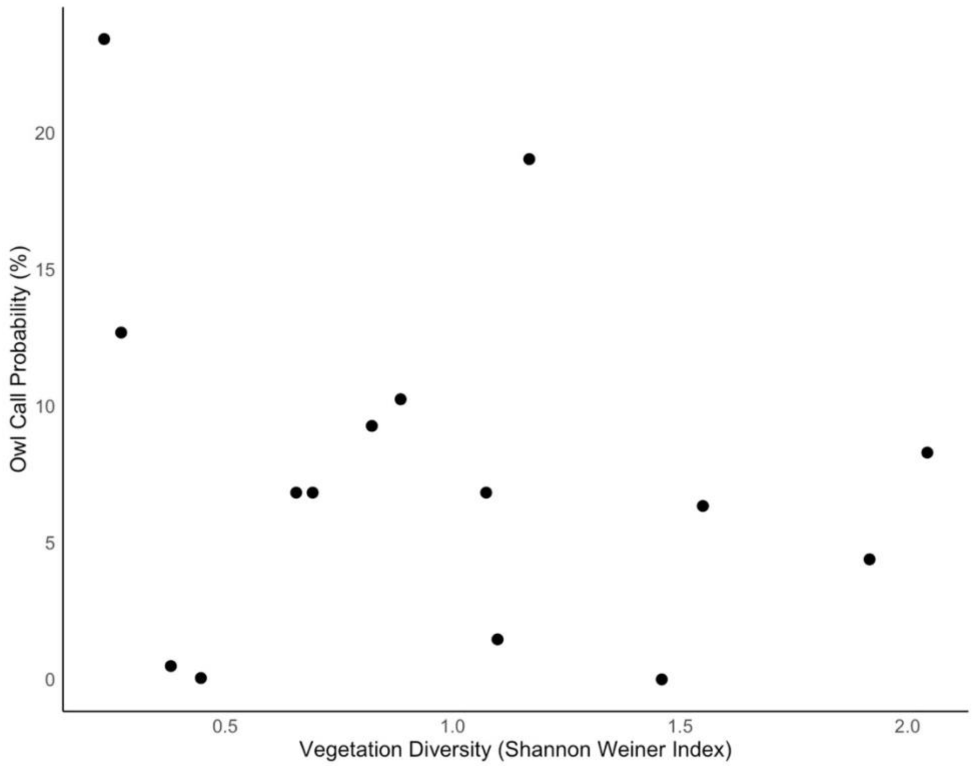

Figure 2. The effect of vegetation diversity on owl call probability. Probability of owl call is expressed as a percentage to help interpret the results more easily and was calculated by multiplying the call probability proportion by 100. Each data point represents a site.

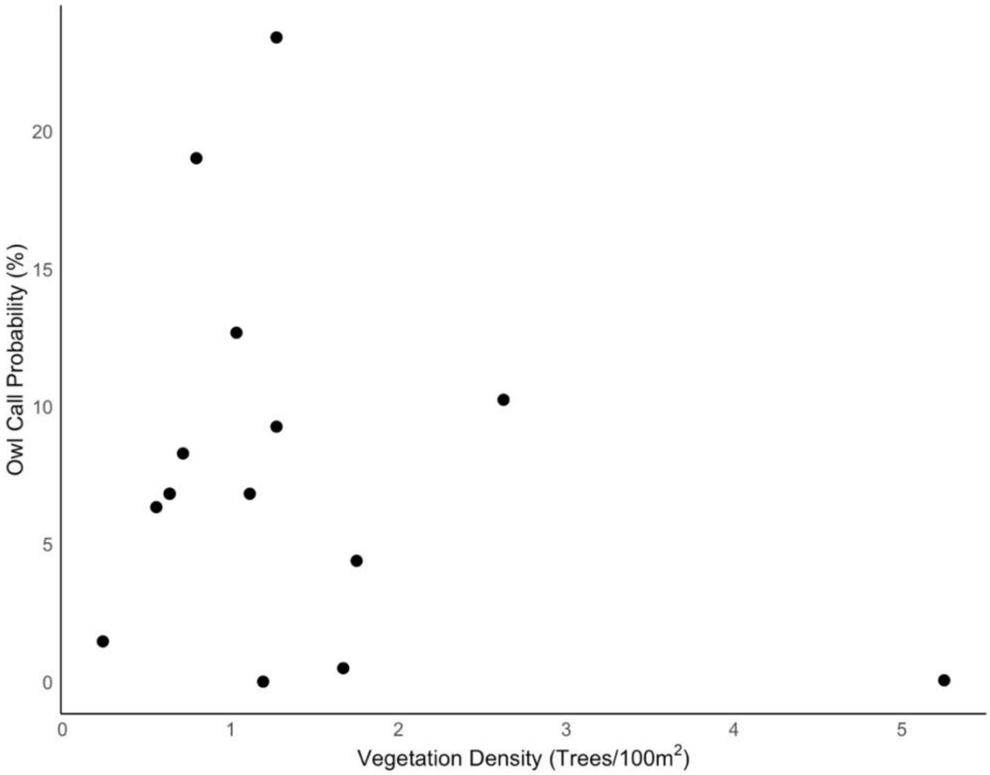

Figure 3. The effect of vegetation density on owl call probability. Probability of Owl Call is expressed as a percentage to help interpret the results more easily and was calculated by multiplying the call probability proportion by 100. Each data point represents a site; however, despite there being 15 sites, there are only 14 data points, because sites 7 and 8 had the same value of density and call probability.

Anthropogenic Noise and Scops Owl Call Probability Overnight

NDSI values ranged from -0.36 to 0.95, with a mean NDSI value of 0.12, indicating that the general soundscape was biophony-dominated. Figure 4 summarises the soundscape type of each site, based on mean NDSI values. Two sites (sites 11 and 12) had an anthrophony dominated soundscape, six sites had a mixed soundscape, and seven sites had a biophony dominated soundscape.

Figure 5 shows the effect of time overnight on call probability (5a) and NDSI (5b). Looking at Figure 5a, from 0 to 6 hours after sunset (20:30 to 02:30), owl call probability increased from 0% to 20.27%. From 6 to 9 hours after sunset (02:30 to 05:30), owl call probability decreased back to 0%. It remained at 0% from 9 to 10 hours after sunset (05:30 to 06:30). However, the results of the GLM reveal that time after sunset does not significantly affect owl call probability as a linear relationship (Estimate = 1.29±2.45 SE, $p > 0.05$) or a quadratic relationship (Estimate = -0.15±0.27 SE, $p > 0.05$). Figure 5b shows a positive correlation between the two variables, such that when the time after sunset increases, NDSI increases, indicating decreasing anthrophony. The result of the GLM confirms that this relationship is statistically significant (Estimate = 0.03 ± 0.01, $p < 0.05$).

Figure 6 shows the relationship between NDSI and owl call probability. The results of the GLM reveal that NDSI, thus anthropogenic noise, does not significantly affect owl call probability as a linear relationship (Estimate = 0.833±27.56 SE, $p > 0.05$) or a quadratic relationship (Estimate = 9.42±151.03 SE, $p > 0.05$).

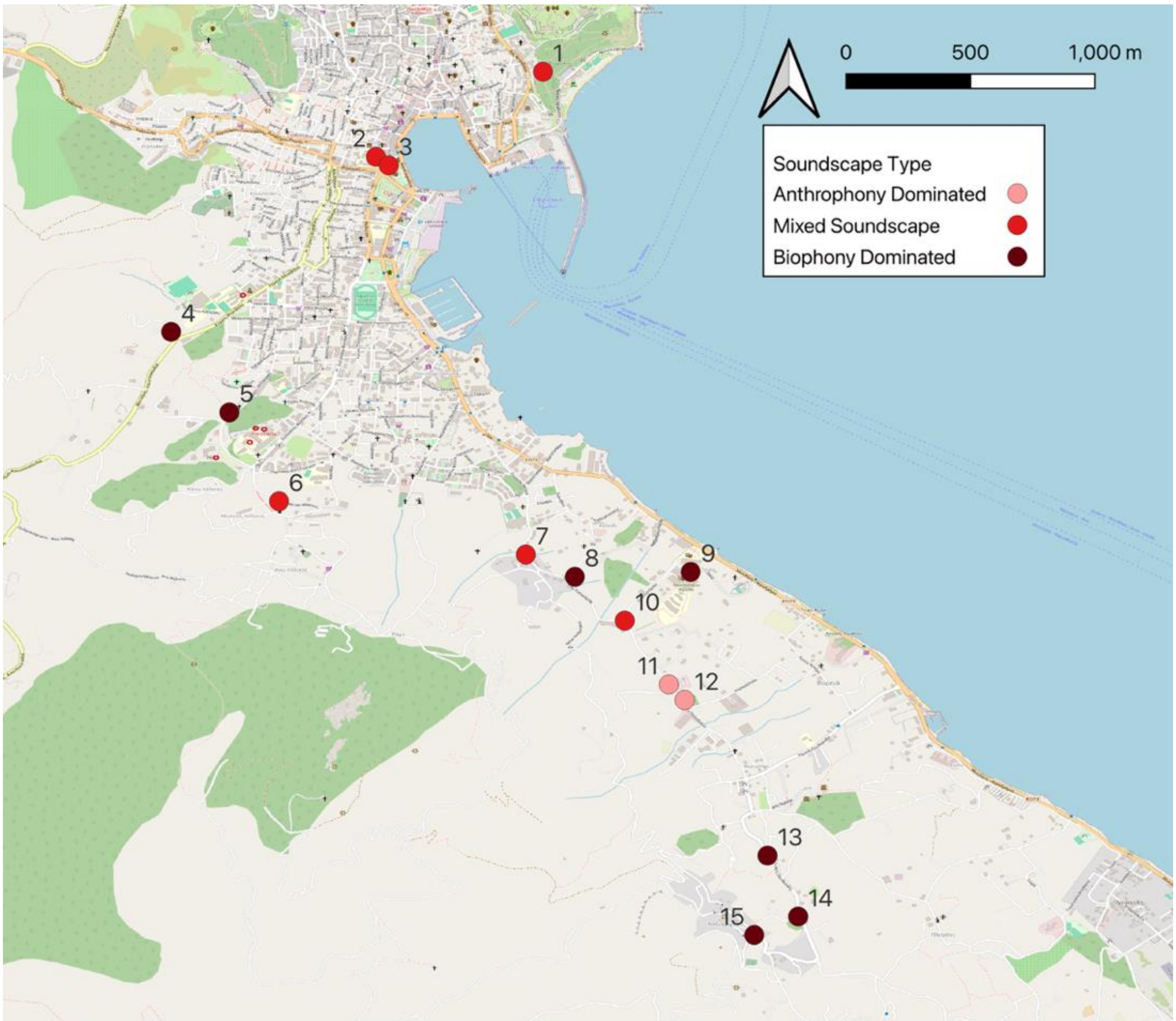

Figure 4. The Soundscape Type of Sampling Sites. A map of Mytilene and the surrounding suburban area, located to the Southeast of the City. Coloured points and number labels represent the 15 sample sites used. Points are colour coordinated by their Soundscape Type based on the mean NDSI value for each site. Pink points represent anthrophony, dominated sites with a mean NDSI between -1 and -0.1. Red points represent sites with a mixed soundscape and a mean NDSI between -0.1 and 0.1. Maroon points represent biophony dominated sites, with a mean NDSI between 0.1 and 1. It should be noted that NDSI was only categorised for this figure, and not for any other figures or statistical analysis. This figure was created using QGIS (QGIS Development Team, 2021).

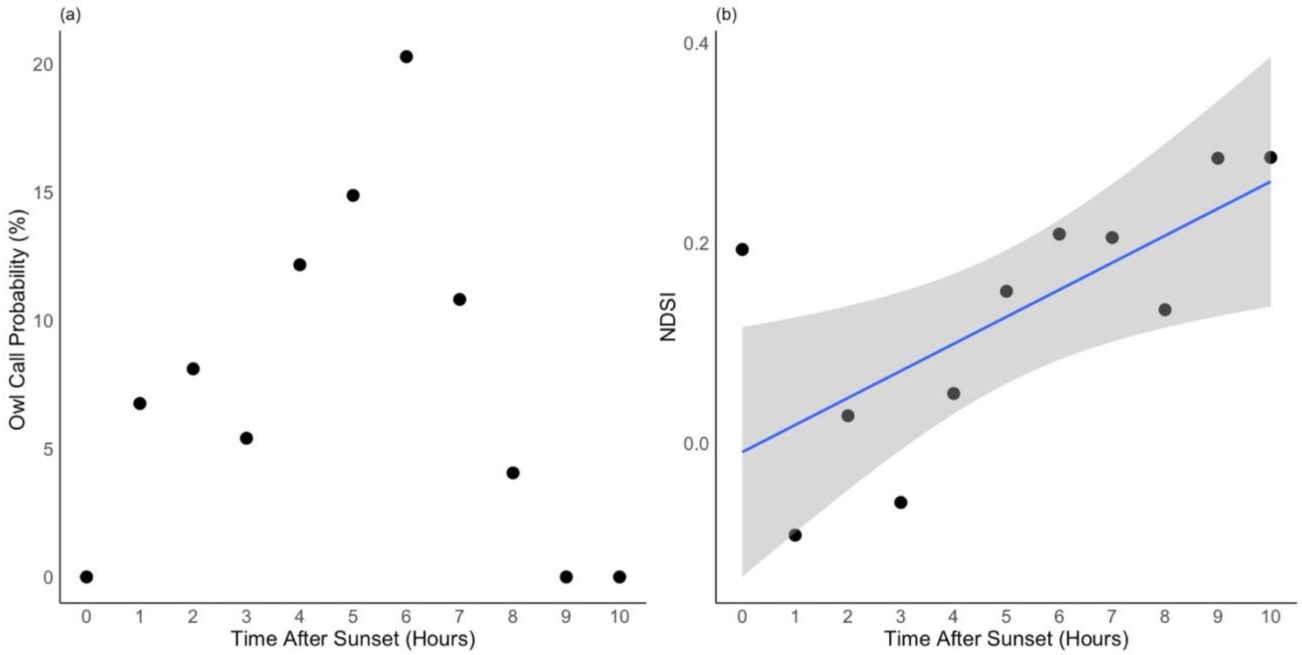

Figure 5. The effect of time after sunset on owl call probability (a) and NDSI (b). When Time After Sunset = 0, the time is 20:30. Therefore, when Time After Sunset = 10, the time is 06:30. Probability of Owl Call is expressed as a percentage to help interpret the results more easily and was calculated by multiplying the call probability proportion by 100. In 5b, the grey shaded area represents the 95% confidence interval around the line of best fit (blue line), which indicates an area of variation around the mean. NDSI is a quantification of anthropogenic noise levels. As NDSI increases from -1 to 1, the degree of anthropogenic noise decreases. When NDSI = 0, anthrophony and biophony are influencing the soundscape equally.

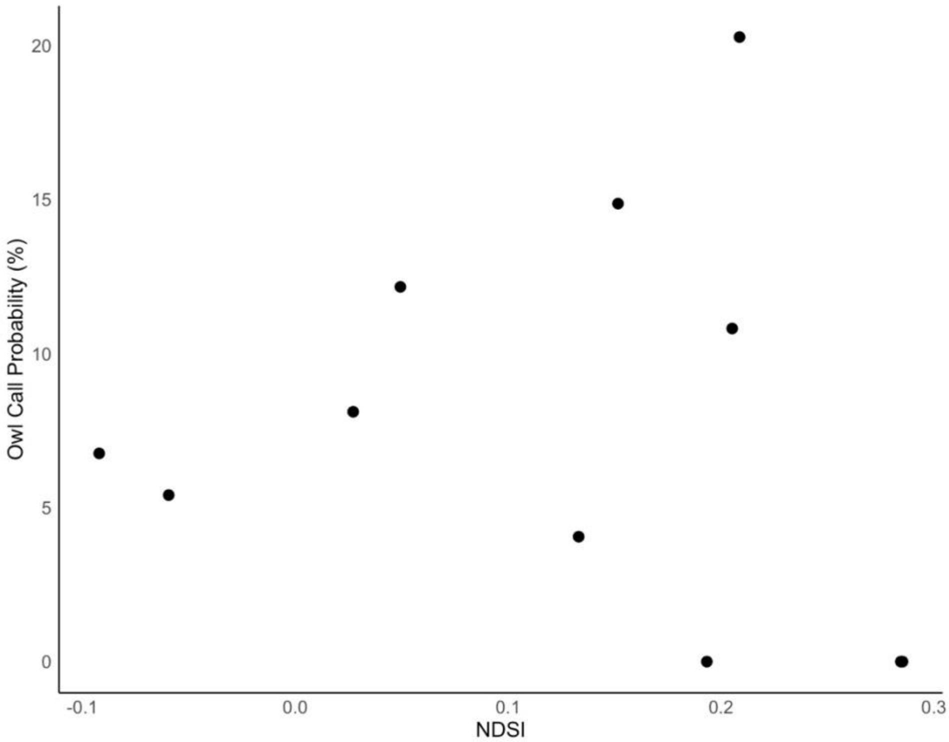

Figure 6. The effect of NDSI on owl call probability (%). Probability of Owl Call is expressed as a percentage to help interpret the results more easily and was calculated by multiplying the call probability proportion by 100. NDSI is a

quantification of anthropogenic noise levels. As NDSI increases from -1 to 1, the degree of anthropogenic noise decreases. When NDSI = 0, anthrophony and biophony are influencing the soundscape equally.

Anthropogenic Noise and Scops Owl Call Frequency

The frequency of individual Scops Owl calls ranged from 1177 to 1547 Hz (Mean = 1269, SD = 84.70). The relationship between NDSI and call frequency is shown in Figure 7, where it appears that there is no linear relationship, but potentially a quadratic relationship. The results of the LMM, however, tell us that the effect of NDSI, hence anthropogenic noise, on the frequency of Scops Owl calls is not significant as a linear relationship (Estimate = 45.67± 52.31 SE, $p > 0.05$) or a quadratic relationship (Estimate = -57.13±79.15 SE, $p > 0.05$).

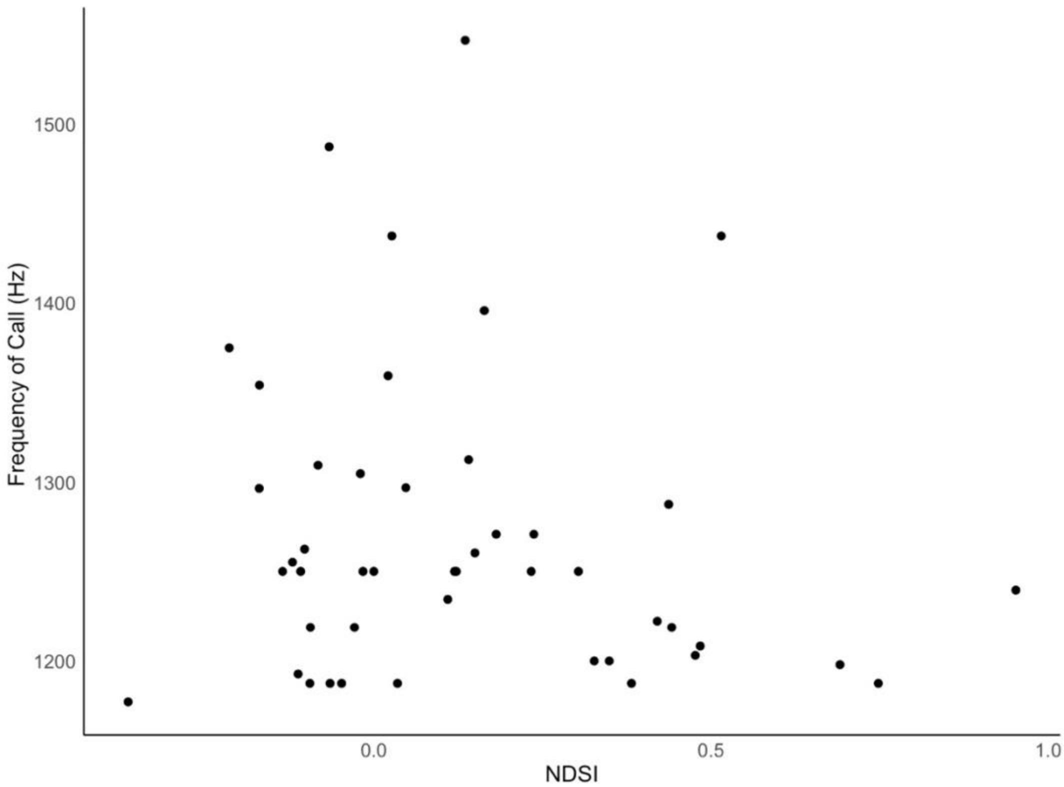

Figure 7. The effect of NDSI on the frequency of Scops Owl Calls (Hz). NDSI is a quantification of anthropogenic noise levels. As NDSI increases from -1 to 1, the degree of anthropogenic noise decreases. When NDSI = 0, anthrophony and biophony are influencing the soundscape equally.

Discussion

This study aimed to understand the influence of vegetation and anthropogenic factors on the distribution and behaviour of Scops Owls in Mytilene and the surrounding suburban area. The effect of vegetation diversity on Scops Owl call probability does not support the hypothesis that areas of higher vegetation diversity show greater Scops Owl presence. Similarly, the effect of vegetation density does not support the hypothesis that areas of greater vegetation density show lower Scops Owl presence. Therefore, I must accept both null hypotheses that there is no significant effect of vegetation diversity or vegetation density on Scops Owl presence. The effect of NDSI and time after sunset on Scops Owl call probability does not support the hypothesis that as anthropogenic noise levels decrease before increasing overnight, Scops Owl presence will increase before decreasing. Therefore, I must accept the null hypothesis that there is no significant effect of anthropogenic noise levels on Scops Owl presence overnight. The effect of time after sunset on NDSI is significant but does not support the hypothesis that anthropogenic noise levels will decrease before increasing overnight. Therefore, I must accept a revised hypothesis that anthropogenic noise levels significantly decrease overnight. The effect of anthropogenic noise on call frequency does not support the hypothesis that as anthropogenic noise levels increase, the frequency of Scops Owl calls will decrease. Therefore, I must accept the null hypothesis that there is no significant effect of anthropogenic noise on Scops Owl call frequency.

Many studies suggest that animals are distributed in areas with greater prey diversity and abundance (Menq and Anjos, 2015, Theux et al., 2022, Martínez et al., 2007). Scops Owls predominantly occur in areas that contain greater insect richness (Martínez et al., 2007). Theux et al., (2022) found that Scops Owl habitat suitability correlated positively with orthopteran abundance. High vegetation diversity can result in increased levels of overall insect diversity (Mutke et al., 2005), and high habitat diversity can support orthopteran abundance (Marini et al., 2010). Here, there is no apparent pattern in where the Scops Owls are distributed between sites based on vegetation diversity. This suggests that they do not need their habitat or territory to be in the proximity of high food availability to optimise fitness and survival. This could be because food availability and insect richness are very high across the study area, which would reduce overall competition for food. Moreover, Scops Owls are not limited in their mobility, and their inconspicuous appearance helps them avoid predators, so even though it may be more energetically costly, they can travel beyond their territory to forage. With this in mind, prioritising food availability, hence vegetation diversity, above other factors in habitat selection may not optimise success, especially if those other factors are limited. For example, if food is abundant but the number of breeding females is low, a male should choose the territory that best attracts females, as opposed to the territory that has the greatest food sources. This is because, at this location, mate availability is the factor that limits the individual's success.

Research suggests that the presence of open areas of space is important for different species of owls. This may be because these areas can aid in nest building (Menq and Anjos, 2015). For example, *Otus flammeolus* prefers nests near open areas of vegetation to accommodate flying at low heights (McCallum and Gehlbach, 1988). This also emphasises how small details of an individual's behaviour can influence their habitat selection. Theux et al., (2022) found that vegetation density was the strongest predictor of Scops Owl habitat suitability, with an optimal coverage of 20-40%. In the present study, vegetation density ranged from 0.24-5.25%, with a mean of 1.38%, which is far lower than the optimal density proposed. Regardless, this did not impact Scops Owl presence, and even at extremely low vegetation densities, there was a large range of call probabilities. Therefore, the results suggest that vegetation density is not a strong contributing factor in Scops Owl distribution or territory selection in Mytilene. Though diversity and density give a good overview of the vegetation structure within an area, it is important to consider the multitude of other vegetative influences that could dictate Scops Owl distribution at these sites. For example, age structure, canopy height, or the presence of particular species of trees (Menq and Anjos, 2015, McCallum and Gehlbach, 1988). It is also worth noting that many studies find that the most suitable habitats for Scops Owls reflect a combination of landscape and vegetation characteristics (Theux et al., 2022, Martínez et al., 2007). Therefore, in Mytilene and the surrounding area, further vegetation analysis into the factors mentioned earlier (e.g. age structure), combined with the results of this study, could be more informative.

The results show that most sites had a biophony dominated soundscape, and even when anthrophony was dominant, the minimum NDSI value was only -0.36, which is still relatively close to a mixed soundscape. A biophony dominated value could either suggest that anthropogenic noise levels were particularly low or that biological noise levels were particularly high. Therefore, even though the results suggest that anthropogenic noise levels are continuously decreasing, they may actually be stable or increasing, but biological noise is increasing to a greater degree. It is also very likely that diurnal birds show strong singing activity in the morning (Dominoni et al., 2016, Foppen et al., 2024), which would further contribute to biophony. This explains why NDSI doesn't decrease in the early hours of the morning as predicted.

Many studies have highlighted the effect that anthropogenic factors have on the activity, behaviour and success of animals (Foppen et al., 2024, Dominoni et al., 2020, Dominoni et al., 2016, Halfwerk et al., 2011, Passarotto et al., 2025). If these changes do not increase survival, urban habitats will become unsuitable, impacting animal distribution and habitat selection. The effect of anthropogenic factors on the timing of behaviours has been demonstrated widely in diurnal birds (Dominoni et al., 2016, Foppen et al., 2024); however, less so in nocturnal birds. Though the effect of time after sunset on call probability was not significant in this study, results show that call probability peaks at 02:30. This is surprising considering other research that suggests peak calling activity occurs between sunset and midnight (Ganey, 1990, Sevcik et al., 2019). It is possible that during this time, general noise levels were particularly high, which masked the Scops Owl calls, however, it should not be ruled out that other factors are resulting in delayed activity. Another anthropogenic influence that can impact nocturnal species is artificial light at night, and many suggest that this works in conjunction with anthropogenic noise (Dominoni et al., 2020, Foppen et al., 2024). Passarotto et al., (2025) demonstrates how this combination decreased the foraging success of Tawny Owls as they could not successfully identify the acoustic signals of prey and relied more heavily on visual predation. If this were the case for Tawny Owls in Mytilene, it would reduce the risk of Scops Owl predation, making it less necessary for Scops Owls to prioritise low predator abundance in habitat selection. Dominoni et al., (2020) found that urban birds showed a greater decrease in activity levels in response to anthropogenic noise compared to rural birds, suggesting that an individual's degree of exposure to anthropogenic noise impacts their response. Although Mytilene is considered urban, anthropogenic noise levels were relatively low throughout the study period. Therefore, it is possible that Scops Owls here have not been exposed to the levels of anthropogenic noise required to elicit any measurable response. The results of this study suggest that at these sites, anthropogenic noise levels overnight are unlikely to affect Scops Owl calling activity, hence implying that individuals are not prioritising particularly loud or quiet areas in their distribution or habitat selection.

Studies have demonstrated how birds can modify the acoustic parameters of their calls over time, or in response to certain stimuli, such as the presence of competitors, or anthropogenic noise (Dragonetti, 2007, Grieco, 2022, Bahía et al., 2024). Greico (2022) found that male Scops Owls reduced their call frequency during competition. Here, no change in call frequency was observed, suggesting that the Scops Owls do not perceive anthropogenic noise as a threat to their reproductive success or survival. This may be because anthropogenic noise levels are not severe enough to mask their calls, or that they recognise it as foreign, thus not worth competing with. It is also important to consider the physiological and ecological consequences of altering a call. Changing frequency, or another vocal parameter, will come with an energy cost to the individual and may also convey a different message, which could impact interactions. For instance, it could make them more detectable by acoustic predators or appear less suitable to mates. Therefore, an individual must strike a balance between maximising successful communication while reducing the likelihood of these consequences. It is possible that in Mytilene, anthropogenic noise levels were not high enough for the Scops Owls to risk this trade-off; therefore, call frequency did not change. Lots of studies involve measuring how individuals alter their calls through more rigorous spectrogram analysis (Bahía et al., 2024) and suggest that many Scops Owls vary aspects of their calls over time (Dragonetti, 2007). Therefore, Scops Owl calls may alter in response to anthropogenic noise, but the aspects that change differ between individuals. For example, some may alter frequency, whereas others alter amplitude (Bahía et al., 2024). Therefore, I cannot rule out individual responses to anthropogenic noise; however, it is evident that this was not consistent across the entire population.

These results, compared with existing literature, suggest that the development of smaller towns and cities may be less impactful for Scops Owls than the expansion of existing, large cities. However, because the sites in this study were primarily biophony dominated, the full impact of anthropogenic noise remains unknown. So, I suggest that future research should start to prioritise experimental studies or those that exist on a larger scale, for example, utilising a large urban gradient. An additional potential limitation of this study is that a positive correlation between owl call probability and owl presence has been assumed, based on their highly territorial behaviour and the large number of replicates obtained from my data collection. If a call is heard in a recording, it confirms the Scops Owl's presence at that given time and location. However, if no call is heard, it does not confirm absence, as the individual(s) might be present but not calling. Therefore, because this is an assumption, it cannot be ruled out as an explanation for the results. Another limitation is that if noise levels were particularly high, the likelihood of a Scops Owl call being heard and identified was reduced. Many recordings contained loud noise, for example, dogs barking, cars, loud music, etc., all of which would have prevented a Scops Owl from being identified if it were calling, hence decreasing the accuracy of the results.

In conclusion, the results of this study show that neither vegetation diversity nor density affects the presence of Scops Owls in Mytilene, suggesting that individuals do not prioritise these vegetation characteristics in their habitat selection. Anthropogenic noise levels did not affect Scops Owl presence overnight, nor did it affect the frequency of their calls. Though these results are not significant, they are positive. They suggest that anthropogenic noise has not reached a level in Mytilene where it impacts the Scops Owl's distribution, forcing them into more rural habitats. It also implies that the area provides individuals with abundant resources, such that their success is not limited by the vegetation of their immediate habitat. However, that is not to say that these factors will never impact this species here, and further monitoring of Scops Owls and other nocturnal species is necessary to understand how this progresses as urbanisation and the destruction of natural habitats increase. Not only could these findings be beneficial for informing future research, but they also highlight the complexity of animal distribution and behaviour. It is not a universally applied concept and largely depends on the specific habitat, location, and species, as well as how these components interact.

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Appendix A. Formulae

Shannon-Weiner Index:

$$H' = -\sum_{i=1}^{S} pi * \ln(pi)$$

The formula used to calculate the Shannon-Weiner Index per site, where pi is the proportion of trees/shrubs of species ‘i’ in the sample.

Vegetation Density:

$$Density = \frac{N}{1256.64} \text{ x } 100$$

The formula used to calculate vegetation density per site, where N is the number of trees/shrubs in the sample area.

Appendix B. R Outputs

Vegetation Diversity and Density Correlation Test:

```
	Spearman's rank correlation rho

data:  data1$Vegetation_Shannon_Index and data1$Density
S = 749.34, p-value = 0.2177
alternative hypothesis: true rho is not equal to 0
sample estimates:
       rho 
-0.3381043 
```

Call probability ~ Vegetation Diversity + Vegetation Density:

```
Call:
glm(formula = Proportion_presence ~ Vegetation_Shannon_Index + 
    Density, family = binomial(), data = data1)

Coefficients:
                         Estimate Std. Error z value
(Intercept)               -1.4782     2.6631  -0.555
Vegetation_Shannon_Index  -0.5948     1.9654  -0.303
Density                   -0.3561     1.2079  -0.295
                         Pr(>|z|)
(Intercept)                 0.579
Vegetation_Shannon_Index    0.762
Density                     0.768

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 0.95047  on 14  degrees of freedom
Residual deviance: 0.78493  on 12  degrees of freedom
AIC: 8.4306

Number of Fisher Scoring iterations: 6
```

Call Probability ~Time After Suset + NDSI:

```
Call:
glm(formula = Presence_proportion ~ Time_After_Sunset + I(Time_After_Sunset^2) + 
    NDSI + I(NDSI^2), family = binomial(), data = data4)

Coefficients:
                       Estimate Std. Error z value Pr(>|z|)
(Intercept)             -4.6873     5.5654  -0.842    0.400
Time_After_Sunset        1.2864     2.4500   0.525    0.600
I(Time_After_Sunset^2)  -0.1465     0.2688  -0.545    0.586
NDSI                     0.8328    27.5613   0.030    0.976
I(NDSI^2)                9.4174   151.0313   0.062    0.950

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 0.76543  on 10  degrees of freedom
Residual deviance: 0.17869  on  6  degrees of freedom
AIC: 11.759

Number of Fisher Scoring iterations: 7
```

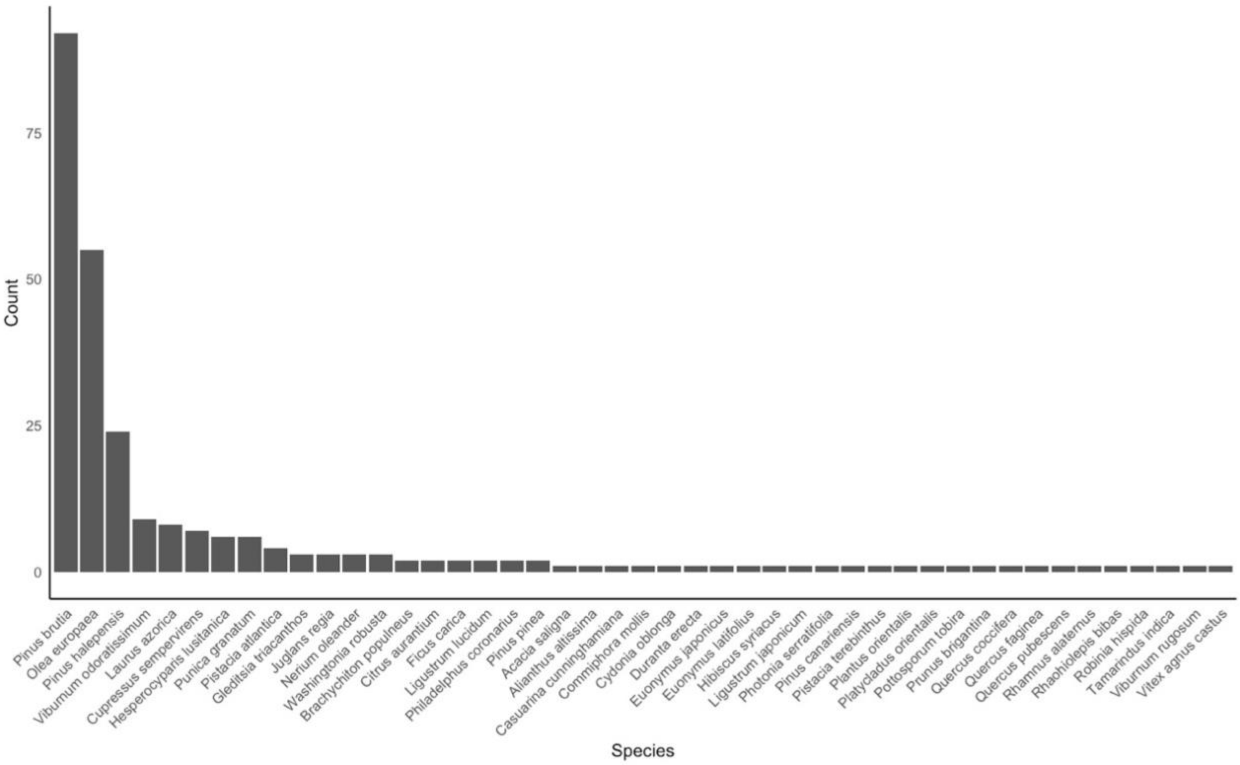
NDSI ~ Time After Suset:

```
Call:
glm(formula = NDSI ~ Time_After_Sunset, data = data4)

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      -0.009073   0.055173  -0.164   0.8730
Time_After_Sunset  0.027020   0.009326   2.897   0.0177 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.009566886)

    Null deviance: 0.166410  on 10  degrees of freedom
Residual deviance: 0.086102  on  9  degrees of freedom
AIC: -16.135

Number of Fisher Scoring iterations: 2
```

Call Frequency ~ NDSI

```
Linear mixed model fit by REML. t-tests use
  Satterthwaite's method [lmerModLmerTest]
Formula:
Call_frequency ~ NDSI + I(NDSI^2) + (1 | Site)
   Data: data2

REML criterion at convergence: 483.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7841 -0.4218 -0.2003  0.2498  2.2424

Random effects:
 Groups   Name        Variance Std.Dev.
 Site     (Intercept) 6664     81.63
 Residual             2217     47.09
Number of obs: 46, groups:  Site, 13

Fixed effects:
            Estimate Std. Error      df t value
(Intercept)  1279.00      24.56   12.07  52.077
NDSI           45.67      52.31   34.85   0.873
I(NDSI^2)     -57.13      79.15   32.25  -0.722
            Pr(>|t|)
(Intercept) 1.42e-15 ***
NDSI           0.389
I(NDSI^2)      0.476
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
          (Intr) NDSI
NDSI      -0.066
I(NDSI^2) -0.066 -0.724
```

<u>Appendix C. Vegetation Species Counts</u>



Bar chart showing the number of trees or shrubs of each species of vegetation found across all 15 sites.

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