Expert Driven Habitat Suitability Modelling for the Magellanic Woodpecker in Karukinka Natural Park, Tierra del Fuego, Chile

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Abstract

Habitat suitability modelling is an approach to study the geographical distribution of a species on a large scale. It has been widely applied in many fields including wildlife management, habitat assessment and habitat prediction. In this paper, an expert driven approach was applied using Multi Criteria Evaluation (MCE) and Geographical Information Systems (GIS) to produce a habitat suitability map of the Magellanic woodpecker (*Campephilus magellanicus)* in Karukinka Natural Park. This vulnerable species has been highlighted as a potential flagship species for the Patagonian *Nothofagus* forests. The model was defined by consulting literature and experts on the environmental requirements of the species. The habitat suitability successfully highlighted areas of the park with potential for species presence. This information can be used by ecologists to assess the conservation status of the species by focussing future field investigations. This research highlighted the need for expert driven models when there is a lack of species distribution data. This is often the case for rare species or areas lacking sufficient study. In these instances data driven models are often unsuitable.

Acknowledgements

Declaration

This dissertation is my own unaided work and has not been submitted for a further degree at any other Higher Education Institution. It does not exceed the word limit of 10,000 words.

Signed:

Date: September 25th, 2009

This dissertation uses data, research and/or other formative material or resources that have been made available to the author within the following place of work or collaborative research institution: Wildlife Conservation Society. However, the undersign testifies that the dissertation is an individual and self-motivated study undertaken by the author alone for the sole purpose of achieving a Master's degree and not as part of existing or future obligatory research commitments for this company/institution

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List of Acronyms

ENFA   Ecological Niche Factor Analysis

ESRI   Environmental Sensitivities Research Institute

GLM   Generalised Linear Model

MCE   Multi Criteria Evaluation

NASA   National Aeronautics and Space Administration

HSM   Habitat Suitability Modelling

HSI   Habitat Suitability Index

IUCN   International Union for Conservation of Nature

DBH   diameter at breast height

WCS   Wildlife Conservation Society

WLC   Weighted Linear Combination

1. Introduction

Habitat suitability modelling (HSM) is a tool for predicting the suitability of a species based on known affinities with environmental parameters. Geographical information systems (GIS) can be used to map the outcome of these models to display areas of potential distribution for a species.

The aim of this project is to work in conjunction with the Wildlife Conservation Society (WCS) in Karukinka Natural Park on the island of Tierra del Fuego, Chile to produce a habitat suitability map for the Magellanic woodpecker (*Campephilus magellanicus*). The Magellanic woodpecker is the largest woodpecker in the Americas and is distributed from Linares in Mid Chile to the island of Tierra del Fuego in Patagonia. The Magellanic woodpecker is a bio-indicator for old undisturbed forests and also a keystone species for these environments (Ojeda et al 2007). Bio-indicators are usually defined as species whose status and ecology provide information on the overall condition of an ecosystem (Heywood & Watson, 1995). A keystone species has a disproportionate effect on its environment relative to its abundance (Paine 1995).

Due to the distinctive red plumage of the male's crown, the woodpecker has been highlighted as having potential to be a flagship species for protecting biodiversity in Patagonia (see figure 1.1). A flagship species is one chosen to represent an environmental cause, such as an ecosystem in need of conservation. These species are chosen for their vulnerability, attractiveness or distinctiveness in order to best engender support and acknowledgment from the public at large. Socio-ecological studies suggest that this species can be transformed into a symbol for the conservation of pristine Patagonian forests (Arango et al 2007).

The Magellanic Woodpecker is not listed as endangered. In fact the IUCN Red List of Threatened Species gives the species a status of Least Concern (IUCN 2008). However, the species is believed to be vulnerable in the Magallanes region (Wildlife Conservation Society 2009). The species has declined in numbers or disappeared from several parts of its original range (36º-56º S) and is considered a vulnerable species dependent on old-growth forest elements (Ojeda 2006). Much more research is required before the true conservation status of this enigmatic species can be ascertained.

The Karukinka Natural Park represents an area of 272,000 hectares donated by Goldman Sachs to the WCS in 2003. The park houses a huge variety of flora and fauna in a unique wild landscape considered vital for Global conservation. Expeditions into the park are costly and use up a lot of resources in terms of work hours and fuel. The main aim of the habitat suitability map will be to highlight areas of the park where the Magellanic woodpecker is likely to be present so field studies can be implemented in a cost effective manner. The area of study consists of the Karukinka Natural Park and also its surrounding area to highlight new areas for potential conservation or perhaps even an extension of the park boundary.

A series of datasets representing environmental parameters such as elevation, vegetation type and hydrology will be analysed to produce the habitat suitability map. Due to the lack of species distribution data in the study area it is not possible to use statistical packages such as Biomapper. These packages analyse the environment where the species has been found (presence data) and also where it has not been found (absence data) and predict other suitable areas where the species may exist. The rarity of the Magellanic woodpecker and relative lack of study means that this data is not available in a statistically robust form for the study area. Therefore an expert driven approach to habitat suitability modelling is required. This approach involves using past research papers and current expert opinion to

build up a model of environmental factors that decipher habitat suitability for the species. Multi Criteria Evaluation (MCE) which is a type of decision support strategy can then be applied using a GIS package to produce the habitat suitability map.

Figure 1.1 Male Magellanic woodpecker

Figure 1.2 Karukinka Natural Park.Source: Wildlife Conservation Society 2009.

2. Aims and Objectives

1)   To carry out a thorough review of scientific papers on habitat suitability modelling and the environmental requirements and preferences of the Magellanic woodpecker.

2)   To further define the requirements of the Magellanic woodpecker by consulting with local ecologists and experts on the species. This consultation will also help produce a weighting scheme for the different environmental factors. The consultation will be facilitated by the creation of a website for online interaction between experts on both the species and the ecology of the park.

3)   To produce a habitat suitability map of Karukinka Park and surrounding area for the Magellanic woodpecker using a GIS and Multi Criteria Evaluation to help facilitate species location within the park.

4)   To use the habitat suitability to identify areas outside the park that may harbour the species. This could result in highlighting these areas for study, influencing forest management in these areas and even giving cause for a possible extension of the park boundary.

3. Literature Review

This section first reviews the literature on the different methods of habitat suitability modelling and then goes on to discuss research into the habitat requirements and preferences of the Magellanic woodpecker.

3.1 Habitat suitability modelling

The last 15 years has seen the rise of habitat suitability modelling which aims to predict the occurrence of species depending on the make-up of environmental factors. Habitat suitability models are often used to predict the likelihood of occurrence of a species on the basis of habitat attributes that influence its survival, growth and reproduction (Gibson et al 2004). The output of Habitat suitability modelling is normally a habitat suitability map. The map displays locations of suitability for a given species within a habitat suitability index (HSI) which normally ranges from 0-1 where 0 indicates a non-suitable habitat and 1 a habitat most suitable.

A key aspect of any habitat suitability study is the nature of the training data. In the case of habitat suitability modelling this is data on where the species is currently found (distribution data). Training data can consist of presence data, presence and absence data, and abundance data (Eastman 2006). Presence data records where the species has been observed and absence data records where the species has been observed to be absent. Abundance data is data about the volume of a species that is presumed to exist everywhere throughout the area of study. It is also possible to conduct a habitat suitability analysis with no training data. This is often the case when the species is either rare or the habitat has not been studied.

A review of some of the different methods of HS Modelling has been undertaken. These include Ecological Niche Factor Analysis (ENFA), Generalised Linear Modelling (GLM) and Multi Criteria Evaluation (MCE). ENFA and GLM are examples of empirical models whereas MCE can be applied in a theoretical model. Empirical models statistically determine the set of rules for a species and its distribution. These data driven models are basically computed by fitting a statistical or numerical model on environmental data and species distribution data (Hirzel 2009). Theoretical models are expert driven and rely on expert opinion and research to decide the rules and weighting of each rule.

ENFA aims at summarising a large number of variously correlated ecogeographical variables into a small number of independent, ecologically meaningful factors which contain the major part of the habitat information (Hirzel *et al* 2002). ENFA only requires species presence data unlike classical methods such as logistic regression and GLM which require absence data in addition to presence data. Biomapper is an application that was developed to conduct ENFA. It is essentially a kit of GIS and statistical tools designed to produce habitat suitability maps (Hirzel 2009).

Hirzel (2001) who incidentally also developed the Biomapper software conducted a comparison study of ENFA and GLM using a virtual species simulation. Three scenarios were simulated: spreading, at equilibrium and overabundance. The results showed that ENFA was the most robust in terms of data quality and quantity and produced good results for all 3 scenarios. GLM did not perform well for the spreading scenario but performed better than ENFA in the overabundant scenario.

Xuezhi *et al* (2008) used Biomapper software to model habitat suitability for Giant Pandas (*Ailuropoda melanoleuca)* in the Sichuan Province of China. ENFA was chosen due to a lack of absence data as pandas do not leave much evidence of presence therefore absence is difficult to record. The results showed that pandas prefer coniferous forests at elevations

above 2128 metres. The panda also avoids habitats disturbed by humans thus farmland creation was highlighted as a major threat. The study also highlighted the need for a new reservation to increase connectivity between other protected areas.

Santos et al (2006) also used ENFA analysis with Biomapper to model the distribution of a species of snake (*Vipera latastei*) in the Iberian Peninsula. Altitude and slope were the major constraining factors along with the negative impact of human land transformation and human population density. The ENFA was deemed to be an outstanding method to evaluate the factors that limit the distribution of a widespread species when absence data is lacking. The analysis helped evaluate the conservation status of *V. latastei*.

Another method for creating HS maps is to use Multi Criteria Evaluation (MCE). This involves creating separate map raster layers for the ecogeographical variables (factors), assigning weights and combining the layers to produce a final suitability map. The assigning of weights is key and always brings in an element of subjectivity. A MCE approach is the preferred option in the absence of training data. There are a number of different approaches to MCE such as the *Boolean Approach* and *Weighted Linear Combination* (Eastman 2006). These are discussed in more detail in section 4.5.

Store & Kangas (2001) researched the integration of MCE and GIS-based habitat suitability analysis for a species of forest fungi (*Skeletocutis odora*). An expert on fungi and an expert on soil science were consulted to weight the different environmental factors. The separate factors were created as map layers and added together using a GIS. Sub-Priority functions were used to avoid having to classify continuous data. This avoids using crisp boundaries and gives a more realistic fuzzy approach. A key finding from the research was the use of sensitivity analysis. This analysis showed that small changes to the weighting system had a large impact on the location of optimal habitats thus highlighting the influence of subjective expert advice.

Clevenger et al (2002) compared three types of GIS-based habitat model (empirical, expert literature based and expert opinion based) for determining habitat linkage for the Black Bear (*Ursus americanus*) in North America. The performance of the models was validated against an independent data set. Statistical tests and tests on the description on the linkages classes showed that the expert literature model most closely approximated the empirical model. Expert opinion models were less in agreement with the empirical model. The expert opinion models were believed to perform poorly due to an overestimation of the effect of riparian habitat compared with the literature.

Vincenzi et al (2007) compared three HS models for the estimation of commercial yield potential for a species of Clam (*Tapes philippinarum)* in Sacca di Goro Lagoon, Italy. The three models were an expert driven habitat suitability index model , a habitat suitability conditional model calibrated with observational data and finally a habitat suitability mixed model that combines expert opinion with regression analysis. The habitat suitability mixed model first uses logical regression to identify areas where the clams are likely to be present and then applies the expert driven functions of the habitat suitability index model to those areas. The expert driven functions were defined by consultation with local fishermen working in the lagoon and other lagoons in the North Adriatic. The models were then validated against an independent dataset. Both the habitat suitability index and habitat suitability conditional models performed well against the validation dataset. Due to the large sample size which allows for sound calibration and validation it was concluded that the habitat suitability conditional model was the best option as it was not expert driven and so is not subject to an intrinsic bias that cannot be quantified. However Vincenzi *et al* go on to state that rigorous data driven models cannot always be developed for all species and that expert driven models are a good alternative if solid knowledge has been gathered through practical experience and the expert opinion is sufficiently reliable.

3.2 Environmental requirements of the Magellanic woodpecker

Literature on the Magellanic woodpecker is relatively scarce though research has increased in recent years. The main focus for this section of the review will be on the studies by Vergera & Schlatter (2004) and McBride (2000) as these studies were conducted on Tierra del Fuego which has a unique climate and ecology.

3.2.1 Vegetation cover

The Magellanic woodpecker inhabits mature deciduous and evergreen *Nothofagus* forests (Short, 1970). The common name for the genus *Nothofagus* is Southern Beeches which consists of 35 species of trees and shrub native to the Southern Hemisphere. The forests of Tierra del Fuego represent the most Southern group of *Nothofagus* woods. There are three main types of forest on Tierra del Fuego: mixed temperate forests of deciduous lenga (*N. pumilo)* and evergreen coihue(*N. betuloides*); pure lenga forests; and deciduous ñirre (*N. antartica)* forest.

Vergera & Schlatter (2004) conducted studies on Tierra del Fuego and found that woodpecker abudance was greater in mixed lenga and coihue forests. Mixed *Nothofagus* forests are are more diverse in understudy vegetation which may provide more foraging resources for the woodpecker. Also lenga does not produce sap which is an energetic food source for the woodpecker that supplements the normal food source of wood boring lavae (*Cerambycid*). Coihue does produce sap which is another reason why mixed forest would be advantageous to the woodpecker. McBride's (2000) studies , also on Tierra del Fuego further highlight the advantage of mixed forests by observing higher foraging activity in lenga forests that contained pockets of ñirre. Ñirre is preferred for foraging while Lenga is preferred for nest building.

The Magellanic woodpecker favours mature undisturbed forest. Larger trees are more suitable for creating nests and woodpeckers will only select trees with a trunk diameter

>30 cm dbh (diameter at breast height) (Vergera & Schlatter 2004). Age of trees is also associated with the development of heart rot in *Nothofagus*. Heart rot is a fungal disease affecting trees and a key precursor to woodpecker nest building (Harestad & Keisker 1989).

Ojeda (2007) researched crown dieback events as key processes for enabling cavity excavation in lenga trees. Crown dieback is a measure of the percentage of branch tips in the crown of a tree that are dead. Degree of crown dieback was found to be a primary variable for explaining Magellanic woodpecker tree selection. Crown dieback events can be induced by insect outbreaks and extreme climatic events. This contrasts with previous work where dbh and age were considered the important determinants for cavity tree selection.

Forests of anthropogenic origin are unlikely to be suitable for nesting as the trees will often not be large enough in diameter. McBride (2000) found no trees with nest sign younger than 97 years with the mean age of all cavity trees being 187 years old. Forest management programs with harvest rotations of approx 100 years are therefore not going to provide a suitable habitat.

3.2.2 Proximity to beaver ponds and peatlands

The North American beaver (*Castor canadensis*) was introduced into Tierra del Fuego in 1946 and due to abundant food sources and lodging sites coupled with the lack of predators or competitors has undergone rapid population growth and range expansion (Lizarralde et al 1993). The mean colony density in the Chilean part of Tierra del Fuego is approximately 1 per km watercourse (Skewes et al 2006). The beaver is in effect fully expanded along the Fuegian fluvial system. Studies indicate that beaver dams are modifying the ecosystem by locally raising the water table and expanding wetland areas (Lizarralde et al 1993).

Figure 3.1 Beaver Ponds and associated forest destruction on Tierra del Fuego. (Source: Lizzaralde et al 1993)

Studies by Vergera & Schlatter (2004) and McBride (2000) show that woodpecker activity is correlated with proximity to beaver ponds and peatlands. Foraging signs were significantly greater along transects near beaver marsh and lake edges. It has been suggested that trees near these humid and waterlogged areas could be more prone to attack by fungus and wood boring coleopterans (Vergera & Schlatter 2004). This would facilitate nest creation and provide the woodpecker with an increased food source. Snag (dead tree) density is also likely to be higher in flooded forests adjacent to beaver ponds or boggy peatland. Vergera & Schlatter (2004) found that woodpecker abundance increased with snag density as snags make suitable cavity trees. However McBride (2000) found that 95% of cavity trees were live. The strong winds that are present on Tierra del Fuego may make dead trees

unsuitable. Trees with enough heart rot to enable cavity excavation and enough vigour to resist strong winds are the ideal.

3.3.3 Elevation

Early observations by Reynolds (1934) indicated that the Magellanic woodpecker was less common in montane regions of Tierra del Fuego than the lower regions. This could in part be to differing vegetation types but Short (1982) does suggest that the woodpeckers exist at all elevations up to the treeline. McBride (2000) found that there were no cavity trees above 400 m with most cavity trees between 150-300 m for Lenga forests and 0-250 m for ñirre forests. McBride concluded for his study area that only low to mid-elevation (< 300 m) forests are used as cavity habitat. Forage intensity was also greatest below this level.

3.3.4 Proximity to roads and settlements

From consulting the limited literature on the Magellanic woodpecker and also literature on other large woodpeckers it is unclear to what extent woodpeckers are sensitive to direct human disturbance. Woodpeckers are generally believed to be sensitive birds. However, ecologists from the WCS have seen Magellanic woodpeckers just a few yards from roads and farms on Tierra del Fuego.

4.0 Methodology

As stated in the introduction, the lack of training data (species presence/absence data) for this project means that data driven statistical HS models such as ENFA and GLM are ruled out. One option available is a MCE method using literature and current expert opinion to decide on both the environmental factors to be used and the weighting scheme to be applied to those factors.

4.1 Hardware and software

A Windows Vista laptop was used along with student licensed version of ESRI ArcGIS with ArcCatalog and ArcMap. The Spatial Analyst extension was used with ArcMap. A student licensed copy of Idrisi Andes was also used to prepare and conduct the MCE. Microsoft Excel was used to produce graphs of the data.

4.2 Supporting website

A public website was developed to create an online forum for discussing the environmental factors that influence Magellanic woodpecker habitat suitability. The URL of the website is https://sites.google.com/site/campephilusgis/. The website was created using Google Sites, an online website creation service which allows users to create feature rich websites with no programming knowledge. A basic website can be created in a matter of minutes and can easily include file upload and discussion forum functionality. Ecologists from the WCS and other woodpecker experts were given access to the website either through their personal Google account if they had one or by using a specially created generic account. The comments left on the website are also listed in Appendix 1.

The aims of the website were:

- To create a forum for discussing the environmental factors that influence habitat suitability.

- To allow experts to approve and comment on the chosen weighting scheme for the environmental factors.

- To generate interest in the project. The more experts on board the more information and advice can be inputted into the model.

4.3 Data sources

Table 4.1 is a summary of the all the data used for this investigation. The data source, format and date of acquisition are recorded. Datasets were chosen if the literature and consultation with experts suggested the data was relevant to habitat suitability and importantly, if the data was available with full or near full coverage of the study area.

Table 4.1 Data Sources

Data	Environmental Factor	Source	Acquired	Format
Vegetation	Vegetation Cover, Proximity to Peatland	CONAF (Corporación Nacional Forestal de Chile)	2003	ESRI Shapefile
Hydrology	Proximity to Rivers	Direccion General de Aguas	2005	ESRI Shapefile
Roads	Proximity to Roads	MOP , direccion de obras publicas	2007	ESRI Shapefile
Elevation	Elevation	SRTM-CIGAR	2001	Arc-Formatted ASCII Raster
Woodpecker Sightings	Presence Data	WCS Ecologists	2008/09	Markings on a map/ GPS Locations

4.3.1 Vegetation data

This qualitative dataset covers the region known as Region de Magallanes y Antractica Chilena also known as Patagonian Chile. The data for Tierra del Fuego was acquired by aerial photography in 2003 (CONAF 2006). The dataset contains fields for land use such as mature forest, peatland, lakes, steppe etc and importantly also contains species make-up for a given location. An example would be a land use of dense mature forest with a species makeup of lenga and coihue trees. The coverage of the study area is not quite complete. There is a region where no aerial photography was acquired (see Figure 4.1). This area is only a small fraction of the study area but is still significant. It was originally decided to use Landsat satellite data to assist with defining vegetation suitability. However, the quality of the vegetation dataset was deemed high enough to not necessitate the use of additional satellite data. The data was used to categorise the forest ecosystems of the study area and to produce the proximity to peatland data.

4.3.2 Hydrological data

The hydrological data was provided by the WCS but was sourced from the Direccion General de Aguas (The Chilean Water Authority). The data came in ESRI shapefile format and displays the river network for Chile. An additional field of use is river name. The data was used to produce the proximity to river data.

4.3.3 Road data

The road data was provided by MOP (Minstrio de obras publicos). The dataset only contains data about large roads of which there are few on Tierra del Fuego. The study area is fairly remote and traffic is expected to be minimal particularly near the forested areas of interest. The data was used to produce the proximity to roads data.

4.3.4 Elevation data

The elevation data was acquired from the CGIAR-CSI[1] website (CGIAR-CSI 2009). This data was originally acquired by NASA during the Shuttle Radar Topography Mission (SRTM) , an 11 day mission that took place in February 2000. This dataset came with data voids which tended to occur in areas over water bodies, or areas with snow and mountainous regions (CGIAR-CSI 2009). The CGIAR-CSI SRTM dataset has undergone post processing to complete these voids through interpolation techniques. The data is free to download and comes in the format of arc-formatted ASCII rasters. The resolution of the data is 90m.

4.3.5 Woodpecker sighting data

This dataset represents Magellanic woodpecker sightings by WCS ecologists within the study area. The data was acquired from 2008 with the latest point being acquired as recent as September 2009. Due to lack of studies and the rarity of the species there are only 7 point locations for woodpecker sightings (WS1-7). Only four of the sightings are located within the park boundary. The data were acquired by two methods. The first was by manually recreating points within ArcMap to mirror location points on a map provided by WCS ecologists. The second was input of GPS location data provided by ecologists in the field. Additional GPS locations can easily be added to an ArcMap feature class using the *Add X-Y data* tool. As has been repeatedly stated this dataset is not large enough to drive an data driven habitat suitability model such as ENFA.

4.4 Data preparation

It was decided to use ArcGIS for the initial preparation and visualisation of the data. The reasons for this were familiarity with the software along with its renowned data interoperability. All data layers used in the analysis were imported into an ESRI geodatabase as feature classes using ArcCatalog. All feature classes were in the UTM 19S

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[1] Consortium Group for International Agricultural Research – Consortium for Spatial Information

coordinate system. The elevation, vegetation, rivers and roads layers were all imported into ArcMap where they were clipped to fit the designated study area using the ArcMap *Clip* tool.

4.4.1 Conversion to raster

All data layers have to be in raster format to conduct the multi criteria evaluation (MCE). Therefore the vegetation, rivers and roads layers needed to be converted from vector format. The elevation data was already in raster format. The ArcMap *FeatureToRaster* tool was used to create the raster image layers. A cell size of 100m was initially used for faster processing times and lower file storage space during the initial stages of the research. The final analysis was done using a 30m cell size. This resolution was deemed adequate given the study area and context of the research. There are however some issues with using a 30m resolution for the rasterisation of rivers and roads. These are discussed in section 5.4.2.

4.4.2 Raster reclassification

It was necessary to reclassify some of the raster layers before conducting the MCE. For the River, Road and Peatbog layers the reclassification process was very simple. These layers would be analysed for proximity to the feature in question. Therefore all cells that represented the location of a feature were reclassified to 1 and cells that did not represent a feature were reclassified to 0. This process is called masking and was achieved using the Reclassify tool which is part of the *Spatial Analyst* extension in ArcMap. These masked layers were used with the *distance* tool to produce the proximity layers (see section 4.4.4).

The reclassification of the Vegetation layer was more complex as it involved assigning a suitability rating for each vegetation category. The values assigned were decided upon by consulting the literature of Magellanic woodpeckers and by communicating with experts on the Campephilus-GIS website (See appendix 1). Values ranged from 0 (unsuitable) to 4

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(most suitable). All vegetation cover that was not mature forest was given a zero rating as cavity excavation requires adult trees of at least 30 dbh (Vergera & Schlatter 2004). All anthropogenic forest was given a category of 1 as again trees are unlikely to be of a substantial width for cavity excavation (McBride 2000, and website feedback see Appendix 1). Open mature forest was given a category of 1, semi-dense a category of 2 and dense a category of 3. Woodpecker abundance was found by Vergera & Schlatter (2004) to increase with canopy cover. Vegetation zones that showed a mix of tree species had their category increased by 1. Both McBride (2000) and Vergera & Schlatter (2004) found that abundance increased with a mix of tree species (see section 3.2.1). The reclassification table is shown below and was approved by various experts on the Campephilus-GIS website (see Appendix 1).

It was also necessary to create a vegetation mask layer which acts a constraint criterion in the MCE (see section 4.5.1). This layer represents all areas where the woodpecker could possibly be found i.e. mature forest. It was created using the *Reclassify* tool. All cells with a value between 1-4 were reclassified to 1 thus producing a map with cells values of 1 representing mature forest and cell values of zero representing unsuitable vegetation cover.

4.4.3 Conversion to Idrisi format

The MCE analysis will be undertaken using Idrisi Andes GIS software. Idrisi has a number of modules that facilitate standardisation, weighting and evaluation for MCE. The conversion from ArcMap raster to Idrisi raster format was achieved by first converting the rasters to ASCII format using the *Raster to ASCII* tool in ArcMap. The ASCII files can then be converted to Idrisi raster format using the *Arcraster* tool in Idrisi.

Table 4.2 Vegetation suitability classification

Description	Species mix	Category
Open Mature Native Forest	Lenga	1
	Lenga , Ñirre	2
Semi-Dense Mature Native Forest	Lenga	2
	Lenga, Ñirre	3
	Lenga, Coihue	3
Dense Mature Native Forest	Lenga	3
	Lenga, Ñirre	4
	Lenga, Coihue	4
Dense Forest of anthropogenic origin	Lenga, Coihue	1
Semi-Dense Forest of anthropogenic origin	Lenga, Ñirre	1
	Lenga, Coihue	1

4.4.4 Creation of proximity layers

The three proximity layers (Rivers, Peatlands and Roads) were created in Idrisi using the
Distance tool. The *Distance* tool calculates the Euclidean distance from each cell to the
nearest target feature. The input map for the tool must be a mask raster layer with cell
values of anything other than zero representing the target feature (as prepared in section
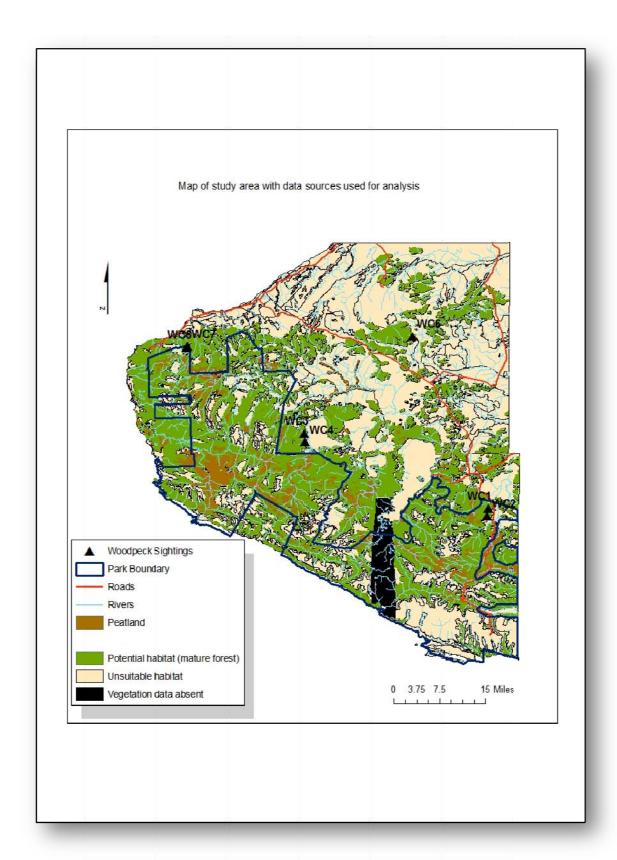4.4.2).

Figure 4.1 Study area with datasets used for the analysis.

4.5 MCE and weighted linear combination

Due to the continuous nature of most of the data and the lack of robust training data it was decided to use MCE with *weighted linear combination* (WLC) to produce the habitat suitability map. Factors are combined by applying a weight to each followed by a summation of the results to produce a suitability map (Eastmen 2006).

$$S = \sum w_i \ x_i$$

S = suitability

w_i = weight of factor i

x_i = criterion score of factor i

The decision criterion for WLC can be divided into factors and constraints. Factors are criterion that enhance or detract from the suitability of a given location. Constraints limit the locations that can be used in the analysis. For this analysis the factors are vegetation cover, proximity to rivers, proximity to peatland, proximity to roads and elevation. The only constraint in the analysis is mature forest. Woodpeckers will only be found in areas of mature forest regardless of the values of the other factors.

Before the final suitability index is calculated the factors needs to be standardised to a common numeric range (e.g. 0-1) and then combined using an assigned weighted average. The resulting map can then be masked by the constraint. The standardisation process and weighting was approved by experts on the Campephilus-GIS website (see appendix 1).

4.5.1 Factor standardisation: fuzzy sets

In the Boolean approach to MCE, factor constraints are either considered suitable (1) or unsuitable (0). This is very crude or 'crisp' view where something is either one thing or another and nothing inbetween. This approach is often unsuitable particularly for the natural environment and habitat suitability modelling. Nature is not so simplistic. If we take

for example the proximity to roads factor for this analysis and pose that all land within

500m of a road is unsuitable for woodpeckers. Using the Boolean approach, a point 499m

from the road would be given a value of 1 and a point 501m from the road would be give a

value of 0. Also there is no grading within the class. A point 10 m from the road has the

same suitability as a point 390m from the road. These types of Boolean classification are

known as *Crisp sets*.

An alternative and in many cases more realistic approach is to use *Fuzzy sets*. Fuzzy sets are

classes without sharp boundaries that exhibit a gradual transition between membership (1)

and non-membership (0). The degree of membership for a fuzzy set is defined by a

membership function. There are three common types of membership function: *Linear; J-*

shaped; and *sigmoidal.* Sigmoidal functions are defined by a cosine function and are

probably the most common type of membership function used (Eastman 2006). Figure 4.4

shows some of the different types of sigmoidal function available.
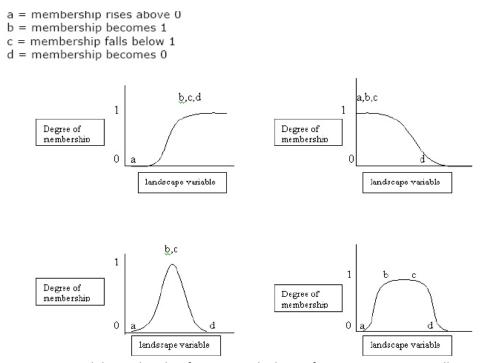
Figure 4.2 Sigmoidal membership functions. Clockwise from top: monotonically increasing ;

monotonically decreasing; symmetrical and symmetrical plateau.

If we again use the example of proximity to roads and pose that being within 100 m of a road is completely unsuitable and from 100 to 500m suitability increases continuously from 0 to 1 with all values after 500m being 1. This is an example of a monotonically increasing sigmoidal membership function with points a, b and c at 100m and point d at 500m.

The *Fuzzy* tool in Idrisi can be used to standardise to a common numeric range (either 0-1 or 0-255) by applying a fuzzy membership function. Figure 4.5 shows a screenshot of the tool filled out to produce the proximity to road standardisation described above.

Figure 4.3 Screenshot of Idrisi Fuzzy tool filled out to produce standardisation for the proximity to roads factor

4.5.2 Elevation standardisation

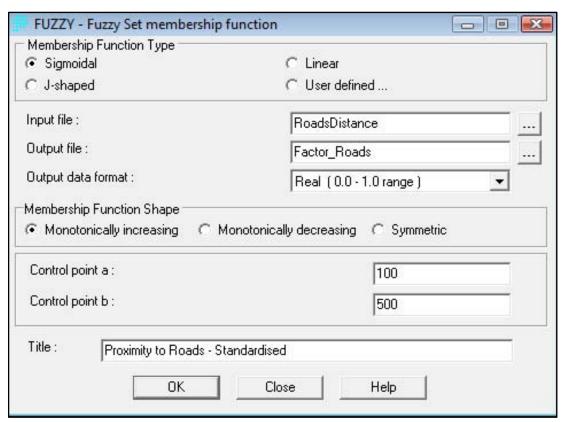From the research carried out by McBride (2000) and also by the comments left by McBride on the Campephilus-GIS website (See Appendix 1) it was decided to use a sigmoidal monotonically decreasing membership function with control points a,b and c at 300 and point d at 500m. This was to reflect the optimum suitability found below elevations of 300m. Suitability is set to 1 from elevations from 0m elevation up to 300m before declining steadily to zero at 500m. Elevations above 500m are deemed unsuitable and have a suitability value of zero.

4.5.3 Proximity to rivers and peatland standardisation

Both McBride (2000) and Vergera & Schlatter (2004) found that woodpecker abundance was inversely correlated with distance to beaver ponds and peatlands (see section 3.2.2). Beaver colonies are now so widespread it was deemed acceptable to use distance to rivers as a measure of distance to beaver ponds. It is challenging to quantify and justify just how far the influence of these features will reach. More research on hydrology and local soil conditions is needed. It was decided that suitability will decrease slowly as you move away from these features up to a distance of 300m. Therefore a sigmoidal monotonically decreasing membership function was chosen with control points at 0 m and 300m.

4.5.4 Proximity to roads standardisation

Again this is a factor that is hard to quantify without more studies. Woodpeckers are generally thought of as sensitive birds and will shun disturbed environments (Short 1970). It was decided that all land within 100m of a road would be unsuitable and would then increase in suitability up to a distance of 500m after which proximity to roads would have no effect. A sigmoidal monotonically increasing membership function was used with control points at 100m and 500m.

4.5.5 Vegetation cover standardisation

The *Fuzzy* tool was used to standardise continuous data. However, the Vegetation cover is qualitative categorical data which needs to be standardised using the Idrisi *Assign* tool which is essentially a reclassification tool. The vegetation cover raster has five categories ranging from 0-4 with 0 indicating zero suitability and 4 indicating maximum suitability. The *Assign* tool was used to standardise these values to the 0-1 scale. This was achieved using the scheme in table 4.3.

Table 4.3 Vegetation category standardisation

Vegetation Category	Standardisation value
0	0
1	0.25
2	0.50
3	0.75
4	1

4.5.6 Weighting

The different criterion factors will not have an equal influence on habitat suitability. The WLC method allows the different factors to be assigned a weight. Weighting expresses the importance of each factor relative to the others. The weighting scheme was decided by consulting the literature and expert feedback on the Campephilus-GIS website (see appendix 1). The application of weights therefore brings in another layer of subjectivity to the model.

When there are several factors being used in WLC it can become difficult to evaluate the weighting scheme. A pairwise comparison technique developed by Saaty (1977) in the context of a decision making process known an Analytical Hierarchical Process (AHP) can be

applied to aid weighting decisions. Saaty's method involves weights being derived by comparing the weights on a pair by pair basis to ease decision making. For example, is elevation more important than vegetation? Is vegetation more important than proximity to rivers? etc. Ratings are on a 9 point continuous scale (see figure 4.4). If for example proximity to roads is deemed *very strongly* more important than elevation then a score of 7 would be given. If the reverse were the case then a score of 1/7 would be given. The scores are entered into pairwise comparison matrix (see figure 4.4) and the principal eigenvector is computed to produce a best fit of weights. The Idrisi *Weight* module has been developed to calculate the principal eigenvector directly from a pairwise comparison matrix. The weights produced must all sum to 1 which is a requirement of the WLC procedure. The module also produces a *consistency ratio*. The consistency ratio (CR) was proposed by Saaty (1977) and indicates the probability that the matrix scores were randomly created. Saaty suggests that a matrix with a CR ratio greater than 0.1 should be re-evaluated.

An initial pairwise matrix was completed and published on the Campephilus-GIS website to be viewed and commented on by experts. Also a blank pairwise matrix template in excel format could be downloaded from the website by experts. The experts could then complete the matrix themselves and upload back to the website.
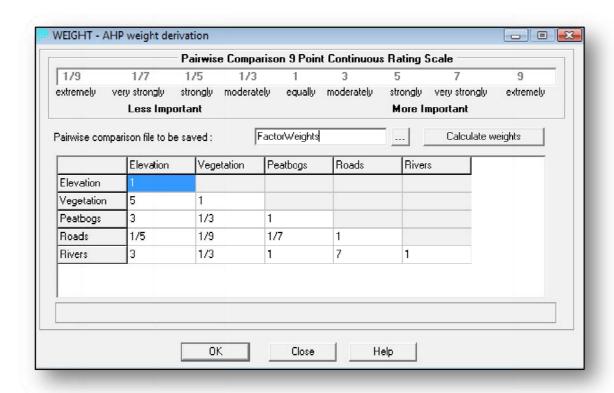
Figure 4.4 Idrisi weight module filled out with pairwise comparison matrix suggested by

Claudia Silva.

Table 4.4 Weighting values calculated by weight module

Factor	Weight
Elevation	0.0919
Vegetation	0.4694
Peat Bogs	0.2039
Roads	0.0308
Rivers	0.2039
Total	**1**
CR Ratio	**0.04 (acceptable)**

Completing and deciding on a final pairwise comparison matrix was challenging and far

from an exact science. An initial pairwise matrix was completed by the author using

evidence from the literature review and comments from experts. Vegetation is clearly the

dominant factor as tree species; tree density and age have a strong influence on cavity excavation and foraging suitability. Proximity to peatland was deemed to have the next strongest influence due to the effect these features have on the forest microclimate. Proximity to Rivers/Beaver Ponds was at first given a slightly lower weighting than peatland due to less water movement. Elevation was deemed important but significantly less when weighed against the above mentioned factors. Proximity to roads was given a low weighting due to frequent sightings of woodpeckers close to roads and settlements (see appendix 1).

Claudia Silva a biologist and bird specialist at WCS reviewed the matrix and uploaded her own version. Her matrix gave equal weighting to proximity to peatland and proximity to rivers due to the lack evidence to suggest that one was stronger than the other. Elevation was given a slightly higher rating due to her interpretation of the literature and roads were given a weaker weighting (see appendix 1). It was decided to use the matrix uploaded by Claudia due to her greater knowledge of both the species and the habitat along with her academic background as a biologist. As will be discussed in section 5.4.3, it would have been ideal to have more collaborators take part in the pairwise comparison process. Figure 4.4 shows the values from the matrix uploaded by Claudia Silva. Table 4.4 shows the weighting as calculated by the *weight* tool. The CR ratio for the matrix is 0.04 and therefore acceptable.

4.5.7 Evaluation

Once the factors have been standardised and weighted the weight linear combination can be completed. The *MCE* module in Idrisi is used to combine the standardised factors, the vegetation mask constraint and the weighting scheme to produce the habitat suitability map (see figure 4.5). The resulting map will display the habitat suitability index (HSI) for each cell on the scale of 0-1 with 1 equalling most suitable.
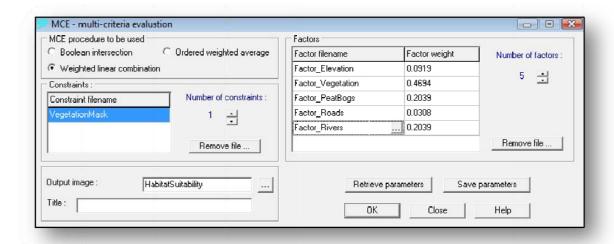
Figure 4.5 MCE tool filled out with parameters to create the habitat suitability map

4.5.8 Macro modeller

Once the methodology had been finalised the Idrisi *Macro Modeller* was used to create a model of the Idrisi MCE process (see figure 4.5). The Idrisi *Macro Modeller* is a graphical environment for building and executing multi-step models. Facilities are included for batch processing (running many inputs through the same model to produce many outputs) and for dynamic modelling (using the output of one iteration of a model as an input into the next iteration). The advantage of using the modeller was that the analysis could be run again and again using different parameters. The parameters used for standardisation and weighting were under constant review and were being constantly refined after further consultation with the literature and by expert feedback on the Campephilus-GIS website. The macro modeller was also of benefit when it came to running the model to conduct sensitivity analysis (see section 4.5.9).

4.5.9 Sensitivity analysis

Using the *macro modeller*, different weighting schemes were applied to assess the sensitivity of the model to changes in factor weighting. The model was run with no weighting or more accurately equal weighting for all factors. The model was also run with reverse weighting factors. This was achieved by creating a pairwise comparison matrix

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which was the reciprocal of the scheme used in the original analysis. HSI maps were produced in Idrisi for each scenario. The HSI for all scenarios at each of the 7 woodpecker sighting points was identified for comparison.

4.6 Presentation of final habitat suitability map

ArcGIS was preferred over Idrisi as the application for producing and presenting the final map. This was due to familiarity with the software and its superior presentation functionality. The habitat suitability map was converted from Idrisi raster format to ASCII using the *Arcraster* tool and then converted back into ESRI format using the *ASCII To Raster* tool in ArcMap.

The HS raster was then viewed in ArcMap along with the Karukinka Park Boundary and Woodpecker Sightings layer. The HS layer was symbolised to show the Habitat suitability index with a scale of 0-1. A topographic layer was then added from the ESRI online resource website (ESRI 2008). The area which was not covered by the aerial photography data is also added as a layer and highlighted as this represents an area of the map where habitat suitability remains unknown.
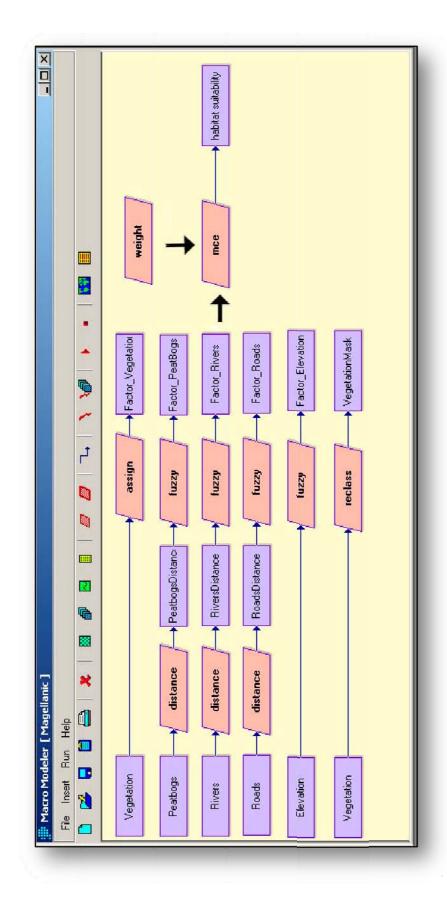
Figure 4.5 Idrisi macro model of the MCE analysis.

5. Results and Discussion

This section will present and analyse the results from the methodology outlined in section 4. Firstly there is an overview of the habitat suitability map, followed by a discussion on the limitations of the model, sensitivity analysis, model validation and data quality.

5.1 Overview of results

Figure 5.1 displays the habitat suitability map of the study area for the Magellanic woodpecker. Figure 5.3 shows the habitat suitability category as a percentage of the mature forest area within the study area. Only 0.4% of the potential habitat was in the low suitability category with the vast majority of the area being in the low-medium (59%) , high-medium (37.2%) ,with 3.4% in the most suitable category. A very large percentage of cells (25% of forested area) had an HSI of 0.47. These cells tended to occur in the Central and Northern part of the study area with a vegetation category of 3 where river density, road density and elevation were relatively low.

As would be expected due to the high weighting of the vegetation factor the areas of highest HSI within the study area coincide with areas with a vegetation category of 4 (dense mature forest with a mix of species). Within these areas the most suitable locations are found along rivers and on the edges of peatland with mid-range elevation. Within the park boundary there are some notable areas with high HSI. These include the area around the Rio Condor in the Eastern section of the park, the area running along the Rio Paralelo in the Southern Central part of the park and in the North East of the park to the east of Rio Bueno (see figures 1.2 and 5.1). Outside of the park boundary there are areas to the North of the study area around point WC6 that show a high HSI again coinciding with

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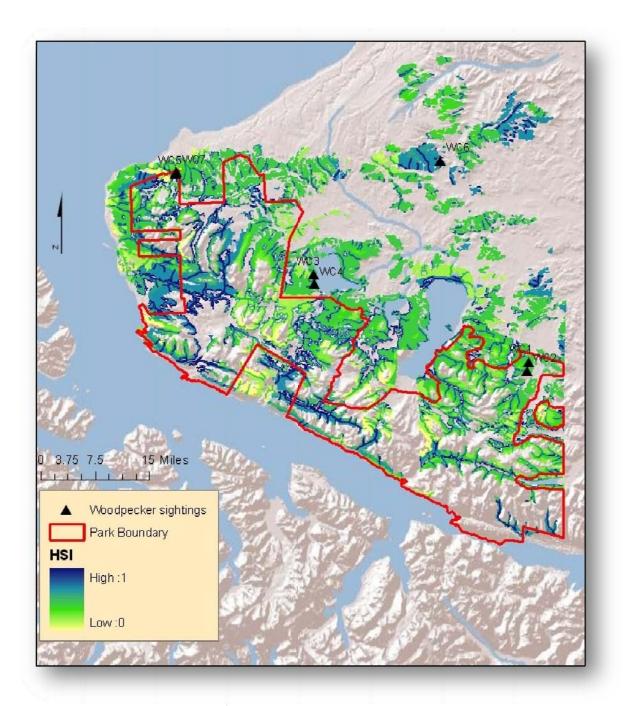Figure 5.1 Habitat suitability map for the Magellanic woodpecker in Karukinka Natural Park and surrounding area.

category 4 vegetation cover and proximity to rivers. Also the area around the northern

shores of Lago Blanco and Lago Lynch and a region to the North of points WC3 and WC4

near Vicuna show a high HSI.
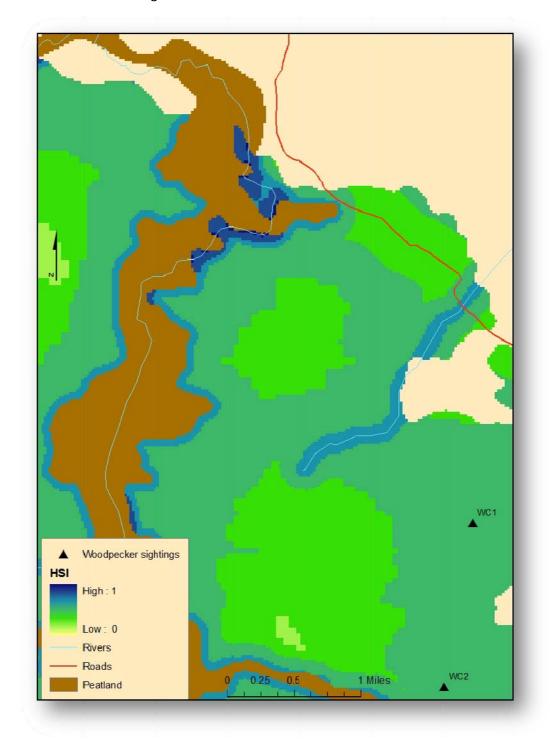
Figure 5.2 Close up view of habitat suitability map to show the effect of environmental

factors on the HSI

Figure 5.2 focuses on a region of the study area just to the North-East of points WS1 and

WS2. The map clearly highlights the effect of rivers, roads and peatland on the HSI. The

land adjacent to rivers and peatland boundaries has a higher HSI and the land adjacent to

the road shows a decrease in HSI. Areas where the rivers and peatland borders coincide

reflect highest habitat suitability.
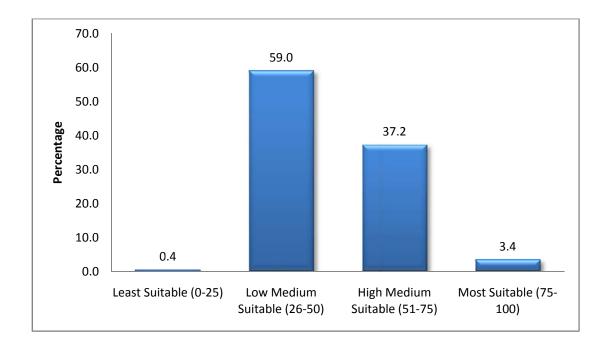
Figure 5.3 Habitat suitability categories as percentage of suitable habitat (mature forest)

5.2 Model validation

A key stage in any model process of the natural environment is validation. The performance

of a habitat suitability model should be tested against population data (Brooks 1997). As is

often the case with rare species in relatively unstudied areas the data is not available in a

robust enough form. If more distribution data becomes available with further studies of the

region then the model could be validated. This validation would most likely focus on using

the model for a smaller area that would fit the distribution data. The model being valid in

one area does not necessarily mean it is valid in another. However, some validation would increase the confidence of the model. Table 5.1 shows the HSI value for each of the 7 woodpecker sightings. Although this is small dataset it is noted that all points were unsurprisingly found in the area of suitable habitat and all points with the exception of WC7 having medium HSI values.

5.3 Sensitivity analysis results

Figure 5.4 and Table 5.1 show the results of the sensitivity analysis. The aim of the sensitivity analysis is to give an indication of how sensitive the model is to changes in the weighting scheme. For the no weighting scenario there was an average increase of 0.08 in HSI compared to the proposed weighting for the seven sighting locations. For the scenario with reversed weighting there was a rather large average increase of 0.27 for the HSI. Figure 5.4 shows the HSI maps for the three different weighting scenarios (normal weighting, no weighting and reverse weighting). The difference between the proposed weighting map and the no weighting map are significant but not extreme and the same trends remain. This suggests the model is stable. The reverse weighting scenario produces an extremely different map with very high HIS throughout. This is mainly due to the high road weighting. Most of the study area is distant from main roads so the HSI is high across the study area. These results indicate that the model is stable but sensitive to different weighting. The model is of course designed to be sensitive as weighting is a key part of the WLC and expert driven process. However this analysis does highlight the subjective nature of the model.
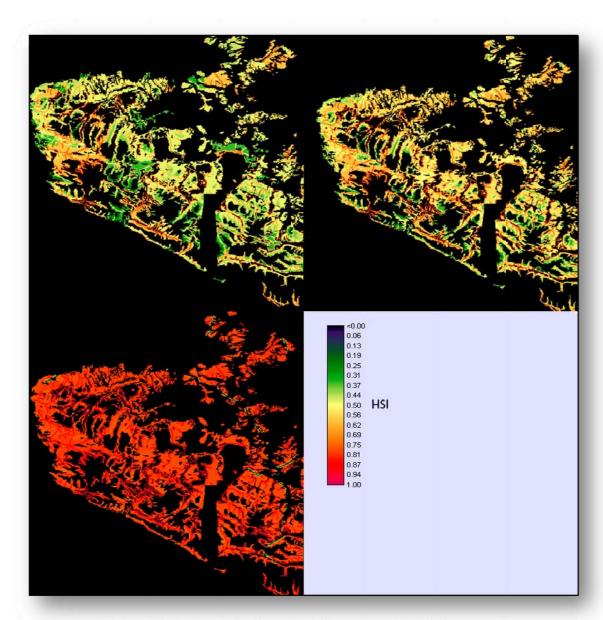
Figure 5.4 Sensitivity analysis. Clockwise from top left. proposed weighting scenario, no weighting scenario and reverse weighting scenario.

Table 5.1 HSI values for the woodpecker sighting locations along with the HSI values for the sensitivity analysis

Woodpecker Sighting Location	HSI	HSI (no weighting)	HSI (reversed weighting)
WS1	0.47	0.55	0.78
WS2	0.47	0.55	0.78
WS3	0.47	0.55	0.78
WS4	0.47	0.55	0.78
WS5	0.62	0.69	0.87
WS6	0.59	0.60	0.79
WS7	0.20	0.36	0.75

5.4 Model limitations

This section will address the limitations of the model with reference to the representation of the different environmental factors as well as factors that were excluded from the model.

5.4.1 Influence of beaver colonies

The literature backed by expert opinion suggested that beaver ponds have a positive effect on woodpecker abundance. It would have been beneficial to the model to have had detailed information on the location of active and derelict beaver colonies along with colony size and beaver pond size. Although this data was available for regions of the study area the coverage was not adequate for the scale of the study. Due to the extensive nature of beaver colonies on Tierra del Fuego there is belief amongst ecologist at the WCS that they have exploited the full capacity of the Fuegian river system. The assumption was made that proximity to all sections of river can be used as a measure of proximity to beaver ponds. This is a slightly crude approach and will bring in a level of inaccuracy.

There is also doubt amongst experts about the beneficial effects of beaver ponds on habitat suitability in the long term. The beneficial effect may only last while the trees in the drowned area are dying and partly rotten and not completely dead. The forests have had millennia to adapt to the effects of peat bogs but only 60 years to adapt to the high impact engineering of the beaver. The long term effects of the beaver ponds could be damaging to habitat suitability as affected forest areas will take a long time to recover once dead (Vergera & Schlatter 2004; McBride website comment. Appendix 1).

The model may need to be modified in the near future as there are plans to completely eradicate the beaver on Tierra del Fuego. The Government and conservation groups are calling for eradication due to damage to the ecosystem from beaver engineering and tree felling.

However, even if the beaver is completely eradicated there is still likely to be a relationship between habit suitability for woodpeckers and proximity to rivers. There is conventional wisdom among local Fuegians (indigenous tribes) and ranch hands that the woodpeckers are found "where damp".

Recent research by Ojeda (2006) suggests that woodpeckers avoid creating nests near ravines. The noise from even small fast moving streams can interfere with woodpecker mating rituals. The streams are loudest during the spring which coincides with the breeding season. These streams are likely to be smaller fast running channels unsuitable for beaver dams. The model could be modified to incorporate and differentiate both *lentic* (Beaver ponds) and *lotic* (fast moving water bodies) environments. The difficulty would be in identifying these zones. Aerial photography or field identification would be necessary.

5.4.2 Excluded factors

There are many factors that contribute to habitat suitability for cavity excavation that can be identified in the field. Some of these factors could not be included in the model simply because the data coverage did not exist for the study area. Factors that were excluded were diameter of trees at breast height (dbh); snag density (density of dead trees) and degree of heart rot and crown dieback (% of branch tips in the crown that are dead).

Cavity excavation is unlikely to occur in trees with a dbh less than 30cm. Average dbh values for sections of forest would have been useful for grading suitability and even excluding certain sections of forest. It is also possible though perhaps unlikely that anthropogenic forests could given time reach this average dbh and become suitable. This data could be collected in the field with particular focus on younger forests and forests of anthropogenic origin. If a shelter wood harvesting technique is being used then it is possible that old trees with suitable dbh and heart rot characteristics could still exists in these stands.

Although studies suggest that woodpeckers don't use dead trees but prefer half dead trees (McBride 2000; Ojeda 2007) snag density would be a useful indicator of the presence of partly dead trees. Degree of crown-dieback could also be recorded for sections of forest. These measurements are useful indicators of suitability but would be fairly resource intensive to record and it would be difficult to cover large areas, particularly for a large scale GIS model covering the species range.

5.4.3 Model subjectivity

HSI models are particularly affected by subjective judgement and model uncertainty, especially when experts estimate the type of environmental factors and the relative

importance of each (Ray & Burgman 2005). An expert driven model is by definition going to contain a high degree of subjectivity. The choice of factors and how to empirically apply them and weight them was a subjective process involving the advice of experts and from consulting literature on the Magellanic woodpecker. The literature was of a good standard and the authors were often cross referenced throughout the literature giving a degree of confidence in the standard of the work. The experts that gave feedback on the Campephilus-GIS website were experienced ecologists with good knowledge of the species and in some cases good working knowledge of Karukinka Park (see appendix 1). The website proved to be a success in creating an online debate on habitat suitability but ideally a there would have been a greater number of contributors. Other experts including authors of key papers were contacted but due to fieldwork commitment and intense academic schedules were unable to contribute to the website in time. Also a wider debate on the weighting scheme would have been beneficial. This could take the form of an online or roundtable debate between several experts with each expert filling in a pairwise comparison matrix. A more reliable and balanced pairwise matrix could then be produced to input into the model. The sensitivity analysis highlighted the sensitivity of the model to changes in the weighting scheme so more collaboration on the production of the scheme would have improved model accuracy. Results from HSM should be interpreted carefully if only a relatively small cohort of experts is used (Yamada et al 2003).

5.4 Data quality

As with any GIS analysis the data quality of the output can only be as good as the data quality inputted at the various stages of analysis. Error will always exist in the data and this error will propagate and accumulate throughput the model and be inherent in the final habitat suitability map. This section highlights the sources of data error throughout the analysis.

5.4.1 Errors in source data

There are a number of errors that can occur in the source data. These include encoding errors in the source data such as exact positioning of rivers, roads and vegetation boundaries. There can be GPS errors in the recording of woodpecker sightings and positions on rivers and roads. There can also be manual digitizing errors in converting the source data to GIS format. The aerial photography for the vegetation cover could contain spatial reference errors along with individual human error in the classification of photos into the correct vegetation category. The boundaries between vegetation types in reality are often fuzzy and so the crisp boundaries of the vegetation dataset will result in positional and attribute error.

5.4.2 Rasterisation errors

All datasets were converted to rasters with a cell size of 30m. This was deemed adequate for data processing speeds and in the general context of the purpose of the analysis. However converting roads and rivers vector features to rasters with a 30m cell size does cause problems. This assumes a minimum river and road width of 30m which is certainly not the case for any road on Tierra del Fuego and most of the rivers will be narrower than this. This causes error in the proximity to roads and rivers analysis.

5.4.3 Data coverage

The data coverage of the factors chosen in the analysis was good. An area to the South West of the study area is missing from the vegetation dataset (see figure 4.6). For reasons not known to the author this area was not covered by aerial photography. Considering the high weighting given to the vegetation factor it was decided that this area be excluded from the model. The area is approximately 20,000 hectares in size and is generally surrounded by area of category 2 vegetation. Elevation in parts of this area is too high for

habitat suitability but it would still be advised to identify vegetation cover in this region to gain full coverage of the park.

5.5 Is the habitat suitability map fit for purpose?

It is the author's opinion that despite any inherent subjectivity and error in the model that the habitat suitability map produced is fit for purpose. That purpose being to highlight areas within Karukinka Natural Park and the surrounding area that are suitable for Magellanic woodpecker nesting and foraging. It is not a requirement for the map to have a very high level of accuracy. The map's purpose is to direct ecologists to areas where woodpeckers may be found and hence reduce time and resources spent on widespread searches for woodpecker sightings.

An expert driven habitat suitability model is never complete and will always have potential to be improved as more research is conducted and as more data on species distribution becomes available. Factor classification, standardisation and weighting can be easily manipulated to produce different results for different scenarios and to accommodate changes in opinions of experts as discussions and research bring new realisations.

6. Conclusions

The section will first state if the objectives set out in Section 2 have been met. It will then discuss recommendations for future habitat suitability modelling of the species.

6.1 Meeting the objectives

1) *To carry out a thorough review of scientific papers on habitat suitability modelling and the environmental requirements and preferences of the Magellanic woodpecker.*

   The objective was met through the study of the vast majority of available literature on the species with particular reference to recent work on Tierra del Fuego. The literature proved thorough in highlighting the habitat requirements of the species although not all these requirements could be inputted into the model due to lack of data coverage (e.g. dbh, snag density, beaver colony location).

2) *To further define the requirements of the Magellanic woodpecker by consulting with local ecologists and experts on the species. This consultation will also help produce a weighting scheme for the different environmental factors. The consultation will be facilitated by the creation of a website for online interaction between experts on the species and the ecology of the park.*

   This objective was met through the creation and use of the Campephilus-GIS website. The environmental factors chosen were commented on by ecologists from the WCS as well as other experts in the field such as Peter McBride. There was also collaboration from Claudia Silva of the WCS in the production of the weighting scheme. The main benefit of the collaboration was to gain local expert opinion on the conditions in Karukinka Park which were absent from the literature review.

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Ideally there would have been more collaboration on the weighting scheme and also more contributions from other experts in the field.

3) *To produce a habitat suitability map of Karukinka Park and surrounding area for the Magellanic woodpecker using a GIS and Multi Criteria Evaluation to help facilitate species location within the park.*

This objective was met through the creation of the habitat suitability map. The map successfully highlighted areas of the park with potential for species presence. It is not currently possible to validate the map with an independent species distribution data set but the habitat suitability model was based on solid expert knowledge and reliable research. Sensitivity analysis showed that the model was stable but sensitive to changes in the weighing scheme.

4) *To use the habitat suitability to identify areas outside the park that may harbour the species. This could result in highlighting these areas for study, influencing forest management in these areas and even giving cause for a possible extension of the park boundary.*

The habitat suitability map highlights area to the North of the park around the North shores of Lago Blanco and Lago Lynch as well as areas around Vicuna and Russafin. These areas may be too far away to warrant an extension to the park and the land use of these areas is not known to the author. Further field research should be directed in these places. Forest management if it exists in these places should take into account areas of high suitability for the Magellanic woodpecker.

6.2 Future extensions of the research

The model can be improved by introducing more environmental factors such as dbh, snag density, degree of crown dieback and beaver colony data. These factors are only likely to be available for smaller scale regions but could possibly be recorded for areas as large as the Park. More research is needed to gain a fuller understanding of the effects of the factors on species abundance and the spatial extent of that influence i.e. proximity reach of beaver ponds and peatland.

The model could also be modified to map habitat suitability across the entire species range. This high level model would just focus on the environmental factors with wide coverage used in this study such as vegetation cover, hydrology and elevation. Satellite imagery could perhaps be used to indicate forest age.

If statistically robust distribution data for the species becomes available then it would be possible to validate the map. Perhaps more importantly there would be a case for designing a new data driven empirical model. In the likelihood of a lack of absence data an ENFA based model using Biomapper would be ideal or a mixed model combining empirical data and expert knowledge such as that developed by Vincenzi et al (2007).

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Appendix 1: Campephilus-GIS Website Comments

Contributors

Claudia Silva   Biologist working for the WCS. Currently researching a masters thesis on the use of Beaver Ponds by birds within Karukinka Park.

Cristóbal Briceño   Veterinary scientist at the WCS who has conducted extensive fieldwork within Karukinka Park.

Ignacio Rodriguez   Veterinary scientist with a specific interest in the Magellanic woodpecker.

Peter McBride   Habitat biologist with extensive field experience in the Pacific Northwest and Patagonia. Wrote a masters thesis on Magellanic woodpecker habitat selection on Tierra del Fuego.

Adrian Hughes   Author and GIS analyst

Comments on Environmental Factors

Claudia Silva - 4 Aug 2009 13:54

I agree with most of the criteria, however I don't believe that any forest of anthropogenic origin should have such high suitability, as cut forest will have less proportion of trees with the large diameters prefered by the woodpeckers. McBrides work supports this.

Also, it might be more accurate to correlate habitat suitability to peat bogs rather than rivers. Both McBride's and Vergara & Schlatter's works relate woodpecker signs to beaver ponds or bogs (swamps). Large peat bogs are easy to locate on the map and more likely to cause tree rottening than rivers, as peat bogs don't have a 'bed' holding the water below the land level.

Adrian Hughes - 5 Aug 2009 01:14

Thanks for your comments Claudia! I will certainly take a look at peat bogs and I will revise the categories for forests of anthropogenic origin.

Ignacio rodriguez - 5 Aug 2009 12:53

Woodpeckers have been seen in exotic mature forests (Jardin Botanico Universidad Austral de Chile). But clearly was a rare observation.

An important point is that this species need nests not only to breed, but also to sleep. Nest characteristics are known for Nahuelbuta Area(Rodriguez, S 2001) and Valeria Ojeda analyzes a microsite around of nests with this info and data related to dispersion capacity you may have a central area with a maximum availability of habitat from these trees "anideros."

I think these birds sleep in old big trees (at least with height and diameter that will allow them to build a nest according Rodriguez, S. 2001 averaged Height: 25 meters and diameter: 82 cm. With a minimum diameter 36 cm), we can think that such trees are critical to their habitat.(Campephilus can eat from smaller trees, but can not build a nest to survive)so i suggest that Semi-Dense Mature Native Forest (Lenga, Nirre and Lenga, Coigue) must have a major category (at least 2, i think they love the N. Dombeyi to nest¡because they have Softwood).

Another issue, when a woodcutter cuts trees, often cut the best specimens (high, straight and healthy), leaving sick trees (let s say with worms) this phenomena can lead forest patches where it is more likely to observe Campephilus eating (as well as the edges of patches where the trees are supposed to be exposed and should get sick more (worms), and it is more easy to see the birds, but this forest theoretically was better habitat before being harvest.This is speculation, I hope these comments help, saludos.

Cristóbal Briceño - 6 Aug 2009 08:40

Hi Adrian,

I don't have much experience with the species myself although I have had the chance to observe their behavior in Tierra del Fuego. I agree with all the categories and I totally agree with having best category for Dense Mature Native Mixed Forest and bringing down Dense Forest of Anthropogenic Origin if the DBH (ideally checked in the field) shows to be smaller to the one preferred by the woodpeckers, as I guess the anthropogenic forest will vary in age since the arrival of forestry business.

I think adding the peat bog is a great idea!

About beavers, different densities have been calculated. In Karukinka we have found an average of 1,09 active colony per km of river which is similar to what Andrade found in 2005. For Ushuaia National park in the Argentinian side, Lizarralde (2004) found a density of 0.7 active colonies. Considering 4 or 5 beavers averaging an active colony (as estimated by Skewes, 2006) I guess it would be possible to extrapolate this values to rivers. If the impact of one colony can be assessed within the surrounding forest in terms of how the woodpecker would increase their densities by means of better habitat, then you could increase the suitability for riparian forest.

I like the two scenarios approach with and without beavers.

Regarding the buffer zone for roads and human settlement, 5km seem an excessive distance to me. How did you come to that number? I have observed (and heard) campephillus being meters away from estancias when old forest is available. I would expect a similar situation for roads, specially 2nd and 3rd order. Perhaps another consideration is that traffic is scarce in the south of the island (where the forest remains).

I hope I am not that wrong.

Saludos,

Cristóbal

Adrian Hughes - 10 Aug 2009 09:10

This masters project is limited by the type of data I have over the coverage of the study area and also by time. The project needs to be completed by end of September, but that is not to say the work cannot be extended beyond this deadline. Fields observation for dbh would be no doubt be a very useful factor along with the age of anthropogenic forests.

The value of 5km for the road/settlement buffer does seem excessive. I just used the value to start the discussion. The buffer would not be uniform but would consist of an initial value say 100m where you would not find any woodpecker nests then an increasing likelihood up to a second distance (5km) where roads and settlements have no effect whatsoever on habitat suitability. As you say 5km is excessive and I would look to bring down this value particularly for a forested area. I have no data for settlement and only data for large roads of which there are few in this area. I think that the roads and settlements will have very little effect in this area.

Perhaps in other regions of the species range these factors could play a greater role?

Peter McBride - 22 Sep 2009 09:38

I've got a couple of general thoughts, and then some more specific observations derived from my fieldwork north and east of your project area in the mid 1990s.

The general thoughts are really suggested points of clarification. First, I'm assuming that "habitat suitability" is intended broadly, encompassing (at least) foraging, breeding, and roosting, as these distinct uses are each considered at different points. It would be good to clarify this up front. Second, what is the spatial resolution of your analysis/mapping? It would also be good to state this, e.g., pixels correspond to 20 or 30m satelite imagery. As an example of these two considerations, in the Monte Cazuelas area (the "archipelagic" scatter NE of Karukinka on your map) forage suitability might have high values in a narrow border - only 1-3 pixels if resolution as above - around some of the larger "islands", corresponding to the nirre fringe to lenga stands. Nesting and roosting uses would have low values for those same border pixels, while a composite value is trickier to guess, but would perhaps trend low regionally.

Now I'll address some more specific considerations, with the caveat that my study area was weighted to central Tierra del Fuego (N & E of Karukinka) and its different landscape patterns. My study sites were almost entirely outside the Coigue zone. As important, in NE TdF nirre forms extensive, monospecific woodlands at the scale of Magellanic woodpecker territory or home range. In that area I found Magellanic woodpeckers nesting in nirre, and indeed the greatest cavity densities of my entire study area. So the interpretation of "using nirre for foraging and lenga for cavity excavation" might be true for the rather distinct landscape of Monte Cazuelas, but not for my general study area. Another consideration is that Monte Cazuelas is situated in somewhat higher elevation, particularly the lenga stands; I've suspected that the lack of lower elevation conditions may contribute to the paucity of use of lenga there. (On that note I should also clarify that all of my lenga study sites fell in the mid (150-300m) to high elevation zones; while usage was clearly greater below 300m, there was no basis of comparison with opportunities below 150m, which I expect may exist in the Karukinka area. Given the limits of my dataset, it would be safer to call the optimum elevation simply <300m.

With regard to the anthropogenic forest category, I wonder if some subsets might be warranted (if feasible). When I collected my field data in the mid 1990s, shelterwood harvesting seemed to be on the cusp of rapid expansion and perhaps replacement of traditional selective logging practices. I was not able to sample shelterwood-harvested stands at enough locations to reliably characterize the effects of this practice, but I was able to confirm that Magellanic woodpeckers will still excavate cavities in some selectively-cut stands. Finally, another but subtler form of anthropogenic forest are grazing-modified nirre woodlands, wherein reproduction and stem density have been greatly altered, though this may not occur in Karukinka area - ?

With regard to weighting of roads as a factor, I agree with the prior comment about not giving this factor undue negative weighting. Relative to Karukinka, my overall study area had greater road density, and I witnessed no strong aversion to roads. It was not uncommon to see forage sign near stand edges, including near roads. As I recall, both active (and successful) breeding attempts that I observed were within 200-300m of roads. Overall it felt like stand condition (age, decadence) and elevation were stronger drivers of use than road proximity, at least beyond the first 100m or so.

As a final comment, while in current conditions I found forage sign concentrated near both beaver-ponds and peat bogs, I am not confident that both edge types will persist with similar suitability over time. I do not have the expertise in hydrology or soil chemistry to better explore this doubt, but simply am acknowledging that even in the glacialogically-youthful landscapes of Tierra del Fuego, the native forests have had millenia of ecological adaptation to peat bog ecotones. In contrast, the same forests have had scarcely six decades of adaptation to beavers' high-impact ecosystem engineering, evidenced by the bleached corona of Nothofagus snags ringing each beaver pond. The gradual or rapid decline of surrounding trees may provide near-term foraging opportunities for the Magellanic woodpecker - which (unlike the tragic case of its Campephilid cousin, the ivory-bill) here enjoy long-lived prey, such as the longhorn beetle larvae that dwell a decade or more in tree boles - but I am not confident of the longer-term suitability of these edges. I advance this concern for further considerations of your reviewers who may have more expertise.

I realize these comments are rather late for your timeframe, but hope they may still be of some service. Please let me know if you have questions. I am pleased that you have undertaken this effort.

Comments on Weighting

Claudia Silva - 10 Sep 2009 18:06

Hi Adrian. I would put rivers and peat bogs at the same place in the ranking. I don't think there is much evidence about one having more influence than the other. If beavers are important and we assume most rivers are colonized by beavers (which is true) than the river factor would be quite important. In fact, rivers and peat bogs were considered indistinctively in Vergara & Schlatter. Also, I'd move up Elevation in the ranking, because it seems to be a relatively important factor, at least that's what I interpret from your bibliographical review.

In the table, I think it'd be better to use the values you wrote down, instead of values in between (such as 1/4 for rivers/vegetation), just to make it easier to read and interpret.

So, in your list, there are five ranks:

1.Vegetation

2.Peat bogs

3.Rivers

4.Elevation

5.Roads

According to the modifications I suggest, the list would now look like this:

1.Vegetation

2.Peat bogs / Rivers

3.Elevation

4.-

5.Roads

I wanted to keep the five places in the ranking, because you defined five grades of importance in your rating scale, and also because I believe that Roads should be more than just one place down from the other factors. So, in your rating scale, the distance between each grade (moderately, strongly, etc) is two units. Since all this process is very intuitive and arbitrary, as there is not so much empirical evidence to support a more accurate scaling and grading, I would like to keep that fixed distance between the environmental factors. So, the maximum difference in importance in my list is that between Vegetation and Roads, a difference of four places If we adjust your Rating Scale to that, than we should grade this difference with a 9 (extremely different). The next largest difference is that between Peat bogs (and Rivers)and Roads, and would correspond to a Very strong difference (7). Youd do the same with the rest of the factors and the result is the table I uploaded. You see the difference between each place of the list (first and second, second and third and so on) is of two units of your rating scale. I think by using this fixed distance between factors, you have a more constant criterion to grade the difference in importance of each factor to one and the others. I we just grade this using or intuition, it adds even more subjectivity to the process.

Adrian Hughes - 14 Sep 2009 09:20

Claudia,

I have found it quite a challenge to apply the weighting scheme. There is little empirical evidence to justify the scheme so this model which is fundamentally expert driven will be subjective.

I do feel confident that vegetation cover should be by far the most influential and that roads will have a minimal influence. I only put peatbogs ahead of the rivers as you mentioned that they may cause more tree rotting due to more water movement and not having a 'river bed' to holding the water below land level. I do think that you are right that with lack of hard evidence we should give these two factors equal weighting.

Thanks for your feedback!