Habitat Suitability Modelling For The Anjouan Scops Owl, A Cryptic Unstudied Species

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List of acronyms

HSM – Habitat suitability model

AUC – Area under the curve

ROC – Receiver operating curve

Abstract

Otus capnodes is a critically endangered scops owl endemic to the island of Anjouan, an island that is part of the Madagascan Biodiversity Hotspot. Its habitat is threatened by deforestation. The species was thought to be extinct until its rediscovery in 1992 and apart from the announcement of its rediscovery no publications have been produced regarding this species.

This study was undertaken in 2010 as the first attempt to map the distribution, assess habitat associations and estimate population. Point counts were used to survey the island across a range of habitats. This data was then used in a habitat suitability model to predict an area of suitable habitat for the species. Distance software was then used for the surveys in this area to produce a population density estimate which then allowed a population estimate to be produced.

The species was found to inhabit natural and degraded forest, extending to plantations near degraded forest. The Habitat suitability model produced a suitable range of 93.4 square kilometres. The population was found to be far higher than previously expected, estimated at 4950.

This research suggests that the species was falsely red listed at critically endangered and should be relisted as endangered. This research highlights the need for thorough research when studying cryptic species before threat categories are assigned.

Acknowledgements

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1. Introduction

Studying understudied species

Fundamental to conservation of a species is an understanding of its biology. Knowledge of the range and habitat preferences are essential for understanding the threats faced (Franklin et al 2009), the changes that are occurring (Wang & Moskovits, 2001) and for evaluating any effect made by conservation action (Long et al., 2008)(Wang & Moskovits, 2001)(Thorn et al., 2009). Detailed information on habitat preference and extent of occurrence can be time consuming and expensive to gather however, and with limited conservation resources available cost effective methods of making accurate predictions are essential. For these reasons Habitat Suitability Modelling (HSM) is used. This statistical approach uses either mechanistic models, those that predict physiological reasons for a species absence, for example frost damage above a certain altitude (Guisan & Zimmermann, 2000), or correlative models, those that identify correlations between environmental variables and species presence and thus use environmental knowledge to predict the probability of species occurrence (Bourg et al., 2005).

These methods are especially useful when dealing with a cryptic species. Presence data may be hard to gather with such species and it may be very difficult to prove that absence data indicates true absence (Thompson et al 2004, Franklin et al 2009). The ability to produce a species distribution map without having to survey every potential location is therefore potentially very useful.

Knowledge of a species range also allows for more accurate threat prediction. The use of relative levels of threat to direct conservation action is widespread (Myers et al., 2000, IUCN, 2010). A risk in using threat to direct conservation action is that cryptic species may have their threat level overestimated (Robbirt et al., 2006). Misdirection of conservation effort can have serious consequences as it can take substantial human, temporal and financial resources to start a conservation effort. This can have serious consequences as it is likely that this detracts these resources from more needy cases.

The production of HSMs in order to assess population size and threat levels is therefore an important first step when dealing with cryptic species.

Aims and objectives

The aim of this research was to further conservation efforts on the critically endangered cryptic species (IUCN, 2010) *Otus capnodes*, the Anjouan Scops Owl by identifying its habitat associations. The study is also a suitable case study for the analysis of previously unstudied species and provides an opportunity to analyse the accuracy of making threat predictions with limited data.

The objectives of this study were to:

- Produce a habitat suitability model.
- Identify the habitat associations of the species.
- Develop a monitoring protocol that could be continued in future years.
- Produce a population estimate.

Thesis structure

The background (section 2) presents an overview of the study area, the biological background, the survey methods and HSM.

The methods (section 3) detail the methodology of the survey and the analysis.

The results (section 4) present the results of the study and the analytical analysis of the data.

The discussion (section 5) illustrates caveats of the data, provides an interpretation of the results and details conservation implications of the research.

2. Background

Geography

The island of Anjouan is part of the Comoros archipelago, four volcanic islands located In the Mozambique channel, north of Madagascar (see figure 2.1) (IGN 1995). Three of the islands, Grand Comore, Moheli and Anjouan, make up the Union of the Comoros. The fourth, Mayotte, remains under French administration as the "Collective departmentale de Mayotte".

Figure 2.1 The geographical location of the Comoros

Anjouan has a surface area of 424 square kilometres with a maximum altitude of 1568m (IGN 1995). Its volcanic past leaves it with a series of steep and narrow ridges. It has very small remaining areas of primary forest, largely restricted to inaccessible slopes. The secondary forest is degraded and suffers extensive human impact. The majority of the island is covered by plantations and overexploited infertile soils. The rainfall ranges between 1400mm on the south east coast and 2700mm on the south west coast (Battistini and Vernin 1984). The islands have a hot, wet season from November to April and a cooler, drier season from May to October.

Economic situation

The main economic activity on Anjouan is agriculture, making up 39.9% of the Comoros GDP in 2004 (IMF, 2004). The major export crops are vanilla, cloves and ylangylang (CIA world factbook 2010). The price of vanilla has decreased due to Madagascan and Indonesian competition and the availability of synthetic substitutes whilst the clove market crashed worldwide in the mid 1980s. Clove prices have recovered since but have not returned to previous prices. Ylangylang has remained economically favourable although the industry is not working to full capacity due to aging plantations and inadequate processing equipment (Harrison Church, 2005).

Although the neighbouring islands of Moheli and Grand Comore have a small tourism and ecotourism industry, Anjouan has none. The political instability, lack of infrastructure and erratic power and water supplies make it unlikely that tourism will develop in the near future.

A major pressure to conservation effort on Anjouan is the high population density. Anjouan has the highest population density of the Comorian islands and has an increasing population with a growth rate of around 2.766% (CIA world factbook 2010).

Biodiversity

The Comoros is typical of many isolated island groups in showing high numbers of endemic species, Indeed the islands are part of the Madagascar biodiversity hotspot (Myers et al., 2000). The islands endemic species include *Pteropus livingstonii*, the livingstones fruit bat and the Comoros island fruit bat, *Roussettus obliviosus.*

Threats to biodiversity

The main threats to the forest based biodiversity on the island are deforestation and erosion (Mohammed Said 2000, Mohammed Said 2009). Between 1990 and 1995 the deforestation rates were the fourth highest in the world at 5.8 %. Deforestation is largely driven by poverty, both to sell forest products and to clear potential cultivation land (Mohammed Said 2000). This situation is unlikely to change as the population is rapidly increasing and the islands resources are finite.

Previous work

Otus capnodes went without documentation between 1887 and 1992, until which it was thought to be extinct, until Roger Safford et al (1992) rediscovered the owl. He documented the morphology of the owl from two captured individuals. He also estimated the population size at 100-200 pairs (Safford, 1993). Since then a small number of small scale surveys have been made but without any publications (Unpublished reports Birdlife International, 2010, IUCN, 2010). This lack of previous work adds challenges to the experimental design.

Red list classification

O. capnodes is currently listed as critically endangered (IUCN, 2010). The listing is due to a population estimate of fewer than 250 mature individuals (IUCN, 2010) and is based upon the population estimates by Safford et al and two other unpublished reports (IUCN, 2010).

Morphology as described by Roger Safford

Only two specimens have been described (Safford, 1993), although there are photographs of two more that were not handled (C.Marsh 2005). The wing measurements were 173cm, tail of 80cm and a weight of 119g.

Using biology of similar owl species to make predictions about O.capnodes

Whilst the lack of information on the biology of *Otus capnodes* can cause problems, the biology of other owls, especially scops owls could be used to infer likely biological characteristics. The *Otus* or scops owl genus is widespread, being found in five biogeographic areas (Indo-Malaya, Afrotropics, Nearctic, Neotropics, Palearctic) (Howard & Moore, 1991). The Otus genus has its centre of diversity in Eurasia with 26 species (Fuchs et al., 2008). There are secondary radiations in Africa; four species, and the Indian Ocean with six or seven species (Fuchs et al., 2008). In the western Indian Ocean there are several species endemic to small islands, thought to have arrived 3.6 MYA; *O. Capnodes* from Anjouan, *O. mayottensis* from Mayotte, *O.moheliensis* from Mohéli, *O. pauliani* from Grande Comore, and *O. rutilus*/*O. madagascariensis* from Madagascar and *O.insularis* from the granitic Seychelles. These species are unfortunately very poorly known. *O. Moheliensis* for example was first described in 1998 (Lafontaine & Moulaert, 1998). It is only in the last 20 years that specific species status for *Otus. pauliani*, *O. capnodes*, *O. madagascariensis* and *O. Mayottensis* has been acknowledged, using morphological and vocalisation data (Fuchs et al., 2008)(Lewis, 1998)("Herremans et al.),(Safford, 1993, Rasmussen et al., 2000).

A genetical study by Fuchs et al (2008) suggested that the Comorian birds are significantly distinct genetically whilst being part of identifiable evolutionary group. They attribute this to a simultaneous invasion event followed by rapid evolution. It has also been noted, both by Fuchs et al (2008) and by comparison of recordings (Bird calls of the Comoros 2010) that the calls of *Otus pauliani*, *O. capnodes*, *O.moheliensis* and *O. Mayottensis* are very different, see figure 2.2. Fuchs et al (2008) suggest that while the differences in calls may be significant, the relationships between evolutionary divergence and differences in calls "are not related in any simple or obvious way". An example of this is the existence of memes. Due to the manner in which birds learn calls it is possible for birds of the same species to have different calls in different locations (Baker & Gammon, 2008).

The combination of lack of research and the potential for evolutionary divergence causing behavioural differences therefore means that comparative predictive studies for this species are limited. However whilst comparative studies may not be possible using evolutionarily and geographically close species, convergent evolution and

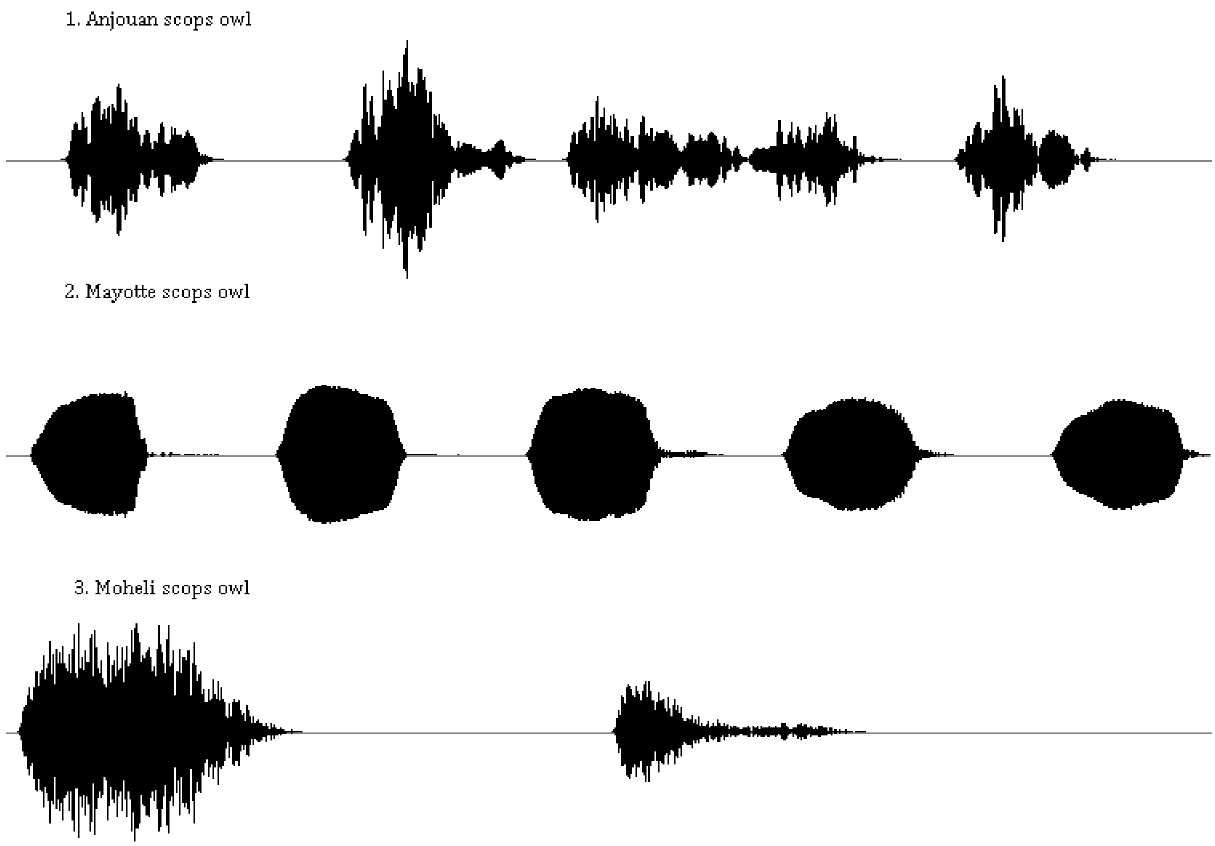


Figure 2.2 The calls of the Anjouan, Mayotte and Moheli scops owls.

owl species in different areas may provide some potential for comparison. Comparisons and predictions for methodology and survey techniques can therefore be made to some extent but biological predictions will be limited.

Biology of the Otus genus

The *Otus* genus are nocturnal hunters that mainly eat insects, the larger species also eating rodents, reptiles and small birds (Hekstra, 1973). They are territorial and use song to defend their territories (Currie et al., 2002)(Hekstra, 1973).Their territory sizes vary; *Otus pauliani* has a territory of around 5ha (Herremans et al.) where as *Otus insularis* has a territory size of around 25ha (Currie et al., 2004). They are relatively short lived; Galeotti and Sacchi (2001) noted that the oldest ringed specimen of Otus scops discovered was six years old. The genus inhabit a variety of habitats, many inhabiting farmland (Martinez et al., 2002), different types of woodland (Rene de Roland. &

Thorstrom., 2009)(Currie et al., 2004b) and mountainous grassland (Marchesi & Sergio, 2005). Their nesting habits vary, many use hollow trees (Currie et al., 2004a) whilst some burrow (Conway et al., 2008)and nest in rocks (Marchesi & Sergio, 2005). Ultimately the *Otus* genus is very varied in its biology and therefore predictions were difficult to produce.

Methodology

Detection

Detection or recording (recording defined as detection during a survey) of birds can often be difficult. Foliage can prevent visual confirmation, they are fast moving and many birds leave few signs that could be used as indirect indicators. For these reasons birdsong is often used for detection (Bibby & Burgess, 1992). The advantages of using birdsong as a surrogate for presence is that it allows data collection in species that might otherwise be highly difficult to study. It can also greatly increase the quantity of data that can be collected per unit effort. Bird calls however are not a random occurrence and so there are sources of error (Currie et al., 2002)(Severinghaus, 2000). There is a wide range of biological reasons for calls and calling can infer a cost (Galeotti et al., 1997). This means that understanding the potential reasons for differences in detection is vital in understudied species. For example, Penteriani et al(2002) showed that *Bubo bubo* alters its territorial calling according to density; the threat of territory invasion is lower in low densities so the effort of territory protection, and therefore frequency of calls, is lower. Changes in call frequency over seasons may be significant enough to produce different population estimates between surveys, producing a false trend if surveys are conducted rarely and during different seasons (Currie et al., 2002). The sex can also be a large factor, for example, in many species the males call to protect territories or to attract mates, whilst the females are relatively silent(Galeotti et al., 1997). Ignorance of this fact could skew a population estimate.

Survey options

There are three main methods of surveying birds (Bibby & Burgess, 1992); line transects(Buckland et al., 2008), point count surveys (Buckland et al., 2008)and mapping. Mapping involves comprehensively searching a designated area and producing an accurate population estimate for the given area (Bibby & Burgess, 1992). This method is however very time consuming. It is also not suited to the remaining forest areas on the island which are on steep slopes and therefore difficult to transverse.

Line transects entail following fixed straight lines at a constant walk. Individuals are then recorded (Buckland et al., 2008). Due to the topography of the island however this method is not viable.

The most viable method is point counts. This method entails making counts of individuals at a series of separate locations(Buckland et al., 2004)(Buckland et al., 2008). This method is the best suited to difficult terrain as so long as the point counts are a minimum distance away from each other any route can be taken. This method also allows for the use of playback, a common tool in surveying cryptic owls (Hannah, 2009)(Currie et al., 2004b, Penteriani et al., 2010).

Issues with using presence and absence data

A problem encountered by all methods in estimating population density is that the probability of detecting a bird in the search area is often not 100% ((Buckland et al., 2004)(MacKenzie et al., 2002). This means that whilst presence data (assuming correct identification) is relatively reliable, absence data only indicates that no recordings were made (MacKenzie, 2005). For this reason pseudo-absence data is often discussed, defined as absence of detection but not proof of absence of the species.

There are a number of methods for dealing with this problem. Presence data can be used alone, taking detected bird presence as an indicator of occupation but not taking absence of detection as evidence for absence of occupation (Fielding & Bell, 1997). This removes some of the error introduced by psuedoabsence data but not all (Cianfrani et al., 2010).

Alternatively the probability of detection can be calculated in a number of ways. The most appropriate to this study is the distance method .

The distance method

This method assumes that the probability of detection is 1 if the bird is 0 metres from the observer (Buckland et al., 2008)and that the probability of detection decreases as the distance from the observer increases(Buckland et al., 2004). It is also assumed that the density of individuals is the same for all distances from the observer. By analysing the frequency of detection at different distances a probability of detection curve can be produced which indicates the probability of detection at different distances from the observer. The detection probability can be combined with detection records using software such as Distance to produce population density estimates . This method has a number of important assumptions. Buckland et al have considered the distance method extensively and detail the main assumptions as follows (Bourg et al., 2005)(Buckland et al., 2004).

1) The detection probability of a bird at the point or line is 100%.

2) Birds are detected at their initial location. If birds move into the survey area or away from the observer before detection this can alter the density estimates.

3) The distance between a bird and the observer is recorded accurately.

4) If birds exist in clusters it is assumed that the size of the clusters is accurately measured.

5) It is assumed that the sampled area is representative of the surveyed area.

This method is very well established and has been shown to produce accurate results (Marques et al., 2001, Morgan et al., 2006)(Buckland et al., 2004). Its requirements however can be limiting factors in its use, for example, error in estimating distance can have a large effect. Buckland et al showed an average underestimation of 10% in the distance estimates can result in a 17% population underestimation (Buckland et al.2001).

Playback

A well established method of increasing detection probability is to use playback (Zuberogoitia. & Campos., 1998)(Buckland et al., 2008). Playback is defined as the process by which a recording of a song is played in order to instigate a reaction from other members of the species, thus aiding in their detection (normally, all though not always, from the same species(Wilkins & Husak, 2006)). The reasons behind the responses can vary but are often due to territory defence (Currie et al., 2004). This method is often used when factors such as large territories, low vocal activity or low population density make detection difficult (Currie et al., 2004). The methods vary between species and habitats. The basic method entails playing a recording and then listening for responses. It is common to play a recording of a natural phrase of bird song succeeded by a pause to allow listening for responses. The lengths of the phrases, of the total playback period and of the pauses vary greatly between birds and surveys and often depend on the biology of the species being studied. As bird calls are an important communication vector for birds there are many factors that affect playback and these must be understood in order to correctly interpret the results.

Variations in methodology

An area in which the methods vary between species and surveys is in the length of the playback period. Owls with large territories often require long playback periods, for example in surveying *Otus insularis* and *Otus elegens botelensis,* twenty minute playback period were used (Currie et al., 2004b, Severinghaus, 2000). In contrast, when Galleotti et al studied *Otus scops* and Alba-Zúñiga *Megascops seductus* they used a three minute playback period (Galeotti et al., 1997)(Alba-Zuniga et al., 2009). Even within species the methods vary; in 2002 Currie et al studied *Otus insularis* using 12 minute playback periods (Currie et al., 2002). The main risk by using increased listening periods is that double counting can occur, so the length of playback is a function of maximising detection probability and minimising double counting chance.

Season

Response to playback has been found to vary throughout the year. This may be due to a range of factors such as seasonal climatic change or behavioural cycles, such as breeding seasons. Currie et al (2002) found that response to playback in *Otus insularis* varied throughout the year, peaking in February and October. There is also variation in the amounts by which different species responses change between seasons (Zuberogoitia. & Campos., 1998).

Biology of the recorded call

Bird calls are used to communicate a variety of messages. As such the nature of the recorded call can potentially have an impact upon its effectiveness.

The sex of the recording can be important; species have been shown to adjust their territorial response according to the sex of the intruder (Galeotti et al., 1997), possibly due to the benefits of polygamy. This is important because the use of a certain call may therefore only instigate responses from one sex.

A species may have different calls between individuals according to age, relationship or territory status etc. Many species have different calls according to activity, for example duetting with a mate or defending territory. Different calls may pose different territorial threats (Severinghaus, 2000)and so instigate different levels of response. This means that understanding of the call being played in playback can be crucial to fully exploiting its potential.

Habitat suitability models

A problem facing many conservation efforts is lack of detailed knowledge of the distribution of the species with which they work. Gathering such information via field research is however time consuming. For this reason habitat suitability models are used.

Definition

A common method of predicting the actual or potential geographic range of a species is to identify the correlations between environmental variables and occupancy of the species (Guisan & Zimmermann, 2000). The distribution of environmental variables can then be used to predict distribution of the species. For example, if we wish to find the potential range of a plant that best suits dry chalky soils then simply locating areas with chalky soils and low precipitation will generate a potential species range. It is important to note that this method will usually identify the potential range not the actual range, I.e. it will assume the species is in equilibrium with the habitat (Franklin, 2009).

Creating the model

A model is usually created using detailed information about the environment combined with species presence data. The environmental data can come from a range of sources such as maps, survey data and remote sensing. Satellite imaging tools such as Landsat 7 and ASTER (GDEM) collect a range of surface data, such as elevation, moisture content and light reflectance(NASA, 2010, Reuter et al., 2009). Light reflectance is collected for a wide range of wavelengths. These can then be used in conjunction with other factors to predict vegetation types, e.g. forest or plantation (NASA, 2010, Reuter et al., 2009). These factors are then input into a model which assesses their correlation with species presence and/or absence data (Franklin 2009). In order to do this the model considers each pixel individually, identifying correlations between the values for each factor and presence or absence.

Inputting species data

Species data often comes as a combination of presence and absence data. Models can be run using either presence or absence data or both (Franklin, 2009). The choice is normally a factor of which form of data is best obtained under field conditions. A large difference between presence and absence data is that presence data signifies the detection of an individual (assuming correct identification etc) whereas absence merely indicates lack of detection, psuedoabsence (Manley et al., 2005). Psuedoabsence data can be due three main reasons;

i) Non-detection, where the subject is there but merely not detected (Franklin, 2009).
ii) Absence can be due to historical reasons rather than habitat suitability, such as overhunting in that area (Franklin, 2009).
iii) Absence due to unsuitable habitat (Franklin, 2009).

If the reason for detected absence can be identified (for example by identifying the detection probability using the methods above) then absence data can be very useful in a model. In many cases however this is not possible and so only presence data is used (Fielding & Bell, 1997).

3. Methods

Study area

One of the aims of this study was to discover the distribution of *O capnodes* on the island of Anjouan, thus the study aimed to visit all regions of the island during the survey. The survey was conducted between the 10th of May and the 10th of July. Whilst reports indicate that *O. capnodes* is a forest dependent species this was not assumed and a range of habitat were selected for the survey. This included habitats which cover only small areas of the island such as the mangrove forests.

For the purpose of this survey the habitats were classified into three categories; natural forest, degraded forest and plantations. Natural forest comprised of dense forest with little or no visible human impact. Degraded forest retained forest structure, for example canopy etc, but suffered from some form of human impact. Forest utilisation within the degraded forest category consisted of tree cutting for firewood or construction. Thus indicators included tree stumps, wood chippings, and wide paths along with tree density and canopy cover. Plantations were defined as areas where forest had been removed and agricultural practices were present. Areas where deforestation had caused erosion and left infertile soil were also included in the plantation category.

Pilot study

Pilot studies trialling point counts were conducted at Hombo and Paje (see figure 3.1). These were conducted by S.Lloyd and all three local technicians; Abubakar, Ishaka Said and Amelaid Houmadi. The surveys were conducted along 2-3 Kilometre paths that encompassed all four habitat types. Point counts were conducted at 200m intervals, using a Garmin GPS for distance measurements. At each point there was a listening period of 10 minutes followed by a playback period of 10 minutes. The timing of this was based loosely on the protocol for *Otus insularis* and designed to evaluate the efficiency of both playback and silent listening (Currie et al., 2004). The playback period consisted of a minute of playback followed by a minute of silence repeated for ten minutes. During the first three point counts different playback patterns were tested and the responses observed. Data on the habitat, location and position of the owl relative to the observers was recorded. During this pilot study the following observations were made.

i) The density of owls was high. On a number of occasions five owls were detected in a single point count.
ii) The owls were very vocally active, singing most of the time.
iii) Most birds were detected within the first 5 minutes of listening.
iv) The number of the birds and the movement could become confusing after around 10 minutes listening.
v) The distance between the observer and the owl was difficult to estimate. This was due to the sharp relief of the terrain and the fact that the darkness meant no visual confirmation was possible.
vi) Movement between points was slow due to difficult terrain.
vii) Weather was unpredictable and could stop data collection.

viii) The birds started singing at 18:20 and continued to call until at least 22:00

ix) Playback caused the owls to react in a number of ways. Some approached the observers calling, others fell silent.

x) Reactions to playback were normally rapid

These observations lead to the following experimental design.

A pilot study was also conducted in mangrove habitat as the area of mangroves on the island was too small to be sampled using the point count surveys and no owls were heard.

Morning surveys were trialled however the call frequency was much lower so it was decided not to include them in the survey.

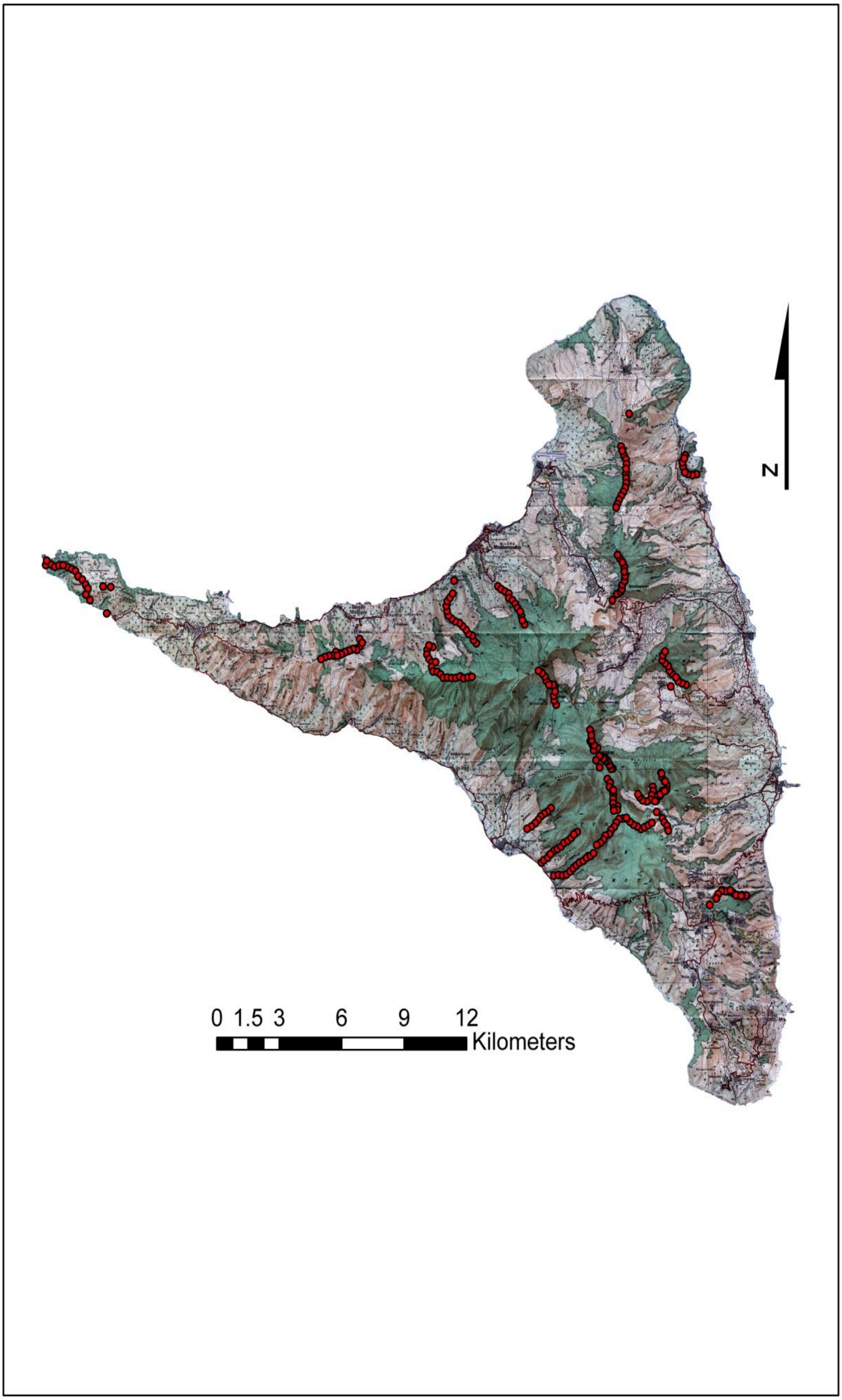


Figure 3.1 The survey routes.

Survey design

The Point Count method was used. This was to allow flexibility of routes (the paths along which point counts are made), safety due to difficult terrain and to limit the noise that might hinder the study of a cryptic species. Routes were located to meet the following requirements. Firstly it was ensured that a representative and statistically useful sample of different habitats at different altitudes was obtained. Secondly, as little was known about the habitat range of the bird surveys were conducted across the island to ensure that all egions were surveyed, including all discreet forest areas. Thirdly any uncommon habitats on the island were surveyed as previous knowledge of the species was not sufficient to rule out any habitat type as a part of the species range. Recce surveys (Morgan et al., 2006)were carried out between point counts in areas where owls had not been previously located, such as forests consisting of invasive species.

The survey covered 213 usable separate points along 17 routes. Assuming each point count represents on average a circle of 100m radius this represents 6.7 km2 total area surveyed. Of these surveys 113 were in plantations, 39 in natural forest and 69 in degraded forest. The survey effort can be seen in figure 3.1.

Designing Routes and conducting point counts

Routes were visited twice, once during the day to establish good design and gather habitat and GPS data and once during the night to conduct the survey.

During the daytime visits paths were identified that were suitable for surveying. A number of factors were considered, including: Length, time taken to walk the length of the route and safety. Points were then marked a minimum of 200m apart. Each route consisted of between 7 and 15 points depending on how long it took to walk between points. Coordinates of points were recorded using a Garmin GPS handheld unit. The habitat within a 20m radius was recorded as the habitat at the point and a map of the surrounding habitat outside the 20m radius was sketched in order to identify the habitat of calling owls.

Surveys were conducted between 18:20 and 22:00 when the pilot study indicated the owls were most vocal. The observers walked along routes stopping at the predetermined points to conduct point counts. A point count consisted of a 5 minute silent listening period (as most owls were heard in this time during the study period) followed by a 3 minute playback period. As part of the project was to train local technicians in the protocol there were occasionally delays in commencing playback. These delays were rarely more than a minute and when they occurred no birds were recorded during the pause. If an owl was heard data was recorded on the following:

i) The habitat at its location.
ii) The time.
iii) The orientation from the observer.
iv) Its altitude relative to the observer.
v) Whether it was part of a couple.
vi) Whether it responded to playback.

Recordings were excluded for the following reasons: if they were suspected to have been recorded in previous point counts, if they were flying and if they were suspected to be a previously recorded owl that had moved. Point counts were excluded if there was bad weather or if the GPS did not have signal.

In order to minimise observer bias S.Lloyd was present at all surveys.

Playback

Playback consisted of a tape that alternated between 20 seconds of song and 20 seconds of silence. This pattern of calling imitates the natural song pattern of the species and it also aided listening. The speakers were pointed directly up in order to direct search in all directions equally. Pilot studies indicated that there were a range of reactions to the playback. Some birds approached the playback whilst others fell silent. The playback was therefore conducted after the silent listening period. The song used for the playback came from “Bird calls of the Comoros”. An Ipod nano and a Veho 360 speaker was used to play the playback.

Calling activity of other species

To assess potential for misidentification other avifaunal species heard calling were recorded. There was very little vocal activity from species other than *O.capnodes* during the nights. There were recordings of *Tyto alba* and *Coracopsis vasa comorensis* (Greater Vasa Parrot). These calls are easily distinguishable from *O.capnodes.* The scarcity and difference of the non *O.capnodes* calls suggest that false data due to misidentification was negligible.

Analysis

Nonspatial analysis

A nonspatial analysis was conducted to identify habitat preferences of the species. The presence/psuedoabsence rates between point counts at different habitats were compared using a binomial generalised linear model to assess whether there was variation between habitats. A Poisson distributed generalised linear model was used to assess whether owls were detected at different densities at different habitats.

Table 3.1 The environmental variables used to create the HSM

Layer	Indicator of	Source
Green light	Vegetation	Landsat 7 and EO-1
Brightness	Bare and cultivated land	Landsat 7 and EO-1
Slope	Steepness of slope	SRTM and ASTER
Elevation	Elevation	SRTM and ASTER
Moistness	Water levels	Landsat 7 and EO-1
Proximity to roads	Proximity to roads	IGN map
Proximity to villages	Proximity to villages	IGN map
Proximity to streams	Proximity to streams	IGN map

Analysis of playback

A line of best fit for the number of novel owl recordings during the silent listening period was drawn in order to compare the number of novel owls recordings heard during the playback period with the number expected. A Chi squared test was used to determine whether more owls were heard during the first three minutes of silent listening than the three minutes of playback.

Analysis of call frequency

A Chi squared test was used to verify whether call frequency changed throughout the duration of the surveys, i.e. whether call frequency was consistent between 18:00 and 22:00.

Analysis of search effort with regard to elevation

A Chi squared test was used to evaluate whether the search effort was representative of the island.

Habitat Suitability Model

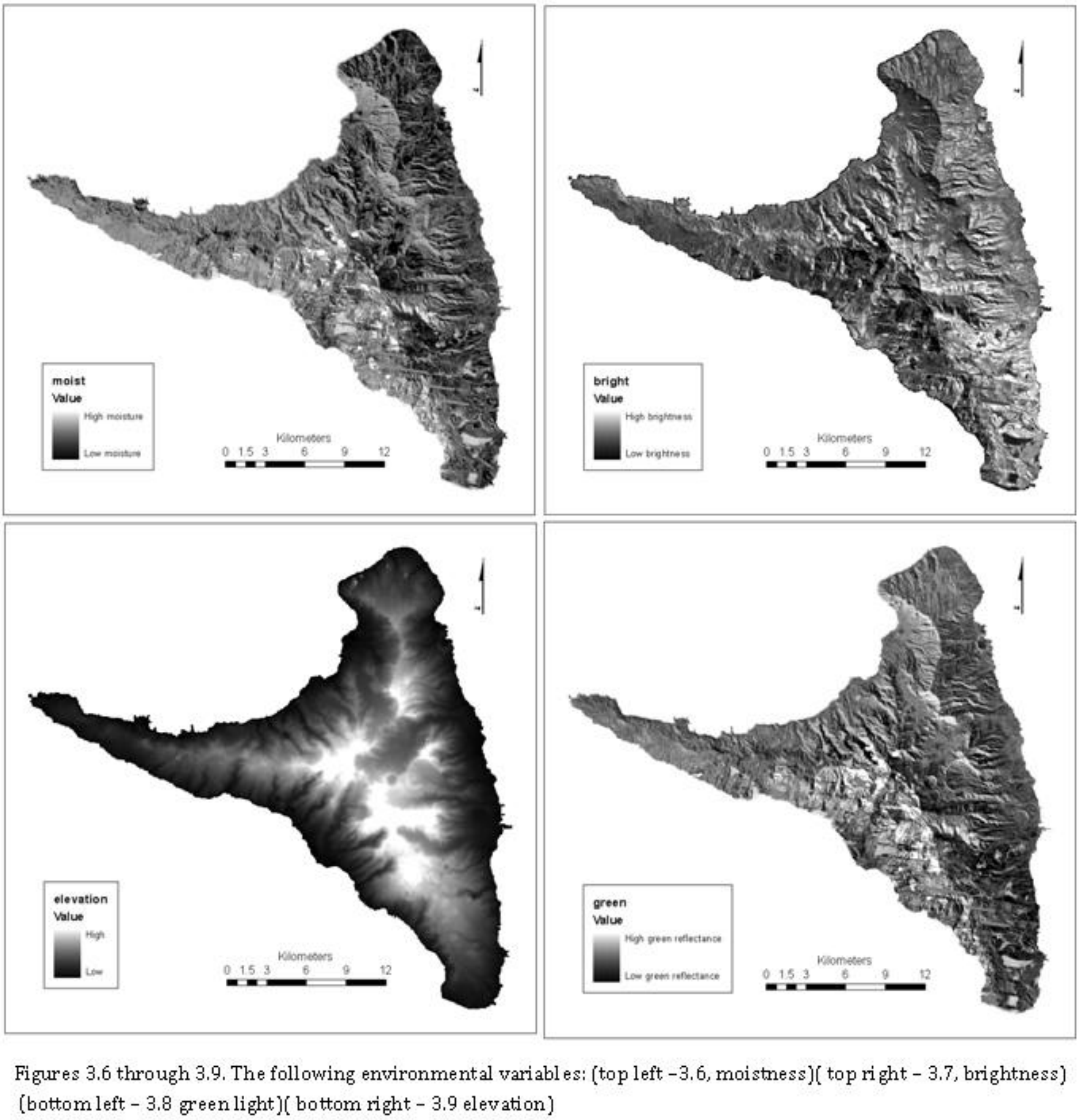
Environmental variable map

The satellite map was produced by Dr Peter Long. The finished product is described here and the methods are detailed in the appendix. The environmental variables can be seen in table 3.1.

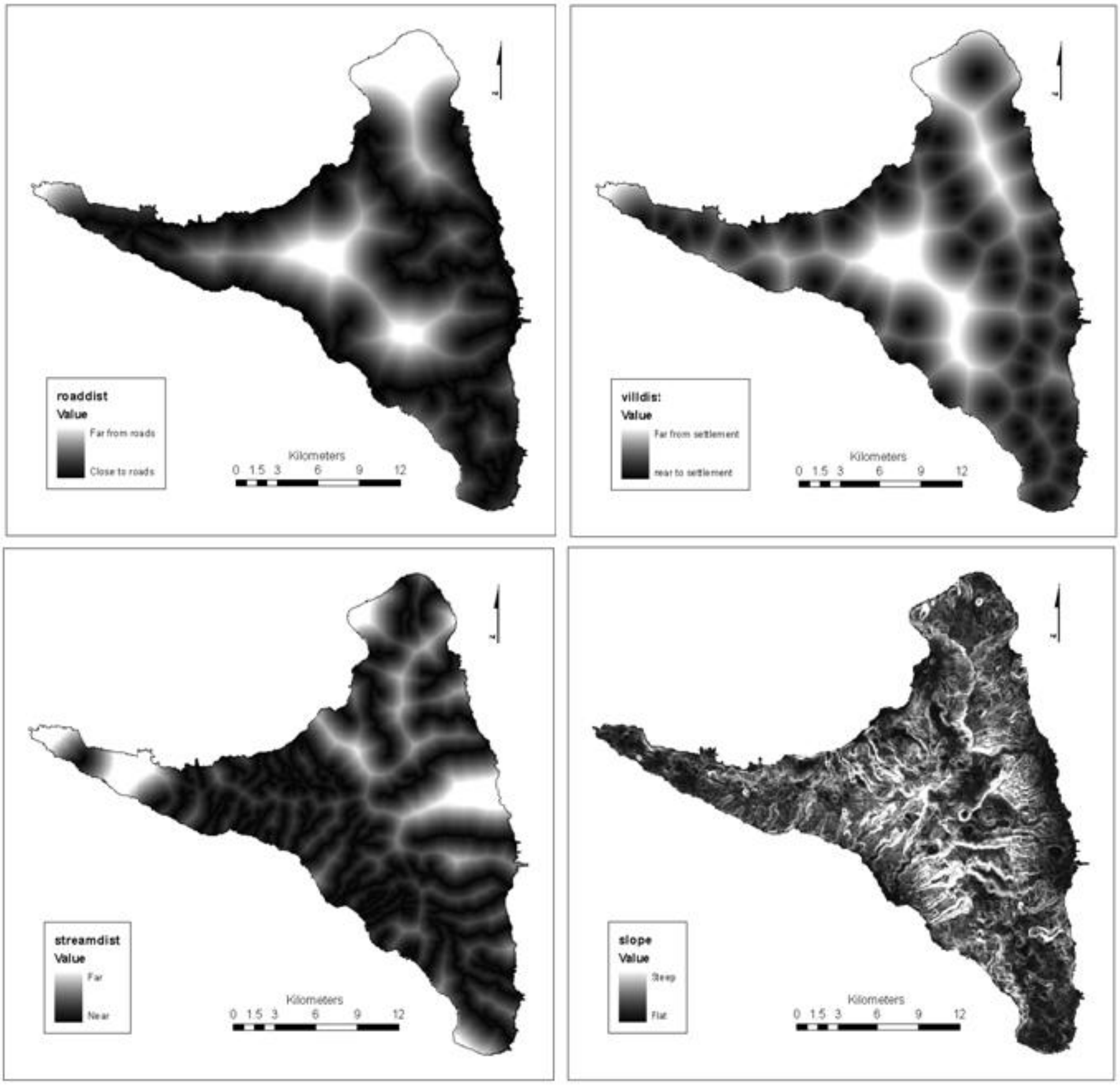
A 1:50,000 topographic map of Anjouan published by IGN was digitised and georeferenced. The root mean square error was very low, at 4.2m which is smaller than one pixel. Shapefiles detailing road, settlement and river presence were then created using onscreen digitisation to a 15m resolution. These were then used to create raster layers of proximity to roads (Figure 3.2), settlements (Figure 3.3) and rivers (Figure 3.4). The raster layers of proximity to roads and villages were used as indicators of human impact.

A digital elevation model was produced by combining two data sources; the 90m resolution data from the SRTM mission and the 30m resolution data from ASTER. Raster layers of slope (Figure 3.5) and elevation (Figure 3.6) were produced to a 15m resolution.

Data from Landsat 7 (ETM+ sensor) and EO-1 (ALI sensor) were used to produce a cloud-free moderate resolution multispectral reflectance mosaic of the study area. Three raster layers were produced at 15m. These detailed; green reflectance (Figure 3.7), an indicator of the level of vegetation, brightness (Figure 3.8) which is an indicator of the amount of cultivated and bare soil and moistness (Figure 3.9) which indicates the amount of water.



Figures 3.6 through 3.9. The following environmental variables: (top left –3.6, moistness)(top right – 3.7, brightness) (bottom left – 3.8 green light)(bottom right – 3.9 elevation)



Figures 3.2 through 3.5. The following environmental variables: (top left – 3.2 proximity to roads) (top right – 3.3 proximity to settlements) (bottom left – 3.4 proximity to rivers) (bottom right – 3.5 slope)

Data input

A map of owl presences was produced by taking the coordinate data for each point and using the bearing and distance to observer to infer the location of the owl. This was then converted to a 38S UMT Coordinate system. A number of random points were generated equal to the number of presences. These were then compared to the presences to indicate whether the presences were more associated with environmental variables than random locations.

Identifying predictive environmental variables

A binomial generalised linear model (GLM) was used to identify which environmental factors mapped by the satellite data have predictive power of owl presences. The presence and absence data was input into the model using the R statistical program and the environmental variables one by one. This compared the pixels that contained presences to the pixels that contained absences and indicated any statistical difference, and thus the predictive power of that variable. This then produced a list of variables that could be used to predict values associated with owl presence. It also provided a figure for the degree to which each factor was a predictor, the B value.

Model validation

In order to obtain model validation the *k*-fold partitioning method was used. This entailed partitioning the data into ten equal sets, each of which was half presence data and half absence data. Nine of the ten partitions were then inputted into a Binomial GLM with the predictive environmental variables using the R statistical program. This was repeated 10 times, using each partition as the validation data set once. This produced a series of minimum adequate models, producing a probability of presence for each pixel on the map, each one made excluding a different tenth of the data. Each of the models was then checked for accuracy by comparing the predictions against actual data of the remaining tenth partition. The predictions were then plotted in confusion matrixes to assess accuracy for a hundred evenly spaced thresholds. From these matrixes the frequency of true positives and false positives are taken. These are then plotted with False positives on the X axis and True positives on the Y axis to produce a Receiver Operating Characteristic (ROC) curve. The area under the curve (AUC) is an indicator of the accuracy of the model. A value between 0.5 and 1 is produced, where 0.5 is the result expected by random results and 1 is perfect prediction.

A discrete habitat suitability map is produced by setting a threshold, above which the species is said to occur and below which it is said not to. This is calculated using a kappa statistic. This is an index of accuracy created by calculating the ratio of false positives to true positives (where higher Kappa equates to higher accuracy). This is then calculated and the Kappa statistic is plotted against the threshold. The highest kappa statistic then indicates the most accurate threshold.

Map creation

A habitat suitability map was created using the following formula (figure 3.10) to combine the predictive environmental variables with their respective B values using the Arcmap GIS software. This produced a map illustrating the probability of occurrence of the owl on each pixel. The kappa curve was then used to choose the most appropriate threshold of probability of occurrence to produce the most accurate habitat suitability map.

$$\Pr(\text{species}) = \frac{e^{(\beta_1[x_1]+\beta_2[x_2]+\beta_3[x_3]...+\beta_n[x_n]...+\beta_0)}}{1+e^{(\beta_1[x_1]+\beta_2[x_2]+\beta_3[x_3]...+\beta_n[x_n]...+\beta_0)}}$$

Figure 3.10.The formula used to create the HSM. The formula is calculated for each pixel. Where X=the variable and B=the B value, a predictor of correlation.

Distance analysis

Population density for the suitable habitat area predicted by the HSM was estimated using the software *Distance* 4.1 to analyse surveys from within the area predicted by the HSM. Owls detected by playback and owls detected over 100m from the observer were excluded. Suitable models recommended by Buckland et al (2001) were considered (BUCKLAND et al., 2001). Goodness of fit test statistics and detection probability histograms were examined. The lowest Akaike's Information Criterion value was used to determine the model, the uniform simple polynomials model.

The population density was then combined with the area of predicted habitat suitability to provide a population estimate. The population estimate was predicted as a range by combining the potential error of both the HSM and the population density estimate.

4. Results

Recordings

In total 285 usable owls recordings were made. The numbers of owls heard in each habitat type (according to the habitat of the owl not the point count) and the pattern of higher owl occupancy being detected in natural and degraded forest can be seen in table 4.1. On average 3 owls were heard per point in natural forest, 2 in degraded forest and 0.3 in plantations as can be seen in figure 4.1.

Generalised linear models were conducted comparing both presence at different habitats (Binomial) and owl density at different habitats (Poisson) (for binomial comparing presence/psuedoabsence P= 2.91e-06, 0.0382, 1.93e-10. For Poisson GLM comparing densities P=1.39e-11, 0.00426 and 1.99e-15). These indicated that there were both significantly more point counts that detected owls and more owls were detected per point count in natural forests than degraded forest and plantations. They also indicated that there were significantly more point counts that detected owls and significantly more owls were detected per point count in degraded forests than in plantations

Table 4.1 The relative survey effort, number of owls detected and number of point counts at which owls were detected by habitat.

habitat	point counts	number of owls	number of point counts with owls present
natural forest	39	118	38
degraded forest	69	134	55
plantations	113	33	32
total	213	285	125

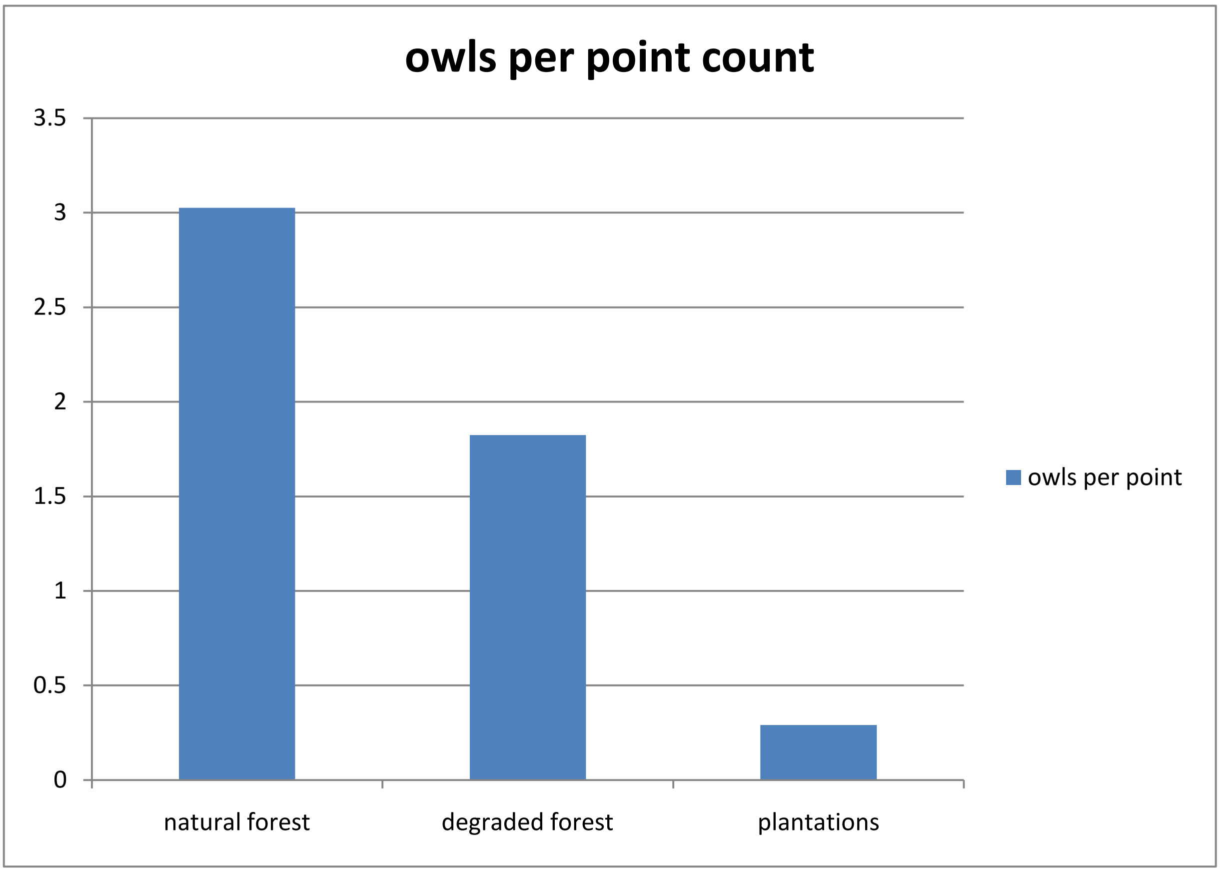


Figure 4.1. The average number of owls recorded per point count (Natural forest standard deviation = 1.38 standard error 0.221, Degraded forest standard deviation = 1.47, Plantations standard deviation = 0.977 standard error = 0.092).

Altitude

Counts were made at a range of elevations although these were not in proportion to the distribution of elevations on the island. This demonstrated using a chi squared test (X-squared = 176.4438, df = 14, p-value < 2.2e-16) As can be seen in figure 4.2 there was a bias towards higher altitudes. This bias was due to the fact that elevation correlates with forest and as surveys were designed to maximise owl presence data, more surveys were conducted at higher elevations.

Detections came from a range of altitudes. The lowest recorded was 44m, although it is likely that this was an anomaly. Whilst the owls did appear to inhabit areas as low as 300m, higher densities were discovered at higher altitudes, for example 800m - 1400m.

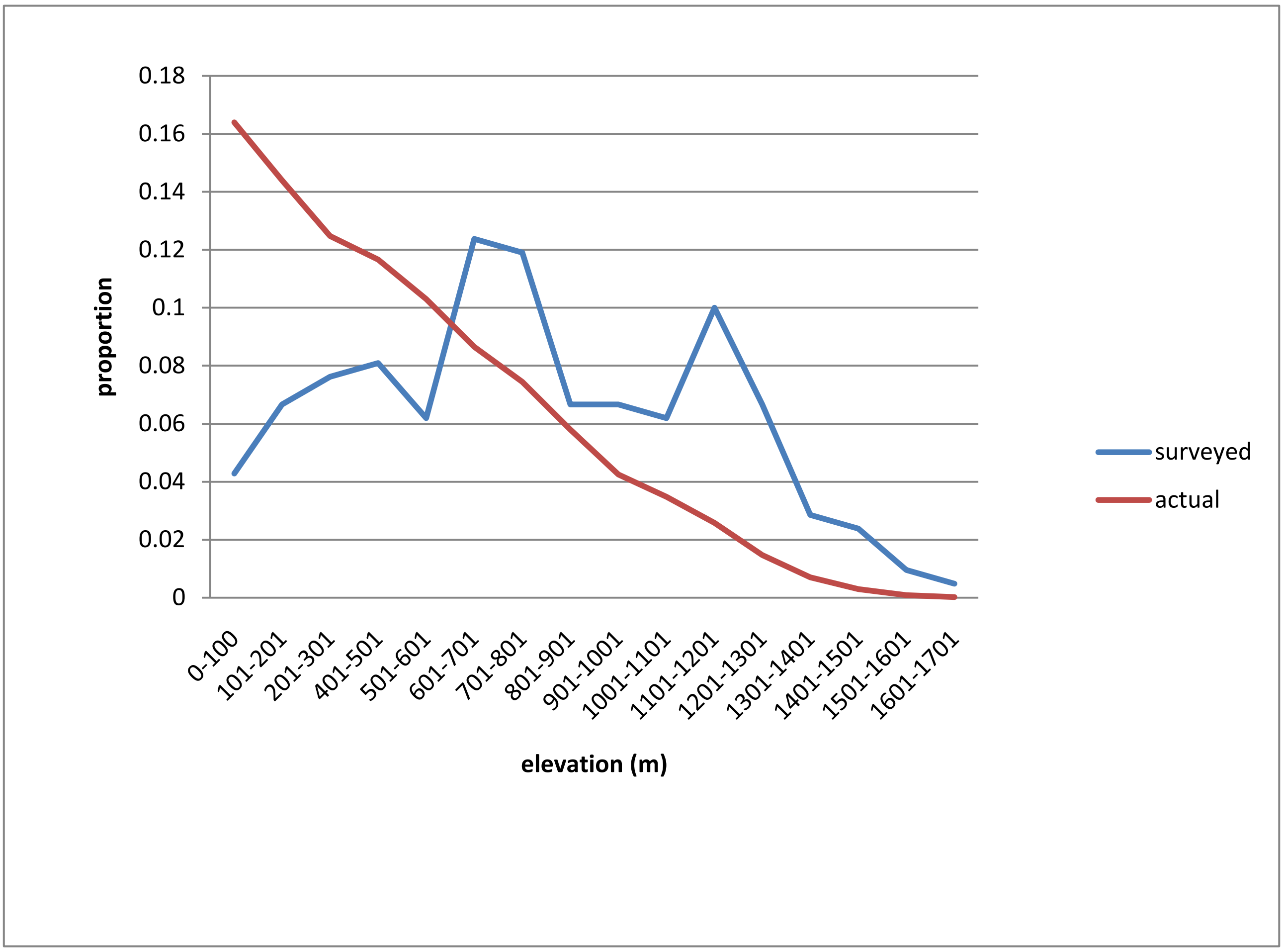


Figure 4.2 The distribution of the elevation of survey effort and the elevation of the island.

Change in song frequency over time

A Chi squared analysis proved that there was no difference between detection rates at different times, i.e. the frequency of bird call remained the same during the study period of 18:00 to 22:00 (X-squared = 16.3419, df = 14, p-value = 0.2929).

Temporal distribution of recordings across the point counts

Figure 4.3 shows the number of minutes into the point count that the birds were first recorded, i.e. the number of minutes that had passed since the start of the point count. As can be seen the majority of birds were recorded at the start of the point counts. The graph goes up to 9 minutes due to occasional delays in starting playback.

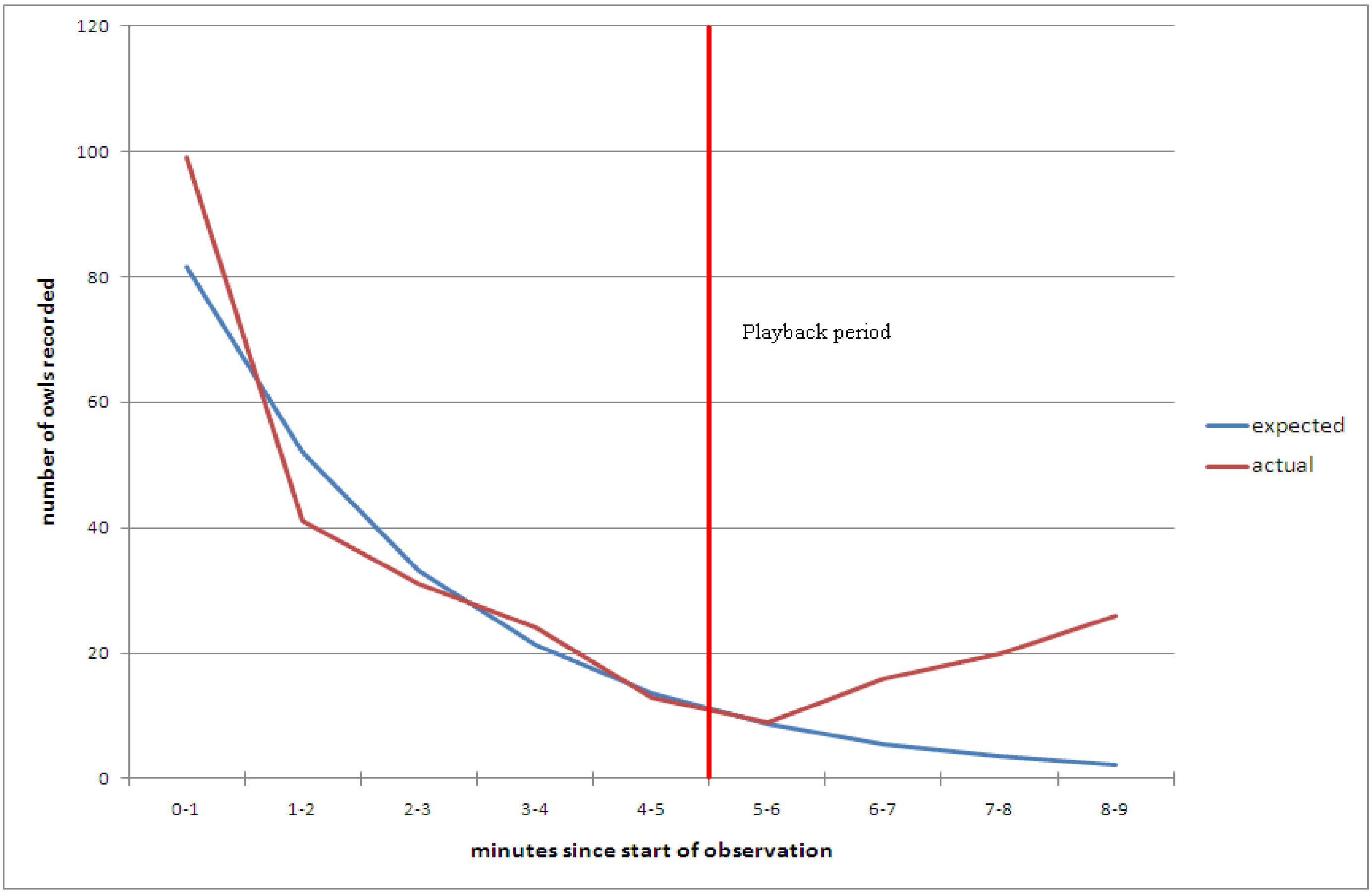


Figure 4.3 The temporal distribution of novel recordings over point counts. The formula of the expected line calculated using the recording during the silent listening period is y = 127.690 (0.638^x) with a correlation coefficient=0.983

Double counting

As can be seen by the fact that 99 of the birds, or 35%, were heard in the first 60 seconds of point counts, calling frequency was high. This meant that owls were easy to track and moving owls were identified. A total of three owls were identified that had been heard in a previous point count, representing a detected overlap of 1% between point counts.

Playback

Of the 285 birds heard, 62 were first heard during the playback period. The total number of birds heard during the three minute playback period, i.e. including previously heard birds, was 144. The total number of birds heard during the first three minutes of listening was 171. A chi squared test indicated the number of birds calling in the absence of playback was higher than the number of birds calling in the presence of playback (X-squared = 4.9279, df = 1, p-value = 0.02643).

Whilst less birds were calling during the playback period, the line of best fit suggests that there was a higher than expected number of new owls (i.e. owls not previously heard) being recorded. Figure 4.3 shows the number of novel owls recorded per minute in comparison with a best fit line for the number of novel owls heard in the silent listening period (y = 127.690 (0.638^x) correlation coefficient=0.983). It can be seen that the expected number of novel owl recordings is much lower than the actual. It is possible that the number of novel birds heard during this period is due to double counting caused by playback induced movement in the birds. A Chi squared test however shows that there is no significant difference between the distances at which the owls were heard at during silent listening and the distances at which owls were heard during playback (X-squared = 14.5434, df = 10, p-value = 0.1496). The data indicates therefore that the playback causes birds to be recorded calling less frequently with the exception of some birds which increase their call frequency.

Habitat suitability modelling

Predictive variables

The following environmental variables were tested for correlation with owl presence: elevation, moistness, distance, green light, brightness of light, distance to

Table 4.2 The results of the GLM.

variable	Estimate (B)	Std error	Z value	Pr(>z)
Intercept	-4.31	0.7435	-5.797	6.75e-09
Elevation	0.004947	4.330e-04	11.427	< 2e-16
Bright	-81.51	31.46	-2.588	0.00965
Green	-89.89	35.94	-2.501	0.01238
Road distance	0.0005493	0.0001059	5.186	2.15e-07

streams, slope, distance to roads and distance to villages. Of these the GLM predicted that elevation, green light, brightness of light and distance to roads were predictive of owl presence (Table 4.2).

Habitat suitability map

A habitat suitability map was produced using GIS arcmap software. The environmental variables elevation, brightness, green light and distance to roads were input with their B numbers in to the formula designated in the methods to produce Figure 4.4.

The kappa curve predicts a threshold of 0.44, see figure 4.5. The map produced by the threshold predicted by the kappa curve predicts suitable habitat in a few areas that are covered in by bare grassland. The total area of the suitable habitat predicted is 93.4km2

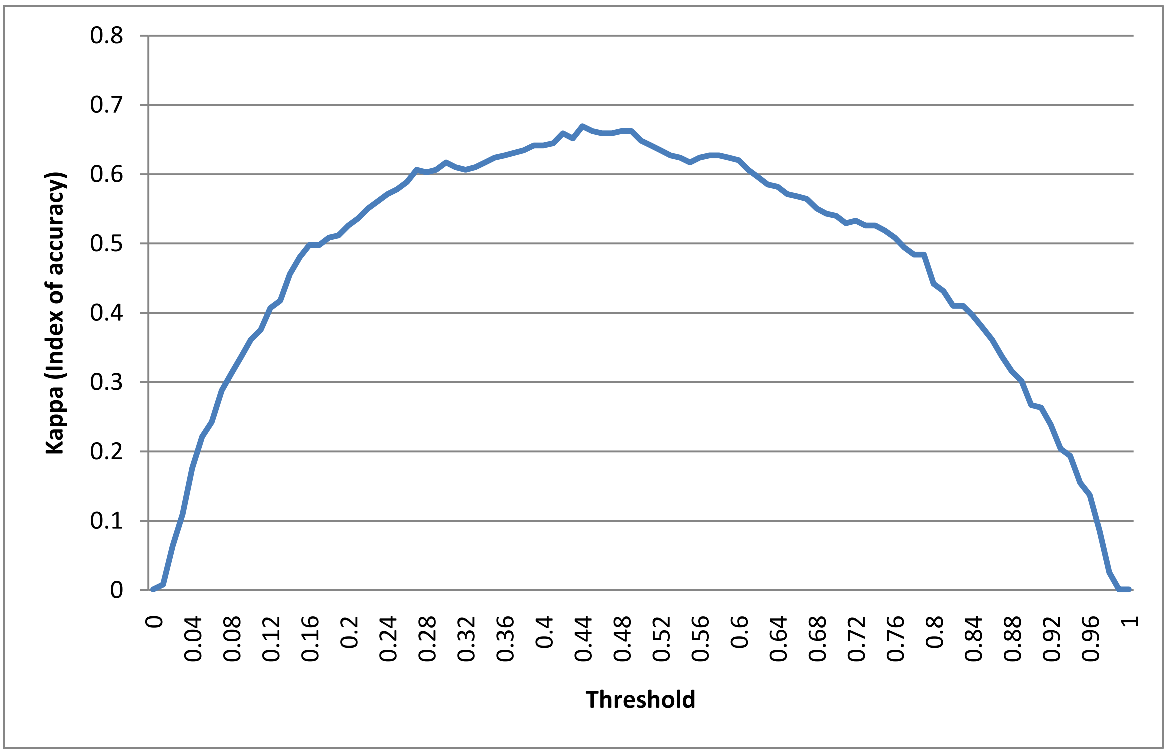


Figure 4.5 Kappa value for a range of thresholds. Kappa calculated for different levels of threshold to identify the highest Kappa value possible, 0.44.

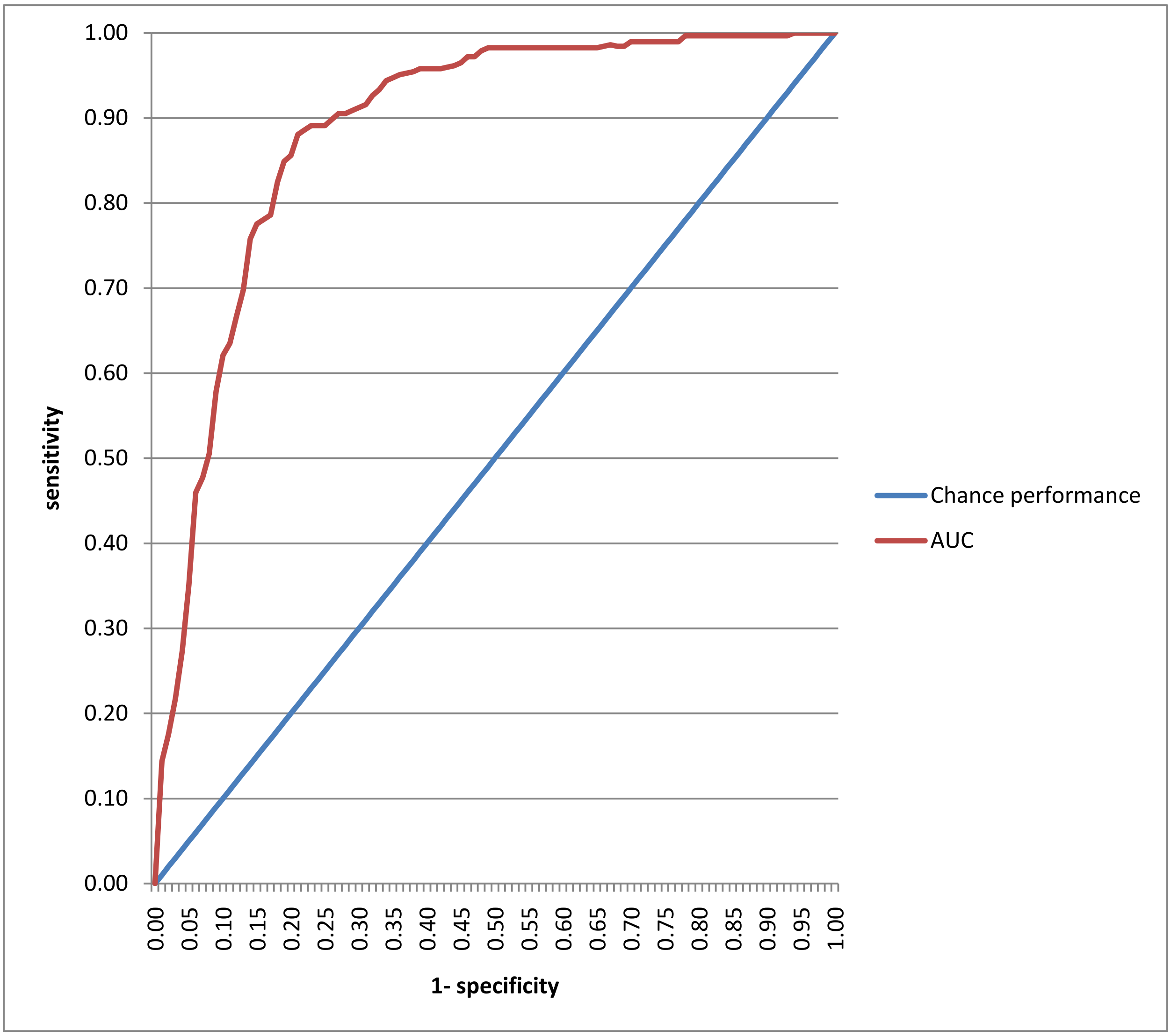


Figure 4.6 Receiver Operating characteristic plot. The chance performance represents the model performance that would be expected by chance alone .The area under the curve is 0.886 with a standard error of 0.013. Sensitivity proportion of true positive results, and 1-specificity is the proportion of false-positive results for each unique threshold in the data

Validation

As detailed in the methods a *k* fold partitioning method was used to validate the GLM. This process produces the ROC curve that can be seen in figure 4.6. The area under the curve is 0.886 with a standard error of 0.013. This suggests that in the final model, a randomly selected pixel will be less suitable than one predicted by the model 88.7% of the time (with a standard error of 0.13%) (Long et al., 2008). This is true for all thresholds.

Population estimate

The population density was estimated at 0.53 owls per hectare (95% confidence intervals 0.443, 0.634 CV=9.12). This combined with the suitable habitat area predicted by the HSM produced a population estimate for *O.capnodes* of 4950. If the 12% error of the HSM is considered this produces 95% confidence intervals of population at 3641 and 6632.

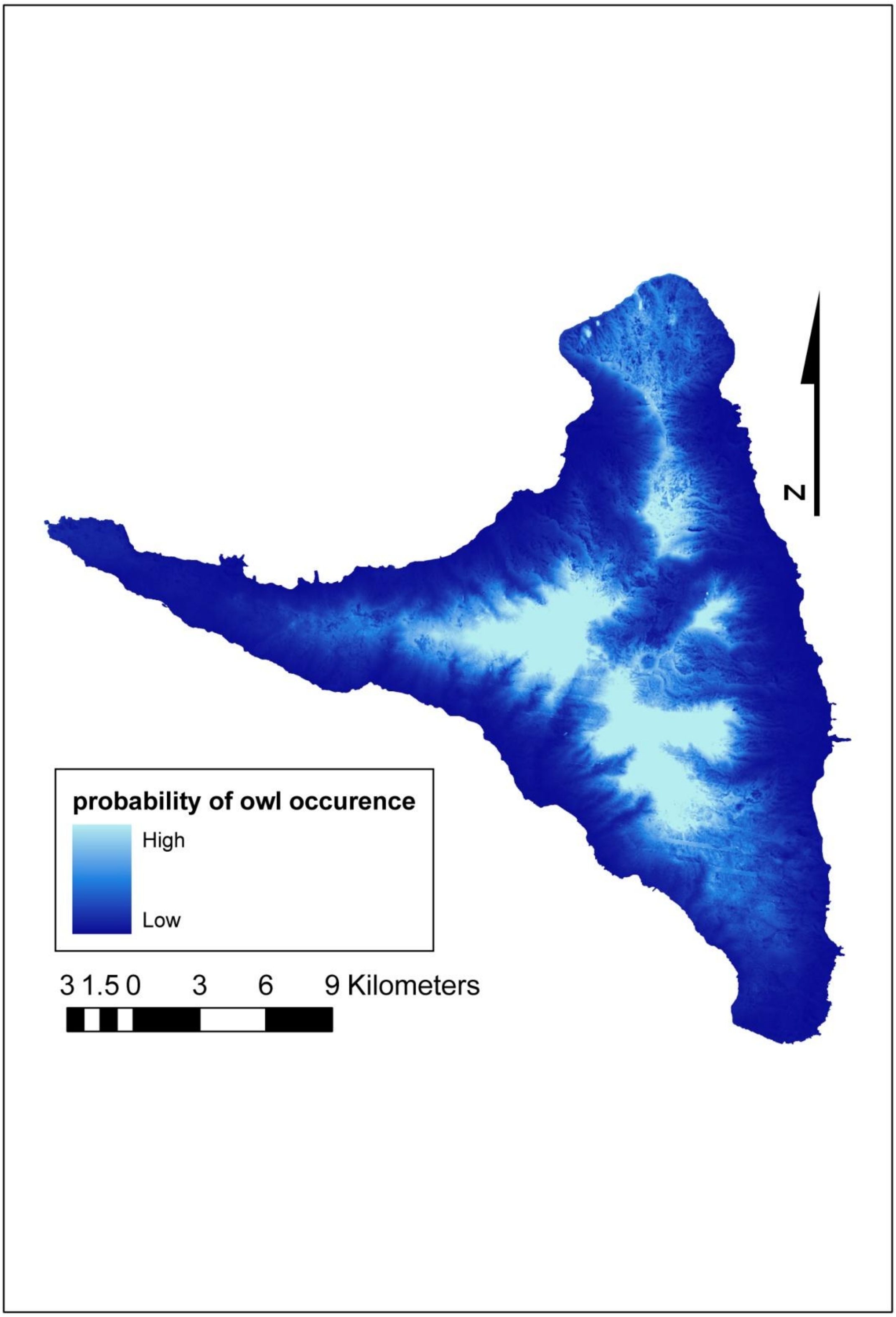


Figure 4.4. The habitat suitability for *O.capnodes* graded by probability of occurrence.

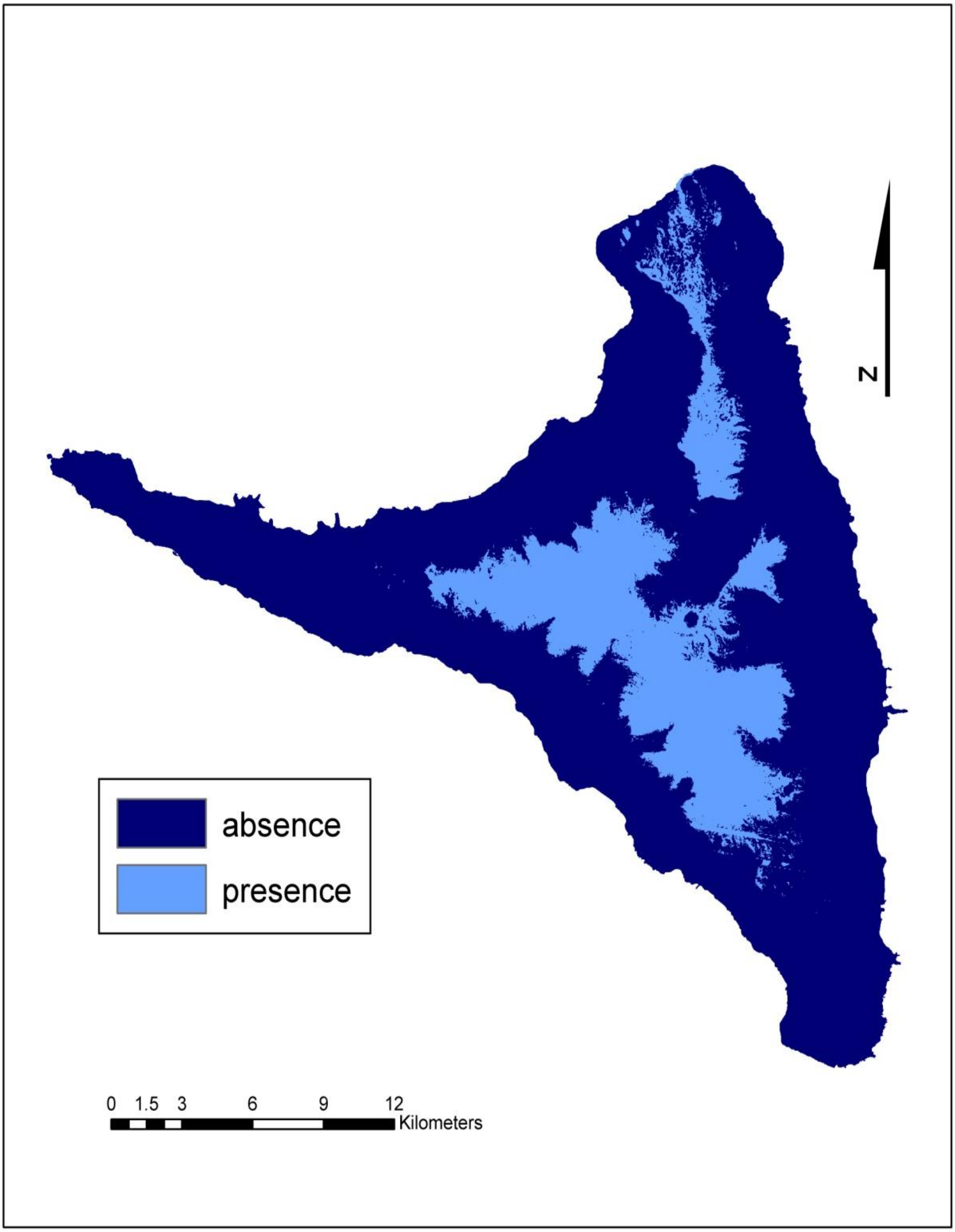


Figure 4.6 The distribution of habitat suitability as predicted by the habitat suitability model with a threshold of 0.44.

5. Discussion

Habitat associations

The results of the nonspatial analysis indicate that natural forest is the preferred habitat for owls with degraded forest being preferred to a lesser degree and plantations being the least suitable. This is as expected; the more pristine habitats show higher owl population densities and as human impact on the forest increases, the populations of the owl decrease. This result does however differ to previous studies which considered only pristine habitat to be suitable (Safford et al 1993). The scale of the survey however is felt to be sufficient to prove that *O.capnodes* inhabits degraded forest.

There were a number of recordings in plantations. This should not be interpreted as plantations being suitable habitat for the species, there are a number of factors to consider. Firstly in many plantations there remain patches of forest trees. In a number of cases birds were recorded in very small forest patches, one was occupying an estimated 50m by 20m patch. Secondly birds detected in plantations were rarely far from forest. This suggests that the birds may be occupying the plantations due to being forced out of higher quality habitat, as opposed to occupying them by choice.

There are a number of possible reasons for the difference in owl occupancy by habitat. There is evidence that the main underlying factor is human impact, the precise mechanism of this force is not yet understood however. A major potential reason is deforestation removing suitable nest sites. It is not known conclusively what constitutes a suitable nest site for *O.capnodes,* however Safford et al (1993) witnessed an owl leaving a tree hollow which they presumed to be a nest site and it is very common amongst owls to use tree hollows for nesting sites (LaHaye & Gutierrez, 1999)(Leadprathom et al., 2009). Plantations are perhaps less likely to contain standing dead wood or species of tree that form hollows. The lack of nest sites in plantations may therefore be a limiting factor in local populations of *O.capnodes* (Newton, 1994).

The lack of *O.capnodes* in human impacted areas may be due to lack of available prey items. It is not known what *O.capnodes* eats, although most scops owls eat insects, small reptiles or mammals (Hekstra, 1973)(Currie et al., 2003). Human impact may either suppress populations to below those capable of supporting owl populations or they may inhibit the owls hunting ability in some manner.

The mere presence of humans may be sufficient to lower local populations. Owl species have been shown to be negatively impacted upon by human presence (Galeotti et al., 2000).

The effect of altitude

Previous studies have thought the owl to prefer higher altitudes (Safford et al 1993). This is hard to examine at the present as elevation is so strongly correlated with forest presence. It is possible to note however that the lowest recording was at 44m above sea level and a number of birds were recorded at around 300m above sea level. Whilst the 44m recording may have been an anomaly, the species has been recorded at 300m previously (Doulton and Marsh, unpublished). The only natural forest point at which the species was not recorded was at the highest point of the island (Ntingi). This was during a particularly cold day and the temperature was lower at that elevation than the rest of the island so temperature may have been the limiting factor.

Habitat suitability model

Of the variables available moistness, slope, distance to villages and distance to rivers were not found to be explanatory and distance from roads, elevation, green reflectance and brightness were identified as explanatory. From this a number of conclusions can be drawn.

Firstly there is no apparent connection between stream presence and owl populations. This is important as the deforestation rate has removed a number of streams from the island, which would have serious consequences if the bird relied upon their presence.

Secondly the exclusion of slope as an indicator suggests that the birds do not prefer slopes but the forests that remain upon them, which is indicated by a combination of elevation and green reflectance.

Village distance was not included, suggesting it is not a suitable indicator of human impact. This is likely due to the naturally difficult terrain of the island; villages may be geographically close to forest areas but in practical terms very far away.

That moistness is excluded is interesting, this may be due to similar water levels in plantations and native forest.

As detailed in the methods, brightness is an indicator of bare or cultivated land. It is therefore unsurprising that it is a predictor of absence of *O.capnodes.*

Elevation is highly correlated with forest presence. It is likely due to this reason that it correlates with owl presence. This does not indicate therefore that the owls prefer higher altitudes, instead that their habitat is over dispersed with respect to altitude. It may be the case that the owls prefer higher altitudes but this would be exceedingly difficult to separate from the effect of the altitude habitat correlation.

It is likely that distance from roads was found to predict owl absence due to it predicting human impact on forest. It is probable that this is because distance to roads correlates with accessibility. This would likely be due to both the fact that a road provides access and that roads are built in areas that are accessible.

Green reflectance is an indicator of forest, and therefore it is not surprising that it predicts owl presence.

Assessing the accuracy of the HSM

The predictions made by the HSM can be seen in figure 4.5. The area of predicted occurrence is for the most part natural and degraded forest. The habitat suitability model therefore produces results similar to those predicted by the nonspatial data analysis, i.e. that the lower the human impact the higher the probability of occurrence of *O.capnodes*. The AUC value of 0.88 is high and indicates an effective prediction of the data available(Fielding & Bell, 1997). It does however suggest that there is an error of 12%. It is also important to note that the model assumes equilibrium between the species and the habitat. The HSM is also limited to information from remote sensing. This could mean that an important environmental variable is excluded from the analysis, e.g. presence of a species of lizard or tree.

It is also important to note that the HSM has pixel sizes of 15m. Habitat fragments of under 15m squared therefore will not be identified.

Determining threshold

It can be beneficial to management to have a map that predicts merely presence and absence as opposed to grades of probability. In predicting an appropriate threshold a Kappa statistic was used. The Kappa curve predicts the most accurate threshold of occurrence to be 0.44. When this was plotted however (Figure 4.6) it produced a map with a number of small errors. The main error was the inclusion of land covered by treeless agricultural land Figures 5.1 through 5.4 but there were also owl recordings excluded. The reason for these errors appears to be the effect of elevation; the predicted area that is not suitable is at a very high altitude, whereas the areas in which owls were recorded but not predicted are in relatively low altitudes.

The AUC value of 0.88 is high but does predict a 12% error. These minor faults are therefore to be expected.

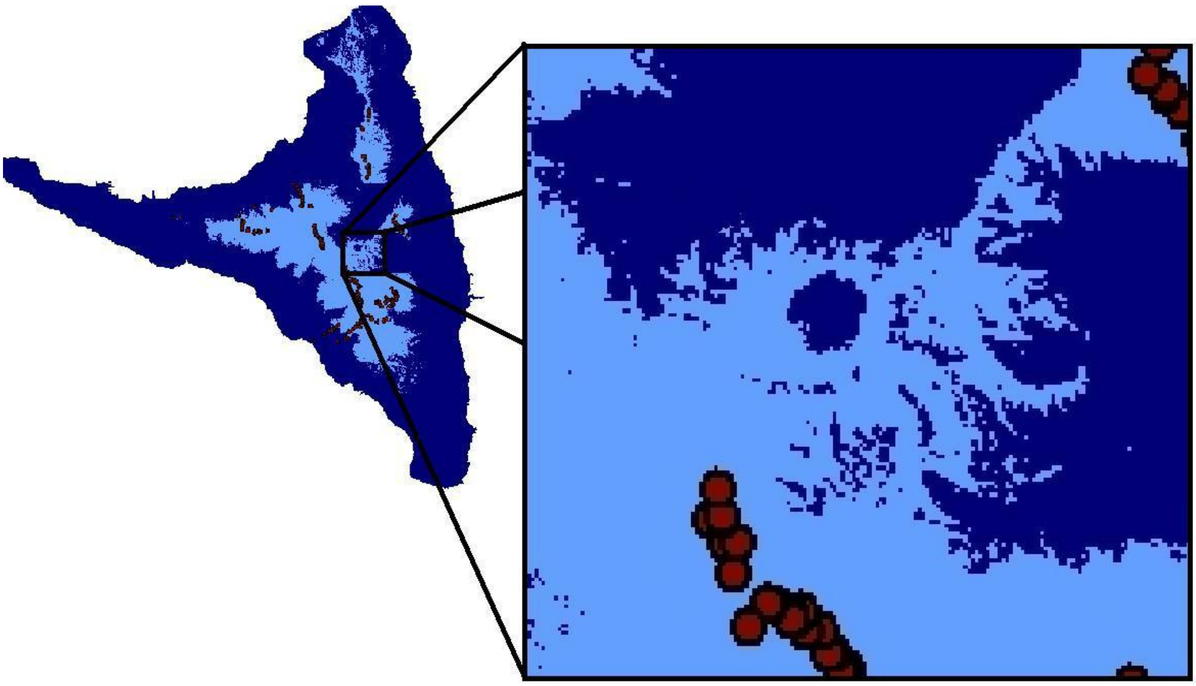


Figure 5.1 A falsely predicted area. The larger map illustrates predicted occupancy and absence at a kappa predicted threshold of 0.44. The area of the SDM illustrated is felt to be an erroneous prediction. This is due to this area being farmland with few to no trees which is shown to be unsuitable habitat by the nonspatial analysis. This can be seen in Figure 5.3.

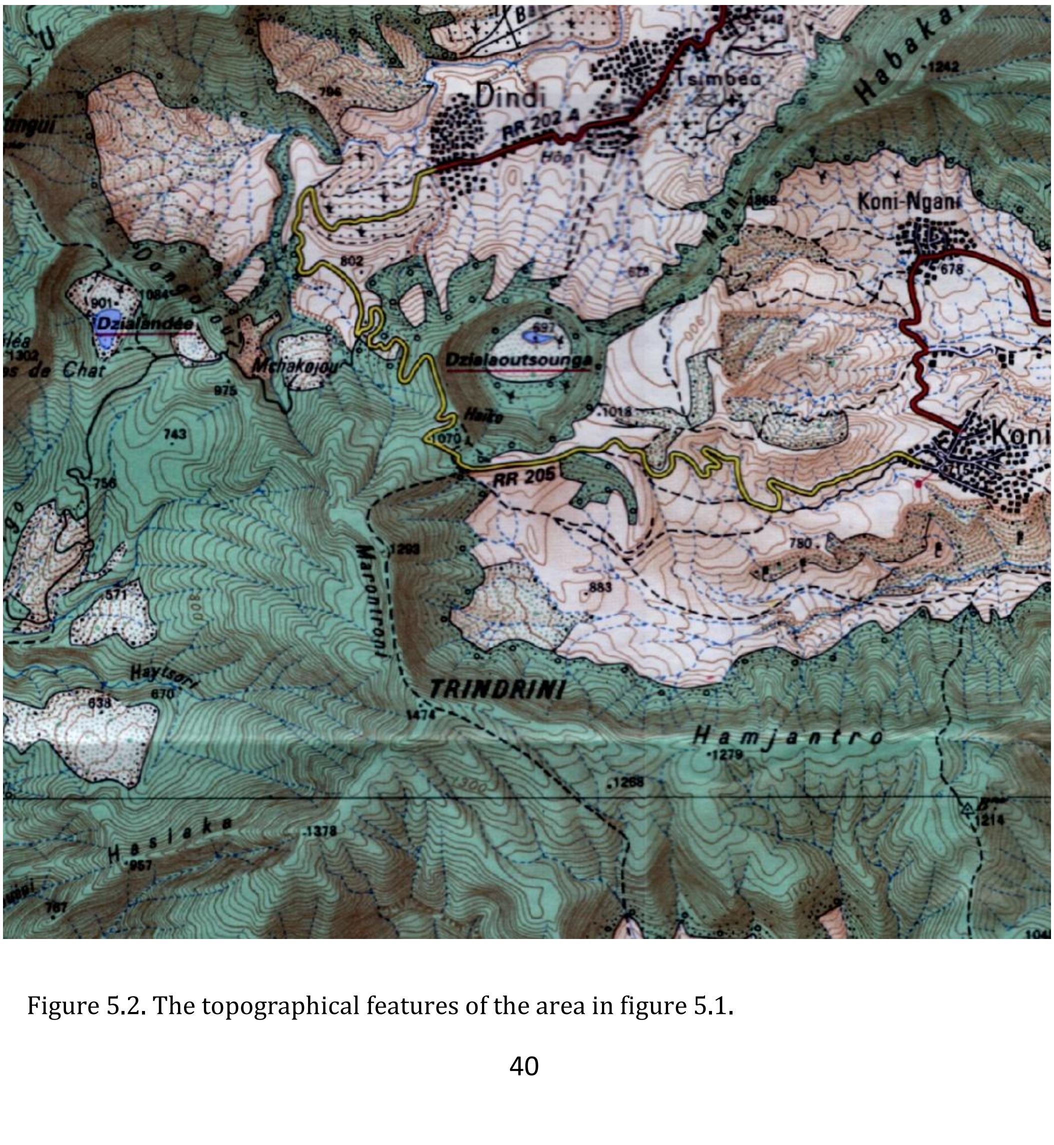


Figure 5.2. The topographical features of the area in figure 5.1.

Figure 5.3 A photo of the area shown in figure 5.1. The peak to the right of the picture is named Trindirin and can be seen in figure 5.2, . As can be seen the forest covers the steep slope but disappears as it reaches lower elevations. The land in between the mountain and the photographer is covered by grass and farmland

Figure 5.4. The land use of the area indicated in 5.1

Playback

As mentioned, playback caused fewer birds to call but appeared to increase the number of novel recordings compared to the trend. Ideally this could be modelled to prove this statistically, however that was beyond the scope of this project. It could be argued that this was due to double counting caused by playback inducing movement in birds. As there was no significant difference between the distances at which the birds were heard in silent listening periods and the distances at which the birds were heard during the playback period however, this suggests that double counting due to movement was likely to be low.

The data suggests therefore that the playback caused many birds to fall silent but encouraged previously silent birds to call. There are a number of possible explanations for this behaviour. In *O.scops* for example it is known that birds show a greater response to members of their own sex with females normally only calling in the presence of an invading female(Galeotti et al., 1997). In the case of *O.capnodes* therefore, it is possible that the playback recording used was a female bird and the novel recorded birds were defending females with the males falling silent in the hope of sexual activity. Ultimately however, it is not possible to identify the reasons behind this phenomenon without further research.

These complexities suggest that playback should perhaps be researched before being included in a monitoring protocol.

Source of error

There are a number of sources of error that must be considered.

Bibby and Buckland (1987) showed that different habitats affect the detection probability of birds. It is possible therefore that there was a different chance of detecting birds in different habitats. Topography was found to have a large effect on the range at which birds can be heard, for example in one unusual valley it was possible to hear a bird high on a hillside from three point counts. This effect is then amplified by the fact that plantations are highly correlated with flat land and forest is highly correlated with steep land.

Double counting is a common source of error for bird surveys (Buckland et al., 2008, Bibby & Buckland, 1987). The high calling frequency of *O.capnodes* meant that it was very easy to keep track of individuals during points. This is illustrated by the fact that 35% of the birds were heard in the first minute of point counts. This also meant that during movement between points birds were easy to identify, meaning that on the rare occasions that it was possible to hear the same individual it was possible to exclude them (three individuals were excluded from second counts). It is possible however that playback may have caused birds to move towards the observer at one point, only to move back to their original position and be recorded at a second point. The fact that there was no significant difference between distance of detection during the playback period and during the silent period suggests that this is unlikely.

The use of paths for routes may have introduced bias. This can come in the form of surveying areas that have increased human activity, increased impact or increased survey of edge areas as paths tend to follow boundaries. This could affect the HSM as the density of owls could be different at the centre of a habitat patch to the edge.

Issues caused by using bird calls as a surrogate for presence

As mentioned the biology of bird calls is complex. Using them as a surrogate for presence therefore introduces a number of potentially fundamental sources of error into the analysis. Many species of bird are documented as using calls for territorial purposes (Currie et al., 2004b, Alba-Zuniga et al., 2009). By inferring from other species it is reasonable to assume that in *O.capnodes* calling is linked to territoriality (Currie et al., 2004a, Galeotti et al., 1997, Alba-Zuniga et al., 2009, Galeotti et al., 2000). As territoriality is associated with sexual activity, this could introduce sources of error as sexual activity could be dependent on suitable conditions. For example, if a requirement of sexual activity was a suitable nesting site then owls may not defend sites that do not include a suitable nest even if they occupy them. To put this into the context of the data it may be that birds were heard less often in plantations due to the fact that they do not defend reproductively useless sites even if they inhabit them. In this case the difference between occupancy in the forest habitats and plantations could be an artifact.

This could also potentially explain the difference in occupancy between degraded forest and natural forest. If the birds defended nesting sites rather than hunting territories then there could be the same density of owls in both habitats, the only difference being the owls were more vocal in natural forest as there was a higher level of nest site defence.

A possible underestimation of the owl population could come from silent owls. In a number of species females are quieter or call less than the males (Galeotti et al., 1997). It has also been noticed that in some owls species males will be tolerated inside the territories of other males if they remain silent and thus do not advertise sexually(Severinghaus, 2000).

It has been noted in a number of other species that bird calling frequency varies according to a number of different factors. These factors must be considered in future monitoring if mistakes are to be avoided. The time of year is a large factor in *Otus insularis* call frequency (Currie et al., 2002), in *Strix aluco* the weather affects calling activity (Lengagne & Slater, 2002) and in *Bubo bubo* the phase of the moon is important (Penteriani et al., 2010). There may also be a relation between the density of owls and the frequency of calling; *Bubo bubo* are known to call less frequently in less densely populated regions as there is less pressure to defend their territory (Penteriani et al., 2002). In so far as it is possible future surveys should therefore be conducted under similar conditions.

Consequences for future monitoring

One aim of this project was to develop a practical and accurate monitoring technique that could be continued in the future. The following methodological proposals have been made.

The basic structure of the survey technique is felt to be sound; point counts produced reliable data in a repeatable manner.

The distance between the point counts was thought to be sufficient to minimise double counting whilst not being so great as to limit data gathering. Three recordings were identified as being recorded in the previous point count which represents a detected overlap of 1%.

The silent listening period was highly successful; the levels of recordings were extremely high. Five minutes also appeared to be an appropriate length of observation time. In future surveys however it is proposed that the playback could be excluded. This is due to a number of reasons. Firstly the behavioural biology of both the owl's calls and of the recorded call is unknown. This means that there could be unknown factors being introduced by its use. Secondly the playback could be powerful enough to affect the behaviour of owls at the proceeding point count. If playback were to be excluded the effect on the data collection must be considered. The average duration of a point count was 18 minutes including walking to the next point. A decrease in the listening period by three minutes would mean an extra point count could be conducted for every six previously conducted. An increase in the number of surveys by 1/6 would increase the number of owl recordings by approximately 12% however playback as accounted for 25% of recordings, this would give a net loss of approximately 13%. As the number of point counts could be increased there would be better spatial data and any unknown error sources caused by ignorance of the mechanism of playback would be removed. Ultimately this is a decision that will need to be made according to the needs of future studies.

During this survey a wide range of habitats were covered in order to ensure that owls were detected in their full range of habitats, i.e. that there were not owls living in unexpected areas. It is therefore possible for future monitoring programs to concentrate on the known populations and areas predicted by the habitat suitability model.

Future monitoring should ideally be conducted at the same time of year. This is due to the fact that birds often vary call frequency throughout the year (Currie et al., 2002, Galeotti et al., 2000).

Population estimate

Distance analysis predicted a population density of 0.53 owls per hectare, which in turn produces a population estimate of 4950. This is a much higher density than previously thought. This is also interesting as it suggests the owls live in dense populations, much denser than many other scops owls. There are a number of caveats to this estimate. Firstly the area predicted as suitable habitat is not uniform in its suitability. There are habitat patches and different levels of human impact. This means that any bias in survey effort towards a habitat type will produce a population density and estimate bias towards the population density of that habitat type. The distribution of habitat types in this area is not known.

Implications for the red list status

The current threat status of critically endangered is based upon the previous population estimates. This project provides evidence for a higher population estimate. It is therefore suggested that the status can be changed to endangered. The deciding factor in that case would be that the area of occupancy is below 500km2 with fewer than five locations and a declining habitat.

This work also suggests that with cryptic species such as *O.capnodes* caution should be observed before applying a red list status. In this case it was due to lack of evidence that the species was listed as critically endangered. It could be argued that this species should have been classified as data deficient rather than making an estimate based on minimal information.

Suggestions for other species

This research suggests that the threat level to this species has been overestimated. This is due to a combination of lack of research and the cryptic nature of the species. This has consequences for research on other species. It highlights the fact that low probability of detection, a cryptic nature, a habitat that is difficult to access and a misunderstanding of the species biology can provide estimates that are inaccurate by orders of magnitude. The categorisation of such species must be approached with caution as a species falsely classified as under great threat could detract the limited financial, social and temporal resources away from species and ecosystems that have greater need.

Future work

This study is the first methodical study on the species but is unlikely to be the last. There are a number of questions relevant to conservation that could lead on from this research.

Owls, as top predators, are occasionally used as indicator species as in many cases they require a complex ecosystem to support them and are dependent on forest quality (Sergio et al., 2008)(Sergio et al., 2005). Future work could examine any potential correlation between owl density and biodiversity. This would aid future conservation monitoring as, now a method has been developed, the owls are relatively easy to survey due to their vocal nature.

An understanding of the effect of human impact on populations of the owl would greatly benefit conservation of the species, i.e. the effect of different levels of forest use on the owl populations. This would facilitate guidelines for sustainable management of the forest for minimum impact on the species to be produced. There are a number of areas on the island where there are graded levels of impact and these would allow assessment of the differing populations of owls in areas of different impact.

If a more accurate HSM were desired then arguably the most effective method would be to use detailed habitat data as an explanatory variable. This however would require a detailed field survey or more accurate remote sensing. Whilst this would be a large task in most cases, given Anjouan's small size and the fact that such data would be useful to or could be carried out during other studies this is a feasible goal.

Management and Conservation implications

The results of this analysis have a number of consequences for management. The first is the simple knowledge of where the owl lives. This means that conservation efforts can be concentrated where the owl exists, rather than risking protecting areas uninhabited by the owl.

The second is a better understanding of the threats faced by the species. Previously it was supposed that the owl was restricted to pristine forest, and thus had a very small population, producing the critically endangered red listing(Safford, 1993). This has now been found to be incorrect; the owl has a much greater range and a much higher population. The fact that the owl inhabits the degraded forest suggests there is a lower albeit still significant threat. There are two reasons for this decreased threat. Firstly the greater range decreases the risk of disasters killing the population. The more important reason however is the ability to cope with forest degradation. The rate of human population increase on the island and the rate of deforestation suggest that the remaining pristine forest is unlikely to remain pristine for much longer. The fact that the owl can survive in degraded forest suggests that impact on these areas will not eradicate the species.

The knowledge that the owl can persist through some degree of human impact also has very important consequences for potential conservation action. If their range was restricted to pristine forests then the options available would be limited due to the high level of destructive forest use. Indeed, if pristine forest were the only suitable habitat then it is likely that protected areas of some form would be the only option. The fact that the owl can persist in degraded forest allows other options for the conservation of this species, for example sustainably managed forest use. This flexibility of conservation options is potentially highly beneficial as conservation action is commonly more effective if it can be tailored to suit local human populations.

The final consequence for conservation action is the ability to track the progress and status of the species in the future. Using the monitoring techniques laid out in this research it will be possible to assess changes in status in the future and potentially to assess therefore, the effects of any conservation action.

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Appendix

Maps of the environmental variables

The maps and the following description of the process were produced by Peter Long

A 1:50000 topographic map of Anjouan published by IGN was used. This was scanned and georeferenced with 15 ground control points using a second order affine transformation to produce a 24bit colour composite coverage with 5m pixels projected to UTM 38S. The root mean square error was 4.2m - less than one pixel. On screen digitising was then used to produce accurate shapefiles of the coastline, settlements, roads and streams.

The roads, streams and settlements shapefiles were used to produce rasters of straight-line distance to streams, distance to roads and distance to settlements at 15m resolution.

The digital elevation model was derived by fusion of 90m resolution elevation data from the SRTM mission and 30m resolution GDEM elevation data produced from the ASTER instrument on Terra (granules: SRTM_f03_p162r068 and ASTGTM_S13E044_DEM). Unfortunately the ASTER GDEM, produced by steroscopic correlation of nadir and backward near-infrared images, is partly cloud contaminated coverage was then resampled to 15m resolution with regularised splines, an exact interpolation method. The USGS and JAXA were the source of these elevation data and both were available free of charge.

The DEMs were used to produce rasters of slope, sin(aspect) and cos(aspect) at 15m resolution.

Recent scenes acquired from the ETM+ sensor on Landsat 7 and the ALI sensor on EO-1 were used to assemble a cloud-free moderate resolution multispectral reflectance mosaic for Anjouan. The source of all EO-1 and Landsat data was the USGS and this data was available free of charge.

WRS ID	path row	Date acquired	Satellite	Sensor	Solar elevation (°)	Scene ID	Gapfill order
WRS-2	p162r068	2010 July 17	EO-1	ALI	43.28	EO1A1620682010198110TC	1
WRS-2	p162r068	2009 June 28	EO-1	ALI	42.43	EO1A1620682009179110T7	2
WRS-2	p162r068	2009 June 09	EO-1	ALI	43.29	EO1A1620682009161110TC	2
WRS-2	p162r068	2010 June 14	Landsat 7	ETM+	44.06	L71162068_06820100614	4
WRS-2	p162r068	2009 July 13	Landsat 7	ETM+	43.86	L71162068_06820090713	5
WRS-2	p162r068	2009 March 23	Landsat 7	ETM+	55.10	L71162068_06820090323	6
WRS-2	p162r068	2009 March 07	Landsat 7	ETM+	55.94	L71162068_06820090307	7
WRS-2	p162r068	2009 February 19	Landsat 7	ETM+	56.13	L71162068_06820090219	8
WRS-2	p162r068	2007 August 25	Landsat 7	ETM+	51.29	L71162068_06820070825	9
WRS-2	p162r068	2007 April 19	Landsat 7	ETM+	51.82	L71162068_06820070419	10

Bands 1,2,3,4,5,7 and 8 (pan) of the Landsat scenes and bands 3,4,5,6,9,10 and 1 (pan) of the EO-1 scenes were projected to UTM 38S, resampled by the nearest-neighbour algorithm to 30m resolution (reflective bands) or 15m (panchromatic bands) and windowed to a common extent bounding Anjouan. All bands of all scenes were then manually cloud masked and the sea surrounding Anjouan was also masked. The raw DNs of each band of each scene were then converted using macros to at-sensor radiance and hence to top of atmosphere reflectance using image metadata (time, day, band Lmin, band Lmax, solar elevation angle) and published coefficients (earth-sun distance on day of year of image acquisition, Thullier spectrum in-band exoatmospheric solar irradiance; Chander, Markham Helder 2009). All image procesing used Idrisi Kilimanjaro (Eastman 2003).

Due to the extreme relief in Anjoaun all bands of all scenes were then terrain corrected to mitigate topographic shadowing using image metadata (solar elevation angle, solar azimuth angle) and an analytical hillshading image derived from a 30m or 15m DEM following the procedure of Shepherd & Dymond (2003). Next, all bands bands of all scenes were sequentially overlaid in a pectate manner such that the first covered the second except where zero (ie no data due to cloud, sea, outside scene extent or in an ETM SLC-off gap) in the order given in the table above to produce a mosaic reflectance product which is atmospherically normalised across space and time and therefore suitable for modelling and monitoring applications. The six mosaics of the 30m reflective bands were then pansharpened to 15m resolution with the 15m mosaic of panchromatic bands by using a local regression method.

A tasseled cap transformation was performed using coefficients for the bands of the Landsat ETM+ sensor (Huang et al., 1998) to reduce the number of dimensions of reflectance data and extract biologically meaningful environmental indices. This produced three rasters at15m resolution: tasseled cap greenness shows the amount of green vegetation, tasseled cap moistness describes the amount of water and tasseled cap brightness represents the amount of bare soil.