The Effect of Touristic Development on Mediterranean Island Wildlife

Eric Krawczyk

A Thesis submitted

in partial fulfillment of the requirements

for the degree of

Master of Conservation Ecology

(Natural Resources & Environment)

At the University of Michigan

April 2017

Thesis Committee:

Johannes Foufopoulos, Associate Professor (Chair)

Kathleen Bergen, Associate Research Scientist (Committee Member)

Abstract: Tourism constitutes a significant income source for the economies of various countries, however it is also associated with a number of negative environmental consequences. These may include the degradation of ecologically valuable stretches of both coastal and inland regions due to diffuse construction of touristic infrastructure, expansion of originally small settlements, and overexploitation of natural resources. In the Mediterranean Sea Basin, impacts on biodiversity are particularly important as the region is recognized as a major biodiversity hotspot of global importance, harboring numerous endemic species. The aim of this project was to evaluate the implications of touristic development for wildlife in a typical Mediterranean island ecosystem landscape (Naxos, Aegean Sea, Greece). Our research approach combined extensive field surveys of birds and reptiles (completed in 2016) with the creation of image-derived spatial data on built infrastructure at two distinct dates, in order to perform a statistical and spatial analysis of biodiversity and its relationship to the built infrastructure. All built infrastructure and change in that infrastructure was mapped using aerial photographs (1982) and Google Earth high spatial resolution imagery (2015). These dates bracketed a period of significant economic shift towards tourism in the region.

Analysis of biodiversity data showed that birds separated into two groups (non-native versus native species), with the former tending to live closer to human development, and the latter further away from development. Reptile abundance increased monotonically with distance from human development. Presence of cats had a negative effect on reptile abundance. Species richness and diversity of both birds and reptiles rose with increasing distance from development. Transect data revealed non-linear increases in animal abundance and species composition at approximately 80-120 m away from buildings and roads. Using the image time series (1982 and 2015) which contrasted the present land use with the land use of 1982, we found that number of build structures increased by 96%, and length of roads by 113%, thus resulting in a reduction of the remaining natural habitat to 20.6% of the study site. However, within rural areas, we found that development became somewhat more clustered, a pattern which may

somewhat mitigate habitat loss when compared to only a strongly diffuse pattern. The results of this study when considered against the body of knowledge from mainland systems suggest that the effects of touristic development in island ecosystems do not appear to differ qualitatively from those of mainland ecosystems. Further studies on other islands should be conducted in order to further understand developmental impacts on local wildlife.

Introduction

Tourism is a force of rapidly growing economic and ecological importance worldwide. Improved means of transportation have made it increasingly cheaper and convenient for humans to travel across great distances, resulting in a recent worldwide boom in tourism. According to Higgins-Desbiolles (2006), “Tourism is, without a doubt, one of the most important forces shaping the world”. Tourism has become, for many countries, a critically important source of revenue and employment (Higgins-Desbiolles 2006). Both touristic activities and their impacts tend to become disproportionately concentrated on these specific areas that are foci of foreign visitor interest whether for historic significance, aesthetic appeal or cultural importance (Andriotis 2010). An example of this are the coastlines of the Mediterranean Basin, which have been attracting increasing numbers of visitors predominately from central and northern Europe. As a result, Mediterranean coastlines across a broad swath of countries are experiencing a rapid expansion of tourist settlements.

Greece is a well-known example of a country that has experienced a rapid expansion of the tourist sector (Dritsakis 2004). In particular in the coastal and island regions of the country, tourism has wrought dramatic changes in the local economies and natural habitats. On many Aegean islands, what was once an economy based on agriculture and fishing, is now driven by tourists visiting to see historic sites and attractive landscapes (Andriotis 2010). Since the onset of tourism around the 1970s, quality of life and employment opportunities have improved dramatically for local residents (Andriotis 2010; Dritsakis 2004; Loumou et al 2000). As numbers of foreign visitors expanded so did the need for housing and accommodations in what are fairly constrained island landscapes. The resulting building boom, resulted not only in an outward expansion of pre-existing settlements but also in the construction of large numbers of rental accommodations and second homes in previously rural landscapes, especially close to beaches (Loumou et al 2000).

Although tourism undoubtedly has had an intensely positive effects on the economy of Mediterranean countries, it has also resulted in increased consumption of resources and led to widespread environmental degradation (Andriotis 2010). The transition from traditional agricultural societies to a modern mixed economy that focuses predominantly on tourism and profits has resulted in a wide range of profound changes to these coastal and island habitats most affected by touristic expansion (Loumou et al 2000). It is therefore particularly important to investigate wildlife on island ecosystems due to their reduced dispersal rates, reduced gene flow, and higher probability of speciation on islands, when compared to their mainland counterparts (Stuart et al 2012). Islands harbor unique habitats that can contain species only found on a single island. On the mainland, substantial research has been done regarding the response of animals to human development. Although there are many species that have adapted to co-exist with human presence (Clergeau et al 1998; Blair 1999; Crooks et al 2004; Bock et al 2008) it is probably true that the majority of species are negatively affected by human development (Koenig et al 2001; Audsley et al 2006; Sutherland 2009; Tryjanowski et al 2015).While much research has been conducted on the effects of tourism on human populations, the economy, and agriculture in the Mediterranean, relatively little is known about the spatial impacts of tourism on biodiversity, especially on wildlife communities (Dritsakis 2004; Haralambopoulos and Pizam 1996; Loumou et al 2000). Furthermore, even less is known about how touristic development effects wildlife populations on island ecosystems.

The overall aim of this study is to quantify the effects of touristic development on a typical lowland Mediterranean habitat. The main objective of our research is to determine changes of wildlife population size, as well as species richness and diversity across a gradient of human presence. Use of a gradient allows us to determine the extent of the footprint of human activities across a natural landscape and then assess influence on habitat and wildlife. We also examined species identity in order to determine whether composition of bird and reptile species community changes in relation to distance from development. The goal was to determine at what distance does abundance and diversity of birds and reptiles change in relation to development. In order to accomplish the above objective, we carried out biodiversity surveys in the field, and mapped out all built environments (buildings and roads) using aerial photography and other high spatial resolution imagery.

To further determine the extent of tourism change on resident wildlife populations, we quantified the increase in number of new buildings and associated roads in the study region over the past 33 years. Using mapping based on two dates of photography/imagery (1982 and 2015) we were able to determine the changes in housing and road infrastructure between the two dates. We then were able to determine change in the human-built infrastructure and its impact on loss of available habitat based on our field surveys on the distance effects for different species groups. This was further complemented by a spatial analysis of distance between buildings and density of both roads and buildings brought on by the recent tourist housing boom to determine if buildings have become more diffuse, clustered, or a mixture (Gonzalez-Abraham et al 2007).

Methods

Study Area and Sample Sites Selection

Fieldwork was conducted between May and July 2016 on the island of Naxos in the Cyclades archipelago (Aegean Sea, Greece). Naxos (446 km^2, 37°08’N, 25° 25’E) is one of the largest islands in the cluster and is located in the Mediterranean Basin, a major biodiversity hotspot (Myers et al 2000; Victor unpublished). Naxos experiences Mediterranean climate with mild wet winters and warm, dry summers (Nastos et al 2010; Kizos and Koulouri 2006). Both coastal and inland regions are predominantly covered by sclerophyllous scrub habitat, also known as ‘phrygana’. This plant community is very species rich and is dominated by *Genista acanthoclada*, *Coridothymus capitatus*, and *Sarcopoterium spinosum*. Phrygana plants are aridity-adapted, summer-deciduous, and are characterized by a high proportion of aromatic or spinose taxa (Bergmeier and Dimopoulos 2003). Most of the island is comprised of limestone and flysch substrates and its physiography is characterized by mountainous terrain and rocky landscapes. However, the west side of the island is comprised of a wide coastal plain flanked by sandy beaches and fertile soil amenable to farming but also suitable for touristic development.

Naxos is representative of many coastal regions of the Mediterranean Basin where expanding touristic development has been fragmenting lowland habitats. Starting in the 1970s, tourism has steadily expanded on Naxos taking the form of many small settlements along the coastline (Figure 13). A result is an increase in buildings being constructed for a variety of purposes related to tourist accommodation, food, and outdoor activities such as scuba diving, boating, or horseback riding. While many buildings were constructed for rental to international short-term visitors, there are also substantial number of houses that are either build as summer vacation homes or to be occupied by retirees, expatriates or even migrant labor. It is typical that many such buildings are concentrated near beaches because many visitors come to Naxos not just for the esthetic beauty of the natural environment but also for the swimming and sunbathing opportunities.

Our surveys focused on the presence of birds and reptiles, which are the two most ecologically important groups of vertebrates in the Aegean Sea region. These groups have also been shown to be sensitive to human disturbance and have been suggested as useful indicator species (Smart et al. 2005; Suarez-Rubio et al. 2011). To quantify the effects for human disturbance we focused on the impacts of built infrastructure in the form of buildings and roads on resident wildlife. Study locations were identified through a multi-step process. Focusing on the western region of Naxos, where most of touristic development is taking place, we first used satellite images to identify candidate areas were natural vegetation communities prevailed. During subsequent field visits we then determined suitability based on vegetation composition, human occupancy of a focal building, and absence of nearby structures or human activities that might confound survey results. At each location, we further identified a linear transect that started at a site of human infrastructure (either a building or a road), and ended deep inside an otherwise undisturbed natural vegetation community. To avoid confounding effects, road locations for transects were selected to be outside settlements and away from buildings, and building transects were laid out so as to avoid the presence of roads. At each building, we also collected additional data on presence of other factors that may affect wildlife presence such as surface water and food (typical in the form of stored animal feed used for livestock) (Audsley et al. 2006; Bock et al. 2008). Furthermore, we collected information on the presence of resident cats (potential predators), since previous research has suggested that they have the potential to affect wildlife populations (Li et al. 2014). A total of 30 buildings and 20 road transects were found to be suitable for further study.

Bird Surveys

To determine the effects of buildings on resident bird populations, one of us (EK) conducted bird surveys, each along a 300-m linear transect away from a currently inhabited buildings and into nearby natural habitat. Surveys were conducted at four sampling stations located at 20, 120, 220, and 320 m along the transect. To avoid possible confounding effects of agricultural activity, sampling stations were located in natural vegetation communities. At each station, all birds inside a 50 m radius were recorded. The first station was located at 20 m rather than at 0 m from the building in order to avoid disturbing the building's inhabitants. Bird surveys were conducted during the three-hour time period following sunrise (typically around 6:00 AM) coincident with peak bird activity. At each station, bird presence was recorded over a five-minute period following a one-minute initial grace period to let animals recover from the disturbance caused by the arriving observer. Only individual birds that were heard or that were sedentary within the survey zone were recorded, fly-overs were excluded (Odell and Knight 2001; Merenlender et al. 2009). Species ID and distance from observer, in meters (m), were recorded using a rangefinder (Simmons Model 801405). Surveys were conducted daily during the breeding season unless inclement weather conditions affected bird detection, such as strong winds, overcast sky, or rain (Odell and Knight 2001).

To determine the effects of roads on resident bird populations, one of us (EK) conducted bird surveys along a 200-m linear transect away from the road. Surveys were conducted at three sampling stations located at 20, 120, and 220 m away from the road. Survey time, frequency and protocol were the same as for the bird surveys conducted at housing transects.

Reptile Surveys

To determine the effects of buildings on resident reptile populations, one of us (EK) conducted 200-m long reptile surveys along the near transects used for bird surveys. To avoid possible confounding effects of agricultural activity transects were located in natural vegetation communities. Reptile transects started at 20 m away from each focal building in order to avoid disturbing the building's residents. Reptiles were recorded if they were detected within one arm's length (i.e. a total corridor width of 1.8 m) from the central transect line. We recorded the species ID of each individual, and also determined the approximate distance from the focal transect building using a rangefinder (Simmons, Model 801405). To avoid the confounding effects of inappropriate ambient conditions on reptile numbers and to take advantage of reptile activity patterns we started all reptile surveys around 5:00 PM and concluded them at sundown. Surveys were conducted only under favorable weather conductions, such as winds <2Bft, presence of sun, and ambient temperatures between 20-25^{o}C.

To determine the effects of roads on resident reptile populations, one of the authors (EK) conducted reptile surveys along 100-meter linear transects away from typical paved roads. Survey time and protocol are the same as the surveys conducted on reptiles at our housing study sites. Surveys were conducted each day unless ambient conditions interfered with available survey methodologies.

Statistical Analysis.

To obtain accurate estimates of bird density we used the software package Distance provided by the Distance project website sponsored by the Wildlife Conservation Society (Thomas et al. 2010). This software package helps correct observer bias during wildlife surveys which are assumed to be skewed towards missing individuals that are too far from the observer to be detected. Based on the Distance software algorithms, we corrected the numbers of individuals detected during surveys based on the distance from the observer at which each bird was detected (see Odell and Knight 2001). For the analysis we grouped adjusted bird populations together with non-adjusted bird populations since the highest adjustment factor of sampled populations successfully readjusted was always less than 1.6, using the same criteria as in other studies (Bock et al. 2008). The Distance software package was not used for reptile data because the areas surveyed along the transects were small enough were complete estimates of the populations could be achieved (Audsley et al. 2006). Due to the presence of many zeros (0) in the dataset we grouped reptile observations into 40 m long distance bins. Species richness was calculated as the number of unique species found at each station (for birds) or distance bin (for reptiles). A Shannon-Wiener diversity index was calculated using species richness data in order to determine how diverse the bird and reptile communities are within the sampling sites. The statistical analyses were conducted in R-studio 1.0.136, and graphs were created in SPSS version 24 (Rstudio 2015; IBM Corp 2016). All Shannon-Wiener diversity index analyses were performed using a linear mixed effect model (Hager et al 2013). A generalized linear mixed effects model was used in order to complete the analysis on species richness, reptile abundance, and bird abundance.

Spatial Analysis of Habitat and Human Infrastructural Change

Mapped data of built infrastructure on Naxos in 2015 and 1982 were created using photographs and imagery from various sources. Aerial photographs obtained from the Hellenic Military Geography Service (HMGS) were used for the 1982 map (HMGS 1982). These were then compared to recent satellite photographs of 2015 Naxos acquired from Google Earth (Google Inc. 2017). All images were georectified using ERDAS_IMAGINE 2016 (Hexagon Geospatial 2016). Existing contemporary major roads GIS data provided by MapCruzin.com and OpenStreetMap.org were used as the reference layer during the georectification process (OpenStreetMap Foundation 2017). Once photographs were georectified they were mosaicked into two large compound images (one for 1982 and one for 2015) and image and road layers were added into ArcGIS 10.4.1 (ESRI 2017). The projection of the images was WGS_1984_UTM_Zone_35N and the datum was D_WGS_1984. For each of the georectified maps, the road layer was then manually edited in order to accommodate all paved roads within the study region at each date. Roads that were not present in 1982 were deleted, and any other smaller roads that were not present in the existing roads GIS data were added for either or both 1982 and 2015. Roads were mapped as linear features at the scale of 1:100000. A building layer was then created to locate all the various buildings within the study area, with buildings mapped as point features. The above mapping resulted in four shapefiles: one for roads and one for buildings at each date. Once completed, a total number of the buildings (N) and length of roads (in km) were extracted from the mapped data. A buffer was then mapped around the set of point and linear features using the buffer tool to estimate the amount of total disturbance of the study area. Overlap of the building and roads layers were then joined together using the 'Dissolve' tool. The buildings and roads layer were then put into a single dataset by using the 'Union' and 'Dissolve' tools and a total disturbance area was calculated using calculate geometry. This was done for both 1982 and 2015.

Because we were most interested in understanding the effects of touristic development on the landscape in terms of intensification of development into rural areas rather than intensification within existing urban areas (such as the city of Naxos), we stratified our study area. Procedures were implemented in ArcGIS 10.4.1 (ESRI 2016). Dense settlement areas (the city of Naxos plus several later traditional village communities) were identified as polygons and then masked out from the rest of the landscape in the GIS data. We then calculated separate building relationships in the strata containing the traditional settlement areas versus the traditionally more rural regions. We used the ArcGIS 'Near' tool to calculate distance (m) to the nearest other building for each point in the buildings layer. Mean distance between buildings was then determined by averaging these distance values and the values were compared between 1982 and 2015.

As an additional visualization of the influence of touristic development on the landscape, a building density map was created using the ArcGIS 'point density' tool. To do this, we used the buildings layer along with a 100-m cell size, a radius of 8 cells, and hectares for the area unit. Similarly, a roads density layer was created using the 'line density' tool. In this tool we used the roads layer along with a 100-m cell size, a 150-m search radius, and the area units of square kilometers. The density values in both maps were then classified and displayed in the map legends using a modified natural breaks algorithm that was customized in order to have a consistent distribution for the mapped data of both dates. The building density maps were created in order to assist in evaluating the output of the clustering data (mean distance described above) showing that built infrastructure is becoming more clustered. The roads density maps were created in order to help identify where future development is likely to occur.

Results

Effects of Buildings on Birds

Over the course of the 2016 field season, we made 776 bird observations belonging to 21 different breeding bird species. The species were divided into two categories, native and non-native (non-native consisting of house sparrows [*Passer domesticus*], and rock doves [*Columba livia*]). A generalized linear mixed effects model (GLME) analysis for the non-native species revealed a significant negative trend between bird abundance and distance from a building. While there was a significant decline between the first and second station (declining from an average 6.96 to 0.34 individuals detected), beyond this there was no further significant change at more distance stations (Figure 1, Table 1). The complementary generalized linear mixed effect model for native taxa reveals, in contrast, a significantly positive rise in bird numbers with increasing distance from a building (Figure 1). In the native group, abundance increased on average from 2.91 to 6.31 individuals detected between the first and second station. When comparing the first station with the other three sampling stations, a statistically significant difference was found in both the native and non-native species but in opposite directions (Table 1).

For the analysis of species richness and the Shannon Diversity Index (SDI) we pooled all bird species into a single analysis due to the lack of sufficient sample size in the non-native species category. Both species richness and Shannon diversity index displayed monotonic increases from the first to the last sampling station (Figure 2 and 3). Species richness showed an increasing trend as distance from the building increased, with the average number of species detected rising from 2.77 to 3.57 between the first and last station. However, the analysis on species richness only displayed marginal significance in the distance comparison between the first station and the other three stations, with p-values ranging between 0.1 and 0.05 (Table 2). The analysis for the SDI showed a statistically significant distance effect when comparing the first station with the other three, with the average index number increasing from 0.41 to 1.02 and p-values below 0.05 (Table 3).

Effects of Buildings on Reptiles

Over the course of the field season we made 114 detections of 10 different reptile species. Reptile abundances were pooled across all taxa due to the small sample size for each species. Our analyses indicated that the mean abundance of reptiles remained low for the first 100 meters and then steadily increased over the remaining distance bins (Figure 4). The average number of reptiles detected increased from 0.47 to 1.23 individuals. Analyses indicated that only the comparison of the first bin against 160 and 200 meters was significant, while the comparison between 40 and 120 meters was only marginally significant (Table 4). Similar marginally significant negative effects of cats, a known reptile predator (Table 4). When the sample of buildings is separated into buildings with and without cats we observed different trends. The buildings with cats display a similar trend to Figure 4 (Figure 11; Table 11). However, the buildings without cats display a slightly U-shaped curve that no longer shows significance when comparing the 0-40 m bin to the remaining bins (Figure 11; Table 12).

Species richness of reptiles showed a similar pattern to the bird trends we recorded earlier. Thus, number of species in each bin rose with increasing distance from the focal building with the average species number detected increasing 0.30 to 0.87 (Figure 5). A comparison analysis demonstrated statistically significant differences between species richness at the closest observation bin near in the building (0-40 m) and the 120, 160, and 200 m bins (Table 5). We were not able to calculate the Shannon-Wiener diversity index of reptiles due to the small number of species involved.

Effects of Roads on Birds

Over the course of the field season we detected 444 birds belonging to 16 different species. Maintaining a parallel structure as with the building impact analysis, we analyzed native and non-native bird species separately. A GLME analysis for native bird species abundance revealed a positive relationship between bird number and distance from the closest road, with a significant increase in the more distant sampling stations relative to first one (respectively 9.33 individuals and 8.89 individuals vs. 6.04) (Figure 6). The GLME analysis indicated that statistical significance was found when comparing the first sampling station to the other two sampling stations (Table 6). In contrast, when running the complementary GLME for non-native species, bird numbers decrease away from the road, however these differences are not significant (Figure 6, Table 6).

For avian species richness and SDI analyses all the bird species were again pooled due to small sample sizes. Both indices were positively related to distance from the road (see Figures 7 and 8). Average bird species increased from 3.05 to 4.30 species when comparing stations at 10 and 210 m from the road. We also detected a parallel increase (from 0.96 to 1.30) in bird SDI when comparing stations as 10 and 210 m from the road. However, the GLME analysis for both species richness and SDI indicated statistical significance when comparing 10 m and 210 m only (Tables 7 and 8).

Effects of Roads on Reptiles

During our reptile field surveys near roads we made 30 detections of 10 different species. Observations were aggregated into two bins (0-50m and 50-100m) with number of reptiles increasing away from road (from an average of 0.1 individuals near the road to an average of 0.85 individuals away; a significant difference; see Table 9, Figure 9). A similar pattern of increasing species richness away from roads (from 0.1 to 0.50 species) was not quite statistically significant (Figure 10 and Table 10).

Changes in Infrastructure

This study focuses on the western section of the island of Naxos. this area, approximately bounded by the city of Naxos in the north and settlement of Pirgaki in the south, encompasses 48.89 km^2 and has experienced the most intense development in the region. In 1982 the total area of development, inclusive of buildings and roads, were restricted to the old city of Naxos and a few traditional village nuclei (Glinado, Galanado, Vivlos and Agios Arsenios), with a few smaller satellite settlements and farm houses scattered throughout the rest of the coastal plain. The roads showed a similar pattern to buildings, being highly clustered in areas where buildings were prominent but also having interconnected lines going towards each developed settlement (Figure 13). Thus during the 1982 analysis we identified 2961 building structures and 144km of roads in the study area (Figures 22 and 23). Our field survey data indicated that areas lying with a 100 m buffer from a building and less than 100 m from a road are largely inappropriate for wildlife. Based on this assumption, we estimate that 33.6km^2 are unavailable habitat for wildlife (Figures 16 and 25). For the 2015 survey we detected 5807 buildings and 307 km of roads, an increase of 96% for buildings and 113% for roads respectively over the 1982 baseline (Figures 13, 22, and 23). As a result, the total area of unsuitable habitat for native bird species and reptiles has now risen to about 38.82 km^2, which is roughly 79.40% of the total study region (Figures 16 and 25).

Changes in Spatial Distribution of Buildings and Density.

Average distance between buildings also changed between the two dates but only in a certain part of the study area. In the high density settlement areas, mean inter-building distance changed only marginally from 18.46m (in 1982) to 18.10 (in 2015) (Figures 18, 19, and 24). In contrast, in the more rural areas the expansive and dispersed establishment of new buildings resulted in a dramatic decrease of inter-building distance from 62.25 meters to 37.04 meters (2015) (Figures 20, 21, and 24).

In summary settlement activity has moved in the last 33 years from settlements in discrete, traditional village nuclei that have expanded into the surrounding area. This is causing more areas that were once spread out farmland to be more clustered, especially along the coastline (Figures 20 and 21). Much of these new settlements are located along the coastal plain, where proximity to sandy beaches has made building construction particularly attractive (Figures 14 and 15).

Discussion

In this study we quantify the spatial extent of the impacts of touristic development on Mediterranean wildlife. We then combine this information with a GIS analysis that determines the amount of the recent expansion of touristic infrastructure across in the main region of touristic development on Naxos to understand the total extent of area impacted by human activities. Our data demonstrate the existence and magnitude of a distance effect on bird and reptile populations in Mediterranean wildlife. Bird densities tend to change most dramatically between 20 and 120 m away from human structures, whether buildings or roads. When all bird species are pooled into a single group the highest bird abundance is closest to the buildings and decreases as distance to the building continues to increase. However, when birds were separated into non-native and native groups it becomes clear that non-native species have the highest densities closest to development, and native species tend to have their highest densities furthest from the development. These trends are comparable to ones found by other researchers (Bock et al. 2008; Glennon et al 2015; Odell and Knight 2001). Several auxiliary factors related to characteristics of buildings tended to lack significant affect. Interestingly, presence of food around a building appears to be associated with decreases in abundance of native species while presence of water seems to decrease abundance of non-native species. During field surveys, we would see mainly the non-native species within our first sampling stations. Beyond the first sampling station we recorded an increasing variety of species with a shift towards native taxa. Overall diversity of species rose with increasing distance from development. The results of our analysis suggest that as touristic development continues to expand, native bird species and the overall avian biodiversity on Naxos will likely decline.

Our results also support the existence of a pronounced distance effect in reptiles. Reptile abundance and species richness both rose markedly with increasing distance from development. Close to buildings, Aegean wall lizards (*Podarcis erhardii*) and Kotschyi's Geko (*Cyrtopodion kotschyi*) were the only species encountered, while further away many additional reptile species were recorded. Published literature on the subject suggested that cats, whether feral or domestic, may play a critical role in determining lizard abundance (Audsley et al 2006; Li et al 2014). When splitting our database into buildings with, and without cats, we obtained results consistent with these previous conclusions. Presence of cats in a building coincided with a pronounced absence of reptiles close to that building and an abrupt increase to normal background densities beyond a 100 m radius (Figure 11). Species richness also displayed a parallel trend with decreasing species numbers close to buildings with cats only (Figure 12). These results support the argument that not only does construction of buildings have a negative effect on resident reptile communities, but that cats further exacerbate these effects.

The GIS analysis conducted on the present-day and 1980s development maps show a 10.67% increase in degraded habitat over the last 33 years. This increase has created an additional 5.22 km^2 of land that is now largely unsuitable to native bird species and reptiles. As a result, in our study region now only about 20.6% of the research study area (i.e. 10.07 km^2), is fully suitable habitat for wildlife. Buildings are now also being built closer together creating increasingly continuous settlements and villages. Our building density maps (Figure 14) highlight how this activity is mostly concentrated along the beaches of the island, and to a lesser degree in the periphery of older settlements. Our road density map (Figure 15) reveals a high clustering of roads along the coastline in areas of low to moderate building densities. Because road access is often a precursor to additional land-use change such as establishment of houses and other buildings, the road density map may shed light on where building development is likely to expand in the near future. Our results show that continuation of the present development trends is likely to result in further degradation of the remaining suitable wildlife habitat. At the same time, it is expected that these pressures on native wildlife will become exacerbated as non-native species continue to expand in areas of touristic development. Much of the touristic attraction in the region centers the intimate nature experiences the island offers. As a result, this decline in native landscape and wildlife will have the unintended effect of diminishing the overall touristic attraction of the island. This is because many tourists come to these island not only to relax but also take in the natural beauty of the landscape and native wildlife. Unchecked development will ultimately hurt the island’s economy and inadvertently decrease the welfare of the local population.

This study has certain limitations that need to be addressed in future investigations. When using the DISTANCE project program to correct avian population densities, only 14 of the original 25 species could be successfully corrected. This was due to a lack of sufficient data to calculate correction factors for the remaining species. The 11 species were added into the subsequent analysis since we had a large dataset, 1,220 data points of birds. Given the overall large dataset, any non-adjusted species did have only a small effect on the final results. Results were also disproportionately influenced by a single, particularly common non-native species -- the house sparrow (*Passer domesticus*). If house sparrows are removed from the dataset, the negative effects of touristic development on wildlife become even more severe. The reptile dataset is relatively small with only 144 data points. Multiple surveys on the same site could have alleviated this problem and provided more data. However, even with this smaller data set the results still showed significance demonstrating the strength of the negative effects on touristic development on reptiles.

As society continues to expand and develop, the various ecosystems around the world will continue to dwindle. Although there is substantial research on the effects of development on many mainland ecosystems, few papers have studied whether or not mainland and island ecosystems react the same way towards development. Our study indicates that both mainland and island ecosystems appear to respond to touristic development in a similar manner, though more studies are needed in other island ecosystems worldwide. Our research indicates that tourism policy needs to be modified in order to lessen the impact that development has on Mediterranean wildlife communities.

Acknowledgements

We would like to thank the University of Michigan, SNRE, and Rackham for providing the funds and support to conduct this research. We also acknowledge the assistance of Sophie Yu-Pu Chen from the Consulting for Statistics, Computing and Analytical Research (CSCAR) for statistical advice on the analysis. We would like to thank Johanna Fornberg, Sarah Semegen, Blake Graber, Kasey McDonald, Lauren Vesprani, and Panayiotis Pafilis for their help and support during the field season. We lastly would also like to extend our gratitude to Hayden Hedman, Vanessa Tamez, and Zachary Gizicki for their support and advise throughout my entire thesis. Lastly we would also like to thank our friends and family for all their support during the time we conducted this research.

Bibliography

Andriotis, K. 2010. Tourism planning and development in Crete: Recent tourism policies and their efficacy. *Journal of Sustainable Tourism*. 9(4): 298-316.

Audsley, B. W., C. E. Bock, Z. F. Jones, J. H. Bock, and H. M. Smith. 2006. Lizard Abundance in an exurban Southwestern savanna, and the possible importance of roadrunner predation. *American Midland Naturalist*. 155: 391-401.

Bergmeier, E., and P. Dimopoulos. 2003. The vegetation of islets in the Aegean and the relation between the occurrence of islet specialists, island size, and grazing. *Phytocoenologia* 33(2-3): 447-474.

Blair, R. B. 1999. Birds and Butterflies Along an Urban Gradient: Surrogate Taxa for Assessing Biodiversity? *Ecological Applications*. 9: 164-170.

Bock, C. E., Z. E. Jones, and J. H. Bock. 2008. The Oasis Effect: Response of Birds to Exurban Development in a Southwestern Savanna. *Ecological Applications*. 18: 1093-1106.

Casey, J. M., M. E. Wilson, N. Hollingshead, and D. G. Haskell. 2009. The Effects of Exurbanization on Birds and Macroinvertebrate Communities in Deciduous Forests on the Cumberland Plateau, Tennessee. *International Journal of Ecology*. 2009: 1-10.

Clergeau, P., J. L. Savard, G. Mennechiez, and G. Falardeau. 1998. Bird Abundance and Diversity Along an Urban-Rural Gradient: A Comparative Study between Two Cities on Different Continents. *The Condor*. 100: 413-425.

Crooks, K. R., A. V. Suarez, and D. T. Bolger. 2004. Avian assemblages along a gradient of urbanization in a highly fragmented landscape. *Biological Conservation* 115: 451-462.

Dritsakis, N. 2004. Tourism as a long-run economic growth factor: an empirical investigation for Greece using causality analysis. *Tourism Economics.* 10(3): 305-316.

ESRI. 2017. ArcGIS 10.5. Redlands, California.

Glennon, M. J., H. E. Kretser, and J. A. Hilty. 2015. Identifying Common Patterns in Diverse Systems: Effects of Exurban development on Birds of the Adirondack Park and the Greater Yellowstone Ecosystem, USA. *Environmental Management*. 55: 453-466.

Gonzalez-Abraham, C. E., V. C. Radeloff, T. J. Hawbaker, R. B. Hammer, S. I. Stewart, and M. K. Clayton. 2007. Pattern of Houses and Habitat Loss from 1937 to 1999 in Northern Wisconsin, USA. *Ecological Applications*. 17(7): 2011-2023.

Google Inc. (2017). Google Earth (Version 7.1.8.3036) [Software]. Available from https://www.google.com/earth/

Hager, S. B., B. J. Cosentino, K. J. McKay, C. Monson, W. Zuurdeeg, and B. Blevins. 2013. Window Area and Development Drive Spatial Variation in Bird-Window Collisions in an Urban Landscape. *PLoS ONE* 8(1): e53371. doi:10.1371/journal.pone.0053371

Haralambopoulos, N. and A. Pizam. 1996. Perceived Impacts of Tourism: The Case of Samos. *Annals of Tourism Research*. 23(3): 503-526.

Hexagon Geospatial. 2016. Erdas Imagine Professional 2016. Norcross, GA.

Higgins-Desbiolles, F. 2006. More than an “industry”: The forgotten power of tourism as a social force. *Tourism Management.* 27: 1192-1208.

HMGS Greece. 1982. Hellenic Military Geography Service Aerial Photography 1: 8,000. Athens, Greece.

IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.

Kizos, T., and M. Koulouri. 2006. Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. *Environmental Science & Policy*. 9: 330-342.

Koenig, J., R. Shine, and G. Shea. 2001. The Dangers of Life in the City: Patterns of Activity, Injury and Mortality in Suburban Lizards. *Journal of Herpetology*. 36: 62-68.

Li, B., A. Belasen, P. Pafilis, P. Bednekoff, and J. Foufopoulos. 2014. Effects of feral cats on the evolution of anti-predator behaviours in island reptiles: insights from an ancient introduction. *Proc. R. Soc. B.* 281: 1-6.

Loumou, A., C. Giourga, P. Dimitrakopoulos, and S. Koukoulas. 2000. PROFILE: Tourism Contribution to Agro-Ecosystems Conservation: The Case of Lesbos Island, Greece. *Environmental Management*. 26(4): 363-370.

Merenlender, A. M, S. E. Reed, and K. L. Heise. 2009. Exurban development influences woodland bird composition. *Landscape and Urban Planning*. 92: 255-263.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, and G.A.B. da Fonseca, J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature*. 403: 853-858.

Nastos, P.T., Evelpidou, N., and A. Vassilopoulos. 2010. Does climatic change in precipitation drive erosion in Naxos Island, Greece? *Natural Hazards Earth System Science.* 10: 379–382.

Odell, E. A. and R. L. Knight. 2001. Songbirds and Medium-Sized Mammal Communities Associated with Exurban Development in Pitkin County, Colorado. *Conservation Biology*. 15(4): 1143-1150.

OpenStreetMap Foundation. 2017. OpenStreetmap. (http://www.openstreetmap.org/#map=5/51.500/-0.100, last accessed 4-16-2017)

RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Smart, R., M. J. Whiting, and W. Twine. 2005. Lizards and landscapes: integrating field surveys and interviews to assess the impact of human disturbance on lizard assemblages and selected reptiles in a savanna in South Africa. *Biological Conservation*. 122: 23-31.

Stuart, Y.E., J.B. Losos, and A.C. Algar. 2012. The island-mainland species turnover relationship. *Proc. R. Soc. B* doi:10.1098/rspb.2012.0816

Suarez-Rubio, M., P. Leimgruber, and S. C. Renner. 2011. Influence of exurban development on bird species richness and diversity. *Journal of Ornithology*. 152: 461-471.

Sutherland, R. W. 2009. The Effects of Urbanization on Reptiles and Amphibians in the Sandhills Region of North Carolina. Unpublished Duke University Dissertation, 179 pages, *Duke University, Durham, NC.*

Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14. DOI: 10.1111/j.1365-2664.2009.01737.x

Tryjanowski P, Sparks TH, Biaduń W, Brauze T, Hetmański T, Martyka R, et al. 2015. Winter Bird Assemblages in Rural and Urban Environments: A National Survey. *PLoS ONE.* 10(6):e0130299. doi:10.1371/journal.pone.0130299

Victor E.K. 2014. Vertebrate Community Responses to Livestock Grazing in an Ancient Mediterranean Rangeland System: Rethinking the Role of Grazing in Biodiversity Conservation. Unpublished Masters Thesis, 39 pages, *University of Michigan, Ann-Arbor, MI.*

Figures

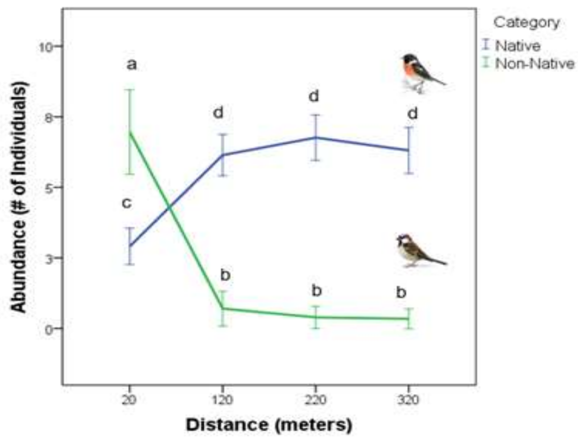


Figure 1: Relative abundance of birds in relationship to distance away from buildings on Naxos. Error bars give the 95% CI. The green line indicates the number of non-native birds and the blue line indicates the number of native birds.

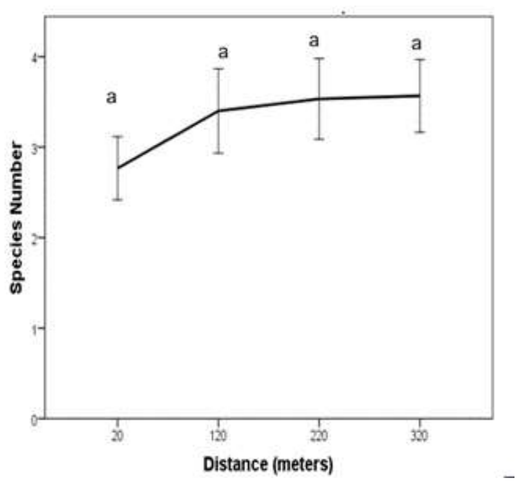


Figure 2: Relative species number of birds in relationship to distance away from buildings on Naxos. Error bars give the 95% CI.

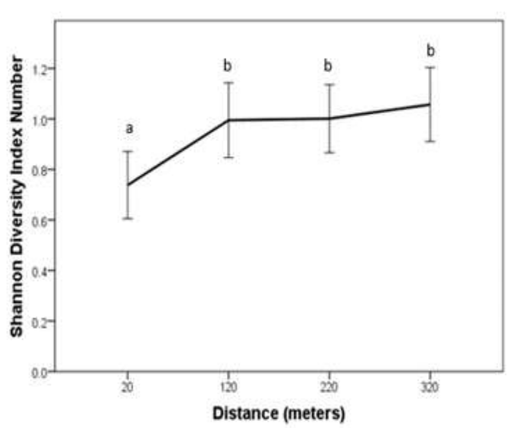


Figure 3: Relative Shannon Diversity index score of birds in relationship to distance away from buildings on Naxos. Error bars give the 95% CI.

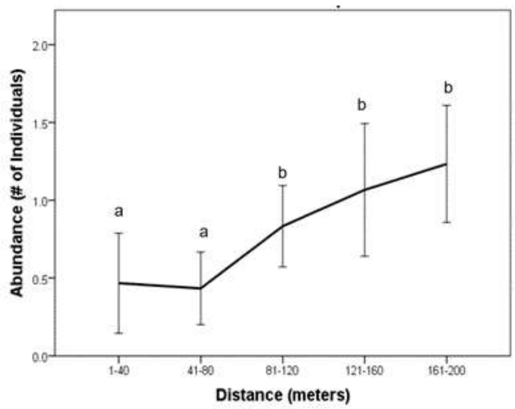


Figure 4: Relative abundance of reptiles in relationship to distance away from buildings on Naxos. Error bars give the 95% CI.

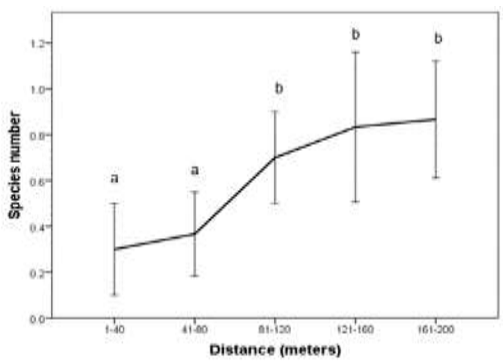


Figure 5: Relative species number of reptiles in relationship to distance away from buildings on Naxos. Error bars give the 95% CI.

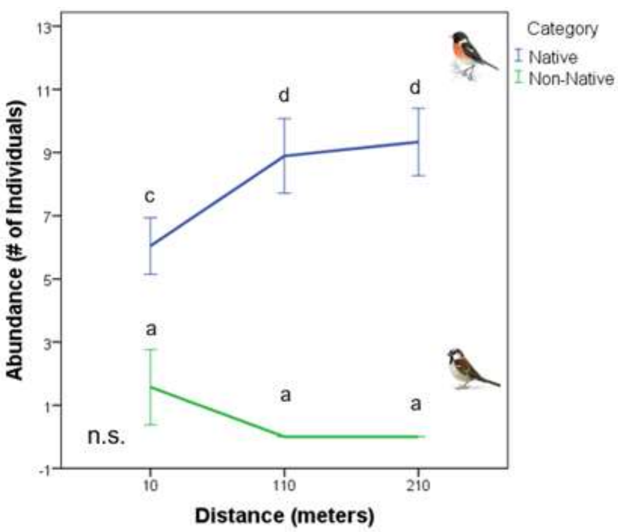


Figure 6: Relative abundance of birds in relationship to distance away from buildings on Naxos. Error bars give the 95% CI. The green line indicates the number of non-native birds and the blue line indicates the number of native birds.

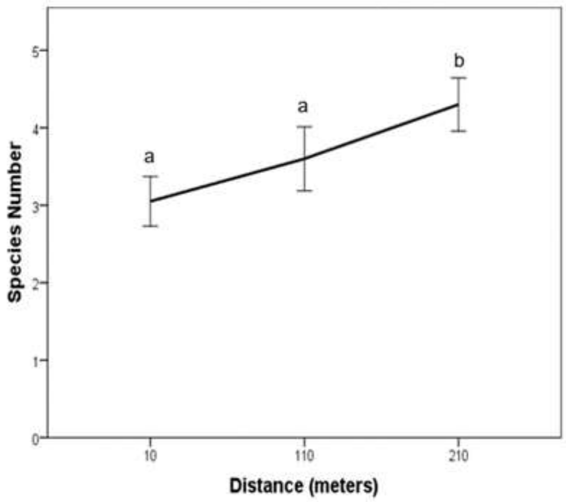


Figure 7: Relative species number of birds in relationship to distance away from roads on Naxos. Error bars give the 95% CI.

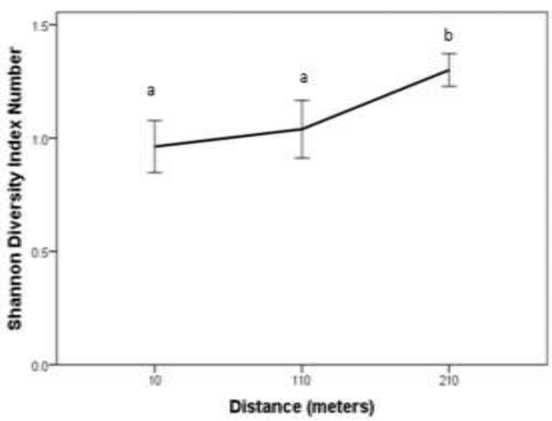


Figure 8: Relative Shannon Diversity index score of birds in relationship to distance away from buildings on Naxos. Error bars give the 95% CI.

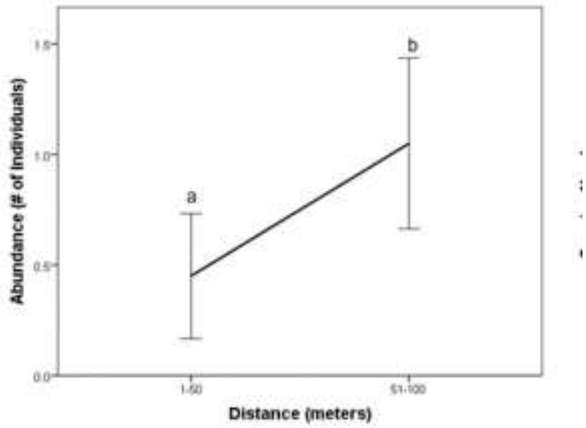


Figure 9: Relative abundance of reptiles in relationship to distance away from roads on Naxos. Error bars give the 95% CI.

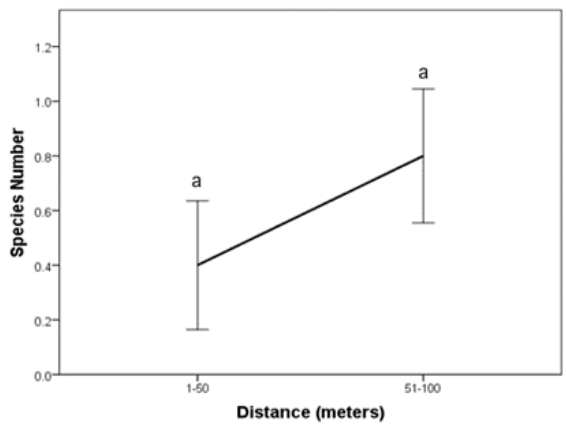


Figure 10: Relative species number of reptiles in relationship to distance away from roads on Naxos. Error bars give the 95% CI.

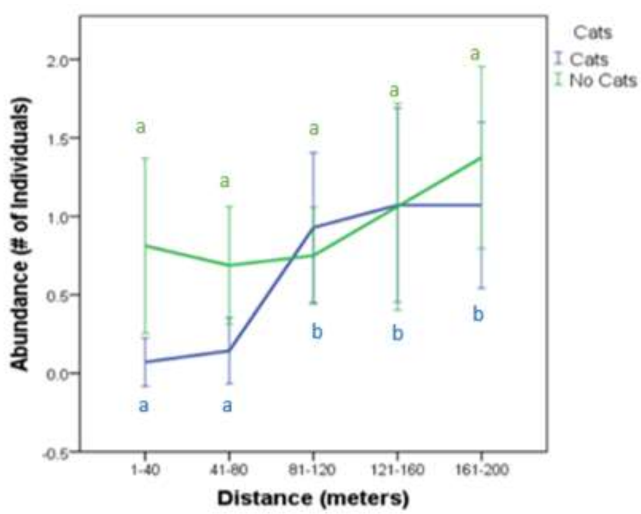


Figure 11: Relative abundance of reptiles in relation to distance away from buildings with and without cats. Error bars give the 95% CI. The green line indicates the buildings without cats and the blue line indicates the buildings with cats.

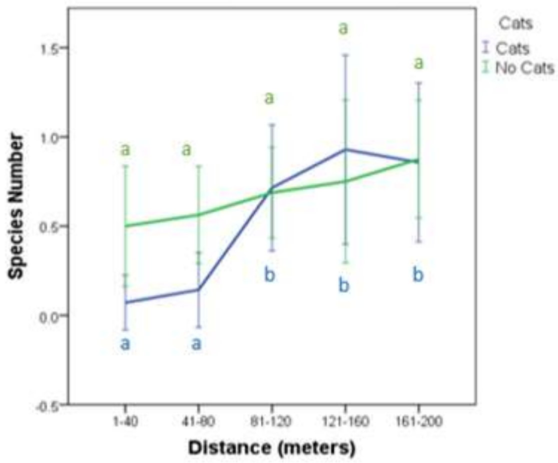


Figure 12: Relative species number of reptiles in relation to distance away from buildings with and without cats. Error bars give the 95% CI. The green line indicates the buildings without cats and the blue line indicates the buildings with cats.

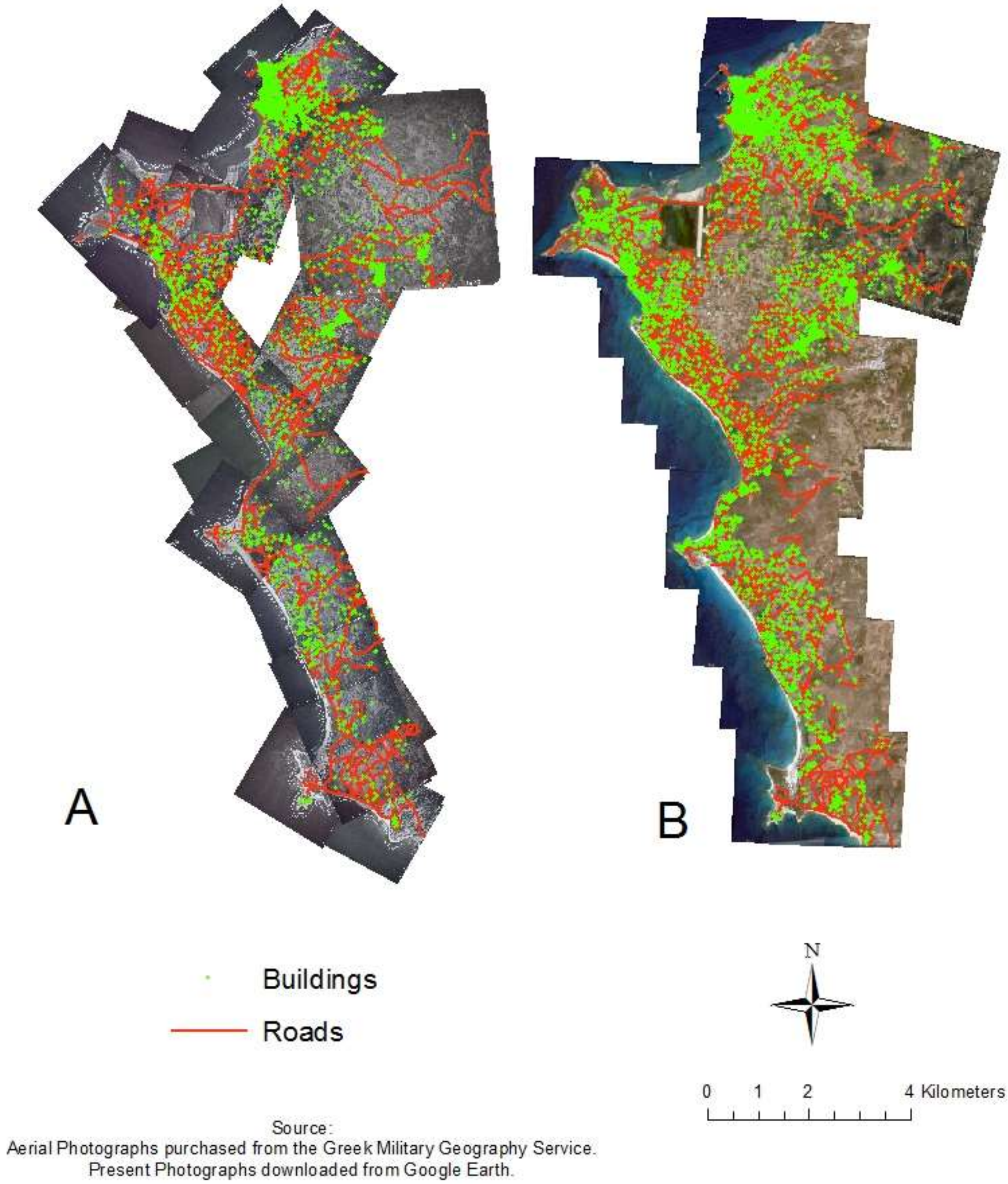
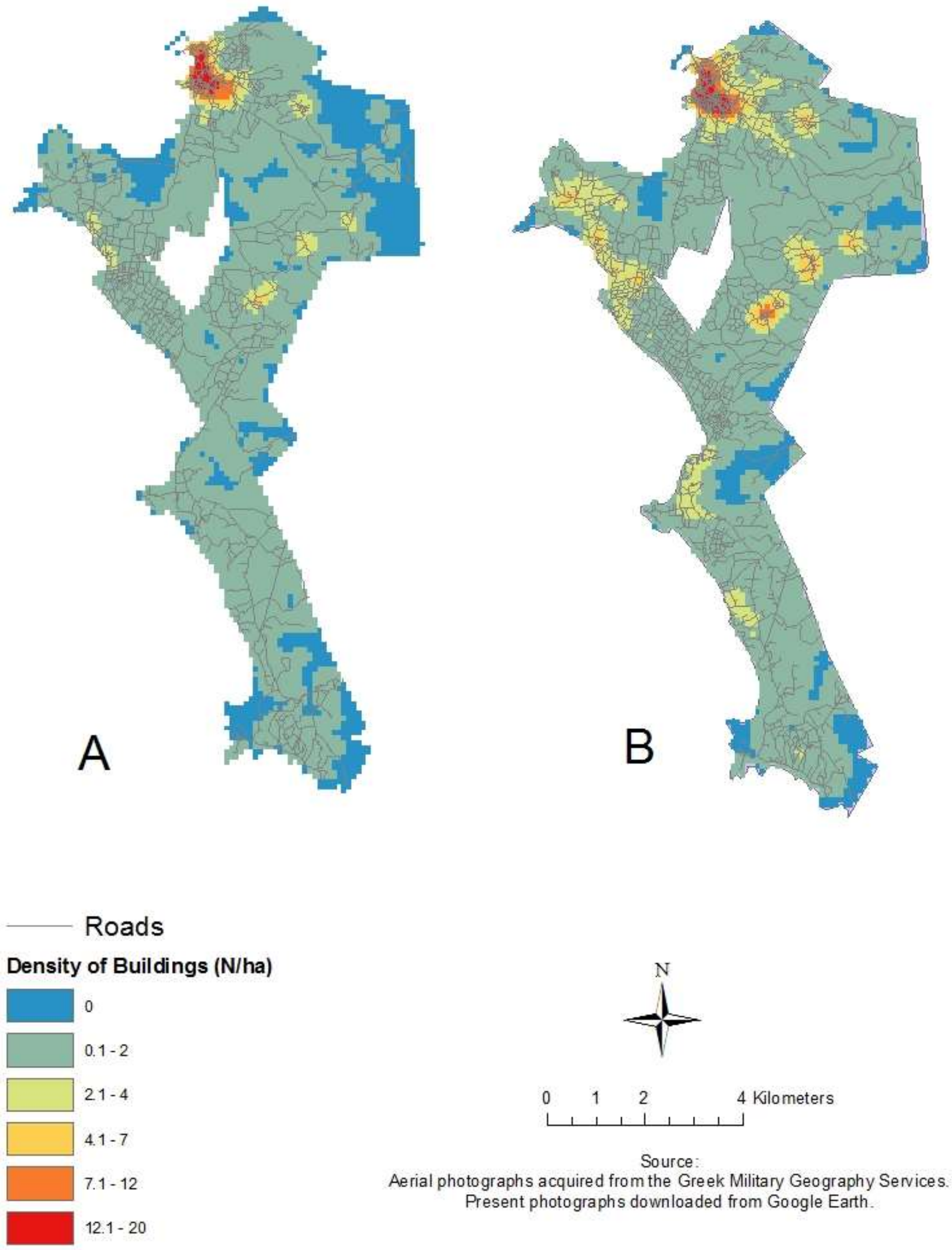


Figure 13: Change in housing and roads between 1982 (A) and 2015 (B). Green indicates housing structures and red roads. Note the increase in number of buildings especially along the coast.



<u>Figure 14</u>. Change in building density in western Naxos between 1982 (A) and 2015 (B). While traditional village cores (evident as light-colored patches in 1982) increased in size, much of the development occurred outside such already high-density areas. The white patch is where data could not be obtained.

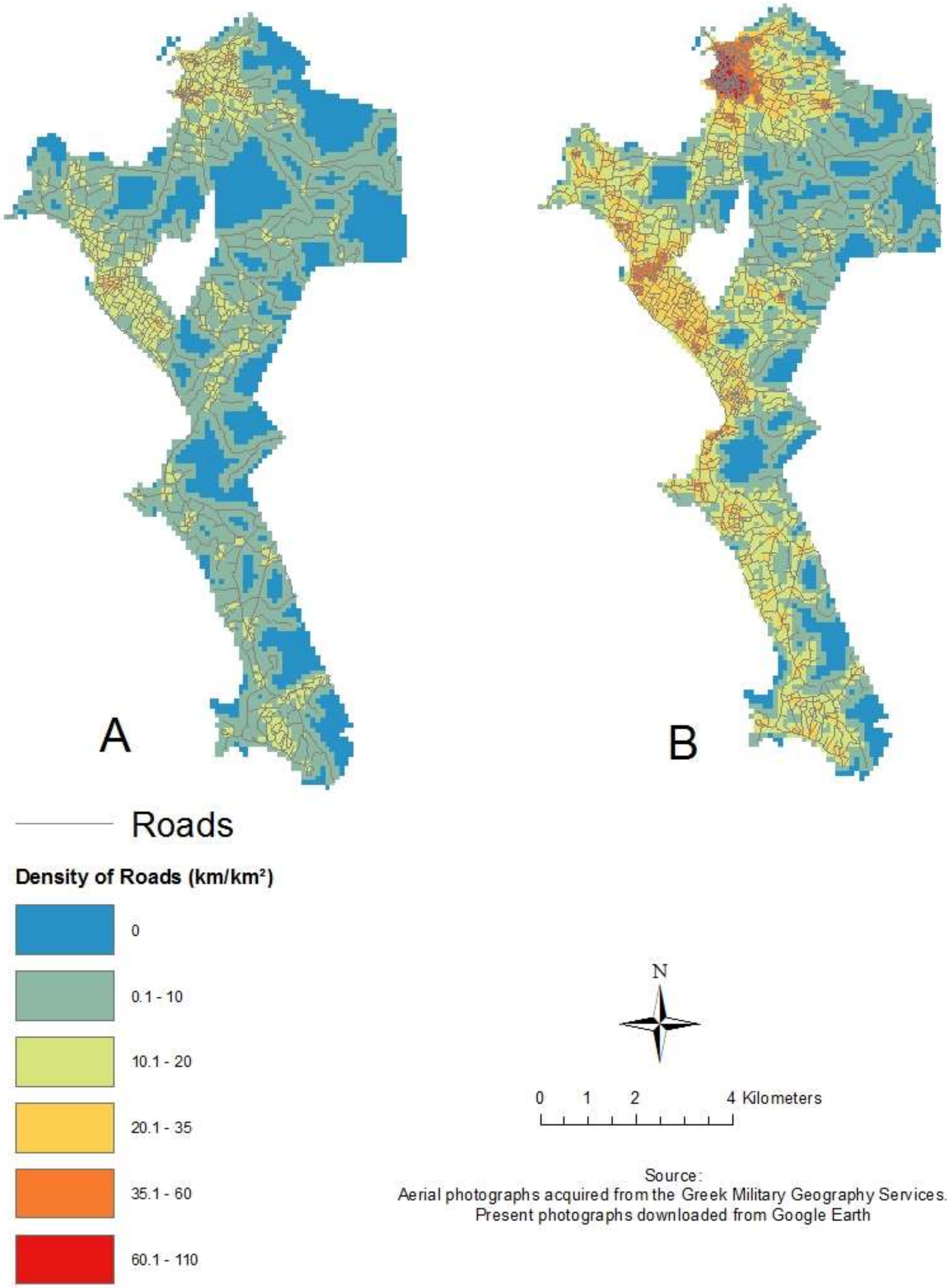


Figure 15. Changes in road density in western Naxos between 1982 (A) and 2015 (B). Most of the new roads were built on the easily accessible plain along the western coastline. The white patch is where data could not be obtained.

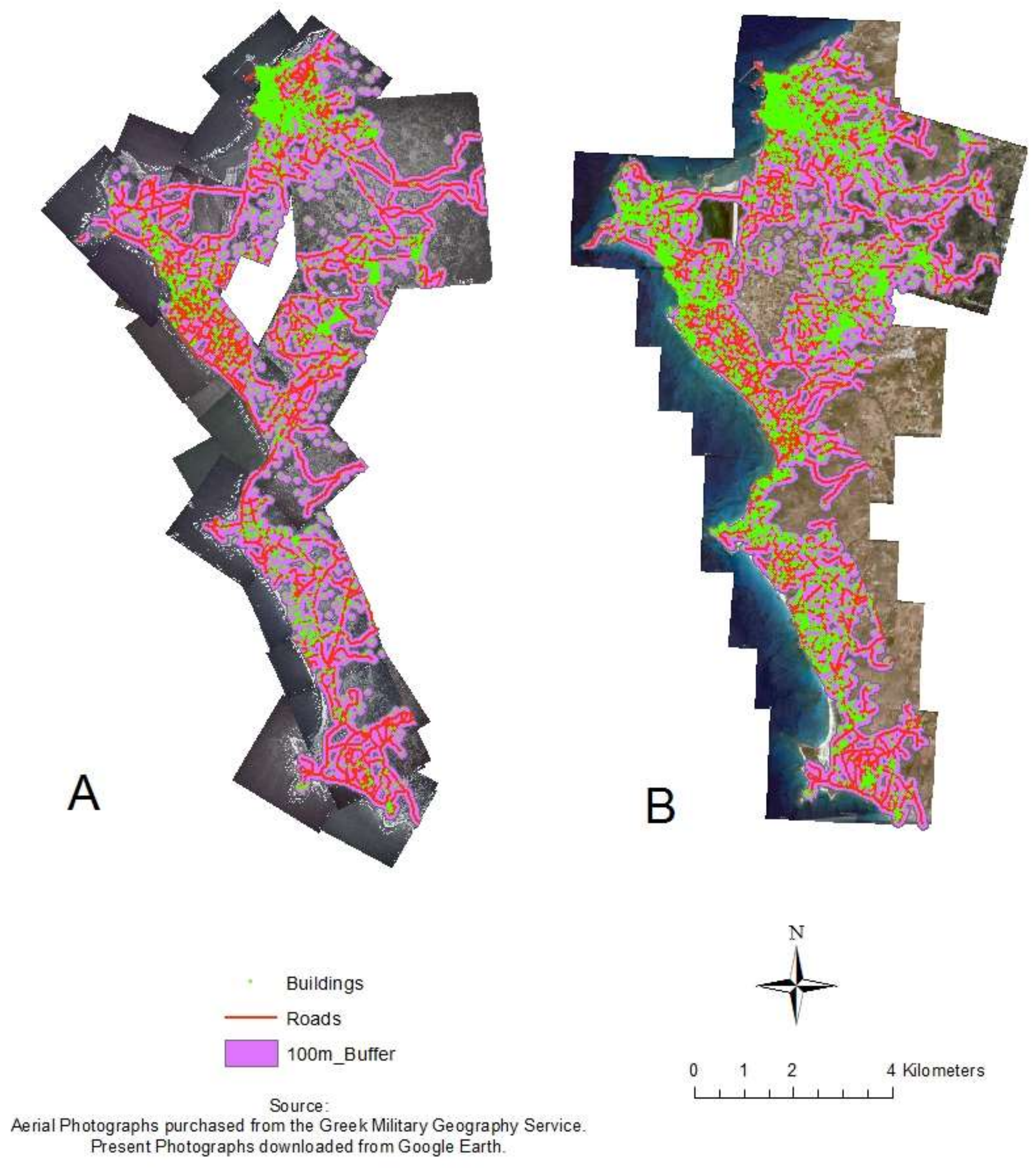


Figure 16. Change in housing and roads between 1982 (A) and 2015 (B). Green indicates housing structures and red roads. The purple area around the roads and buildings layer is the 100 m buffer area that symbolize unsuitable habitat.

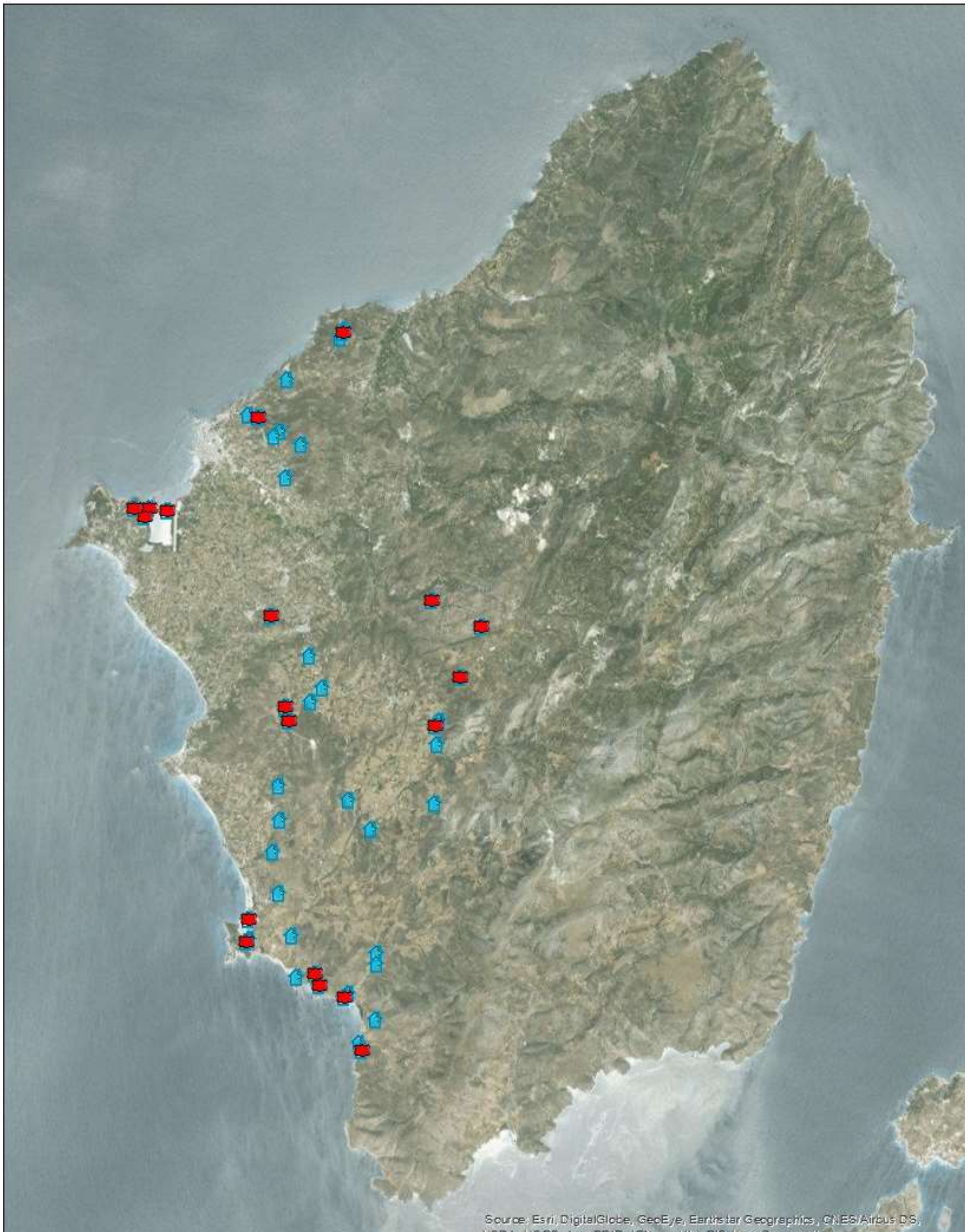


Figure 17. Map of Naxos showing the location of the wildlife sampling sites. The blue markers indicate building sites and red markers indicate road sites.

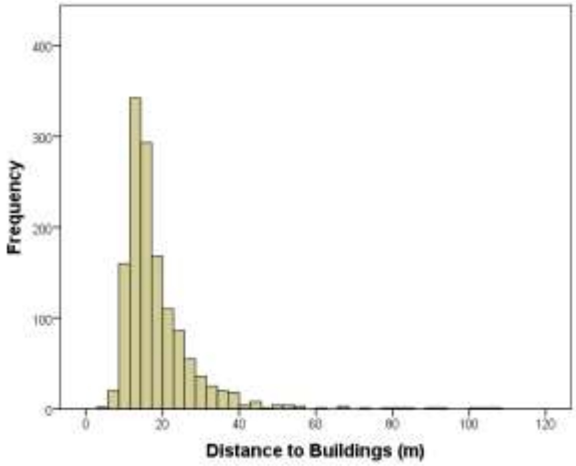


Figure 18. Histogram of distribution of the shortest distances between urban buildings in 1982.

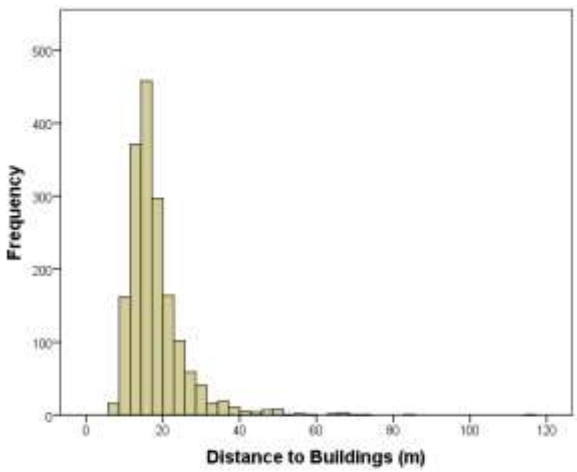


Figure 19. Histogram of distribution of the shortest distances between urban buildings in 2015.

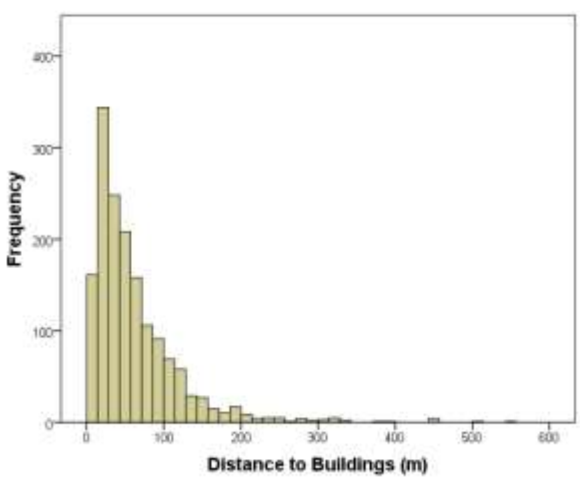
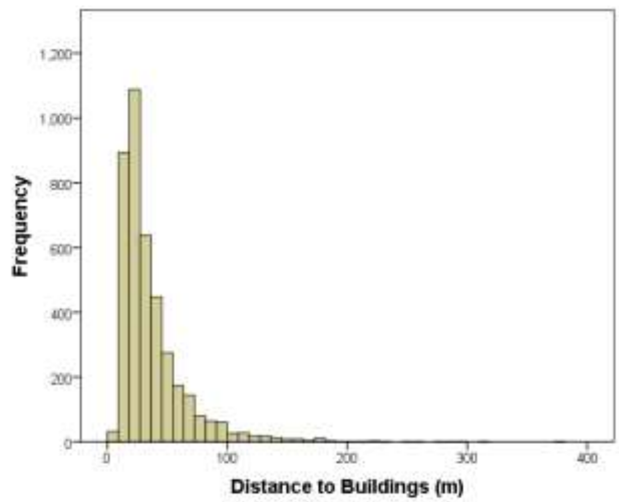
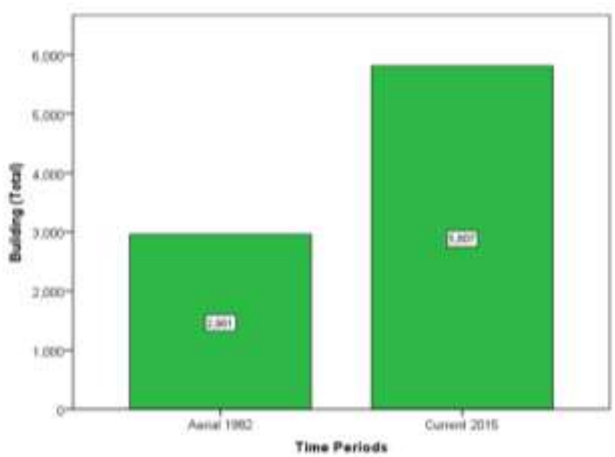


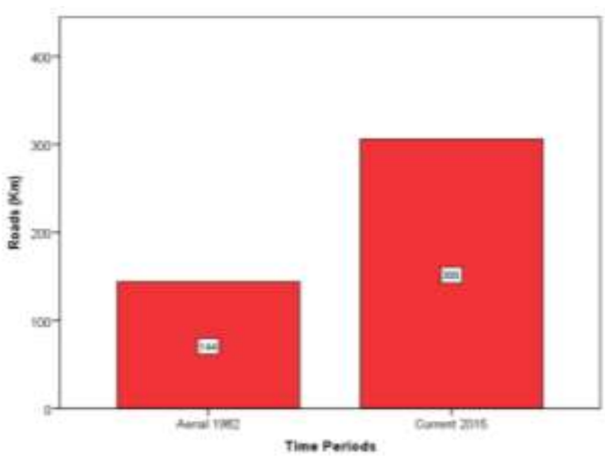
Figure 20. Histogram of distribution of the shortest distances between rural buildings in 1982.



<u>Figure 21.</u> Histogram of distribution of the shortest distances between rural buildings in 2015.



<u>Figure 22.</u> Bar Graph displaying the differences in number of buildings between 1982 and 2015.



<u>Figure 23.</u> Bar graph displaying the difference in length of roads, in km, between 1982 and 2015.

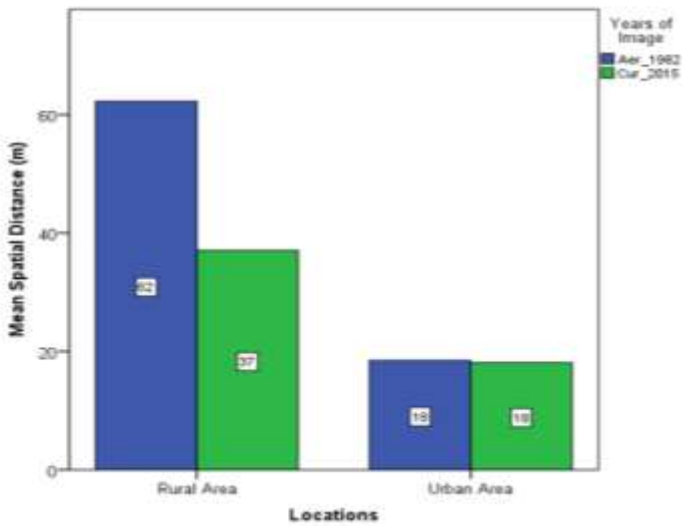


Figure 24. Bar graph Displaying the difference in average distance between buildings for both urban and rural area. The blue line indicates 1982 while the green line indicates 2015

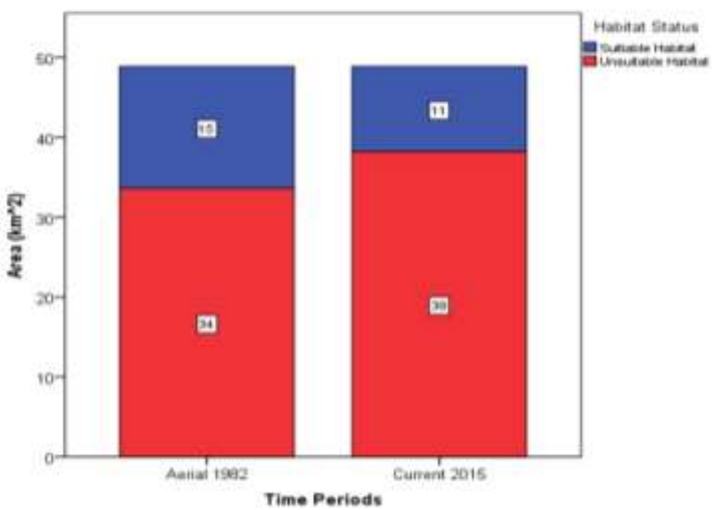


Figure 25. Bar graph displaying the difference between suitable and unsuitable habitat in 1982 and 2015.

Tables

Table 1: Generalized linear mixed effect model of bird abundance against distance from building structures on Naxos A. Non-native birds and B. Native birds. A star indicates statistical significance.

A.

	Estimate	Std. Error	z value	P-value
20 Vs. 120	-2.29	0.2281	-10.037	< 2e-16***
20 Vs. 220	-2.8693	0.2986	-9.61	< 2e-16***
20 Vs. 320	-3.0095	0.3191	-9.43	< 2e-16***
Cats	0.3583	0.265	1.352	0.176
Food	0.468	0.4381	1.068	0.285
Water	-0.3458	0.4895	-0.706	0.48

B.

	Estimate	Std. Error	z value	P-value
20 Vs. 120	0.74757	0.12994	5.753	8.76e-09***
20 Vs. 220	0.84325	0.12802	6.587	4.49e-11***
20 Vs. 320	0.77429	0.12939	5.984	2.17e-09***
Cats	0.04037	0.08803	0.459	0.647
Food	-0.14178	0.13353	-1.062	0.288
Water	0.14564	0.14916	0.976	0.329

Table 2: Generalized linear mixed effect model of bird species richness against distance from building structures on Naxos. A dot indicates marginal significance.

	Estimate	Std. Error	z value	P-value
20 Vs. 120	0.20613	0.14782	1.394	0.1632
20 Vs. 220	0.2446	0.14657	1.669	0.0951 .
20 Vs. 320	0.25399	0.14627	1.736	0.0825 .
Cats	0.18177	0.18053	1.007	0.314
Food	-0.09228	0.19953	-0.462	0.6437
Water	0.06222	0.10757	0.578	0.563

Table 3: Linear mixed effect model of bird Shannon diversity index numbers against distance from building structures on Naxos. A star indicates statistical significance.

	Estimate	Std. Error	DF	t value	P-value
20 Vs. 120	0.25684	0.07662	87	3.352	0.001189 **
20 Vs. 220	0.2631	0.07662	87	3.434	0.000914 ***
20 Vs. 320	0.31916	0.07662	87	4.165	0.000073 ***
Cats	0.0129	0.11134	26	0.116	0.908684
Food	0.14327	0.17713	26	0.809	0.425935
Water	-0.03236	0.1956	26	-0.165	0.86988

Table 4: Generalized linear mixed effect model of reptile abundance against distance from building structures on Naxos. A star indicates statistical significance and a dot indicate marginal significance.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	-0.07411	0.38516	-0.192	0.84743
40 Vs. 120	0.57982	0.33381	1.737	0.08239 .
40 Vs. 160	0.82668	0.32043	2.58	0.00988 **
40 Vs. 200	0.97186	0.31378	3.097	0.00195 **
Food	0.02393	0.42809	0.056	0.95542
Water	0.10079	0.44793	0.225	0.82197
Cats	-0.39166	0.229	-1.71	0.08720 .

Table 5: Generalized linear mixed effect model of reptile species richness against distance from building structures on Naxos. A star indicates marginal significance.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	0.06475	0.13177	0.491	0.62316
40 Vs. 120	0.31841	0.1318	2.416	0.01570 *
40 Vs. 160	0.39837	0.13202	3.018	0.00255 **
40 Vs. 200	0.41349	0.13181	3.137	0.00171 **
Food	-0.14321	0.09095	-1.575	0.11533
Water	-0.10276	0.16307	-0.63	0.52859
Cats	0.10926	0.17424	0.627	0.53063

Table 6: GLME of bird abundance against distance from road structures on Naxos, A. Non-native birds and B. Native birds. A star indicates statistical significance at the 0.05 level.

A. Non-native

	Estimate	Std. Error	z value	P-value
10 Vs. 110	-1.1377	0.8463	-1.344	0.179
10 Vs. 210	-1.1377	0.8463	-1.344	0.179

B. Native

	Estimate	Std. Error	z value	P-value
10 Vs. 110	0.3865	0.11789	3.278	0.001044 **
10 Vs. 210	0.43504	0.11676	3.726	0.000195 ***

Table 7: Generalized linear mixed effect model of bird species richness against distance from roads on Naxos. A star indicates statistical significance at the 0.05 level.

	Estimate	Std. Error	z value	P-value
10 Vs. 110	0.1658	0.174	0.953	0.3407
10 Vs. 210	0.3435	0.1674	2.052	0.0402 *

Table 8: Linear mixed effect model of bird SDI against distance from roads on Naxos. A star indicates statistical significance.

	Estimate	Std. Error	DF	t value	P-value
10 Vs. 110	0.07669	0.07255	57	1.057	0.2985
10 Vs. 210	0.33774	0.07255	57	4.655	1.98e-05 ***

Table 9: Generalized linear mixed effect model of reptile abundance against distance from road structures on Naxos. A star indicates statistical significance.

	Estimate	Std. Error	z value	P-value
50 Vs. 100	0.8473	0.3984	2.127	0.0334 *

Table 10: Generalized linear mixed effect model of reptile species richness against distance from road structures on Naxos.

	Estimate	Std. Error	z value	P-value
50 Vs. 100	0.6931	0.433	1.601	0.10943

Table 11: Generalized linear mixed effect model of reptile abundance against distance from building structures with cats on Naxos. A star indicates marginal significance.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	0.6931	1.2247	0.566	0.57143
40 Vs. 120	2.5649	1.0377	2.472	0.01345*
40 Vs. 160	2.7081	1.0328	2.622	0.00874**
40 Vs. 200	2.7081	1.0328	2.622	0.00874**
Water	0.2877	0.6455	0.446	0.65583
Food	-0.2007	0.527	-0.381	0.70339

Table 12: Generalized linear mixed effect model of reptile abundance against distance from building structures without cats on Naxos.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	-0.16705	0.40967	-0.408	0.683
40 Vs. 120	-0.08004	0.40032	-0.2	0.842
40 Vs. 160	0.26826	0.36844	0.728	0.467
40 Vs. 200	0.52609	0.34983	1.504	0.133
Food	0.21102	0.68276	0.309	0.757
Water	-0.06428	0.68039	-0.094	0.925

Table 13: Generalized linear mixed effect model of reptile species richness against distance from building structures with cats on Naxos. A star indicates marginal significance.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	0.6931	1.2247	0.566	0.5714
40 Vs. 120	2.3026	1.0488	2.195	0.0281*
40 Vs. 160	2.5649	1.0378	2.472	0.0134*
40 Vs. 200	2.4849	1.0408	2.387	0.0170*
Food	-0.4169	0.5334	-0.782	0.4344
Water	0.47	0.6708	0.701	0.4835

Table 14: Generalized linear mixed effect model of reptile species richness against distance from building structures without cats on Naxos.

	Estimate	Std. Error	z value	P-value
40 Vs. 80	0.1178	0.4859	0.242	0.8085
40 Vs. 120	0.3185	0.4647	0.685	0.4931
40 Vs. 160	0.4055	0.4564	0.888	0.3744
40 Vs. 200	0.5596	0.4432	1.263	0.2067
Food	0.1335	0.6124	0.218	0.8274
Water	-0.1178	0.6086	-0.194	0.8465