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Method evaluation of GIS-based prediction tools for biodiversity Habitat suitability for birds in Stockholm, Sweden

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”We abuse land because we regard it as a community belonging to us. When we see it as a community to which we belong we may begin to use it with love and respect”

Aldo Leopold

Preface

PROBE-project

This thesis is part of the research project “Prediction tools for biodiversity in environmental impact assessment”, which is conducted at the department of Land and Water Resources Engineering, Royal Institute of Technology (KTH) in Stockholm, Sweden. It is funded by the Swedish Environmental Protection Agency and is part of the research program “Research to forge the Conservation Chain”, coordinated by the Swedish Biodiversity Centre (CBM), Swedish University of Agricultural Sciences (SLU) and Uppsala University (UU). The Conservation Chain aims at “effective conservation” through research in four different areas: policy measures, the formulation of environmental objectives, indicators, and monitoring. It is called the Conservation Chain because of the logical chain of activities for effective conservation: Objectives – Policy measures – Management measures – Evaluation.

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Sammanfattning

Hur fungerar våra städer som ekosystem? Denna fråga initierade på 1970-talet ett nytt forskningsområde kallat urban ekologi. Svenska städer är från ett europeiskt perspektiv gröna och Stockholm har jämfört med andra storstäder relativt mycket grönområden. Under de senaste decennierna har stadsplaneringen arbetat för att inkludera biologisk mångfald i planeringen, vilket visat sig svårt eftersom det saknas välutvecklade metoder för att kvantifiera och förutsäga påverkan på biodiversiteten. Denna studie jämför två olika användbara prediktionsmodeller som kan förbättra stadsplaneringen.

Syftet med studien var att med hjälp av ett geografiskt informationssystem (GIS) utföra landskapsanalyser för att identifiera och kvantifiera habitat i Stockholm stad för sju fågelarter: mindre hackspett, större hackspett, gröngöling, stenknäck, nötväcka, skogsduva och kattuggla. Två olika prediktionsmodeller jämfördes: en expertbaserad och en empirisk model. I studien har jag använt mig av en biotopkarta som är producerad av Stockholm universitet i samarbete med Stockholm stad (Stockholm Municipality, 1999) samt observationsdata från Rapportsystemet för Fåglar som förvaltas av ArtDatabanken. De rumsliga analyserna har utförts i ArcView 3.3 och ArcGIS 9.1.

Slutsatsen av denna studie är att både expertmodellen och den empiriska modellen är verktyg som kan användas för att förutsäga arters förekomst. Kvantiteten och kvaliteten av data är vitalt för resultatet. I denna studie var expertmodellen, som är baserad på experternas kunskaper och Stockholms vegetationskarta, att föredra framför den empiriska modellen. Den empiriska modellen är baserad på observationsdata, Stockholms vegetationskarta och mjukvaran Genetic Algorithm for Rule-set Production (GARP) för att förutsäga arternas förekomst. Dagens observationsdatabaser bygger ofta på ad hoc data, vilket kan införa en bias i en empirisk modell, främst orsakat av att data inte är insamlade objektivt och att det är olika rumslig upplösning på vegetationskartan och observationerna. Sådana osäkerheter i observationsdatabasen kan ge en överprediktion. Vilken modell man ska använda beror på vilka data som är tillgängliga och vilka kunskaper som finns om organismgruppen. Ska man använda den empiriska modellen så bör man göra det med försiktighet och alltid konsultera experter på olika taxa och naturvårdsbiologi. Det är enklare att förutsäga utbredningen av hotade och ovanliga arter än vanliga arter som har bredare habitatspreferenser.

Abstract

Swedish cities are from a European point of view considered small, sparsely populated and green. Stockholm city has a great deal of its nature and older cultural landscape remaining, which is unusual in large metropolitan areas.

During the last decades the spatial planning of urban environments has faced the challenge of including biodiversity concerns. This has proved to be difficult since there are no well-developed methods for quantifying and predicting the impacts of exploitation on biodiversity. As a result many green areas have been exploited and the flora and fauna are undergoing loss of habitats, fragmentation and alteration due to change in land use. There is an evident need to develop the planning and management methods for biodiversity in urban areas. Moreover, adequate methodologies for systematic and quantifiable predictions are needed.

In this study landscape analyses have been carried out to predict the occurrence and suitable habitat in Stockholm municipality for sever birds: Lesser Spotted Woodpecker, Great Spotted Woodpecker, Green Woodpecker, Hawfinch, Nuthatch, Stock Dove and Tawny Owl. Two different prediction models have been used: an expert model and an empirical model. The basis for the study is a biotope map (Stockholm Municipality, 1999) and a species observation database (administrated by the Swedish Species Information Centre). The spatial analyses were conducted using GIS (ArcView 3.3 and ArcGIS 9.1).

The most important conclusion is that it is possible to predict species distribution with both models. However, the quality and quantity of data is essential for predicting species occurrence. In this study the expert model is preferable since it is based on expert knowledge and a biotope map. The empirical model is based on occurrence data, a biotope map and software called Genetic Algorithm for Rule-set Production (GARP), which predict species distribution. The occurrence data has been gathered in an ad hoc manner. In this model the uncertainties in the occurrence data causes an overprediction mainly due to the bias in the data and the mismatch in the resolution of the biotope map and the occurrence data. The empirical model should consequently be used carefully and one should always consult with experts on different taxa and conservation biology. Which model to use depends on the available data and what knowledge there are in the certain organism group. In general it is easier to predict rare species than common ones that have a wider habitat criterion.

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1 Introduction

1.1 Spatial planning

Planning trends

A century ago 90 percent of the Swedish population lived in rural areas (Länsstyrelsen i Stockholm län, 2003). Today that has shifted and 84 percent live in urban areas (i.e. an area that consists of a group of buildings normally not more than 200 meters apart, and having at least 200 inhabitants per site) (Statistics Sweden, 2002). During the 1960s and 1970s the Swedish cities expanded by the establishment of suburbs outside the city. The last decades, on the contrary, the Swedish spatial planning trend has changed and is now focusing on condensing the cities. As a result green areas within the cities have been exploited. Thus, green areas (green structure) have become more and more fragmented (Blomberg och Burman, 2001). This strong pattern of urbanization is threatening biodiversity.

Stockholm, the capital of Sweden, is located on the coast of the Baltic Sea. The municipality of Stockholm is the largest one in Sweden with 771 000 residents (Stockholm Office of Research and Statistics 2007) and together with 25 other self-governing municipalities it constitutes the County of Stockholm (Länsstyrelsen i Stockholm län, 2003). Stockholm is a city with high population pressure (the municipality increases annually by 8000 people) and the planning strategy is to expand the city inwards (City Planning Committee, 1999). During 1980-1990 green structures declined by eight percent, i.e. 540 hectares in the County of Stockholm (Löfvenhaft och Ihse, 1998). Urban sprawl has resulted in a severe loss of ecosystems in the region, affecting both common and nationally red-listed species of animals and plants (Colding *et al*. 2003). In Stockholm city at least 25 percent of the 412 observed red-listed species have probably disappeared, since they have not been reported since 1974 (Gunilla Hjorth pers. comm.). Amphibians, reptiles and some bird species are previously common species groups that are drastically declining in abundance (Colding *et al*. 2003).

Stockholm's green structure

Green areas have three main functions in society: social, cultural and ecological. The areas are essential for basic knowledge of nature, ecology and biodiversity. Access to nature has also been proven to be important for people's health and wellbeing (Boverket, 1999). The National Institute of Public Health in Sweden is concerned that the decrease in green structure in cities may decrease the opportunities for physical activity (Ulf Eriksson pers. comm.). The Swedish population highly values nature, and a recent study verifies that nine out of ten citizens of the County of Stockholm are interested in outdoor recreation (Länsstyrelsen i Stockholm län, 2004). The visiting frequency in green areas has been shown to be correlated with the distance to the site, with a threshold for high visiting frequencies at two kilometers (Hörnsten, 2001). The green structure gives the city its character and conveys information about the cultural heritage and cultural identity (Boverket, 1999). Moreover, the landscape carries traces of information on the land use of earlier generations (Länsstyrelsen i Stockholm län, 2003). Green areas are the basic condition for biodiversity and can improve local climate and air quality. These areas may also contribute ecological services such as water regulation (i.e. water runoff from the built-up areas can be infiltrated in these areas) (Boverket, 1999).

Biodiversity

Biodiversity has a broad definition which comprises the variability within species, between species and of ecosystems (UNCED, 1992). It is necessary to address biodiversity at all levels of organisation to understand the functioning of green areas. The biodiversity in a green area depends on four basic factors:

- Biodiversity is correlated with the size of the green area. Studies carried out in Stockholm indicate that the number of habitat types increase with patch size up to a threshold level at three square kilometers (Nordmalm *et al*. 1999).
- The landscape structure plays a major role; a more heterogeneous landscape supports a higher species diversity, unless species are affected by fragmentation of habitats.
- Habitat continuity in time affects biodiversity; the older and the more pristine the area is the more species have had the possibility to establish, e.g. oak biotopes in old parks (Nordmalm *et al*. 1999). A quarter of all the threatened species in Sweden depends on old living trees and dead wood for their survival (Andersson and Österlund, 2004). In Stockholm the biotope elements with the greatest amount of biodiversity are old-growth broad-leaved deciduous trees and dead wood (Gothnier *et al*. 1999). Accordingly, the City Council of

Stockholm municipality has designated old broad-leaved deciduous and coniferous forests as one of four ecological sensitive ecosystems, which require consideration when expanding the city (City Planning Committee, 1999).

- Ecological infrastructure (i.e. green areas and green corridors linking them together) is vital for species survival (Nordmalm *et al*. 1999). Green areas in the outer suburbs of the city are interesting from a conservation perspective because they contribute to the dispersal of plants and animals between green areas. The green structure in the Stockholm region is composed of ten wedge-shaped areas, which together with outdoor activity areas, parks, shorelines, and built-up areas with natural vegetation form a network of green areas (City Planning Committee, 1999).

Stockholm planning strategies

Each municipality in Sweden is required to have an up-to-date comprehensive land-use plan, covering the entire municipality (SFS 1987:10). The plan for the municipality of Stockholm (Stockholm City Plan) was adopted in 1999 by the City Council (City Planning Committee, 1999). In the Stockholm City Plan green structure issues are discussed along with the other structures and land use concerns.

Stockholm has expanded in a star-shaped pattern along the traffic routes and as a result, the green wedges between the roads have remained relatively intact. The population of Stockholm municipality is increasing at a high rate, so strategy according to the comprehensive plan is to expand the city inwards and re-use already exploited land (e.g. former industrial areas) while simultaneously conserve valuable green areas to the greatest extent possible (City Planning Committee, 1999). An analysis done by Stockholm municipality shows how the planned exploitation between the years 2004-2007 will affect the different land use categories. It shows that 2.5 percent of the broad-leafed deciduous forest would be affected by the expansion. This could be a significant proportion of the area depending on where they cut down the trees (connectivity) or maybe there is already too little of this biotope left (fragment gradient) considering the fact that this biotope constitutes less then 5.5 percent of the total area of Stockholm today (Stockholm municipality). A main objective and challenge for the municipality is to create an ecologically sustainable society while building 20000 new homes (City Planning Committee, 1999).

The environmental and sustainable development issues have received increasing attention in Swedish politics during recent decades. The Swedish environmental policy is expressed through the environmental quality objectives adopted by the parliament with the intention to adapt the country to long-term sustainability. One of these objectives is “A Good Built Environment”, i.e. buildings and amenities should be located and designed in such a way as to support sustainable management of land, water and other natural resources (Ministry of Sustainable Development, 1998).

Protecting biodiversity

Several conflicts arise when protecting biodiversity in urban environments, first of all the challenge of allocation between different interests such as expansion interests versus biological diversity. Secondly, green areas are often considered as merely unexploited land, and thirdly, it is difficult to price nature. Thus, green areas and consequently biodiversity are often neglected when expanding a city.

Green structure and biodiversity concerns go beyond municipality borders and need to be addressed at a regional scale, since action in one municipality affect neighboring municipalities and their use of the green structure. The County of Stockholm is constituted of 26 municipalities. Thus, a need exists for regional planning to coordinate a biodiversity management system (Länsstyrelsen i Stockholm län, 2003). With regional planning a landscape ecology approach for biodiversity is feasible. This larger scale makes it possible to include factors which are important for biodiversity, such as distribution and configuration of biotopes (Löfvenhaft *et al*. 2002).

Today there are different legal tools to include biodiversity in spatial planning, e.g. environmental impact assessment (EIA) and strategic environmental assessment (SEA). These tools introduce an environmental consideration in the planning phase of projects, plans, policies and programs (Naturvårdsverket, 2000). However, EIAs and SEAs presently lack a good simple analysis tool for visualizing the current state of biodiversity and for analyzing future scenarios. Such a tool could be landscape analysis with GIS and predictions of species distribution patterns.

GIS and spatial planning

GIS tools play a major role in environmental and natural resource planning and are increasingly used both in Sweden and internationally (Eklundh, 2001). GIS offers great potential as an analytical tool in several areas within planning.
GIS can, for example be applied to:

1. Illustrate and handle environmental quality objectives and indicators in spatial planning, e.g. in the comprehensive planning (Boverket och Naturvårdsverket, 2000b).
2. Provide analyses that can be used to identify land use conflicts and to suggest possible solutions.
3. The management of natural resources, in particular as an important tool in conservation biology and wildlife management (Eklundh, 2001).

For landscape ecologists GIS has contributed to enhance interpretation of the landscape, since several factors (e.g. geography and ecology) can be studied simultaneously. At the regional scale it can be difficult to find consistent land-use data, but the access to such data is increasing fast thanks to new techniques. Before GIS tools were developed the analyses of land use data were very time consuming since they were conducted manually. The use of scenario techniques in nature conservation management has been improved with GIS (Haines-Young *et al*. 1993). In spatial planning with a long time perspective it is essential to analyze trends and predict future consequences of expansion plans (Boverket, 2006). Currently scenario techniques are used to a small extent and mostly in SEAs, but the use of this technique will most likely increase with the development of GIS.

The advantages of using GIS in environmental planning include the ability to perform more complex analyses, to handle large amounts of information and to illustrated patterns with pedagogical maps. The disadvantages of using GIS do not have to do with GIS itself, but rather the lack of accessibility of input data and the lack of good GIS-competence, and cross-competence within the fields of planning, environment and GIS (Boverket and Naturvårdsverket, 2000a).

1.2 Species in fragmented landscapes

McArthur and Wilson (1967) are the fathers of the island biogeography theory, regarding species community dynamics for oceanic islands and archipelagoes. The island biogeography model they developed states that the number of species inhabiting an island depends on a dynamic equilibrium between immigration rates and extinction rates. These rates in turn are influenced by the size of the island (area), and the degree of isolation (distance) among the islands and from the mainland. Larger and less isolated islands have a higher equilibrium number of species, due to the fact that immigration rates are predicted to increase and extinction rates to decrease compared to islands that are smaller and more isolated. Davis and Glick (1978) suggested that this idea could be applied to study conservation of urban ecosystems. In this view each city consists of a collection of habitat islands. Habitat island populations of animals and plants may be dependent on immigration from other islands or the surrounding “mainland” for their survival. Hence, the spatial distribution of these islands matters, as does the linkage between urban habitats and rural environment (Adams and Dove, 1989).

The bird species in this study are mostly habitat specialists and sedentary species that are specialized in broad-leaved deciduous forest biotopes. Sedentary birds with a specific habitat preference are likely to be more vulnerable to land-use changes (Enoksson *et al*. 1995). Sedentary birds could also be assumed to be sensitive to changes in landscape structure. Sedentary forest birds species, such as the Marsh Tit (*Parus palustris*), generally occur in the large forest remnants of Stockholm, while small patches are unoccupied. The preference for large patches is due to the fact that they show larger variation in forest coverage, configuration and habitat types. The variation protects the populations against environmental disturbance (Mörtberg, 2001). However, for the habitat generalists like the Nuthatch (*Sitta europaea*) the variation in patch size does not affect the occurrence. Instead isolation seems to be the important factor and the Nuthatch has been found to be much less frequent in isolated patches than in less isolated ones (Enoksson *et al*. 1995).

1.3 Prediction tools

There is a need in spatial planning for adequate methodologies for systematic and quantifiable predictions of species spatial distribution (Gontier *et al*. 2006). If such tools were available today we could avoid some of the negative consequences that city expansion often have on biodiversity, i.e. develop an improved spatial planning. The development of GIS-based prediction models of species distribution is an expanding research field in landscape ecology, spatial ecology and conservation biology. In conservation management the use of predictive models has increased for endangered species, since more powerful statistical tools and GIS have been developed. One advantage with GIS-models is that they can be applied at landscape and regional levels (Gontier *et al*. 2006).

The basis for a habitat suitability model is the assumption that a species choose and use areas that best suit their requirements, e.g. for shelter and food, i.e. higher abundance is expected in high quality habitats. The aims of habitat-based models are to identify remaining potential habitats (Ortigosa *et al*. 2000), quantify habitat quality using habitat attributes considered vital to the species and to predict its spatial distribution (Kliskey *et al*. 1999). The fundamental elements of the models are environmental parameters, such as vegetation, topography, climate (Ortigosa *et al*. 2000) and presence/absence data of the species. In order to preserve endangered species it is crucial that facts about the species' life requirements exist (Meggs *et al*. 2003). The quality and quantity of available data varies considerably, e.g. museum collections or observation databases are often gathered in an ad hoc manner making them more difficult to use (Stockwell and Peterson, 2002).

Genetic Algorithm for Rule Set Production (GARP) is a widespread software for the prediction of species distributions. GARP derives species distribution maps using multivariate statistical models applied to species observation data in combination with environmental parameters (Stockwell *et al*. 2006). GARP can be regarded as an empirical model, as it utilizes empirical observation data. Another approach is to base a prediction model on expert knowledge of the relationship between habitat variables and the presence of a given species. In this study both expert and empirical models have been used as prediction models. They both result in habitat suitability maps, which can be applied in predictions of the distribution of species.

1.4 Study objectives

The purpose of this study is to investigate habitat-based prediction models of species distributions as an efficient method that municipalities can apply in the planning and management of biological diversity. More specifically, this study explores two prediction models, an empirical model and an expert model, and compare them in terms of data needs, usefulness, and prediction results. The study aims to quantify the amount of suitable habitats in Stockholm for seven sedentary bird species that generally depend on broad-leaved deciduous forests. Five of the species are specialists in broad-leaved deciduous forest, while two are more generalists in different forest habitats.

2 Methods

2.1 Study area

I studied the City of Stockholm municipality, which has an area of about 190 square kilometer (Figure 1). The distributions of biotopes are: 45.1% developed land, 19.8% forest, 12.9% water 11.1% semi-open land, 10.0% open land, 1.0% wetland and 0.2% remaining land (Stockholm municipality, 1999). Stockholm municipality is increasing annually by about 8000 inhabitants (City Planning Committee, 1999) and the forecast is that the population will increase by 81 000 during 2006-2015 (Utrednings- och statistikkontoret Stockholm stad 2006). The population pressure is highest in the most central part of Stockholm, which increases with about 3000 annually (Stockholm Office of Research and Statistics 2007).

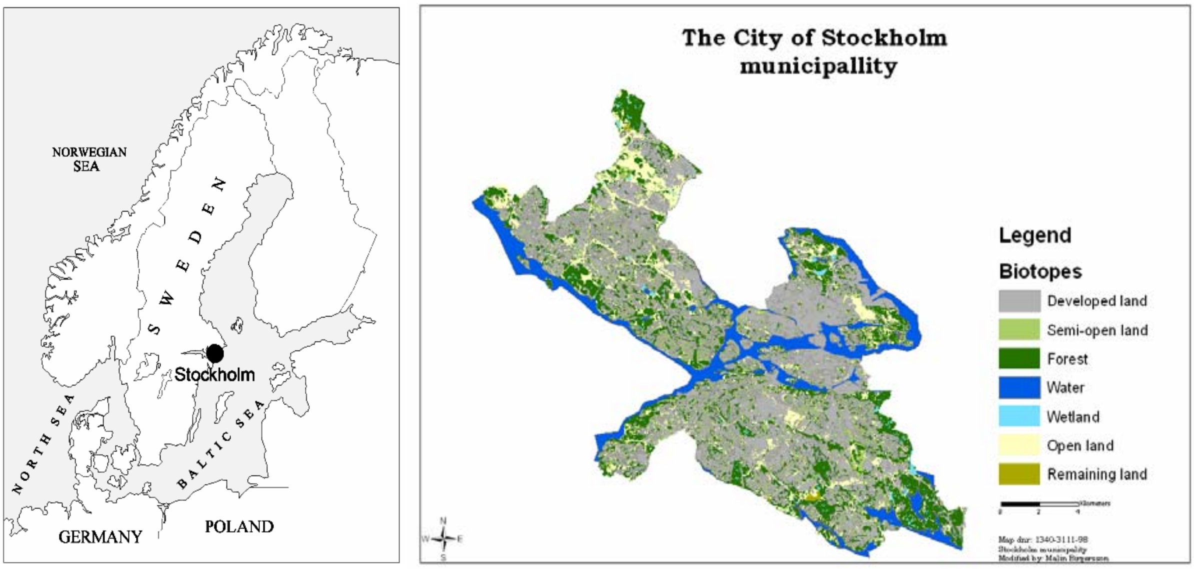

Figure 1: The study area Stockholm city, Sweden.

2.2 Species and habitats

I chose to specialize in broad-leaved deciduous forest biotopes since many species and especially red-listed species are depending on this habitat. The tree species classified as broad-leaved deciduous trees are elm *(Ulmus carpinifolia)*, ash *(Fraxinus excelsior)*, beech *(Fagus sylvatica)*, hornbeam (*Carpinus betulus*), oak (*Quercus robur)*, wild cherry (*Prunus avium)*, lime or linden (*Tilia cordata)* and maple *(Acer platanoides)*. Broad-leaved deciduous forest biotopes are decreasing in Sweden, a trend which has caused declines in populations of many species requiring these biotopes for their survival.

Seven different birds were included in the study (Table 1). The species were selected based on their preference for broad-leaved deciduous biotopes and a minimum of 30 recorded observations in Stockholm. Out of the seven birds, five are considered specialized in broad-leaved deciduous forests biotopes while the Great Spotted Woodpecker *(Dendrocopos major)* and the Nuthatch are generalists using several forest types. Table 1 also indicates the status of each species. The Lesser Spotted Woodpecker (*Dendrocopos minor)* and the Stock Dove *(Columba oenas)* are considered vulnerable whereas the Green Woodpecker *(Picus viridis)* and the Hawfinch *(Coccothraustes coccothraustes)* and the Tawny Owl *(Strix aluco)* are locally/ regionally listed as threatened.

Table 1: Status of studied bird species: CR Critical Endangered, EN Endangered, VU Vulnerable, NT Near Threatened and LR Locally/regionally listed as threatened (The Ark of Species).

Scientific name	Common name	Swedish name	Family name	Status
Dendrocopos minor (Linnaeus, 1758)	Lesser Spotted Woodpecker	Mindre hackspett	PICIDAE (Woodpeckers)	VU
Dendrocopos major (Linnaeus, 1758)	Great Spotted Woodpecker	Större hackspett	PICIDAE (Woodpeckers)	-
Picus viridis Linnaeus, 1758	Green Woodpecker	Gröngöling	PICIDAE (Woodpeckers)	LR
Coccothraustes coccothraustes (Linnaeus, 1758)	Hawfinch	Stenknäck	FRINGILLIDAE (Finches, Crossbills and Allies)	LR
Sitta europaea Linnaeus, 1758	Nuthatch	Nötväcka	SITTIDAE (Nuthatches)	-
Columba oenas Linnaeus, 1758	Stock dove	Skogsduva	COLUMBIDAE (Pigeons and Doves)	VU
Strix aluco Linnaeus, 1758	Tawny owl	Kattuggla	STRIGIDAE (Typical Owls)	LR

2.3 Input data

The biotope map

Spatial analyses and geographical illustration were conducted using the ESRI GIS software ArcView 3.3 and ArcGIS 9.1. All the layers representing the different parameters were converted to raster with 25 meter pixel size. The area of the biotope map is 218 square kilometer. For the GIS-based modeling I have used a biotope database published by Stockholm Municipality and Department of Physical Geography and Quaternary Geology at Stockholm University, dnr 1340-3111-98 (Stockholm municipality, 1999). The map was produced using remote sensing, interpreting infrared aerial photos. The aim of that project was to produce a map of the physical conditions for biodiversity in urban environments to develop basic data for spatial planning. This map is used by the municipality for planning and environmental monitoring, for more information see Löfvenhaft and Ihse (1998). The biotope map applies a classification of land-use with seven main biotopes (Table 2) and gives detailed information about each biotope, such as amount of old-growth trees and dead wood.

Table 2: Biotope classification in the biotope map.

Biotope classification	
Forest	Broad-leaved deciduous forest
	Mixed deciduous and coniferous forest
	Bedrock with scattered Scots pine
	Clear cut/young plantation
	Coniferous forest
	Deciduous forest
Semi-open land	Mesic grassland
	Moist grassland
	Dry grassland
	Bedrock
Open land	Arable land
	Mesic grassland
	Moist grassland
	Dry grassland
	Bedrock
Wetland	Mires
	Forested mires
	Wet forest
Water	Open surface
	With reeds
	With vegetation on the surface
Developed land	Sparse with 30-50% vegetation
	Dense with 10-30% vegetation
	Dense with 0-10% vegetation
Remaining bare ground	

The occurrence data

In the empirical model I used observation data from the Species Gateway. This bird reporting system is developed and administrated by the Swedish Species Information Centre and commissioned by the Swedish Ornithological Society (SOF), with funding from the Swedish Environmental Protection Agency (SEPA). The purpose of the reporting system is to produce distribution maps and identify population changes. The site is open to anyone who wishes to contribute their data (Species Gateway, 2006a). I chose to use occurrence data from 1975-01-01 until 2006-07-07. The year 1975 was chosen due to the fact that at least some species noted there before 1975 could be expected to have disappeared from Stockholm (Gothnier *et al*. 1999). Most of the occurrence data are from the last few years and only about six percent of the observations in the study are from before 1990. Furthermore, the observations included in this study were classified as breeding, probable breeding or possible breeding, i.e. fit at least one of the breeding criterions (Appendix 2).

All observations registered for the purpose to be on the so called “Stockholm concrete list” (a list of bird observations in central Stockholm) were excluded. The aim of this list is for each observer to see as many birds in central Stockholm as possible and to compete to become the “greatest concrete observer” (Species Gateway 2006b). These observations have been left out of this study due to the fact that there is a sampling bias, since the observers are seeking the birds in the central city in a much greater extent than in other areas. Furthermore, multiple observations from the same site were excluded, due to the risk that the same bird could be observed and reported several times, which might result in a bias in habitat preferences and the predicted occurrence of different species.

2.4 Habitat suitability models

In this thesis I have evaluated two different methods, an expert model and an empirical model, used to identify and quantify species habitats in Stockholm City. I have used a biotope map covering Stockholm municipality and based on this map and occurrence data I have conducted my analyses.

Expert model

The expert model relies on information gained through interviewing experts in the selected species. For each species questions regarding their habitat preferences (quality, quantity and connectivity) were formulated. Then the following ornithologists and bird-experts were invited to supply answers regarding the habitat preferences:

- Johan Nilsson — System engineer at the Swedish Species Information Centre working with the web-based reporting system.
- Martin Tjernberg — Researcher at the Swedish Species Information Centre working with the Swedish red-listed vertebrates.
- Tomas Pärt — Professor at the Department of Conservation Biology, SLU working with habitat selection, dispersal and reproduction of birds.
- Åke Berg — Researcher and associate professor at the Department of Conservation Biology at SLU and the Biodiversity Centre (CBM) working with bird fauna in farmland landscapes.

Furthermore, I used literature (Nilsson 1976; Cramp 1985; Nilsson and Pettersson 1990; Wiktander *et al*. 1991; Hansson 1992; Cramp and Perrins (1993, 1994); Redpath 1995; Åberg 1996; Svensson *et al.* 1999; Rolstad *et al*. 2000; Wiktander *et al*. 2001) to supplement the information given by the experts. From expert and literature information I derived the parameters that are assumed to be the driving forces for the distribution and abundance of each species. Parameters used in this study are biotopes, density (shelter), amount of old-growth trees, the amount of dead wood and special food requirements (i.e. biotopes within x meters from the foraging area). For the Tawny Owl and the Stock Dove a foraging area (e.g. open land habitats) within a specific distance to suitable habitats was applied (e.g. broad-leaved deciduous forest was included in the criteria only if it was within 200 meters of open land). The variables were produced from available GIS layers, e.g. the biotope map. Questions regarding territory size, connectivity and dispersal (i.e. what barriers exist and how far birds can spread) were also addressed. For these birds no barriers or limiting spreading factors were identified. Several environmental parameters combined form a habitat criterion for each species, where each 25 meter pixel is assigned with a number. The result from the expert model, with all the parameters taken together, is presented as a habitat suitability map. The habitats are qualified according to levels arbitrarily chosen, which ranges from 0 to 100 (actually 100%, or 1.0), where 100 is considered an ideal habitat and 50 a average good habitat, 20 a marginal habitat and 0 is not considered to be a suitable habitat. The index for a species at a location indicates relative habitat quality rather than actual population levels (Kliskey *et al*. 1999).

Empirical model

An empirical model obtains data from observations that are analyzed statistically or using machine learning methods (Gontier *et al*. 2006). In this study the model uses presence data only, because no absence data are available. The goal of machine learning is to program computers to use data to solve a problem; in this case the coordinates from bird observations obtained from the Species gateway, bird report system (see 2.2 input data).

I used the machine learning model system GARP. All the analyses were done using GARP version 1.1.3, available for download (http://www.lifemapper.org/desktopgarp/). The parameters required for such a modeling system are environmental data and species occurrence data, both geographically referenced. The genetic algorithm creates an ecological niche model for a species that represents the environmental conditions where that species would be able to occur. Each environmental layer represents a different kind of land use, e.g. mature conifer forest.

The basic concept of an algorithm is to create a set of potential solutions (based on four rules) to a problem and then to find the optimal solution through iterative modification and testing of this set. The four rules are:

1. Atomic rules – use one single value of the parameter in the precondition of the rule, e.g. "if the annual rainfall is 400 mm and the biotope is type 5 then the species is present" (Stockwell *et al.* 2006).

2. Logic rules – an adaptation of logistic regression models, e.g. "if the probability for presence is greater than 0.75 the model predicted presence".
3. Bioclim rules – predicts the range of a species from their environmental tolerance, e.g. "if the annual average temperature is >15 degrees C and ≤20 degrees C then predicted presence".
4. Range rules – is a simplification of the bioclim rule. It identifies a number of variables that may be regarded as irrelevant, i.e. all possible predictor parameters need not be used in the rule. "If average temperature is not >23 degrees C and ≤29 degrees C then predicted presence" (Stockwell *et al*. 2006).

The GARP model is self-validated and uses half of the species observations to develop the model and half of the observations are used to test the quality of the model. The quality of a rule is tested against the training data to find the greatest significance and predictive accurency (Gaubert *et al*. 2006). When the set of rules are obtained, GARP determines presence or absence and which rules that have the greatest expected accuracy (Stockwell *et al*. 2006). The result is layers that combined form a map of the predicted distribution of a species. Besides the layers GARP produces a table with the results from all the 100 iterations.

To find the best models and filter out poor models I used the best practice recommendations (Anderson *et al*. 2003): I developed 100 replicate GARP models for each species, retaining models with <20 percent omission error (i.e. the areas actually habitable that are excluded from the prediction) and then eliminated models falling outside of the central 50 percent of the distribution of commission error (i.e. the areas actually presenting inappropriate conditions that are still included in the model prediction). The 10 best-subset models were then added together in ArcGIS using the map calculator to produce a graded prediction map for each species. GARP chooses the best models based on their numbers of omission and commission. (Gaubert *et al*. 2006).

Spatial analyses

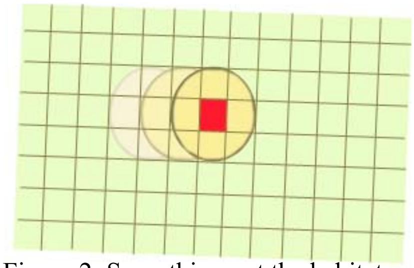

Figure 2: Smoothing out the habitat suitability numbers trough aggregation of pixels within the home-range.

Using a pixel approach causes problems since breeding birds' home-range (i.e. the area over which an animal normally travels in its day to day activities) is larger than the pixel area. To include the home-range while using a pixel-based approach, the spatial analyst tool neighborhood statistics was applied. Through this measure the suitability index of nearest neighboring pixels are used to recalculate a moving average HSI per pixel (Figure 2). Each pixel received a habitat suitability value and the neighborhood statistics were applied with each species specific home-range used as a radius. This resulted in an smoothening of the pixel values within a certain radius across the study area. If an ideal habitat such as broad-leaved deciduous forest with many old trees is surrounded by water this nearest neighborhood application decreases the estimate of habitat quality for a pixel situated in the forest. A negative consequence is that the neighboring water pixel value will correspondingly increase. In the empirical model the neighborhood statistics was used before applying GARP because of the low accuracy of the occurrence data, with the possible result that observations would be assigned to the "wrong biotope".

To reduce edge-effects in the areas where Stockholm municipality ends and another municipality begins I have used Swedish's Land Cover Data (Lantmäteriverket, 2003). This land-use map has less detailed information than the biotope map that has information on how many old trees and how much dead wood that exists.

3 Results

3.1 Maps

The main products of both the expert and empirical models are maps showing the predicted patterns of suitable habitat in the landscape (Figures 3-30). Each predicted habitat map shows a color scheme varying from light pink to dark red, with darker red indicating an area of higher habitat quality. The first map presented for each model is an unmodified map, while the second map in each model has been modified by introducing an arbitrary threshold of habitat suitability. For the expert model the threshold was set to 20, which I defined as a marginal habitat. Biotopes with a lower habitat quality than 20 were excluded in these maps. For the empirical model I chose a threshold of concordance of five predictions of species presence among the ten best-subset GARP models. The 10 models were added together, giving each map pixel a value between 1 and 10, where 10 represents the highest habitat quality and 1 the lowest habitat quality). Then I chose the value 5 as a threshold and excluded areas with a lower value (i.e. with lower habitat quality). The general pattern is that the empirical model predicted larger areas to represent suitable habitats and habitats with high quality compared to the expert model. The scales of habitat suitability are however not directly comparable between the two models, and the threshold levels were arbitrarily chosen.

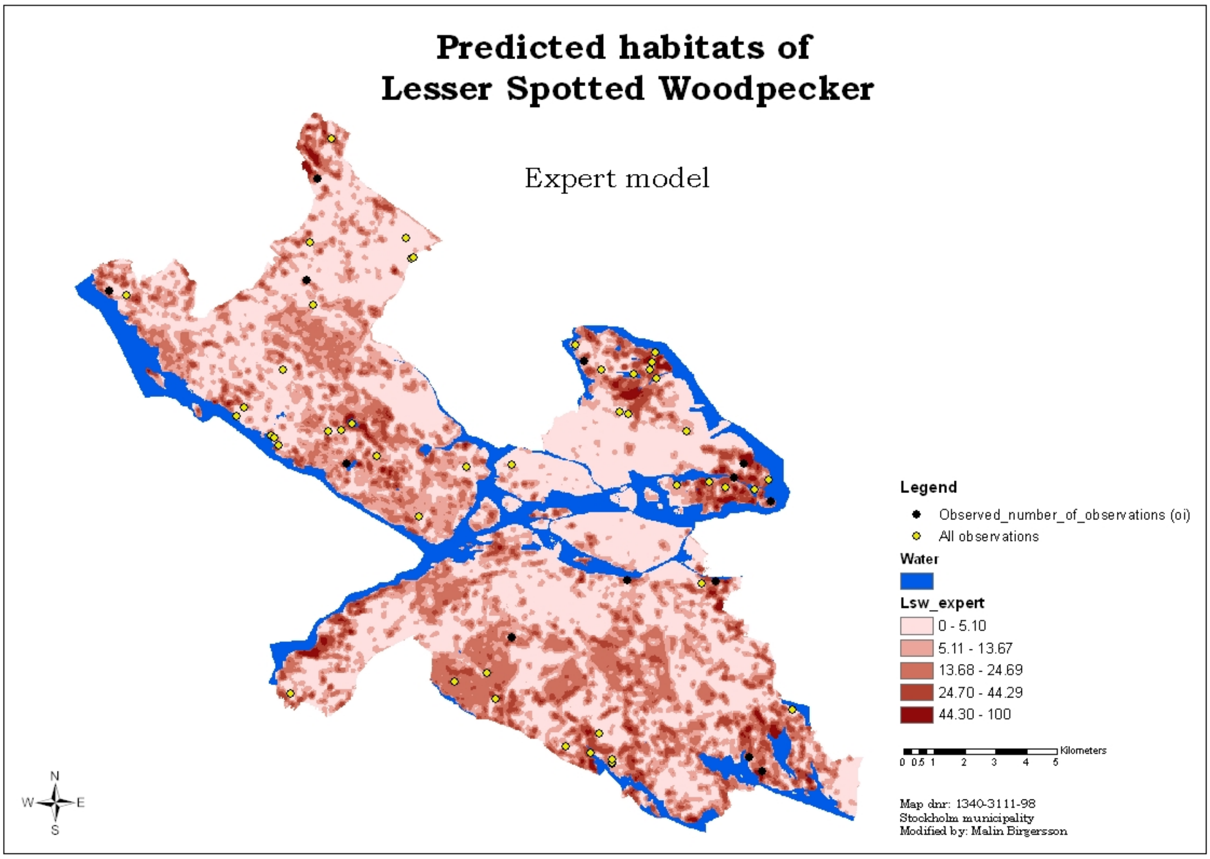

Figure 3: Habitat suitability index map for the Lesser Spotted Woodpecker, generated by an expert model.

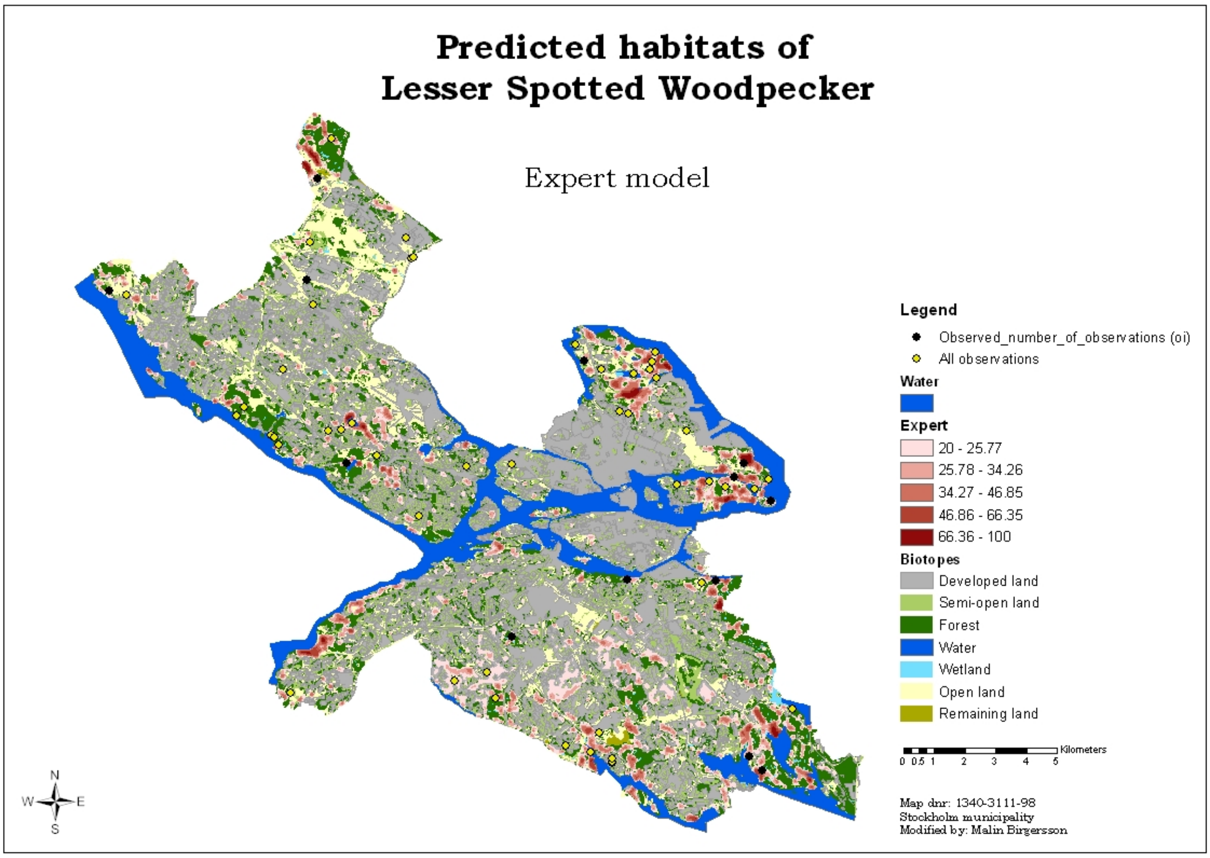

Figure 4: Habitat suitability index map for the Lesser Spotted Woodpecker, generated by an expert model, with a threshold set at index value 20.

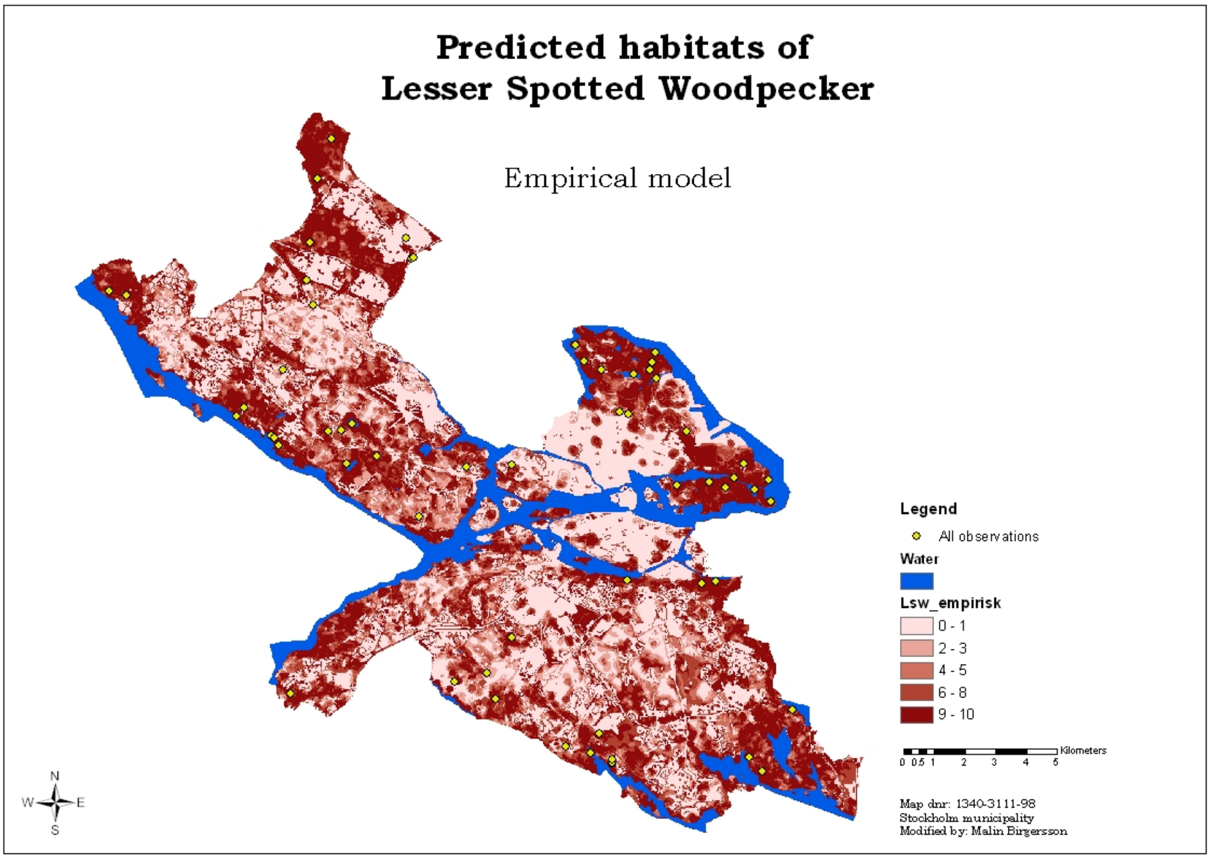

Figure 5: Map of the empirical models predicted habitats of the Lesser Spotted Woodpecker.

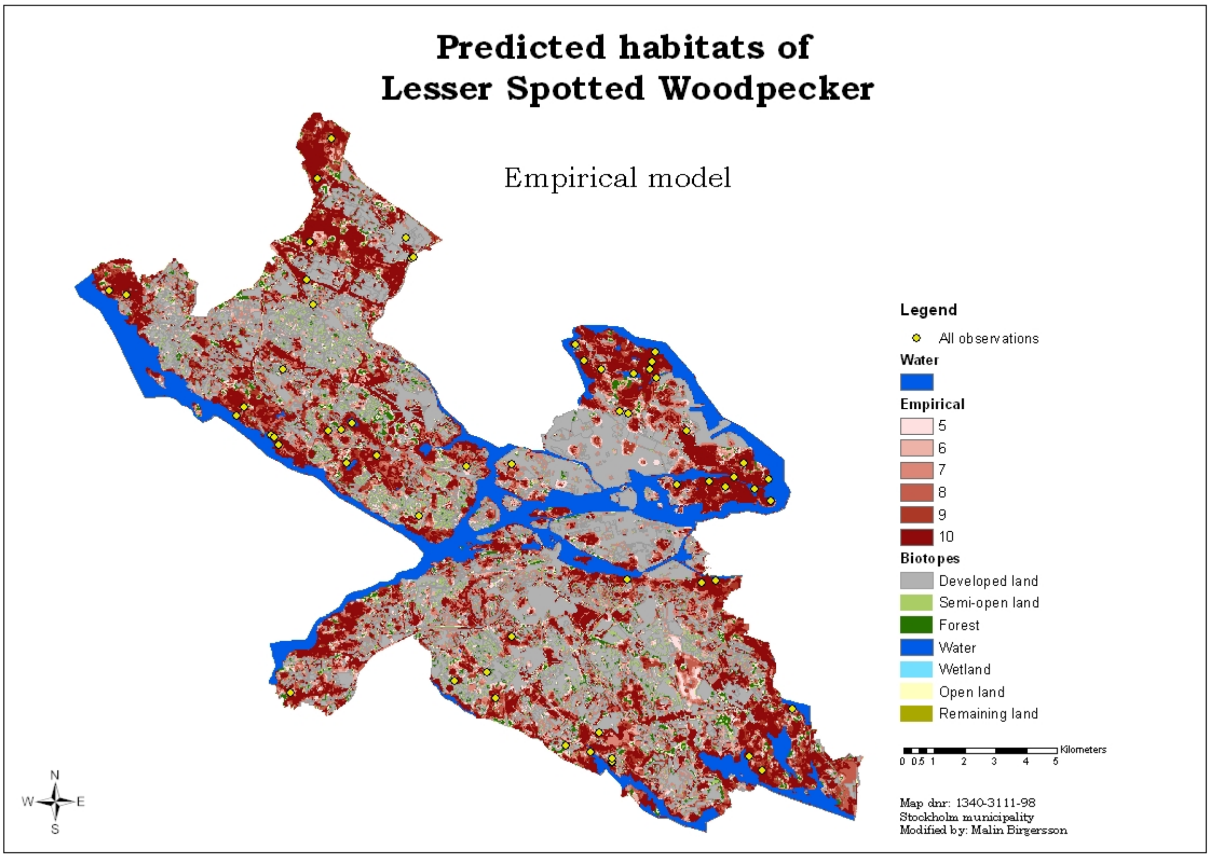

Figure 6: Map of the empirical models predicted habitats of the Lesser Spotted Woodpecker, with a threshold of 0.5.

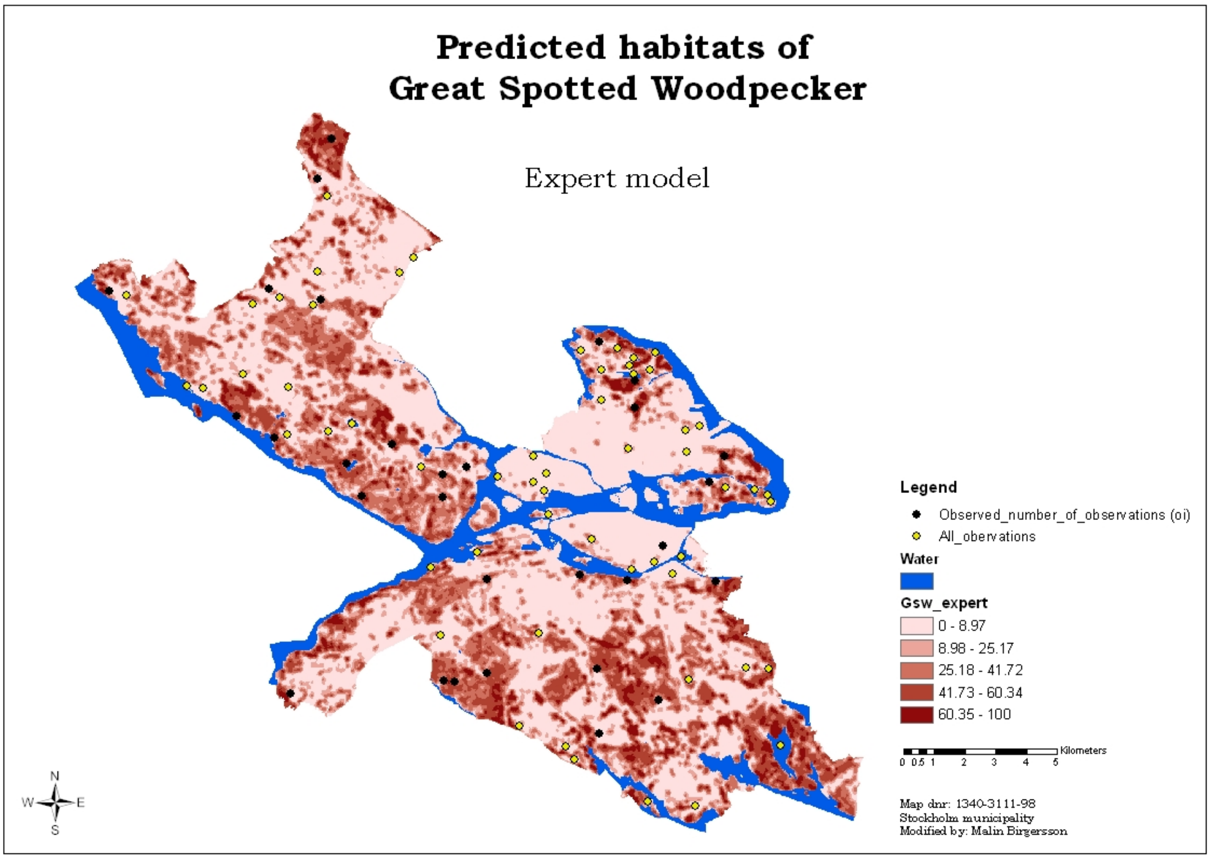

Figure 7: Habitat suitability index map for the Great Spotted Woodpecker, generated by an expert model.

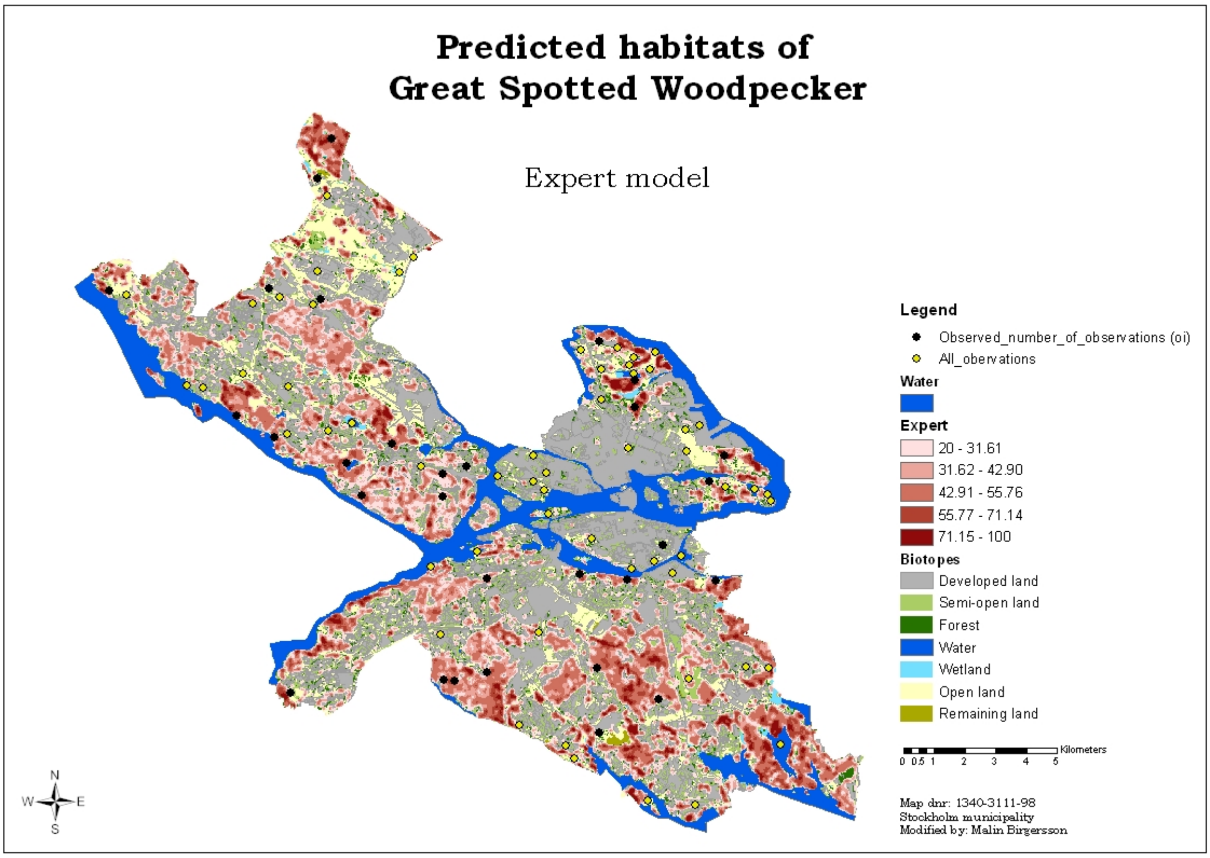

Figure 8: Habitat suitability index map for the Great Spotted Woodpecker, generated by an expert model, with a threshold set at index value 20.

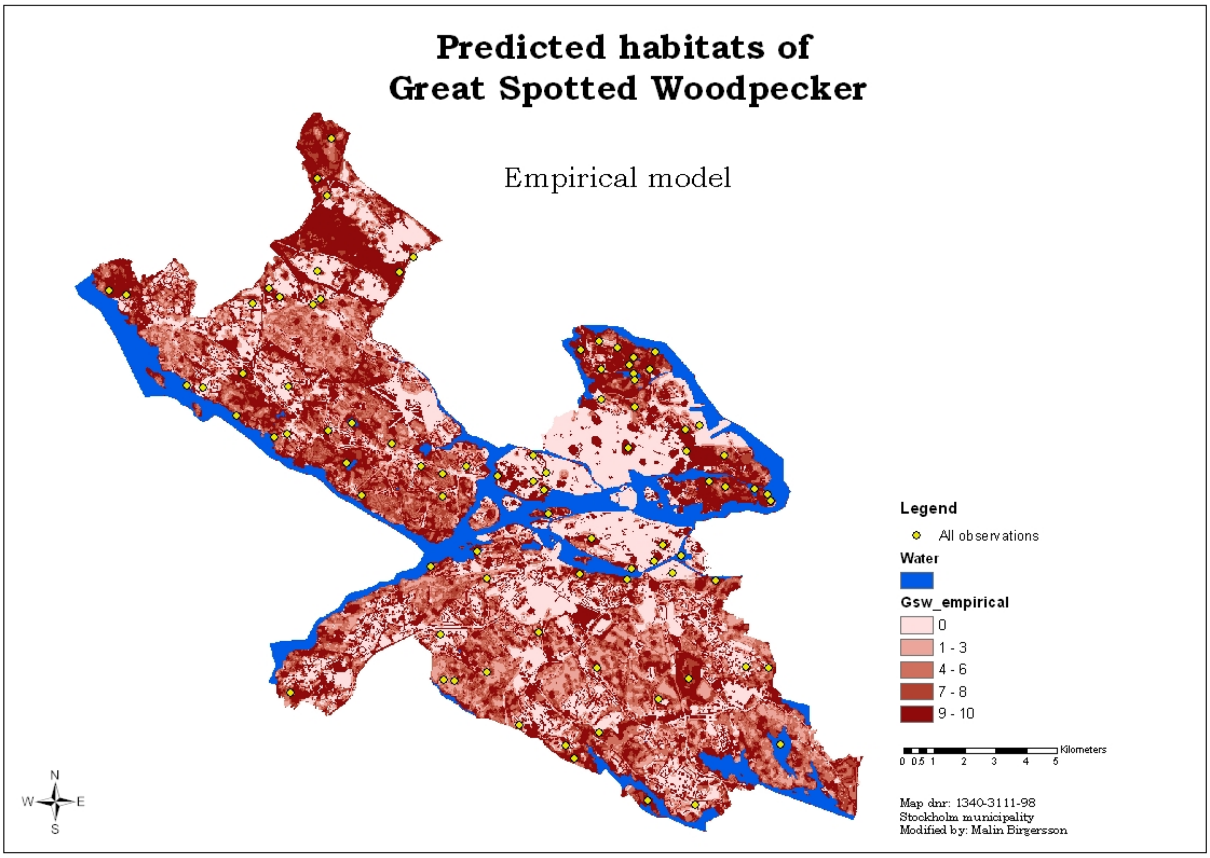

Figure 9: Map of the empirical models predicted habitats of the Great Spotted Woodpecker.

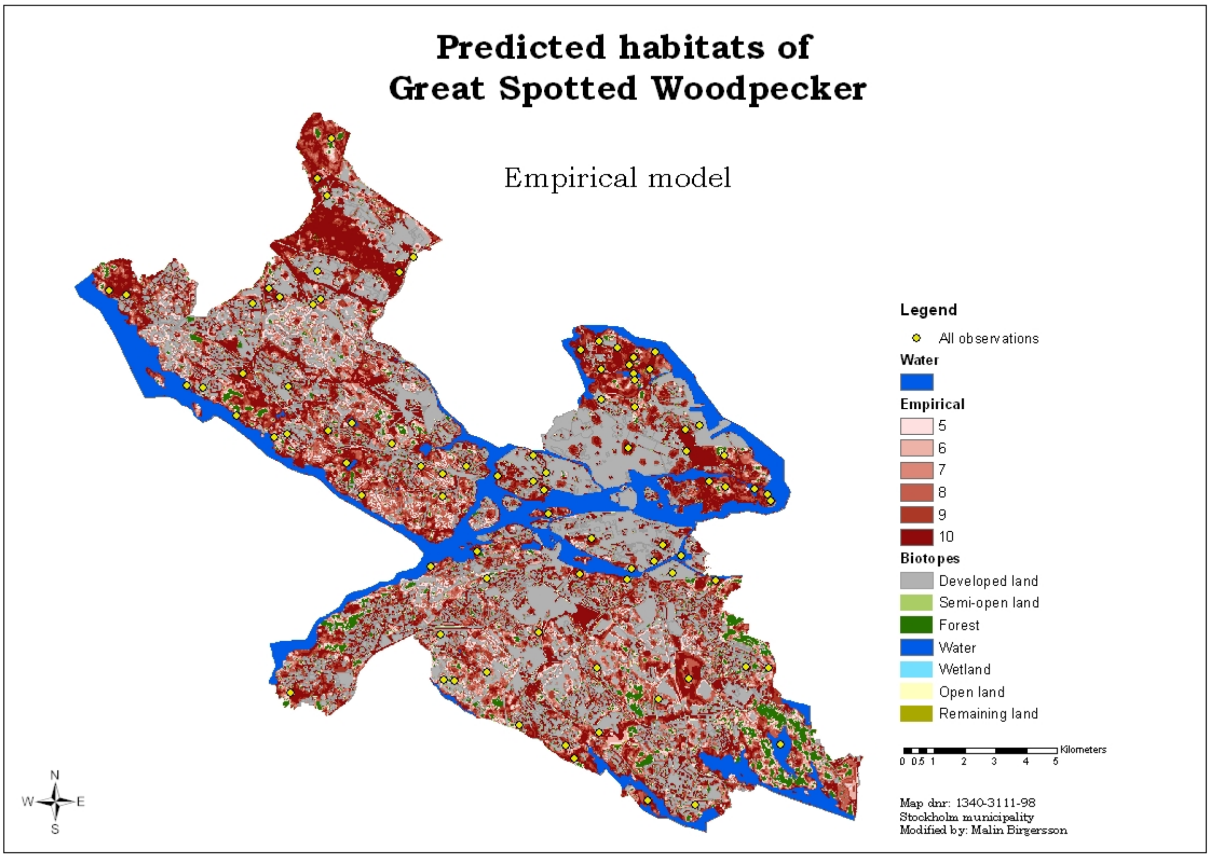

Figure 10: Map of the empirical models predicted habitats of the Great Spotted Woodpecker, with a threshold of 0.5.

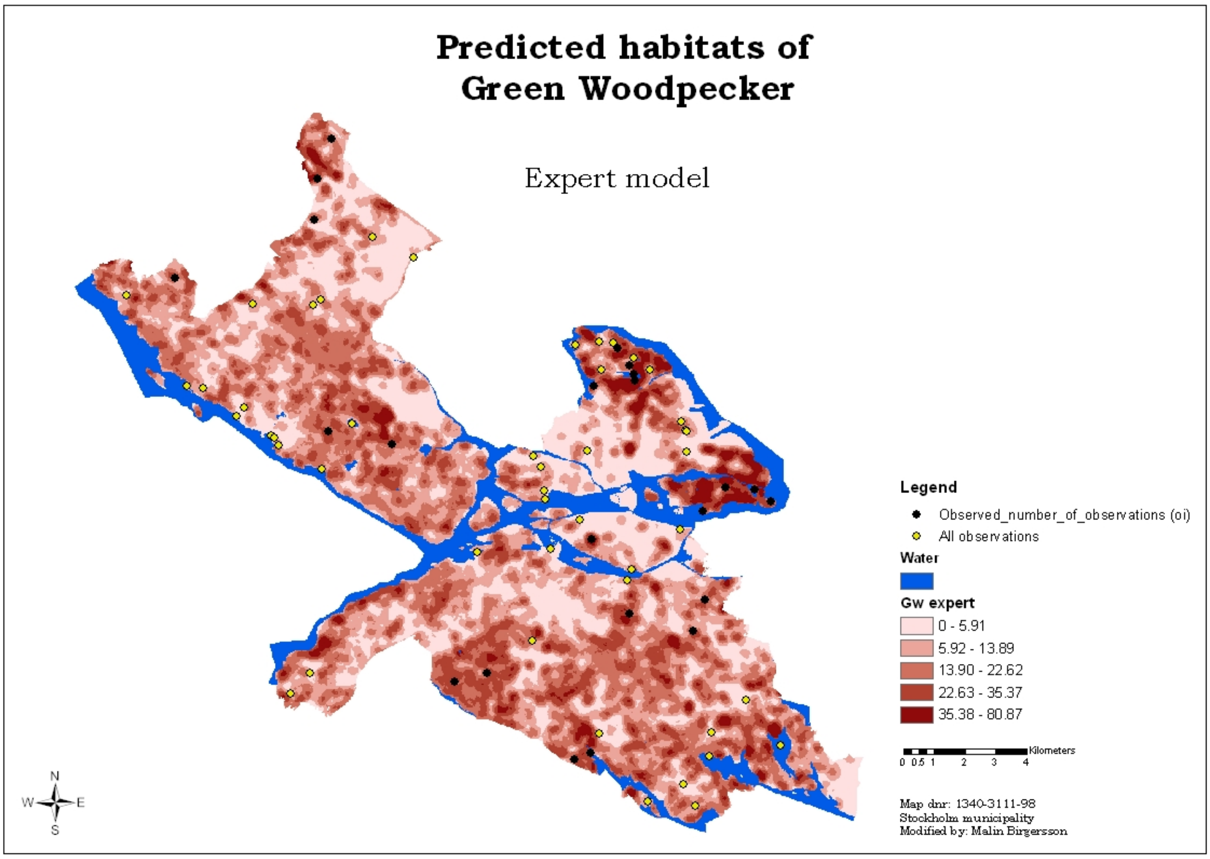

Figure 11: Habitat suitability index map for the Green Woodpecker, generated by an expert model.

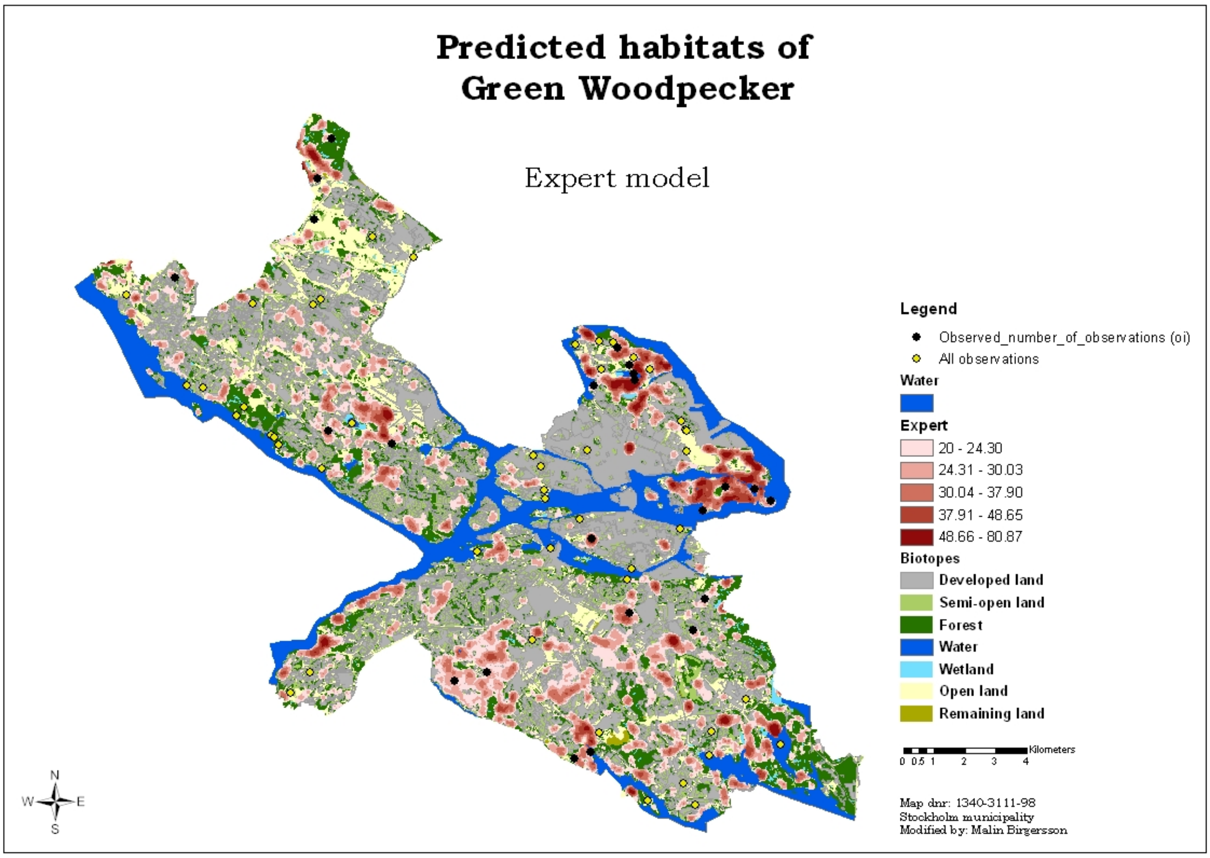

Figure 12: Habitat suitability index map for the Green Woodpecker, generated by an expert model, with a threshold set at index value 20.

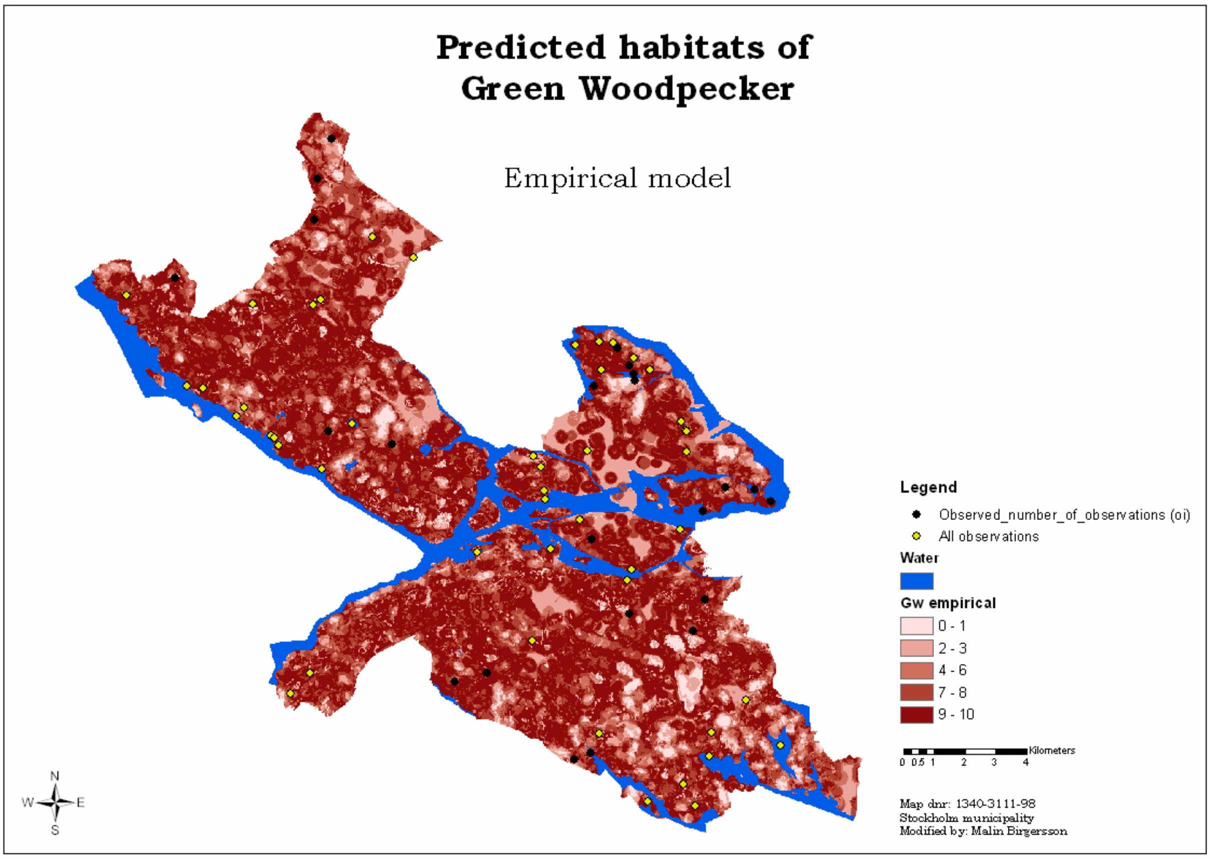

Figure 13: Map of the empirical models predicted habitats of the Green Woodpecker.

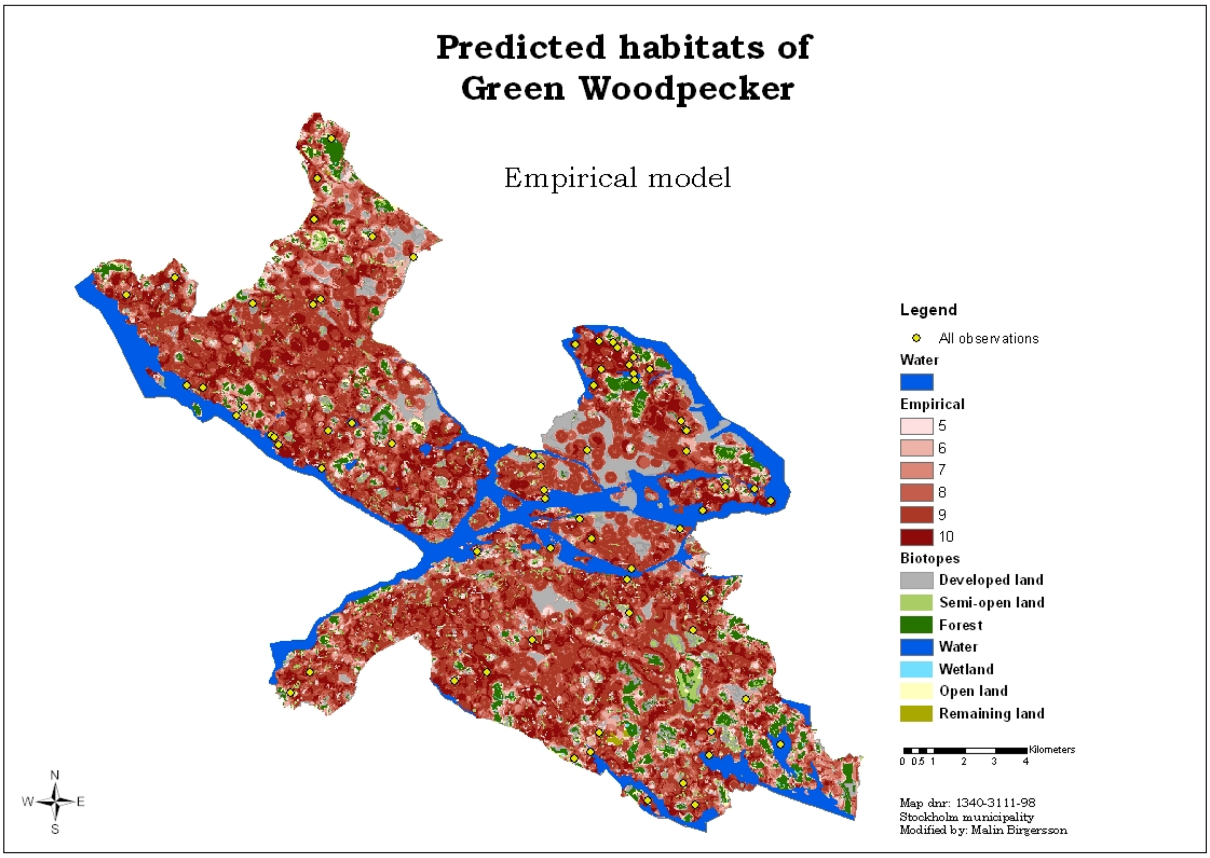

Figure 14: Map of the empirical models predicted habitats of the Green Woodpecker, with a threshold of 0.5.

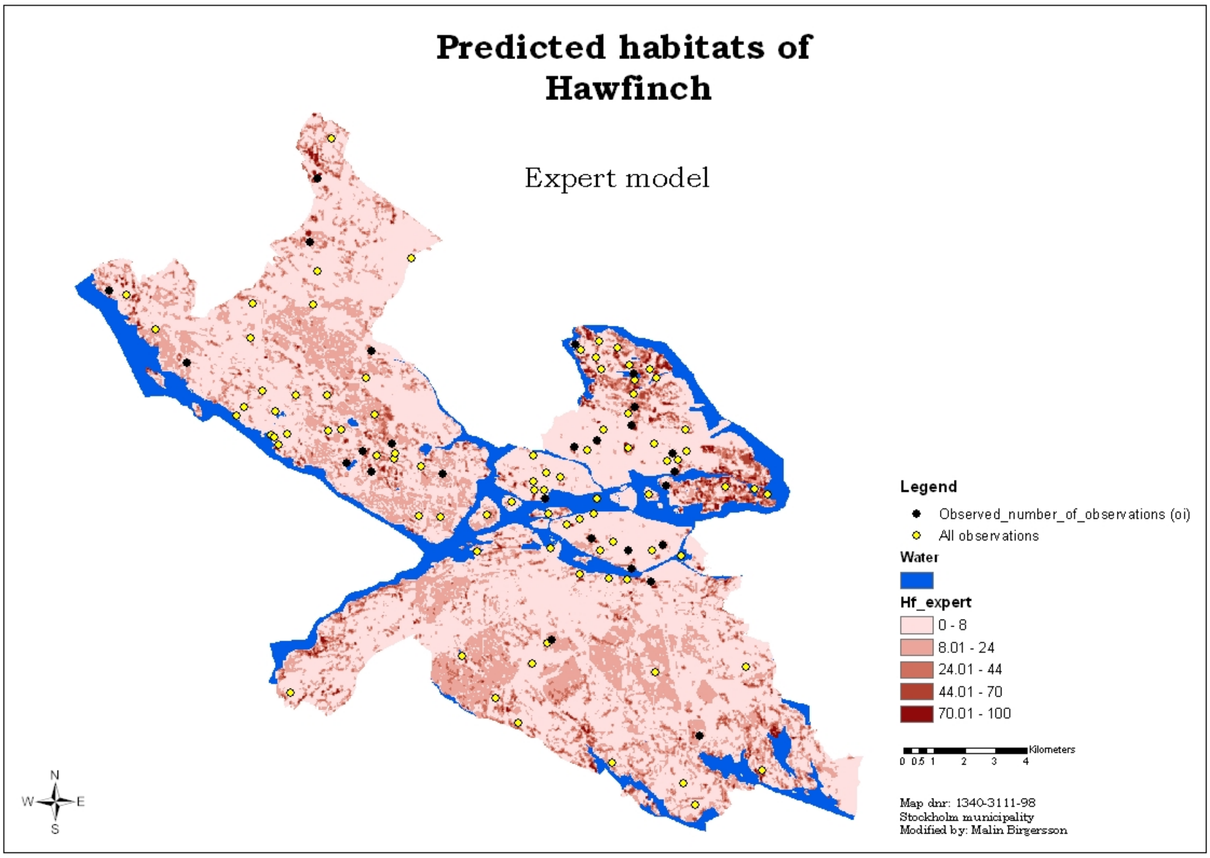

Figure 15: Habitat suitability index map for the Hawfinch, generated by an expert model.

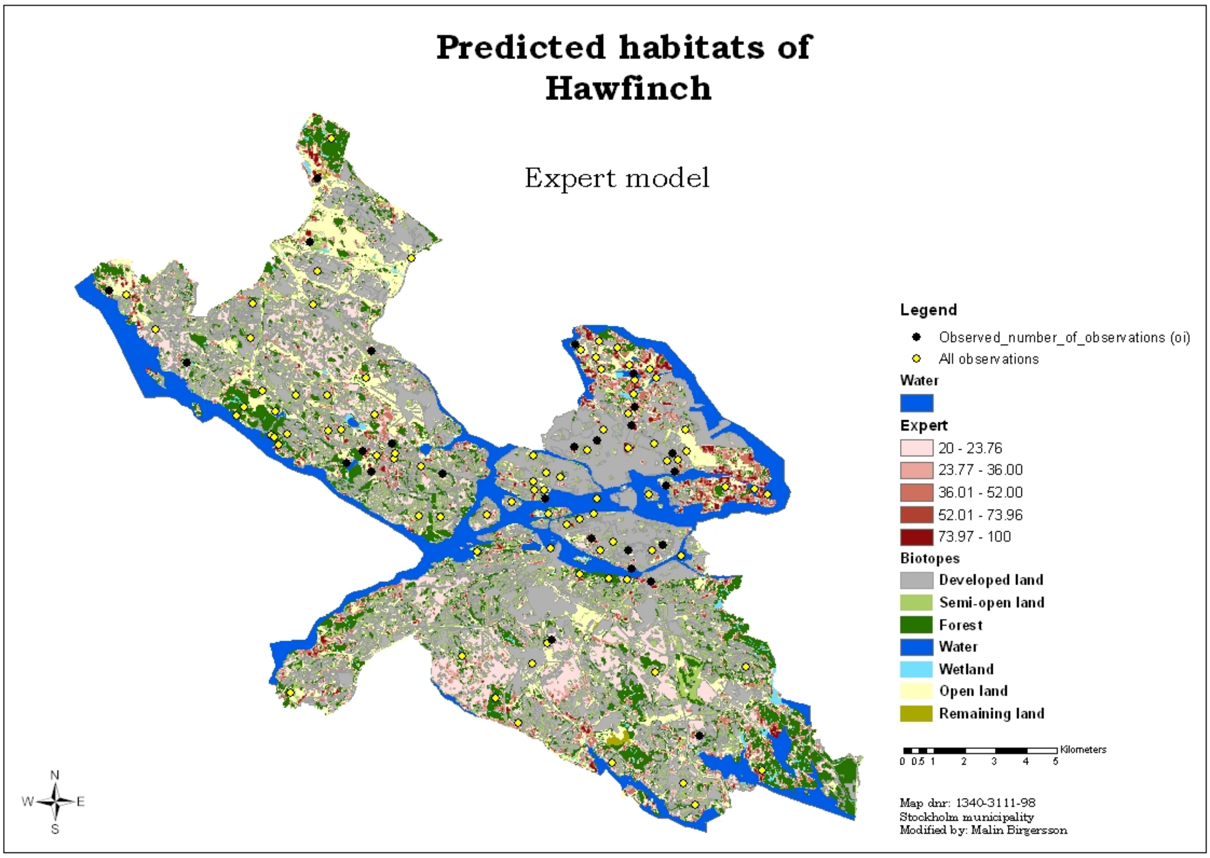

Figure 16: Habitat suitability index map for the Hawfinch, generated by an expert model, with a threshold set at index value 20.

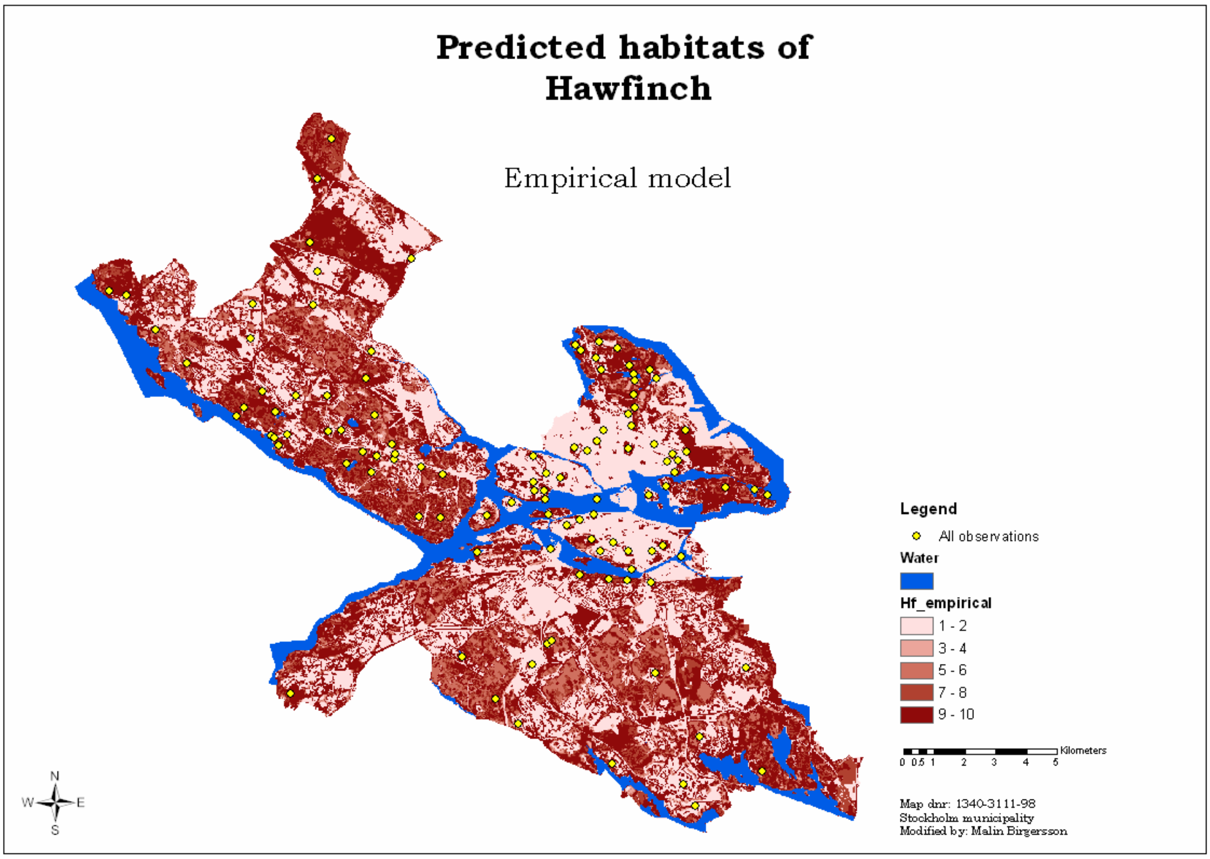

Figure 17: Map of the empirical models predicted habitats of the Hawfinch.

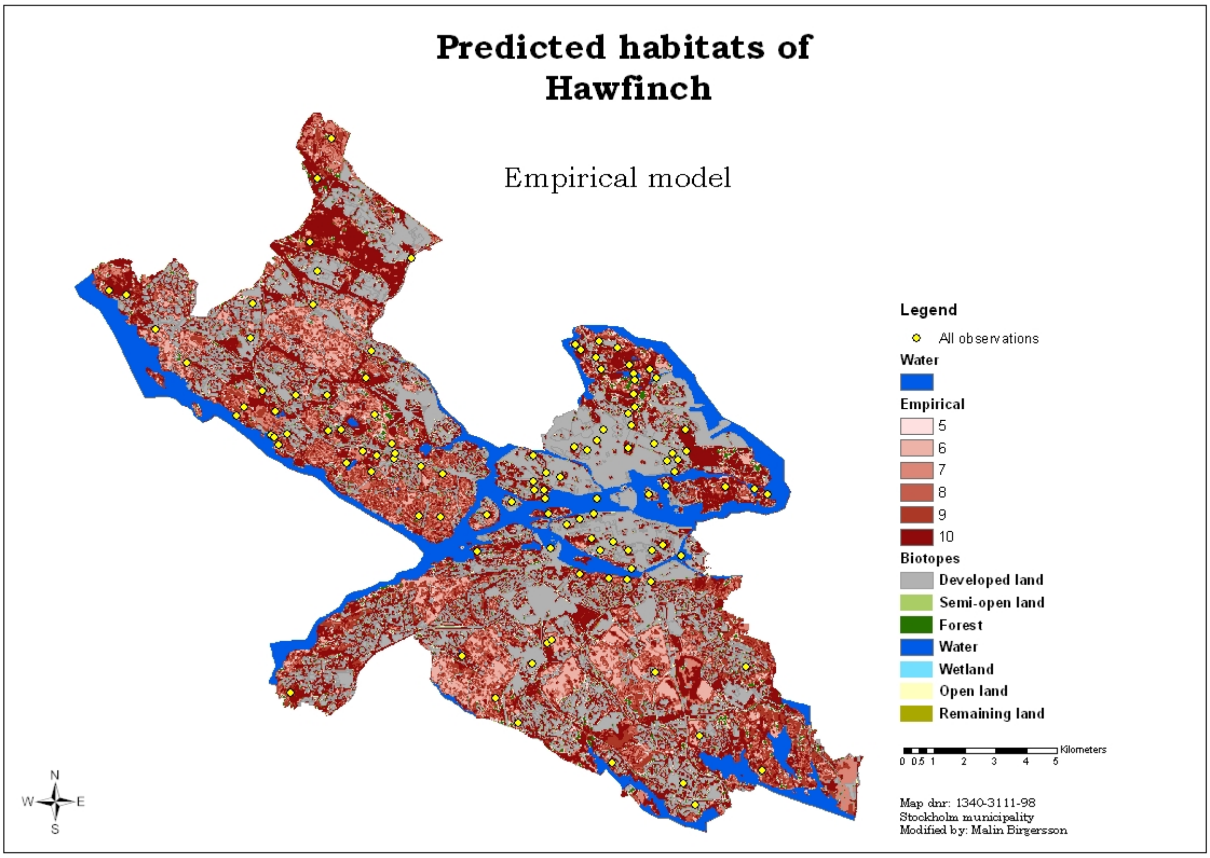

Figure 18: Map of the empirical models predicted habitats of the Hawfinch, with a threshold of 0.5.

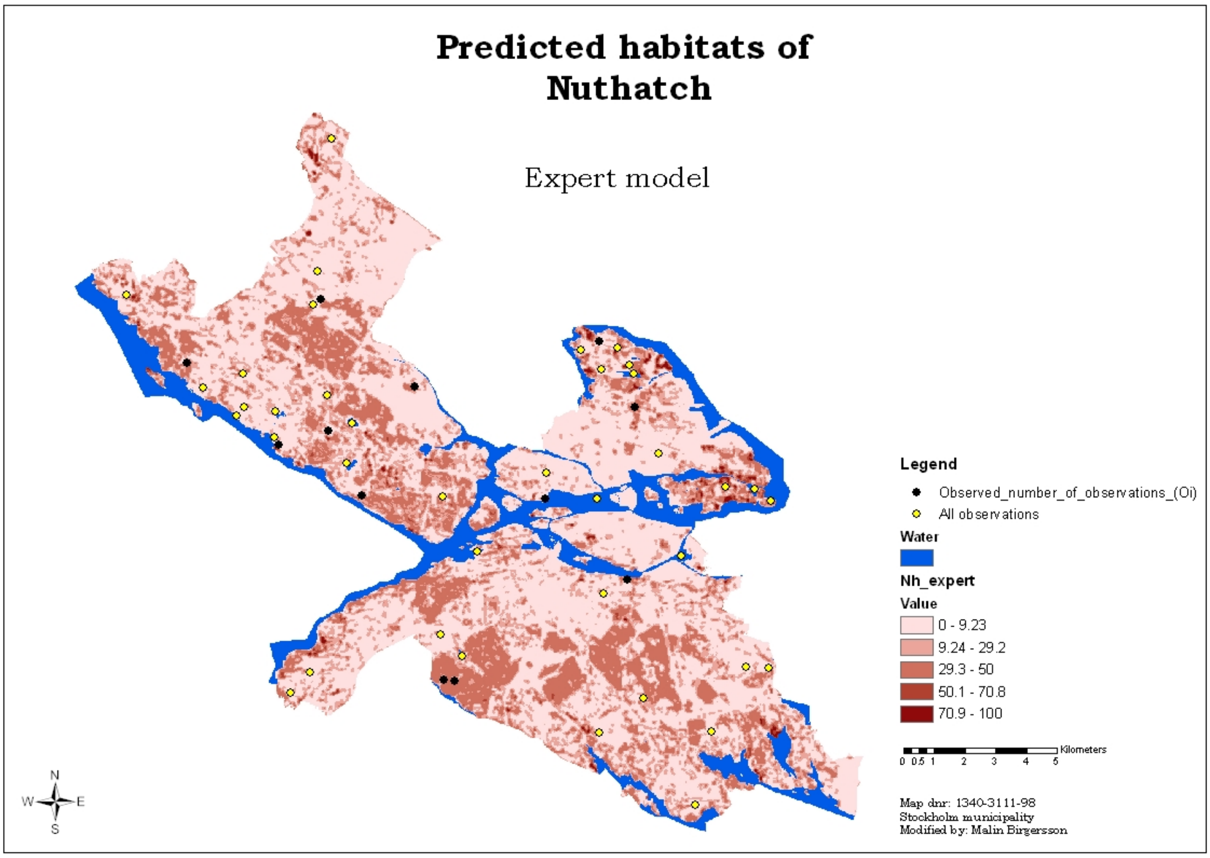

Figure 19: Habitat suitability index map for the Nuthatch, generated by an expert model.

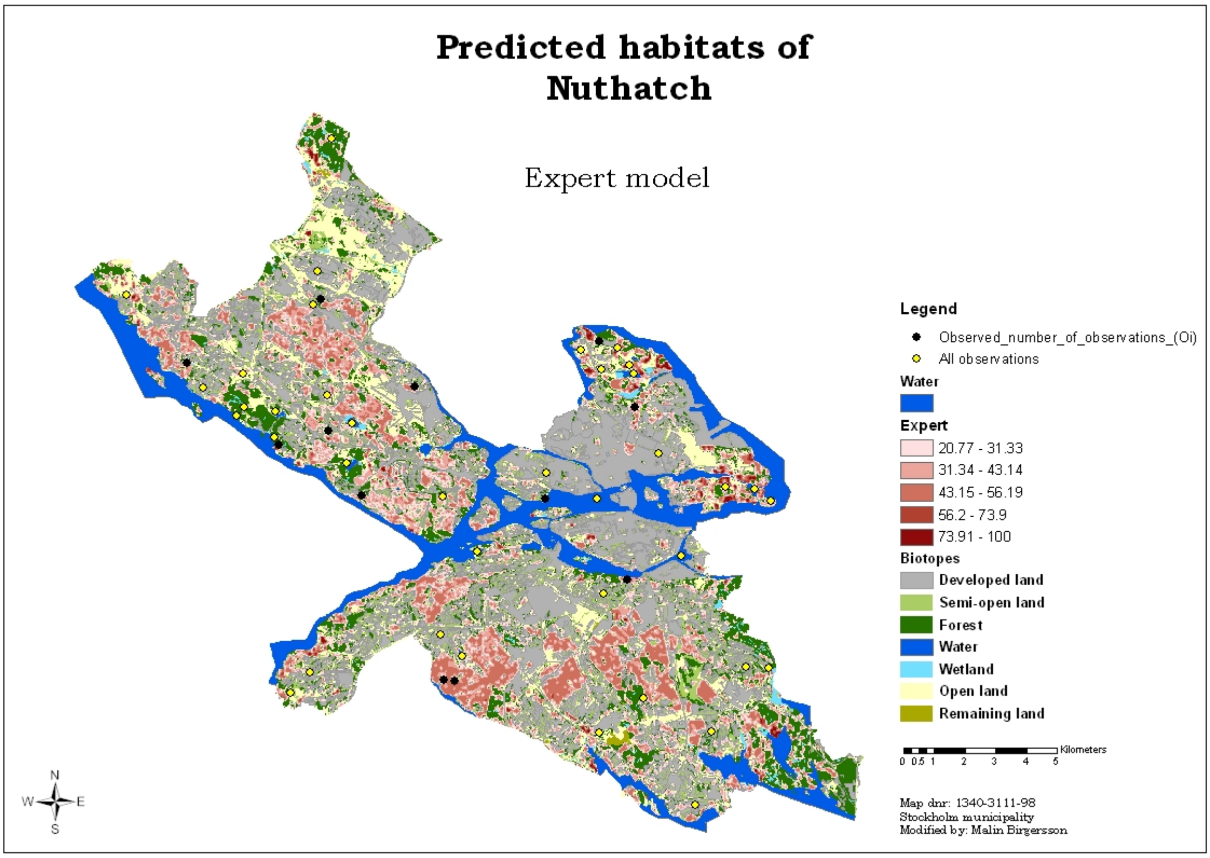

Figure 20: Habitat suitability index map for the Nuthatch, generated by an expert model, with a threshold set at index value 20.

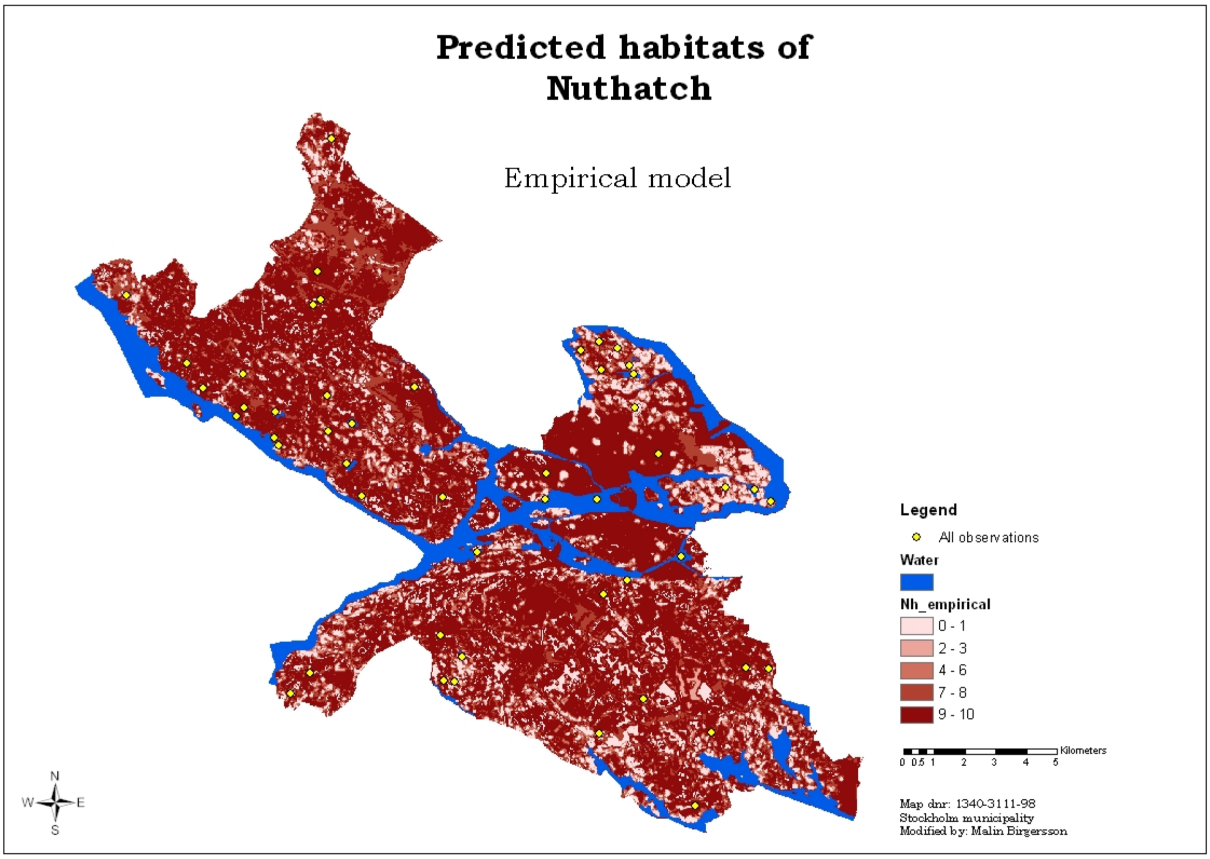

Figure 21: Map of the empirical models predicted habitats of the Nuthatch.

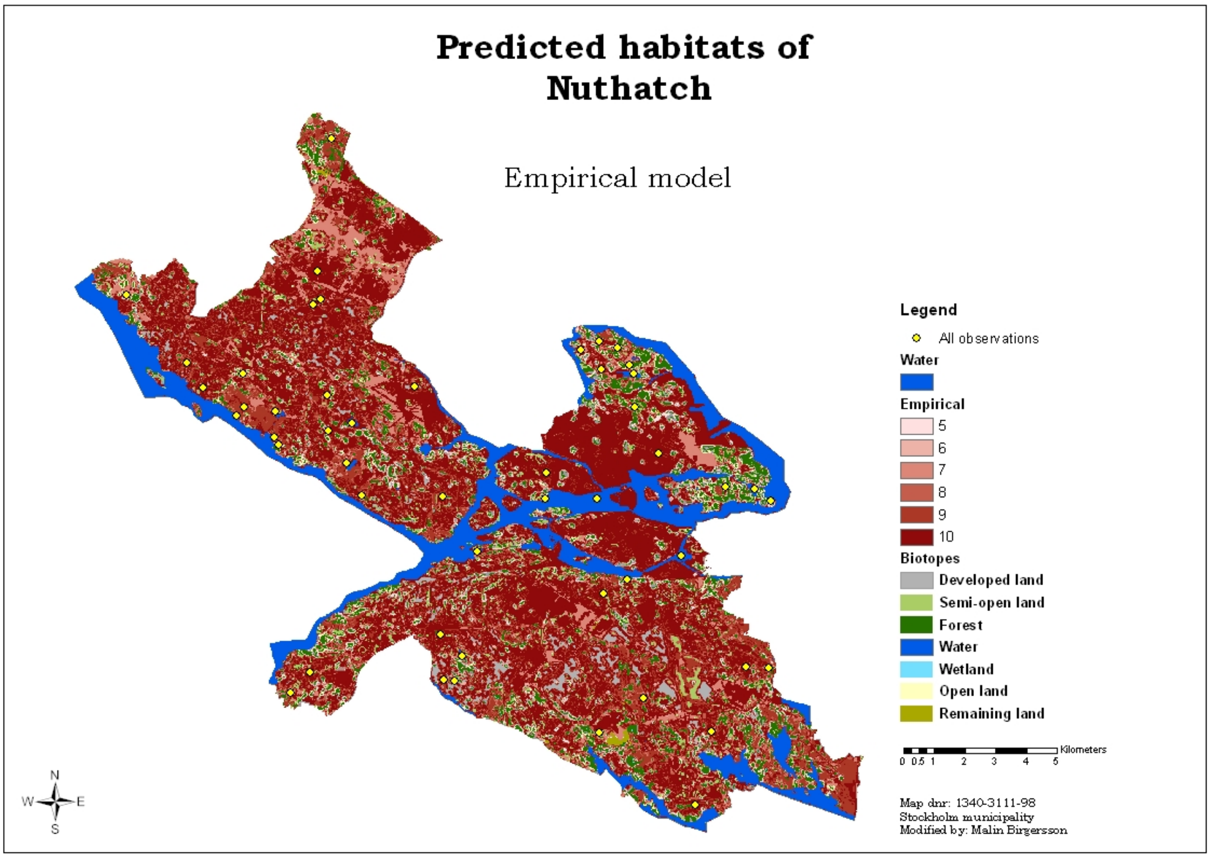

Figure 22: Map of the empirical models predicted habitats of the Nuthatch, with a threshold of 0.5.

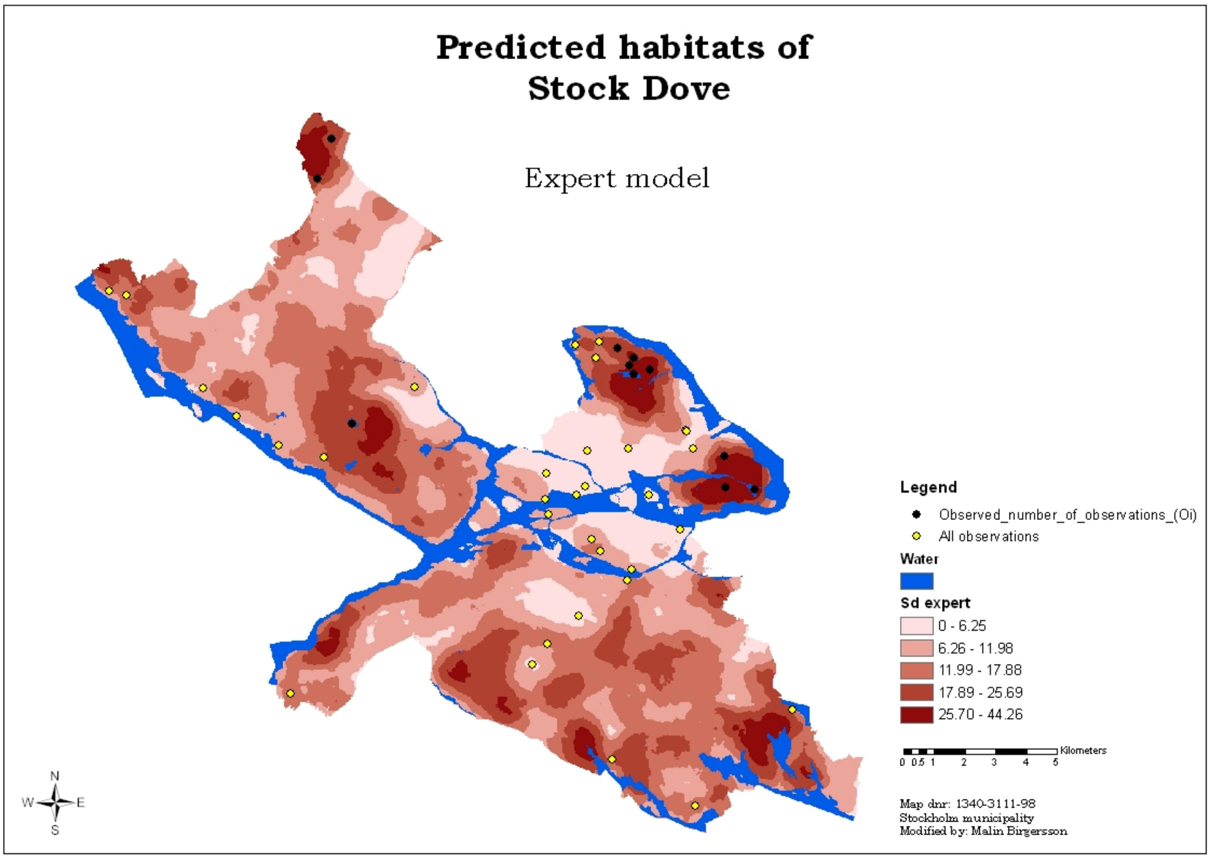

Figure 23 Habitat suitability index map for the Stock Dove, generated by an expert model.

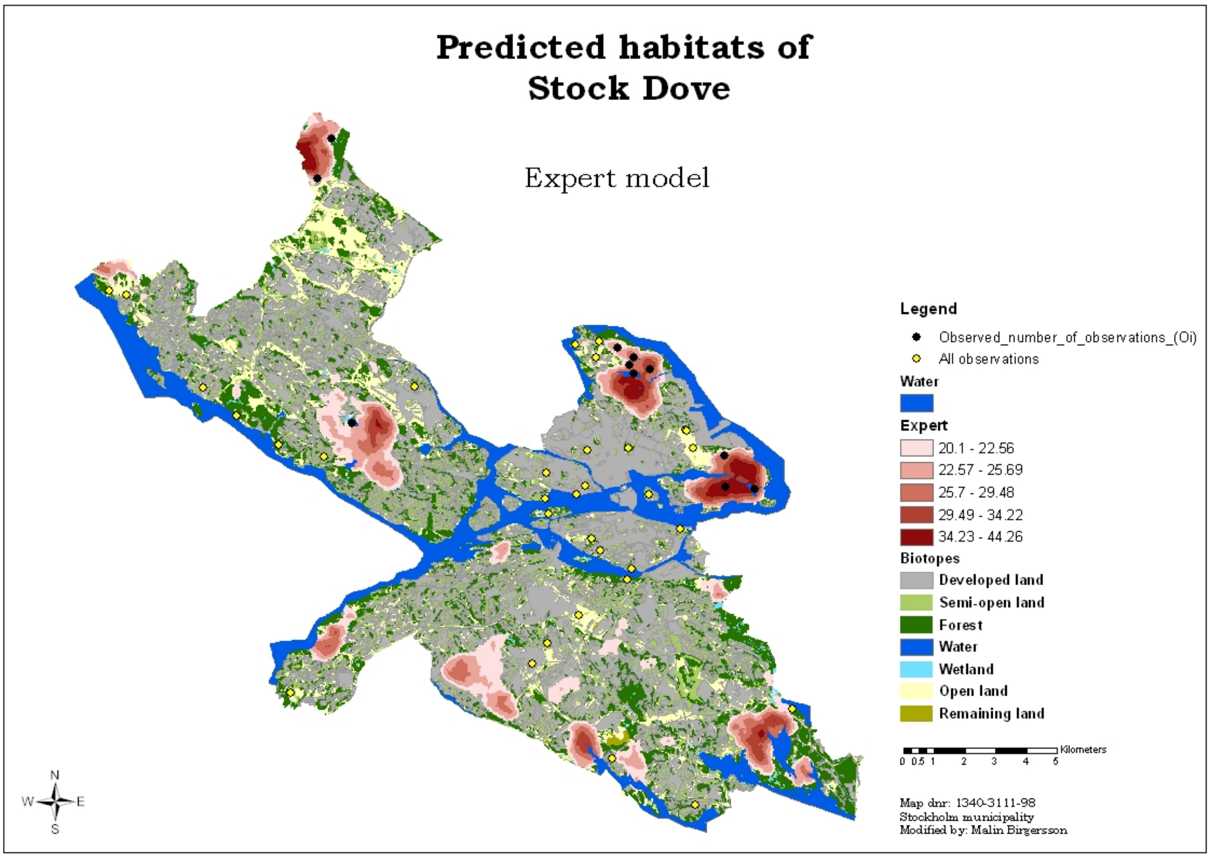

Figure 24: Habitat suitability index map for the Stock Dove, generated by an expert model, with a threshold set at index value 20.

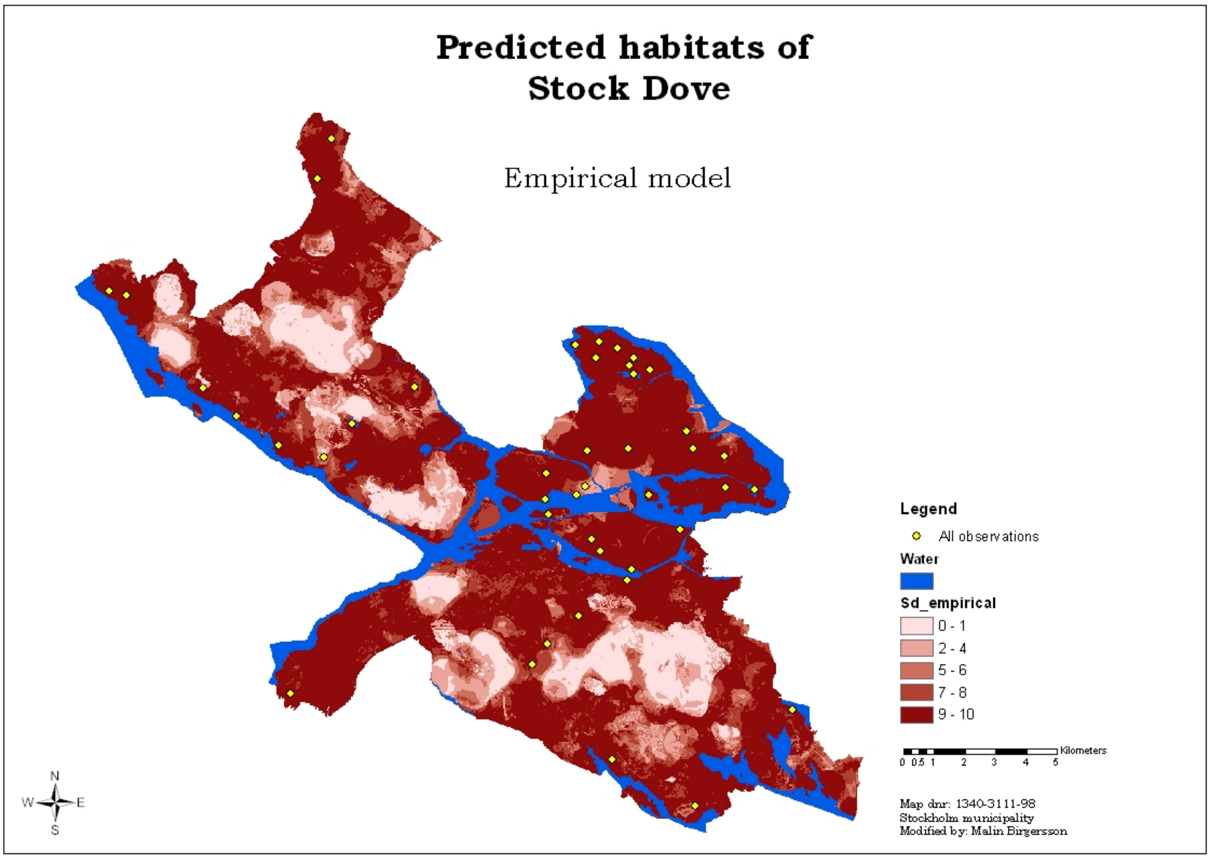

Figure 25: Map of the empirical models predicted habitats of the Stock Dove.

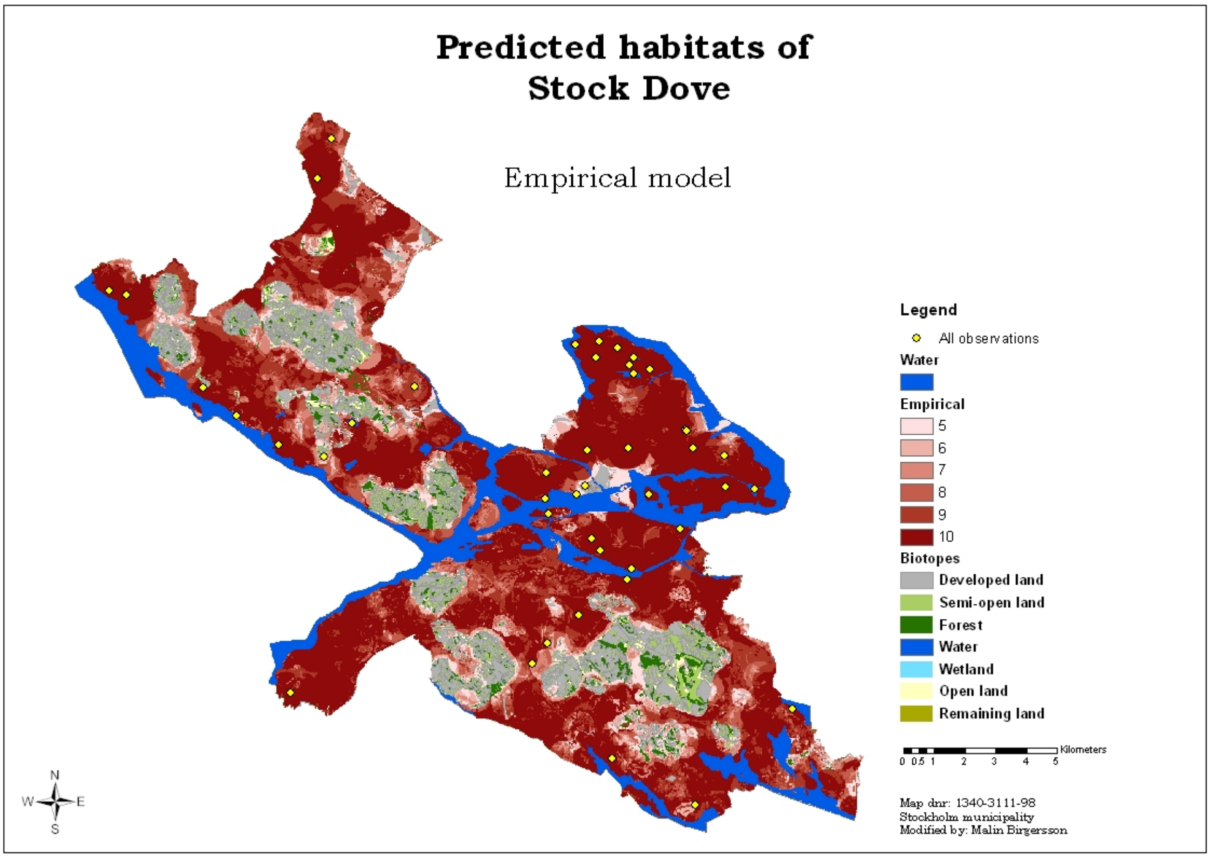

Figure 26: Map of the empirical models predicted habitats of the Stock Dove, with a threshold of 0.5.

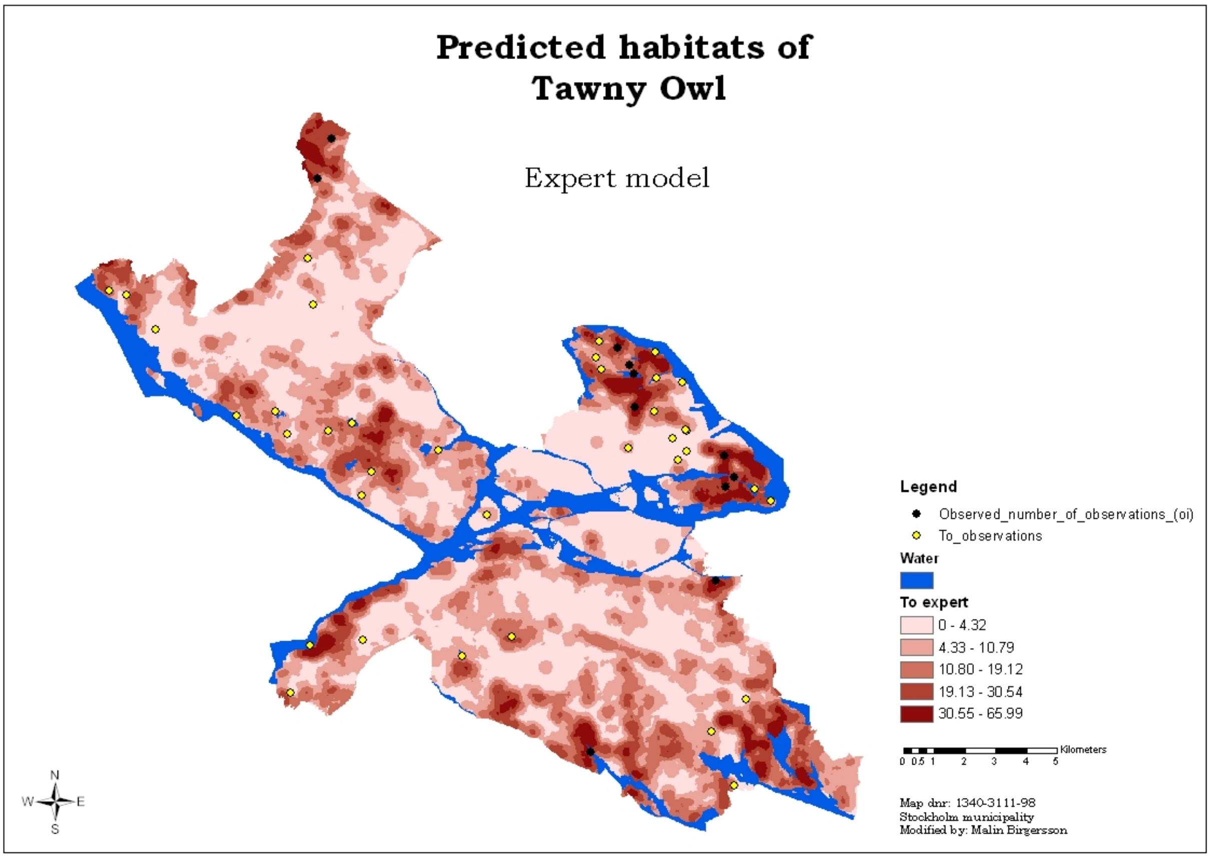

Figure 27: Habitat suitability index map for the Tawny Owl, generated by an expert model.

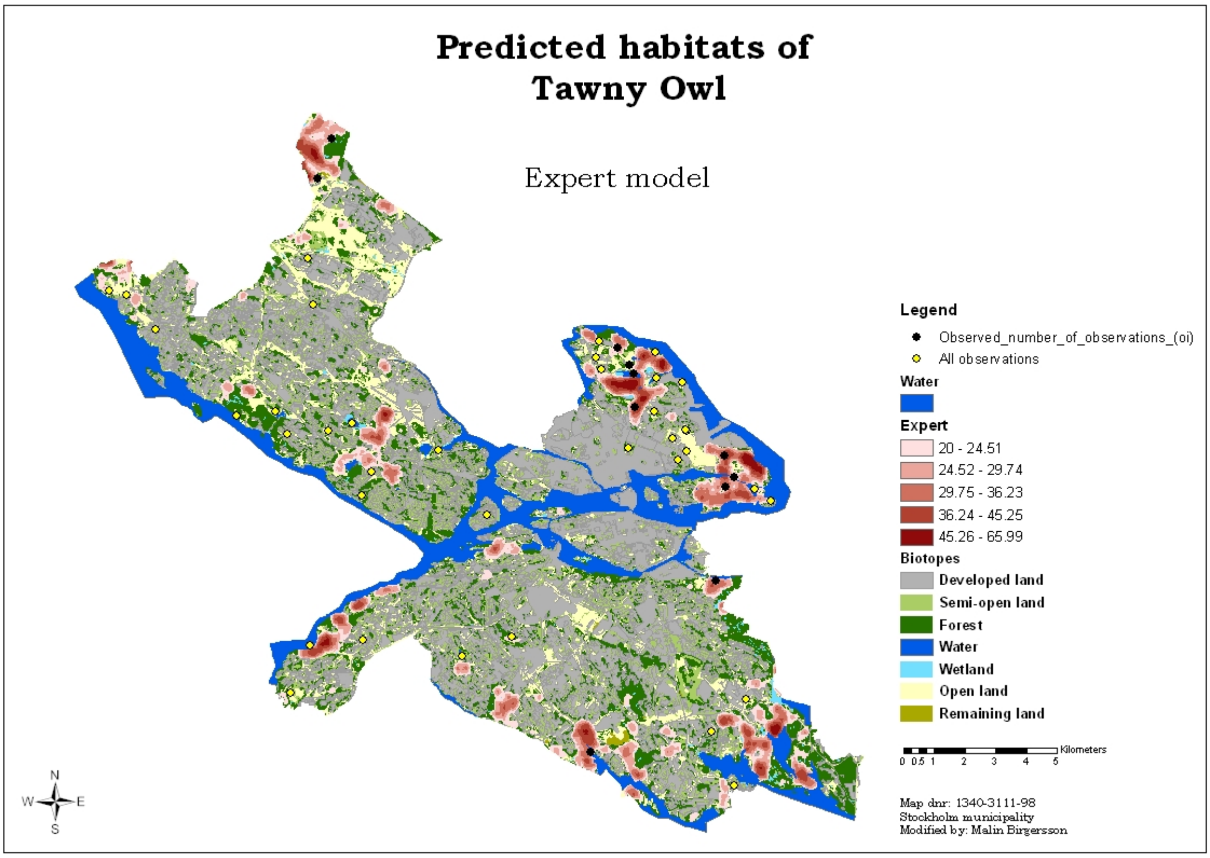

Figure 28: Habitat suitability index map for the Tawny Owl, generated by an expert model, with a threshold set at index value 20.

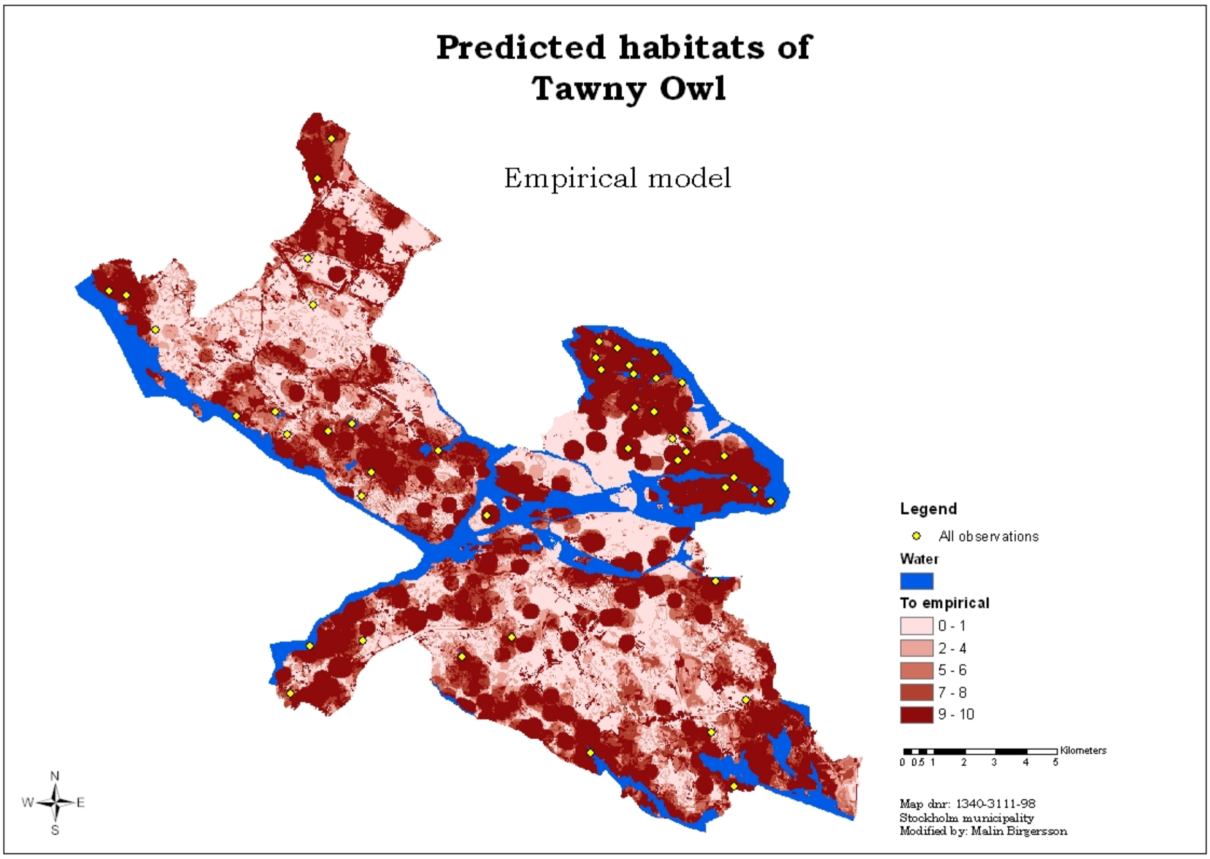

Figure 29: Map of the empirical models predicted habitats of the Tawny Owl.

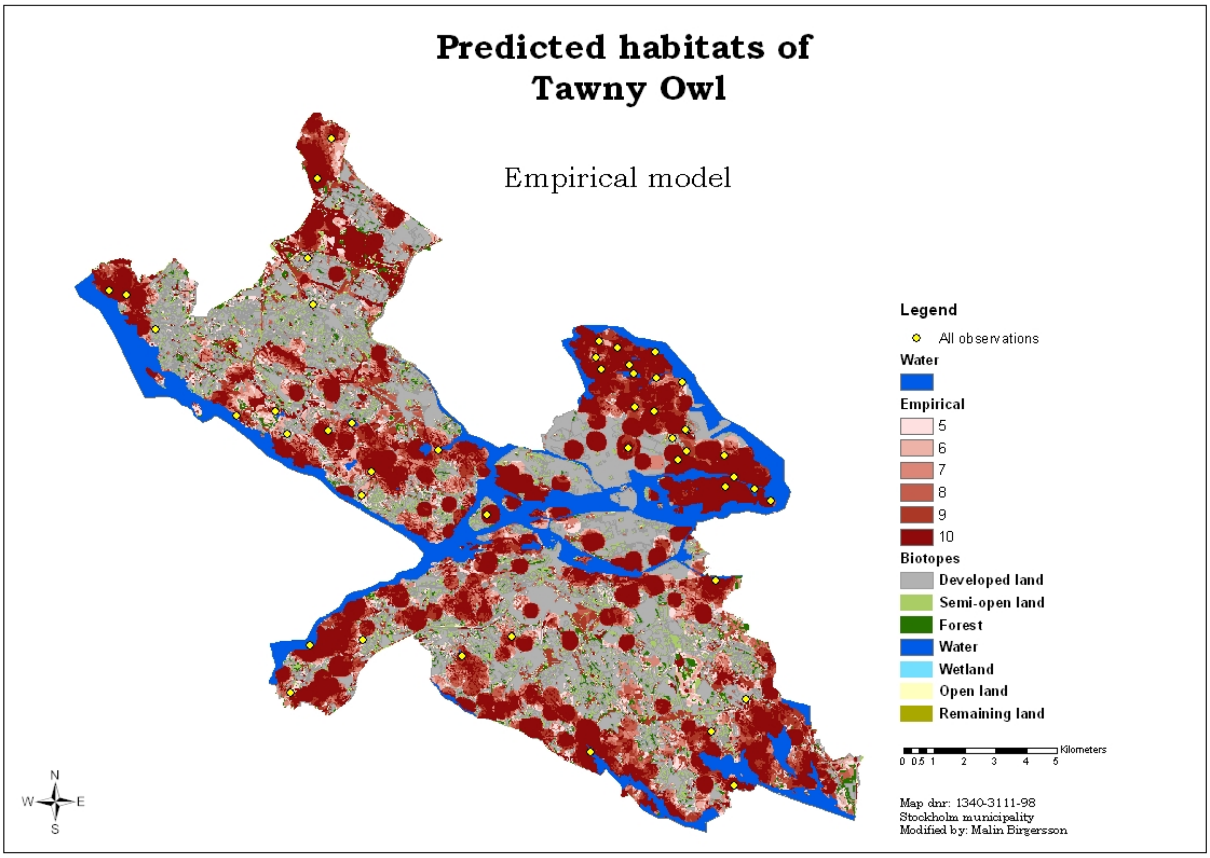

Figure 30: Map of the empirical models predicted habitats of the Tawny Owl, with a threshold of 0.5.

3.2 Expert model

The expert interviews and the literature study resulted in a habitat suitability criterion for each species. All map pixels received a habitat suitability index. An example of how an expert can classify the suitability of the biotopes is showed below in Table 3. The four expert's answer all had 25% weight against each other and when the answers were not uniform the literature had the decisive role. The first obvious result when studying the predicted suitability of habitats of the seven species is that the species that are not threatened (locally, regionally or nationally) have larger areas of suitable habitat available. These two generalist species (the Great Spotted Woodpecker and the Nuthatch) have large areas within the municipality to use as habitats. For the other more habitat-specialized birds there are fewer high quality habitats, i.e. the areas with marginal habitats are large but the patches with ideal habitats are very few and small.

Table 3: Examples of biotopes, with the habitat suitability indexes assigned by the experts.

Biotopes	**Habitat suitability index**
Dense broad-leaved deciduous forest with many old-growth trees and rich in dead wood	Ideal habitat (HSI = 100)
Mature mixed conifer and deciduous forest	Average habitat (HSI = 50)
Extensively managed grassland with deciduous trees	Marginal habitat (HSI = 20)
Developed land without sparse vegetation and no trees or scrubs	Not considered a suitable habitat (HSI = 0)

Validation

The expert models were validated against the independent observation data of the Species Gateway. The reported points of species occurrence were plotted on the habitat suitability index maps for each species, and each match with a predicted suitable habitat area was recorded. The frequency of matches was statistically tested using a one-tailed χ^2-test, to see if the proportion of observations that fell within predicted areas were significantly higher than what could be expected by coincidence (Table 4). The result was significant for all but two species, the Great Spotted Woodpecker and the Nuthatch. A significant test implies concordance between predicted areas of suitable habitat and locations of actual observations of the bird.

Table 4. Validation of the expert models using independent observation data.

Species	χ^2	p-value
Lesser Spotted Woodpecker	5.82	0.0100
Great Spotted Woodpecker	0.20	0.3500
Green Woodpecker	4.11	0.0250
Hawfinch	4.86	0.0250
Nuthatch	0.02	0.4750
Stock Dove	4.88	0.0250
Tawny Owl	6.74	0.0050

For the two species that did not show significant patterns of predicted habitat suitability a modification of the HSI-maps was introduced. To test if the concordance between the expert models and observation data could be scale-dependent I introduced a 100 and a 200 meter buffer zone, which means that an observation that falls within that area is considered a match. The expert model for the Nuthatch was significantly associated with observations both when a 100 and a 200 meter buffer was used, while the Great Spotted Woodpecker showed no significant result with the buffers (Appendix 1). This means that the expert model generally predicted the location of suitable habitat, but not the extent.

3.3 Empirical model

The biotopes that were predicted as important for all the species but the Nuthatch were: deciduous broad-leafed forest and deciduous forest. For the Nuthatch and the Stock Dove there were some biotopes that were unexpected to have such importance, such as developed land with 30-50% vegetation, developed land with 10-30% vegetation and water. In this study water was determined not to be a suitable habitat for these species since they are considered forest depending birds, therefore the water biotope were excluded. All species but the Nuthatch showed a pattern were the forest was more important than the developed land with 10-30% vegetation. The Nuthatch on the other hand showed that the highest quality habitat was developed land and forest was considered a lower quality habitat. Therefore the central city is marked red for the Nuthatch, while the parks are considered less important and marked light pink.

Validation

No independent dataset was available to validate the empirical model, as it was based on the observational data. However, the GARP program does its own validation trough splitting the dataset in two halves, one used for predicting and one for model validation. GARP is susceptible to two types of prediction error: commission and omission error. The GARP validation produces information on the commission (i.e. the areas actually presenting inappropriate conditions that might be included in model predictions) and omission errors (i.e. the areas actually habitable might be excluded from predictions) (Anderson *et al*. 2003). In this study the commission error was much higher than the omission value that often was close to zero. A high commission could mean that the species has not been observed at all the sites pointed out as suitable, but this could be due to that it is an area with few visitors, or it indicates that there exists an overprediction. A low omission value shows that all the sites where the species have been observed also have been predicted as suitable habitats.

3.4 Comparing the maps

Pattern similarities

All the empirical distribution maps, except for Nuthatch, are similar to the distribution patterns in the expert models. The main hot spots have been pointed out and both models indicate the importance of the broad-leafed deciduous forest biotope.

Pattern differences

When comparing the maps from the expert model with the maps from the empirical model the first obvious result is that the GARP model produces maps with seemingly more suitable habitat than do the expert models. The empirical model maps are also darker red, which could be interpreted to indicate that it also found the habitats to have a higher quality than the experts predicted. GARP has identified more suitable biotopes than the experts, mainly biotopes such as developed land with vegetation which encloses parks and gardens. Since GARP found more suitable biotopes and habitats with higher quality it produced a map that is difficult to interpret.

4 Discussion

4.1 Expert model

The expert models produce maps with a strong gradients pointing out the most important hot spots. For the more specialized birds, viz. Lesser Spotted Woodpecker, Green Woodpecker, Hawfinch, Stock Dove and Tawny Owl, the expert model produces a prediction that is supported by occurrence data. The χ^2-test indicates a positive relationship between predicted suitable habitats and the independent occurrence data. For birds with more generalized habitat requirements it was more difficult to predict the /habitat suitability accurately. Predicting generalist species distribution accurately is generally considered difficult independently of using a model with both presence/absence or a model with only presence data (Brotons *et al*. 2004). The Nuthatch result was significant if a buffer of 100 meter was applied to the area of predicted habitats, but for the Greater Spotted Woodpecker no correspondence was found between observational data and the habitat suitability prediction. One reason why the Great Spotted Woodpecker could have a lower accuracy/ more uncertainty in their observations is that this species is more likely to be reported in odd sites, where you would not expect it to be.

Data quality and other uncertainties

The purpose of producing the digital Stockholm biotope map was to enhance the efficiency of spatial planning. It was produced from infrared aerial photos, it has been validated in the field, and it is regarded to be of high quality. Each pixel size is 25x25 meter and is assigned to one biotope, even if it contains several biotopes, e.g. 70 percent developed land with no vegetation (considered as no habitat) and 30 percent broad-leaved deciduous forest (considered an ideal habitat). Such a pixel would in this study be considered as no habitat. This limits the resolution of the biotope map, but it was clearly sufficient for the purposes of this study.

The competence of the experts is diverse, the four experts in this study have different back-grounds and in general I believe they complement each other. However, one reason why the Nuthatch expert model showed poor concordance with observations could be that the experts underestimated their use of gardens in Stockholm, which are included in the biotope class “developed land with 30-50 percent vegetation”.

4.2 Empirical model

The maps produced by GARP predicted larger areas of suitable habitats than the expert models did. Possible explanations to the maps appearance are:

1. The threshold value – The threshold value was chosen in an arbitrary way and is different for the two models.
2. The two HSI-scales are not directly corresponding.
3. Mismatch in scales – between the biotope map and the observations.
4. Expert judgment - the experts have done a different judgment compared to GARP.

All these four explanations can cause the patterns seen in the maps. In this study the main explanation is believed to be a mismatch in scales. This mismatch resulted in an overprediction, as indicated by the fact that GARP included biotopes that are not considered suitable in the expert model. Such biotopes were included because the landscape grains are small in comparison with the home-ranges of the bird species, leading GARP to interpret all these biotopes as suitable (see Figure 33 and text below).

A factor that the experts might have underestimated in the expert model is that birds in a city may change behaviour and modify their habitat preferences, i.e. preferences can become wider since very few of the preferred biotopes exist. This is probably why the Nuthatch was suggested to prefer developed land by the empirical model, but not by the expert model. The Nuthatch prefers forest in general, but in a city with little or nonexistent forests it uses gardens instead. This would mean that the different pattern produced by GARP is not only due to an overprediction, but may also reflect a truer picture than that given by the experts.

The occurrence data is the basis of the GARP model and consequently crucial for the result. The empirical model is more sensitive to data accuracy than the expert model, since the expert model applies condensed information from experts that have knowledge in biology (conservation biology, habitat preferences and landscape ecology etc.). The experts can filter their knowledge and focus on important factors, therefore they may give a more accurate map for species such as birds, where they can rely on a well-established knowledge basis.

Data quality and other uncertainties

There are at least four possible causes of overprediction of suitable habitats in the empirical model, viz. insufficient spatial accuracy in the observation data, a bias in the observations, a mismatch between the spatial scales of observation data and the biotope map, or insufficient sample sizes in the observation data.

1. Spatial accuracy

The aim of the Species Gateway is to produce a bird report of the status of birds in Sweden and therefore the observations are based on fixed sites. There are several factors that could affect the spatial accuracy of the coordinates reported for an observation. First, the fixed sites mean that most reporters will refer to the existing sites in menus, even though the observation was actually made some distance away. Secondly, the reporters may choose sites that are not even the closest ones to the actual observation spot. Thirdly, the actual placement of the fixed sites by the Gateways' report committee may involve biotopes that are not representative of the area (Johan Nilsson pers. comm). An example of the latter is the case where coordinates were placed in the centre of a lake, whereas most birds reported were actually seen in habitats surrounding the lake. The conclusion is that these fixed sites cause a major problem when using this kind of database to landscape analysis.

2. Bias in observations

The observation data used here were gathered in an ad hoc manner, and frequency of visits to different sites varies significantly, which introduces a bias in the dataset. Such a bias is evident both at the local level (within Stockholm), and at the national level (Figure 31). Another problem is the possibility that the same bird could be observed and reported several times. In this study only one observation per site was used (i.e. other observations of the same species done at the same site were excluded from the study). This kind of spatial auto-correlation is an issue when dealing with geographical data, i.e. data is dependent on surrounding data and the degree of dependence increases the closer they are (Mörtberg and Karlström, 2005). This can be reduced by excluding observations that are spatially close together, however, this have not been done is this

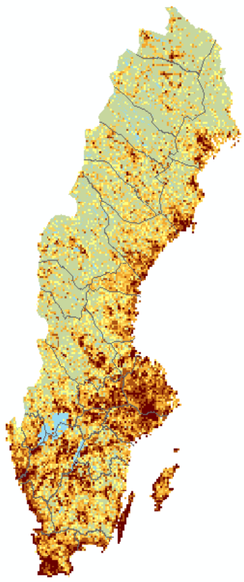

Figure 31: Distribution of observations from the Species Gateway.

study. The conclusion is that this is a problem since the same bird might have been observed in several spots even the same day. Furthermore, people are inclined to report odd observations; hence there may be a bias towards reporting the birds outside their usual habitat to a greater extent than in their regular habitat (Johan Nilsson pers. comm.).

3. Mismatch in scales

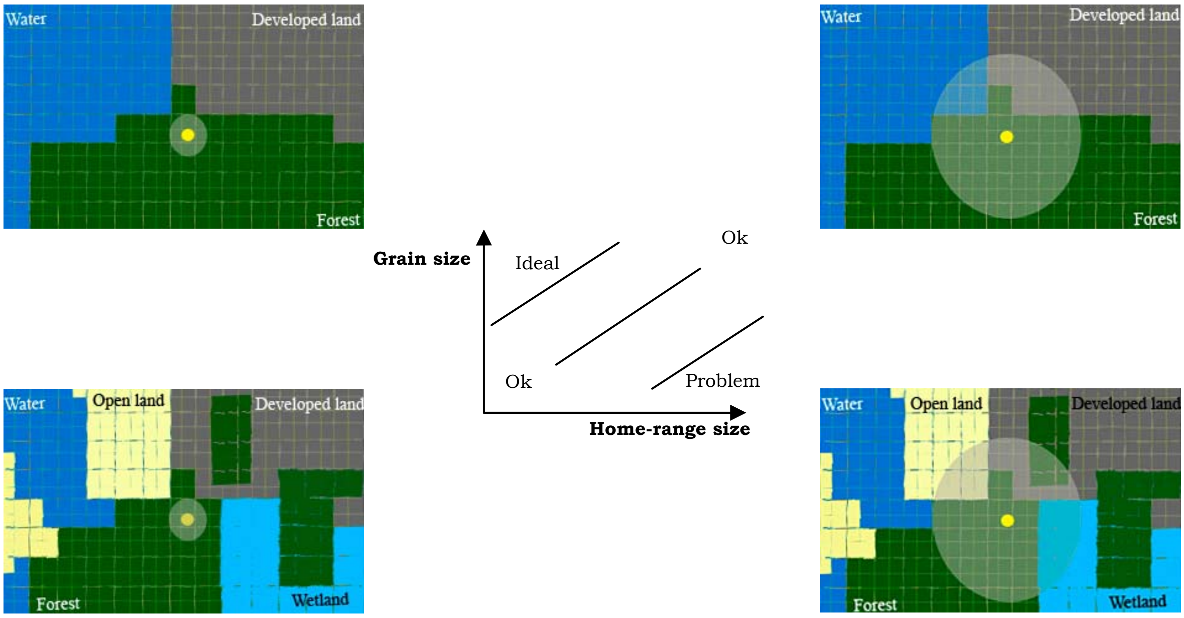

Figure 32: Differences in relative scale between landscape patches (grain size) and home range sizes, and possible interactions (see text for interpretation).

There exists a difference in the relative scale between the landscape grain size (polygons in Figure 32) and the home-range of the bird species (circles in Figure 32). The two upper graphs describe a landscape with large grain sizes (equivalent to large habitat patches), whereas the two lower graphs describe a landscape with small grain sizes. In the two graphs to the left a small home-range has been applied around the actual observation spot. Due to the small size of the home-range, the area covered by them still falls mainly within one single polygon, and GARP may receive no inappropriate information. In the two graphs to the right a large home-range has been applied. In this case home-ranges may include more than one polygon, especially if the grain size is small. Applying a large home-range in comparison to the landscape grain size causes problems, since pixels representing a biotope that is not actually used by the bird may be included. Accordingly, GARP inadvertently interprets this biotope as suitable.

The combination of data used here, observation datasets for birds with large home-ranges, and several different accuracy problems and biases, and a biotope map with high spatial resolution (small grains) may have caused an overprediction problem. When the model is too specific for the data over-fitting might occur and the model may perform poorly. In this study, species with large home-ranges have been predicted to have large areas of suitable habitats, which may be due to an over-prediction caused by a mismatch between scales.

4. Samples sizes

The observation data used here is a rather small dataset gathered in an ad hoc manner, which both are common problems when predicting species occurrence. According to the producers of the GARP software package, GARP has high data efficiency and can perform predictions even on small sample sizes and has an average of 90 percent of maximum accuracy with a minimum dataset of 10 data points (Stockwell *et al*. 2002). The conclusion is that the sample size should not be a major problem here, since there are at least 30 observations in each empirical model.

In this study both spatial accuracy, bias and mismatch in scale were factors that contributed to an overprediction, whereas the sample size in it self was probably less important as a factor.

5 Conclusions

The prediction of species distribution within an area such as Stockholm municipality requires data of high quality in terms of resolution and accuracy. There is a need for a biotope map and a database of the species distribution, preferably with high accuracy or at least two datasets with similar resolution. This study illustrates the usefulness of detailed digital biotope maps. The Stockholm municipality biotope map is a pioneer with detailed information about dead wood and old-growth trees. Without this map this study had been more difficult to conduct.

In this study the expert model was suggested to be more reliable. The main reason why the empirical model is less reliable here is the mismatch in the scales between the occurrence data and the biotope map. This mismatch was the main cause of an overprediction in the empirical model. If an empirical model is applied to this kind of dataset the conclusions from the models should be discussed with experts of the species and the map should be seen as an indicator of where the most important biotopes are rather than the actual occurrence. Saving the suggested hot-spots is no insurance for the survival of the species, since the actual landscape configuration may be important, as is the total amount of habitat available, and hence the population size.

The empirical model is perfect to use when the occurrence data have high accuracy or when the datasets used have the same resolution (i.e. GARP software could have preformed better with a less resolved biotope map). Ideal for this kind of model are large landscape grains and small home-ranges. Moreover, for organisms less well known than birds the empirical model may perform better than an expert model, since their habitat preferences may be unknown and few experts available.

Absence data is another issue; as many databases only have presence data. Using only presence data requires an assumption that the species does not use the areas where it has not been observed. The optimal way would be to have both presence and absence data because then no assumption is necessary. Absence data is especially important when studying species that are sedentary, such as plants. When studying birds absence data is more difficult to use, since a bird that is absent in this moment might be present the next. The possibility to report absence of species is today available at the Species Gateway's bird reporting system and hopefully in the future the observers will start to report this as well as presence of species. Another improvement to the bird reporting systems accuracy is to add the possibility for the observers to enter the exact coordinates for the observation. Today GPS is becoming more commonly used and provides a possibility to add observations with high accuracy. This is even more important for the other less mobile organisms, such as plants.

Higher and higher demands are put on the spatial planning, since most people wants to live in cities, but still close to nature. Less and less green areas are left in the cities and it is crucial to find a tool that enhances the planning. The answer to this could be both expert and empirical models. These models could be a powerful tool, to apply in spatial planning to evaluate the effects of various expansion plans on species distributions. To become the powerful tool it can be there is a need for more studies to enhance the use of these models.

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Appendix

1 Tables of p-value and chi-square

Lesser Spotted Woodpecker		
Area of predicted habitat (m²)	27196788.4	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	60	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	88%	12%
Expected number of observations (E_i)	**88%**	**12%**
Observed number of observations (O_i)	**78%**	**22%**

Chi2	**5.82**	
P	**0.0100**	**Significant**

Lesser Spotted Woodpecker + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	76973045.0	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	60	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	65%	35%
Expected number of observations (E_i)	**65%**	**35%**
Observed number of observations (O_i)	**48%**	**52%**

Chi2	**7.09**	
P	**0.0050**	**Significant**

Lesser Spotted Woodpecker + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	121675021.40	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	60	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	44%	56%
Expected number of observations (E_i)	**44%**	**56%**
Observed number of observations (O_i)	**18%**	**82%**

Chi2	**16.37**	
P	**0.0005**	**Significant**

Great Spotted Woodpecker		
Area of predicted habitat (m²)	79891095.0	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	87	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	63%	37%
Expected number of observations (E_i)	**63%**	**37%**
Observed number of observations (O_i)	**66%**	**34%**

Chi2	**0.20**
P	**0.35**

Great Spotted Woodpecker + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	144085199.6	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	87	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	34%	66%
Expected number of observations (E_i)	**34%**	**66%**
Observed number of observations (O_i)	**32%**	**68%**

Chi2	**0.13**
P	**0.4000**

Great Spotted Woodpecker + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	177565731.9	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	87	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	19%	81%
Expected number of observations (E_i)	**19%**	**81%**
Observed number of observations (O_i)	**16%**	**84%**

Chi2	**0.39**
P	**0.3500**

Green Woodpecker		
Area of predicted habitat (m²)	49592068.70	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	70	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	77%	23%
Expected number of observations (E_i)	**77%**	**23%**
Observed number of observations (O_i)	**67%**	**33%**

Chi2	**4.11**	
P	**0.0250**	**Significant**

Green Woodpecker + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	97421955.30	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	70	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	55%	45%
Expected number of observations (E_i)	**55%**	**45%**
Observed number of observations (O_i)	**51%**	**49%**

Chi2	**0.44**
P	**0.4500**

Green Woodpecker + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	138563420.6	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	70	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	37%	63%
Expected number of observations (E_i)	**37%**	**63%**
Observed number of observations (O_i)	**31%**	**69%**

Chi2	**0.79**
P	**0.2500**

Hawfinch		
Area of predicted habitat (m²)	35477395.3	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	113	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	84%	16%
Expected number of observations (E_i)	**84%**	**16%**
Observed number of observations (O_i)	**76%**	**24%**

Chi2	**4.86**	
P	**0.0250**	**Significant**

Hawfinch + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	135231528.1	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	113	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	38%	62%
Expected number of observations (E_i)	**38%**	**62%**
Observed number of observations (O_i)	**30%**	**70%**

Chi2	**3.06**	
P	**0.0500**	**Significant**

Hawfinch + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	181083519.8	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	113	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	17%	83%
Expected number of observations (E_i)	**17%**	**83%**
Observed number of observations (O_i)	**13%**	**87%**

Chi2	**1.15**
P	**0.1500**

Nuthatch		
Area of predicted habitat (m²)	54432104.60	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	50	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	75%	25%
Expected number of observations (E_i)	**75%**	**25%**
Observed number of observations (O_i)	**76%**	**24%**

Chi2	**0.02**
P	**0.4750**

Nuthatch + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	141295571.70	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	50	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	35%	65%
Expected number of observations (E_i)	**35%**	**65%**
Observed number of observations (O_i)	**24%**	**76%**

Chi2	**2.79**	
P	**0.0500**	**Significant**

Nuthatch + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	184138694.5	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	50	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	16%	84%
Expected number of observations (E_i)	**16%**	**84%**
Observed number of observations (O_i)	**6%**	**94%**

Chi2	**3.54**	
P	**0.0500**	**Significant**

Stock dove		
Area of predicted habitat (m²)	29665583.80	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	44	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	86%	14%
Expected number of observations (E_i)	**86%**	**14%**
Observed number of observations (O_i)	**75%**	**25%**

Chi2	**4.88**	
P	**0.0250**	**Significant**

Stock dove + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	40241007.20	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	44.00	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	82%	18%
Expected number of observations (E_i)	**82%**	**18%**
Observed number of observations (O_i)	**73%**	**27%**

Chi2	**2.29**
P	**0.1000**

Stock dove + 200m buffer		
Area of predicted habitat with a 200m buffer (m²)	117089255.10	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	44.00	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	46%	54%
Expected number of observations (E_i)	**46%**	**54%**
Observed number of observations (O_i)	**68%**	**32%**

Chi2	**8.41**	
P	**0.0050**	**Significant**

Tawny Owl		
Area of predicted habitat (m²)	24306816.60	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	48	
	Absence	Presence
Proportion of area (area of predicted habitat/area of Stockholm municipality)	89%	11%
Expected number of observations (E_i)	**89%**	**11%**
Observed number of observations (O_i)	**77%**	**23%**

Chi2	**6.74**	
P	**0.0050**	**Significant**

Tawny Owl + 100m buffer		
Area of predicted habitat with a 100m buffer (m²)	40666483.70	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	48.00	
	Absence	Presence
Proportion of area (area of predicted habitat with a 100m buffer/area of Stockholm municipality)	81%	19%
Expected number of observations (E_i)	**81%**	**19%**
Observed number of observations (O_i)	**63%**	**38%**

Chi2	**11.29**	
P	**0.0005**	**Significant**

Tawny Owl + 200m buffert		
Area of predicted habitat with a 200m buffer (m²)	57853969.00	
Area of Stockholm municipality (m²)	218373117.0	
Number of observed birds	48.00	
	Absence	Presence
Proportion of area (area of predicted habitat with a 200m buffer/area of Stockholm municipality)	74%	26%
Expected number of observations (E_i)	**74%**	**26%**
Observed number of observations (O_i)	**48%**	**52%**

Chi2	**16.14**	
P	**0.0005**	**Significant**

2 Breeding criterion

Breeding criteria	Breeding classification
Nest with egg/pulli	Breeding
Nest, pulli heard	Breeding
Brood on eggs	Breeding
Eggshell	Breeding
Carrying food for young	Breeding
Carrying faecal sac	Breeding
Visit occupied nest	Breeding
Recently fledged/downy young	Breeding
Used nest	Breeding
Distraction display	Breeding
Nest-building	Probable breeding
Broodpatch	Probable breeding
Agitated behaviour	Probable breeding
Visit possible nest	Probable breeding
Mating	Probable breeding
Permanent territory	Possible breeding
Pair in suitable habitat	Possible breeding
Display/song	Possible breeding
In nesting habitat	Possible breeding

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