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Abstract
The black stork (*Ciconia nigra* L.) was lost from the Swedish fauna in the 1950's. An increased understanding of the need to save endangered species has led to restoration or preservation of populations through reintroductions. To have background information about a species' habitat requirements is important for introduction programs. A habitat model can be used to predict the requirements of the species, and provide suggestions for areas suitable for reintroduction. In this study, a Geographical Information System (GIS) is used to create a model to identify suitable habitats for a potential reintroduction project of black stork in Sweden. The geographical extent in the analysis was limited to the former distribution range of black stork in the southern part of Sweden. My results indicate several suitable black stork habitats in all counties included in the analysis, except the Baltic Sea Island of Gotland. Seven counties contained more than 18 % suitable habitats in relation to the total area of each county. I suggest that these areas should be the primary target areas for black stork reintroduction to Sweden.

Sammanfattning
Den svarta storken (*Ciconia nigra* L.) försvann från den svenska faunan under 1950-talet. En ökad förståelse för behovet av att rädda utrotningshotade arter har lett till återställande eller bevarande av populationer genom återintroduktioner. Att ha bakgrundsinformation om en arts habitatkrav är viktigt för introduktionsprogram. En habitatmodell kan användas för att förutsäga artens krav och ge förslag på områden som är lämpliga för återintroduktion. I denna studie används ett geografiskt informationssystem (GIS) för att skapa en modell som kartlägger lämpliga habitat för en potentiell återintroduktion av svart stork i Sverige. Det geografiska området i analysen begränsades till svarta storkens tidigare utbredningsområde i södra delen av Sverige. Resultatet indikerar på flera lämpliga habitat för svart stork i samtliga län som ingick i analysen, förutom Gotland. Sju län innehöll mer än 18 % lämpliga habitat i förhållande till den totala arealen av varje län. Jag föreslår att dessa områden bör vara de primära målområdena vid en återintroduktion av svart stork till Sverige.

Introduction

In the forest dominated Swedish ecosystem, a number of species have become locally extinct and about five percent of the plant and animal species are threatened (SEPA 2014). The Swedish landscape has been utilized by humans since the most recent glaciation, first by hunters and gatherers (Wygal and Heidenreich 2014) and later through agriculture (Björklund *et al.* 1999). The forests in Sweden have since the beginning of 20th century been gradually used more intensely with the implementation of even-aged, short time rotation forestry and monocultures (Linder and Östlund 1998). This has contributed to a dramatic decrease in the proportion of large and old trees, especially deciduous species. The human-altered changes of the forested landscape have affected many forest dwelling species negatively (de Jong 2002). The human impact in the forest ecosystem is more intense in the south than in the north of Sweden (Björse and Bradshaw 1998).

The recovery of endangered species may involve legislative changes, which could protect a species and enable it to recover (cf. Ruhl 1990), or it could include special conservation methods such as support releases and / or reintroductions of endangered species (cf. Thatcher *et al*. 2006). To reintroduce animals means to deliberately translocate them to an area that is included in their historical, native range but from which they disappeared or became extinct from in the past (IUCN 1998). The objective is to create free-living, stable and self-sustaining populations (Jungius 1985 see Clark and Westrum 1989 pp. 663). The reasons for reintroductions could vary from increase of game species, to solve an animal-human problem or to preserve species (Kleiman, 1989, Fischer and Lindenmayer 2000). To reintroduce species in order to preserve or restore populations is a relatively new application that has emerged as a result of an increased understanding of the need to save endangered species (Seddon *et al.* 2007). The number of individuals released and how well these individuals adapt to their new environment facilitate the success of the attempt (Thatcher *et al*. 2006). Reintroductions should be avoided when the reasons for the initial disappearance remain (IUCN 1998).

Reintroduced animals may originate from breeding facilities (Meltofte 1987) or brought from areas where they still exist in the wild (Sarrazin and Barbault 1996). The construction of a zoo, a breeding facility or similar in Sweden must be approved by the County Administrative Board and the same applies when relocating animals (Djurskyddsförordningen 1988). Breeding facilities require employees who can administer the business and take care of the animals. This will require knowledge about breeding activities, conservation measures as well as training for the employees (Waugh 1988). Various types of insurances, access to electricity and food are additional costs that need to be revised. Reintroduction of endangered species through captive breeding is often impractical due to logistical difficulties and high costs (Kleiman 1989). However, if the public is interested in conservation biology and reintroductions, a part of the costs can be financed through donations, guided tours on a breeding facility or similar (Karesh 1993). Captive breeding and releasing of animals in the wild are often appreciated by the public and attracts attention in the media (Seddon *et al.* 2007). It is essential that the general attitude is positive to an animal reintroduction. If not, it is irrelevant no matter how good the animal adapts to the environment or how big the budget is supporting the project (Tilt 1989 see Reading *et al.* 2002 pp. 145). Public education and information about reintroductions may contribute to continued protection of endangered species in the future (Kleiman 1989).

Biological aspects matter in whether a reintroduction is successful or not (Sarrazin and Barbault 1996). When reintroducing animals, the fitness of an individual can be reduced by a number of biological factors (Montalvo *et al.* 1997). Reduced genetic variation and inbreeding are examples of factors that may occur if the number of individuals released into the wild is too small, as it often is during reintroductions (Jamieson 2011). Inbreeding may for instance adversely affect birds' egg hatching success (Bensch *et al.* 1994). Additional biological aspects affecting the reintroduction success are an animal's behavior or factors such as demographic or ecological processes (Sarrazin and Barbault 1996). It is important that an individual will have the opportunity to preserve their natural behavior in captivity to increase the individual's vitality and its chances of survival for future introductions into the wild (Rabin 2003). It is important to review as much as possible about a species' biological qualifications before a reintroduction can be implemented (Reading *et al.* 2002). The same applies to an animal's environmental requirements as well as its ability to adapt to the habitat it is released into (Armstrong and Seddon 2007).

Species that have become regionally extinct and successfully reintroduced to Sweden include the European beaver (*Castor fiber* L.) (Hartman 1994) and the white stork (*Ciconia ciconia* L.) (Olsson and Rogers 2009). The European beaver disappeared from Sweden around the 1870s and was reintroduced 50 years later (Hartman 1994). The Swedish beaver population has managed to recover quickly thanks to protection measures combined with reintroductions in the original habitat (Halley and Rosell 2002). The white stork was considered as regionally extinct in the 1950s, with the last known (but failed) nesting attempt in 1954 (Olsson and Rogers 2009). The white stork reintroduction project started for more than 20 years ago and has successfully managed to breed and release storks into the wild (Olsson 2007).

Objectives

The black stork (*Cicona nigra* L.) was recognised as a breeding bird species in Sweden up until the 1950s, but has since then been observed only sporadically (Svensson *et al.* 1999). The objectives of this study was to 1) compile historical and current distribution and population trend of the black stork with special emphases on Sweden and the biology (habitat requirements, migratory behaviour, nesting, foraging) of the species, 2) perform a geospatial information system (GIS) analysis of habitats suitable for black stork breeding in south- and central Sweden, and 3) integrate above with practical considerations for reintroduction of black stork in Sweden.

Background

Worldwide trends

The black stork has the most widespread range of occurrence of all the world's storks (Hancock *et al.* 1992) with an approximate global distribution of 13 million square kilometres (BirdLife International 2015). The species has been observed in over one hundred countries (Tamás 2012). The main breeding area is situated in the Palearctic region, in a discontinuous pattern from Scandinavia and Portugal in the west to the northeast of China (Hancock *et al.* 1992). The European nesting black stork has the main wintering area in central or western part of Africa (Luthin 1987) whereas the Asian nesting black stork has the wintering ground in south-eastern China, India or Korea (Pande *et al.* 2006).

The black stork is, despite its wide distribution area, a rare and habitat allegiant species (Hancock *et al*. 1992). It is categorised as endangered in most of the countries where it breeds (Lõhmus *et al.* 2005 Strazds 2011) and registered in Annex 1 of the EU Directive on the Conservation of Wild Birds (Angelstam *et al.* 2004, Lõhmus *et al.* 2005, Treinys *et al.* 2008). The species' status is nonetheless considered as *Least Concern* (LC) on the IUCN Red List of threatened species, since the estimated global population does not appear to have suffered a "30% decline over 10 years or three generations" as required to acquire *Vulnerable* (VU) status (BirdLife International 2015). The worldwide black stork population consists of approximately 24,000 to 44,000 individuals (Wetlands International 2006 see BirdLife International 2015).

The global black stork population' has dropped from the mid-1800s, especially in the central and western parts of Europe (Tucker and Heath 1994). However, this trend has been reversed in many west-European countries and the population is currently considered to be stable in a large proportion of the distribution (Jiguet *et al.* 2011). Recent recolonizations have been documented in Denmark and Belgium (Pihl *et al.* 2003, Tamás 2011). Regionally, however, the trend is still negative. A dramatic population decline is observed in Estonia, Latvia and Lithuania (Treinys *et al*. 2008). The reason behind the decline is unclear (Zieliński 2006) but could be due to an intensified forestry and habitat degradation (Tucker and Heath 1994). Rosenvald and Lõhmus (2003) emphasize that forestry activities are not the only factor behind the population decline, although it is likely to be strongly linked to it. Forest logging escalated in the Baltic countries after 1991 (Kurlavicius *et al.* 2004). This resulted in destruction of nesting habitats and contributed to impaired breeding opportunities (Lõhmus *et al.* 2005). More than 50 % of the European population is currently distributed in Eastern Europe (Chevallier *et al*. 2010), with the highest population density in the Balkan countries, northern Ukraine and Germany (Tjernberg 2010), and in north-eastern Poland and western Russia (Lõhmus *et al.* 2005). A migrating population could be one reason behind the current population increase in Western Europe, where Eastern European black storks turn westward for new nesting sites (Chevallier *et al*. 2010). On the other hand, Treinys *et al*. (2008) argue that it is believed to be an ongoing ecological change in the western and central European populations as they efficaciously establish themselves in fragmented forest areas in agricultural landscapes.

The black stork in Sweden

In Sweden, bones from the oldest remnants of a black stork were found at an excavation near the city of Ystad in the south and are thought to be remains from a nesting female, dated to 3000 BC (Davner 1993). An old Swedish name for the black stork is Odins' swallow [Sw. "odinsvala"] (Svensson *et al*. 1999), likely descended from the Viking Age when the species was considered a messenger from Odin, the chief god in the Viking Age religious belief (Davner 1993). During the mid-19th century, the species could be found from Skåne in the south up to the river Dalälven in central Sweden (Svensson *et al.* 1999, Lindell 2002). However, the distribution and the number of black storks began to reduce rapidly at this time, and in the 20th century the species was lost as a regular breeding bird (Ulfstrand 1973).

The black stork has been observed sporadically since the last documented nesting in 1953 (Svensson *et al.* 1999). In the 1990s, ornithologists and scientists proposed that it was only a matter of time until it was established in the country again (Davner 1993). However, an establishment has so far failed to appear even though black stork observations still occur sporadically. The last documented observations occurred in September 2014 from two different areas in Sweden, Börringesjön in Skåne and from Tåkern in Östergötland. All reported observations during 2014 were from the provinces; Östergötland, Gotland, Västra Götaland, Skåne, Västmanland, Bohuslän and Småland (Svalan 2014).

The reason for its disappearance in Sweden is thought to be shrinkage of suitable nesting sites with adjacent wetlands and small streams (Tjernberg 2005). Intensified forestry with drainage of wetlands may have caused changes in the hydrological structure in forested areas, which in turn may have affected the species negatively (Tucker and Heath 1994). The use of pesticides adjacent to foraging areas may be an additional factor in the population decline (Luthin 1987, Jiguet and Villarubias 2004). Additional underlying causes of the species' disappearance in Sweden can also be linked to threats in other parts of the black stork distribution. The black stork spends roughly half the year in the wintering grounds in west or east Africa, head northwards in April for the breeding season and returns to Africa in the end of August (Lindell 2002) by passing the eastern or western parts of Europe (Bobek *et al.* 2008). Possible threats during the migration include illegal hunting and power line accidents (Tucker and Heath 1994). The Baltic Sea may also serve as a migration barrier that adds to the species' disappearance in Sweden (Davner 1993). However, the black stork tends to migrate longer distances over open water than the white stork (Bauer and Glutz von Blotzheim 1966 see Hancock *et al.* 1992 pp. 71).

Black stork biology

A species' habitat can be defined as: "the resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism" (Hall *et al.* 1997 pp. 175). Morrison *et al.* (2006) identify *resources* as for example food, water or hiding places and *conditions* as abiotic factors such as rainfall and temperature, but also the appearance or nonappearance of competitors and predators. The quality of a habitat depends on the capacity to provide a species or a population with sufficient conditions and resources for its survival (Hall *et al.* 1997). If a habitat is of high quality, it can merely be rated from a species' perspective and the same area can be of high quality for one species but of low quality for another (Gibson 1994). Thus before the implementation of a reintroduction program, it is important to review the needs of a species in more detail. Such a review may include studies of a species' social behaviour, size of home range, and foraging behaviour (Armstrong and Seddon 2007).

The black stork is black and white-coloured (Nilsson 1858) and belongs to the family *Ciconiidae* (Puerta *et al.* 1989). It is a typical forest bird and inhabits old, sparse forests with limited disturbance frequency (Svensson *et al.* 1999) and high density of watercourses and stagnant water (Augutis and Sinkevičius 2005). Urbanised areas are classified as disturbance avoided by the species, though sporadic farms do not appear to have a significant impact on the habitat selection (Augutis and Sinkevičius 2005). Stagnant water bodies, like flooded ditches or marshes, and running watercourses are important when the black stork forages (Jiguet and Villarubias 2004, Dyrcz 2010). The diet consists of mostly fish, reptiles, small mammals and insects (Hampl *et al.* 2005). Unlike the white stork, which forages in open habitats, the black stork forages mostly in closed, isolated forests (Jiguet and Villarubias 2004). If necessary, the species can fly a bit from the nest tree to the foraging site (Jiguet and Villarubias 2004). The nesting site selection is strongly linked to the distance between the closest settlement and / or the nest tree, and to the amount of hydrological network in the forest. A trade-off situation may occur between the choice of an undisturbed nesting site and the distance to suitable foraging grounds (Treinys *et al.* 2009). The distance between the nesting site and the foraging area can vary from six to 40 kilometres (Tucker and Heath 1994, Chevallier *et al.* 2010, Strazds 2011). Nevertheless, the longer the stork has to fly to find food, the higher the fitness cost of living in an undisturbed forest (Treinys *et al*. 2009).

For the choice of the nesting tree, three aspects are essential; 1) the individual ability to build a nest, 2) flyway accessibility to the tree, and 3) safety against avian and terrestrial predators, in particular white-tailed eagle (*Haliaeetus albicilla* L.) and pine marten (*Martes martes* L.) (Strazds 2011). The most important factor to protect the chicks from pine marten is the nests' position on a side branch (away from the tree trunk), while the best protection against the white-tailed eagle is a dense tree crown, which protects the nest from above (Strazds 2011). The stork couple tends to return to the same nest tree if the breeding site is beneficial and the nest could be very voluminous over time and weigh as much as 1000 kilos (Strazds 2003). Thus, a suitable nest tree must be relatively large in order to support the weight of the nest (Lõmus and Sellis 2003, Treinys *et al.* 2008). An average nest tree diameter is estimated to 64 centimetres (Lõmus *et al.* 2005) but it can vary from 22 to 200 centimetres (Strazds 2011). The tree age is of less importance in the choice of nesting site, since trees growing in a nutrient rich area become thicker faster than a tree in poor soil (Lõhmus 2006).

The black stork prefers to nest in forests with high proportion of broadleaved trees (~10 – 20 %) or a high proportion of aspen (~10 – 20 %) if the proportion of broadleaved trees is low (Treinys *et al.* 2009). In Sweden, broadleaved trees are defined as the native tree species; elm (*Ulmus glabra* Huds.), ash (*Fraxinus excelsior* L.), hornbeam (*Carpinus betulus* L.), beech (*Fagus silvatica* L.), oak (*Quercus robur* L.), wild cherry (*Prunus avium* L.), small-leaved lime (*Tilia cordata* Mill.) and Norway maple (*Acer platanoides* L.) (Skogsvårslagen 1979:429). In Europe, the black stork usually prefers to nest in pine (*Pinus sylvestris* L.) or in broadleaved trees such as oak or beech (Hancock *et al*. 1992), but aspen (*Populus tremula* L.) is acceptable where broadleaved trees are sparse (Treinys *et al*. 2009). The black stork avoids nesting in grey alder (*Alnus incana* (L.) Moench) and spruce (Lõhmus and Sellis 2003). Spruce (*Picea abies* L.) has a dense canopy structure and cannot provide for the mating activity, which occurs in the nest (Nilsson 1858) and requires a free height of 1.5 meters (Strazds 2011), and is, thus, inappropriate as nest tree.

There are indications that the black stork is favoured by the presence of the European beaver (Tucker and Heath 1994, Svensson *et al.* 1999). The beaver frequently cause water accumulations during their construction of dams and lodges, which the stork can utilise during its scavenging for food (Svensson *et al.* 1999). In Latvia, a positive correlation between the two species is shown by a high density of black storks in areas where the beaver is most frequent (Strazds 2011). The Swedish beaver population is currently estimated to 100 000 individuals (Törnblom and Henrikson 2011). Beaver observations has been reported from many areas in south and central Sweden (Fig. 1) (Artportalen 2014).

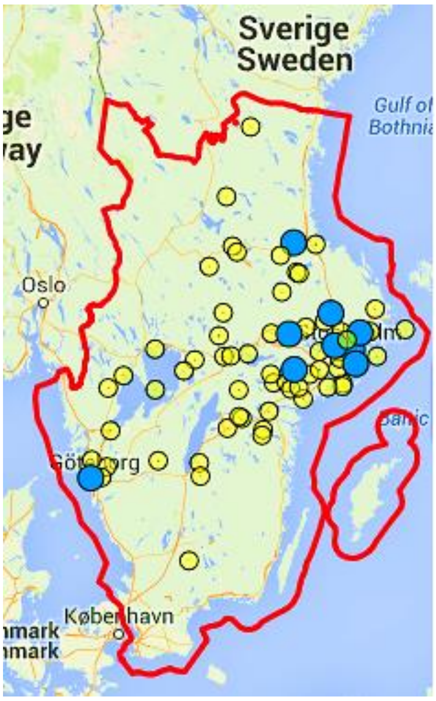

Figure 1. European beaver observations in south and central Sweden between January and December (Artportalen 2014). The blue dots represent several and the yellow dots are individual observations. Kartdata ©2014, GeoBasis-DE/BKG

Methods

Habitat modelling

Geographical Information System (GIS) has been used to describe the geographical distribution of species (Meggs *et al.* 2004, Powell *et al.* 2005, Poirazidis *et al.* 2006). The expected geographic distribution of a species can be predicted by defining a number of features such as vegetation, soil or climate (Powell *et al.* 2005). To have background information about a species' ecological and physical requirements, as well as its sensitivity to disturbance, is important in order to efficiently establish possible conservation measures. If this type of knowledge is missing, it could be extremely valuable to use a model to predict a species' habitat requirements in terms of for example distribution range (Meggs *et al.* 2004). The increasing availability of digitized maps and tools in GIS has contributed to improved territory analysis and characterization of habitats (Thatcher *et al.* 2006). The creation of habitat models in GIS contributes to the development of the conservation biology of species in danger of extinction at several spatial levels (Powell *et al.* 2005). Wintle *et al.* (2005) indicate that if a habitat model is applied properly, it could be a good and repeatable technique to use in the identification of biodiversity values.

GIS target area and habitat attributes

The first step in the study was to determine landscape features in order to define suitable black stork habitats. I decided to distinguish the species' life requisites for the foraging area with the requisites for the nesting area. The safety variables were included in the foraging area (Table 1). To achieve suitable foraging areas, all variables and their minimum values had to be met within an area of at least 2500 hectares. Forest cover of at least 13 %, watercourses of 10 km or more and not more than 5.5 % disturbance objects were average variables estimated from 81 study plots of 2500 hectares each (Treinys *et al.* 2008). An estimated habitat area for one breeding black stork couple is 5000 to 15000 hectares (Tucker and Heath 1994, Jiguet and Villarubias 2004, Tjernberg 2010). However, in this study, 2500 hectares are used to achieve suitable foraging areas since there were variables available within 2500 hectares (Treinys *et al.* 2008). Watercourses in the analysis were defined as running water including everything from a small brook to a large river (SVAR 2011). Smaller water bodies of stagnant water such as flooded ditches were not used in the analysis due to lack of data. The distance of 280 metres between a potential nesting site for black stork and infrastructure elements was recommended in a study by Treinys *et al.* (2009). The value used in this study was rounded to 300 metres, to have a larger marginal to disturbance objects (Table 1).

In order to model suitable nesting sites, all variables had to be met within an area of one hectare (Table 2). Furthermore, at least 125 hectares (5%) within 2500 hectares of habitat suitable for the black stork had to meet the requirements for suitable nesting sites. The area of one hectare as well as the proportion of nesting sites of at least 5 % in an area of 2500 hectares was determined exclusively for the habitat analysis in this study. The variables required for the nesting area were achieved at one hectare, not at pixel level. The standard errors have a tendency to decrease with the number of pixel cells and thus the accuracy of estimation may be improved (Næsset 2002). The maximum proportion of spruce as well as the minimum proportion of broadleaved trees, aspen and pine was obtained from Treinys *et al.* (2009) (Table 2). The minimum value of 29 centimetres for a suitable nesting tree was set based on Strazds (2011). The minimum diameter of a nesting tree was 28.0 centimetres and the average tree diameter in a stand of nesting black storks' was 29.3 centimetres

(Strazds 2011). I decided to use 29 centimetres in my GIS analysis because the laser data used to select the diameter is based on the average diameter of 10 metres field plots, and not for single trees. This means I had to use a relatively small diameter as limit for the nest tree, however all trees larger than 29 centimetres were thus included as well (Table 2).

Table 1. Variables used for the GIS-analysis of potential black stork habitats with associated foraging areas.

Life requisite	Variable	Value	Area
Safety	Distance to infrastructure elements	≥ 300 m	2500 hectares
Safety	Proportion of disturbance objects	≤ 5.5 %	2500 hectares
Foraging	Length of watercourses	≥ 10 km	2500 hectares
Foraging	Forest cover	≥ 13 %	2500 hectares

Table 2. Variables used for the GIS-analysis of potential nesting trees for black stork.

Life requisite	Variable	Value	Area
Nesting	Presence of large, potential nest trees	≥ 29 cm	1 hectare
Nesting	Presence of spruce	≤ 10 %	1 hectare
Nesting	Presence of oak, beech, pine or other deciduous tree species	≥ 30 %	1 hectare
Nesting	The proportion nesting sites	≥ 5 %	2500 hectares

The geographical area used in the analysis was limited to the former distribution range of black stork in the southern part of Sweden, with Dalarna and Gävleborg counties as northern borders (Fig. 2). All the observations of black storks during 2014 were also located south of the river Dalälven (Svalan 2014).

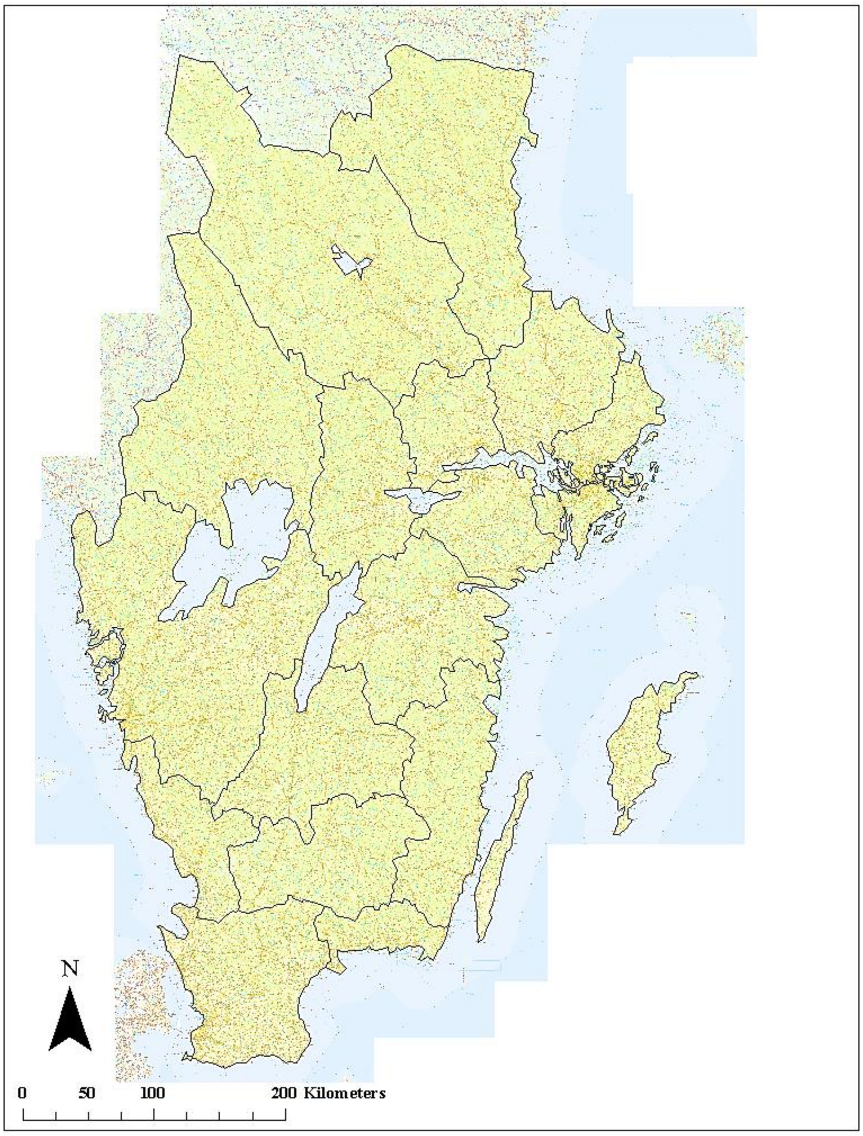

Figure 2. The study area with all 17 counties, which were included in the analysis.

The habitat model

The volumes of the various tree species were extracted from satellite images and field data from the Swedish National Forest Inventory, so-called kNN data (Granqvist Pahlén *et al.* 2004). The name kNN-Sweden comes from the calculation method “k Nearest Neighbour” (Franco-Lopez *et al.* 2001). The information in the kNN-data is uncertain if too small areas are analysed. The standard error of the total volume of tree species is 10 to 15 % for estimates of areas of 100 hectares (Granqvist Pahlén *et al*. 2004). The basal area weighted mean diameters (d_{BW}) of 25 x 50 kilometres field plots were extracted to a raster layer from the National Land Survey NH-scanning and field data from the Swedish National Forest Inventory. The results of some experiments with laser scanning of individual trees, evaluated in a stand level, have a standard error of eight to nine percent for the basal area weighted mean diameter (Nordkvist and Olsson 2013). Roads and railways were selected from the Road map, which contains a detailed and comprehensive description of the Swedish infrastructure. Forest data, watercourses and disturbance objects were extracted from the Swedish Land Cover Data (SMD). SMD is based on the EU classification system CORINE Land Cover (Swedish Environmental Protection Agency 2014). According to SMD, forests are defined as areas with trees of at least 5 metres and with a canopy cover of more than 30% (Ahlcrona 2003). The counties used in the GIS-analysis were selected in the county map of Sweden and extracted to a new polygon layer. All data used in the GIS analysis were converted to the size of the polygon layer of counties (Table 4, Appenix 1).

To meet the criteria of at least 29 centimetres in diameter for the nest trees, the tool Reclassify was used to select the desired values in the raster of diameters. The tool raster calculator was used to construct and execute a map algebra expression for the proportion of suitable nest trees and spruce. Oak, beech, pine and other deciduous tree species were considered as suitable nest trees and were merged into one single layer. This layer was combined with the raster layer with tree diameters larger than 29 centimetres, through the tool Boolean And. Boolean And performed a calculation of the pixel values from the two input rasters. If the pixel values from the two layers, met the criteria at the same cell position, the new pixel value received the value one. If the criteria was not met, the value was zero. The tool Focal Statistics was used to meet the criteria of at least 30 % of suitable nest trees. Focal Statistics calculated for each cell position, the sum or the average of all cell values within a specific area around the cell in question. In this case, a pixel cell was considered to meet the requirement if the average of all pixel cells within 2500 hectares met the requirement of at least 30% of beech, oak, pine or other deciduous species. Then the required value of 30 % was extracted by using the tool Reclassify. In the same manner, the required values for the proportion of spruce, disturbance objects, watercourses and forest cover were extracted to new raster layers. The criteria of at least 300 metres to infrastructure elements was met by using the tool Euclidean Distance, which calculated the Euclidean distance to the road or railway closest by, for respectively cell. When all the desired layers were formed, they were merged into a final layer through Boolean And. The final tool used was Tabulate Area, which calculated the areas between the polygon with counties and the final raster layer with suitable habitats, and created a table with the proportion of suitable habitats for each county (Appendix 3).

Results

The final model in GIS was very extensive with several steps such as conversion of data, calculations and merging of the data layers (Fig. 8 Appendix 3). According to the used criteria variables, suitable habitats were found in every county included in the analysis except Gotland. Seven counties contained more than 18 % suitable habitats in relation to total area of each county (Table 3, Fig. 4, Appendix 4; Fig. 11, 12, 13, 14, 15 and 16). The remaining counties contained less than 10% habitat (Fig. 5, Appendix 4; Fig. 17, 18, 19, 20, 21, 22, 23 and 24). However, Värmland county (Fig. 22) contained a larger amount of suitable habitats compared to Södermanland county (Fig. 11), but smaller percentage of the total area of the county. All counties together contained 21 705 km^2 potential habitats (Table 3).

Table 3. All counties included in the analysis and the proportion of suitable habitats in each of the counties.

Counties	**Area suitable habitats (km^2)**	**Percentage of suitable habitat per county**
Stockholms	210,2	3,2
Uppsala	675,8	8,3
Södermanlands	1120,4	18,5
Östergötlands	2068,1	19,6
Jönköpings	2706,3	25,8
Kronobergs	1747,9	20,7
Kalmar	2116,0	18,9
Gotlands	0,0	0,0
Blekinge	703,7	23,9
Skåne	1001,0	9,1
Hallands	485,6	8,9
Västra Götalands	5283,7	22,1
Värmlands	1483,9	8,4
Örebro	690,1	8,1
Västmanlands	308,2	6,0
Dalarnas	500,1	1,8
Gävleborgs	603,9	3,3
Sum	21704,9	

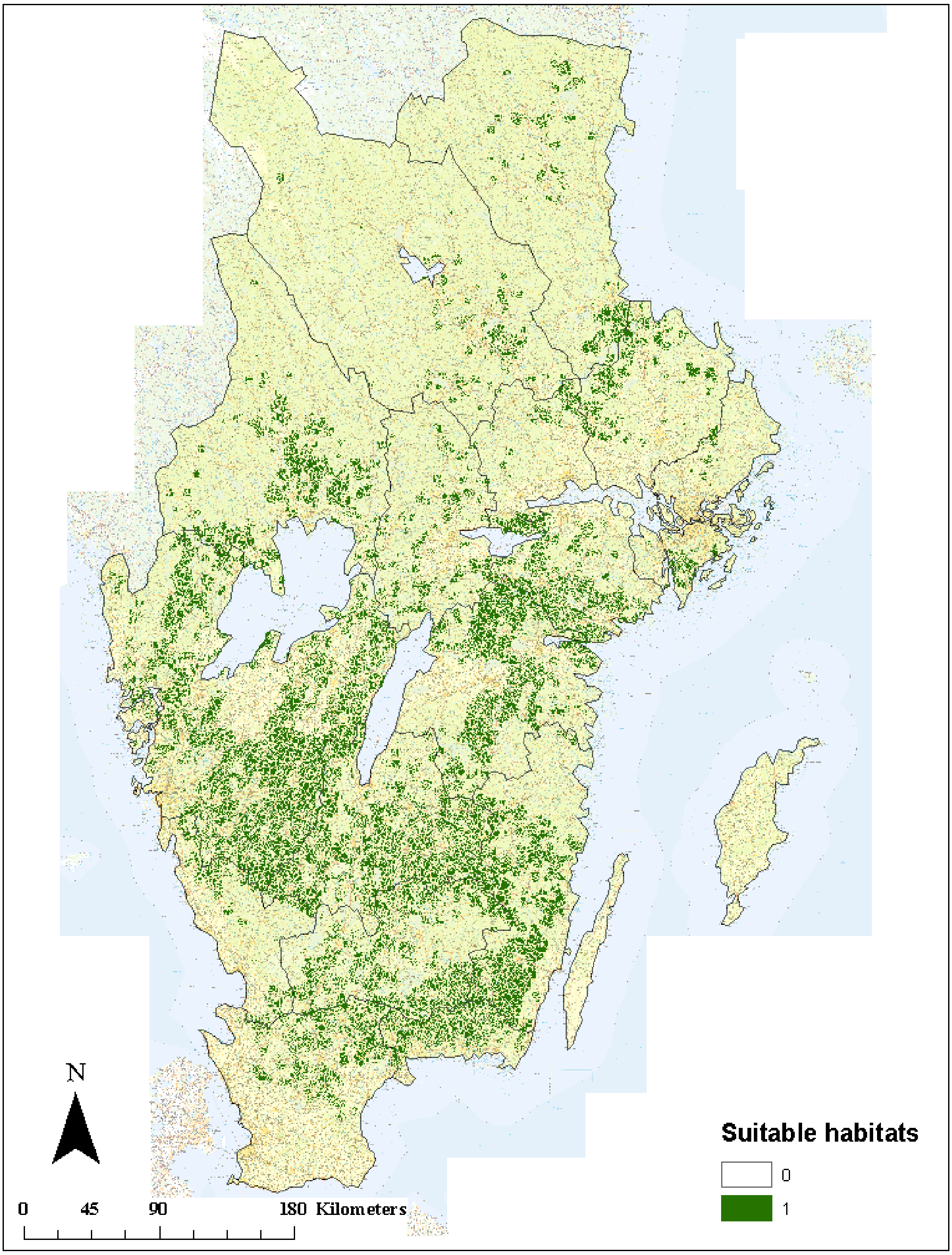

Figure 3. Distribution of suitable habitats for black stork in Sweden. The dark green patches are areas that have fulfilled all the variables in Table 1. © Lantmäteriet, i2014/764.

Figure 4. Blekinge county, with the highest proportion of suitable habitats (23.9 %) in relation the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1.

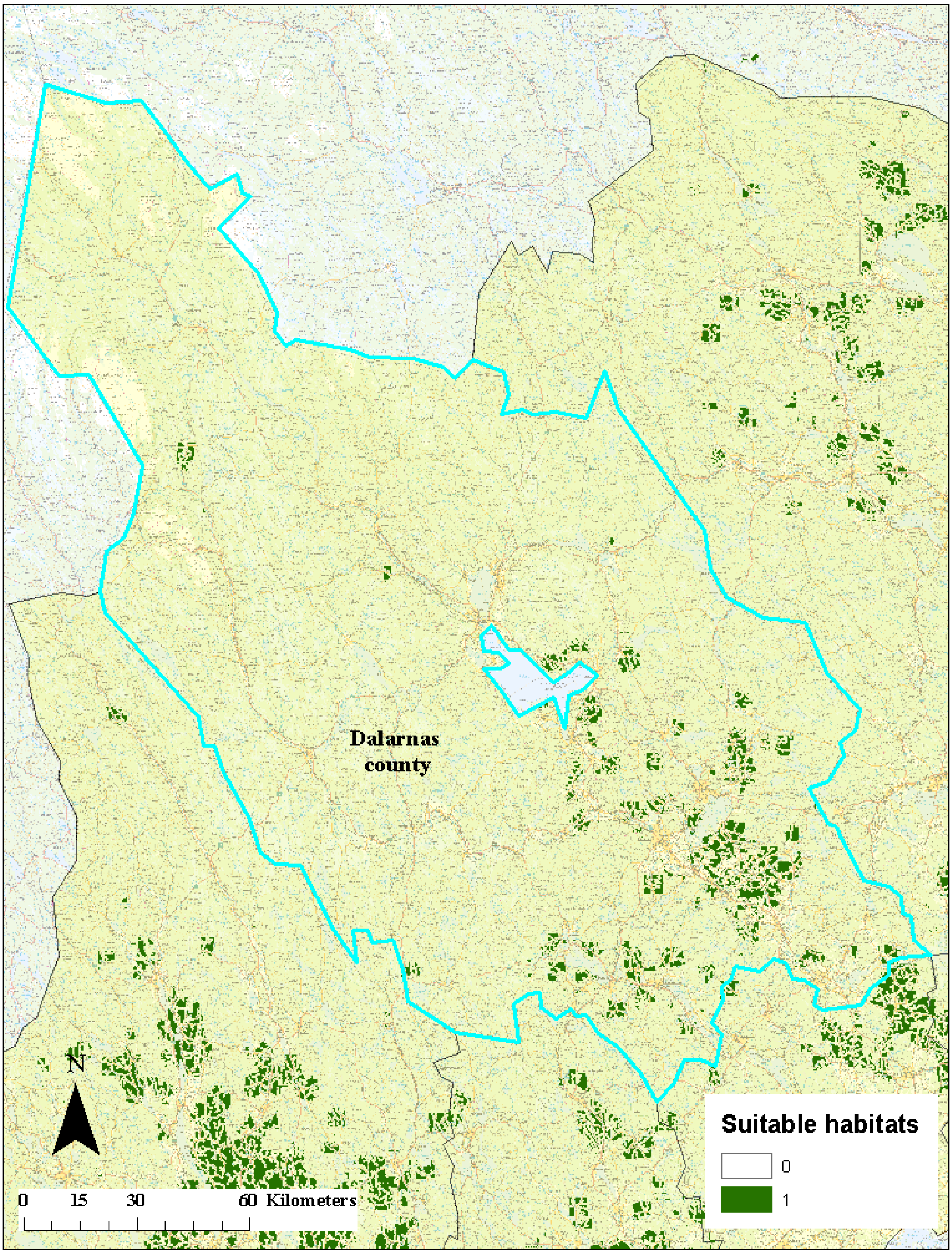

Figure 5. Dalarna county, which besides Gotland, has the lowest proportion of suitable habitats (1.8 %) in relation the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1.
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Discussion

The GIS-analysis

Habitat modelling in GIS as a tool to find suitable habitats for black stork is a cost-efficient survey method. However, it is difficult to exclude errors in the model. No map entering GIS is entirely free of errors since the input data is gathered in the field, estimated and classified etcetera, which will generate some errors (Heuvelink 1998). There may also be internal errors due to uncertainty in the use of formulas and tools in the model (Leung *et al.* 2004). To rectify these errors, the modelling in a GIS can be combined with randomly selected field surveys in order to control the life requisite variables and to test the models' credibility. In connection with this analysis, future projects could review the values of the various life requisite variables. One idea might be to raise the limit for the diameter of suitable nesting trees, which in this analysis were at the smallest possible value. By increasing the demands of the life requisite variables, a model with fewer habitat patches may be created but with a higher quality. Another suggestion might be to examine similar projects that have a proven and successful modelling technique in ArcGIS.

The result of the GIS-analysis suggests that availability of suitable breeding habitats not appear to be a limiting factor for a reintroduction of black stork in Sweden. Particularly potential areas for reintroduction are found in the areas in vicinity to the lakes Vänern, Vättern and Hjälmaren and further south towards Skåne county. It seems realistic that there were no suitable habitat patches on Gotland and in northern Dalarna. Large parts of Dalarna are composed of near-alpine forests and have a harsh climate unsuitable for the black stork. In addition, former distribution of the species ended near Dalälven (Lindell 2002). As there have been speculations about whether the Baltic Sea can act as a barrier for black stork migration (Davner 1993), Gotland with its relatively remote location from the mainland may not be appropriate as nesting site. Nonetheless, observations of the black stork in Gotland occurred in 2014 (Svalan 2014), which could mean that black stork is not prevented from migrating over longer distances of open water as suggested by Davner (1993). Many watercourses on Gotland have, however, been affected by human activities such as bottom material removal, which contributes to an unnatural rapid outflow during the winter and dried up watercourses during the summer (Gullefors and Johanson 2007). The requirement of at least 10 kilometres of contiguous watercourses may be a reason why my analysis did not find suitable habitats on Gotland. In addition to Gotland, the black stork was also observed in for example Västra Götaland and Östergötland (Svalan 2014). However, in contrast to Gotland, there were plenty of suitable habitats in both Västra Götaland and Östergötland.

It is not certain that there must be a contiguous habitat of at least 5000 hectares, since there is limited knowledge about the size of home range needed for a black stork couple, just conjectures (Tucker and Heath 1994, Jiguet and Villarubias 2004, Tjernberg 2010). It is also reasonable to assume that the size of the habitat varies from place to place depending on the quality of the habitat, the higher the quality the smaller area required. The habitat patches from the analysis are close to each other, even if they are separated by roads or other infrastructure elements. I believe the habitat patches may be suitable if they are sufficiently undisturbed and contain enough large trees, since a number of studies indicate that the black stork can fly several kilometres to forage (cf. Strazds 2011).

Reintroduction suitability
Public attitudes can determine if a conservation activity succeeds or fails (Bremner and Park 2007). The support is particularly significant during debatable conservation activities such as species' reintroductions (Jacobson and Duff 1998). The public acceptance towards captive breeding with subsequent reintroductions has increased and consequently the number of reintroduction projects has also increased (Seddon *et al.* 2007). In the white stork reintroduction project, the public attitude is almost exclusively positive towards the captivity and release of individuals (E. Ådahl pers. comm). Thus, the positive attitude towards the white stork project may be indicative of a positive attitude toward a potential reintroduction of the black stork. These two species disappeared from Sweden about the same time period (Olsson and Rogers 2009, Svensson *et al.* 1999). If the time since disappearance would have been larger, it might be more difficult to achieve public acceptance for a reintroduction project. However, the black stork is much more withdraw than the white stork and nests in closed forests far from human disturbance (Jiguet and Villarubias 2004). If public interest becomes too intense, it may create obstacles in the reintroduction of the black stork. Thus, there is a delicate balance between public appreciation and disturbance. The public usually appreciate a close encounter of animals in captivity (Altman 1998). If people are prevented from getting close to or interact with the animals, the attractiveness towards a zoo or a breeding facility usually decreases (Hosey 2005). Released, wild black storks can be extremely difficult to observe since the species is withdrawn and tend to avoid humans. Thus, a potential obstacle for a successful black stork reintroduction is that the public will not be able to report observations, and a possible black stork project might have difficulties to locate released individuals with help from the public.

A reintroduction can be implemented through captive-bred or wild caught animals (Meltofte 1987, Sarrazin and Barbault 1996). The potential for a successful reintroduction is lower when animals are bred in captivity compared to if they are caught in the wild and transported to new habitats (Griffith *et al.* 1989). However, the presumptions for a successful reintroduction of captive bred animals increases if the animals are well managed, have a broad genetic material and are prepared for a life in the wild through a self-contained behavior in the enclosures (Kleiman 1989). For a successful reintroduction in Sweden, several pairs of black stork are needed to reduce risk of inbreeding and increase the gene pool (Jamieson 2011). In the case of a species which experienced a decrease in several countries, it may be sensible to use a breeding facility and not import individuals from other regions. There may also be a risk that wild-caught birds return to the source location (Oppel and Beaven 2002).

At the white stork breeding facility, the birds must be ringed, provided with food of good quality and the enclosures must be cleaned and repaired. The employees must be trained to use techniques to prepare the animals for a life in the wild, where they must be able to search for food, know how to avoid predators and construct nests (Kleiman 1989). The environment in enclosures can be limited to the extent that the animals may develop stress and behavioural problems both during longer (Young 2003) and shorter periods (Coddington and Cree 1995). Employees at the white stork project have not noticed behavioural change in the birds that have resulted in reduced vitality in the wild (E. Ådahl pers. comm.). However, the black stork is different from the white stork in many ways. Numerous adult storks in captivity can behave belligerently towards each other (Bračko and King 2014). More than one black stork couple cannot live in the same enclosure at the same time without risk killing each other (S. Åkeby pers. comm.). By having physically violent birds in individual bird enclosures may contribute to reduced aggression (Bračko and King 2014), but will obviously increase the cost as well as complicate the breeding practically.

The climate has an effect on a species' survival and certain weather conditions or temperature can mean trouble for the species (Olsson 2007). The mortality rate for black stork chicks increases with bad weather conditions (Treinys *et al*. 2007). The underlying causes of the black storks' disappearance in Sweden may be due to climate changes. However, the weather in Sweden has constantly fluctuated from warmer to colder, from dryer to wetter and vice versa and the black stork has been breeding in Sweden since at least 3000 BC (Davner 1993). Also, the black stork does not seem very sensitive to climatic conditions over its wide distribution, from Western Europe to East Asia (Hancock *et al*. 1992). The black stork is however sensitive when it comes to habitat requirements and the choice of nesting site. If a reintroduction program should be launched, Swedish forest management must take into account the species' habitat requirements during logging and leave groups with thick, old trees of mainly oak, beech, aspen and pine. It is also important to avoid drainage of forests to provide wetlands for black stork to forage in. Old forests with high humidity may also be of significance for other endangered species (Berg *et al*. 1995) and thus restoration efforts that aim to create suitable habitats for black stork may also benefit other forest dwelling species.

A reintroduction project should not be implemented in an area where the reason behind the initial disappearance remains (IUCN 1998), thus it may be a good idea to thoroughly investigate the reason behind the black stork disappearance from Sweden. If the cause is believed to be habitat degradation, it may be necessary to restore appropriate areas. To make sure the black stork is introduced to the former living areas can be a matter of vital importance, as it appeared to be one of the success factors behind the Swedish beaver reintroduction (Halley and Rosell 2002). The potential interdependence between beaver and black stork (e.g. Tucker and Heath 1994, Svensson *et al.* 1999) and the current distribution of beaver in Sweden (Figure 2) suggests that there are opportunities to release black stork in areas where two species can coexist, in particular since the observations are consistent with suitable black stork habitats from the GIS analysis.

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Unpublished material

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Appendix one

Table 4. Meta data used in the GIS-analysis

Data set name	Variables	Formation	Resolution (m)	Data year	Coordinate system	Provider
SLU Forest Map: kNN-data	Volume beech (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
SLU Forest Map: kNN-data	Volume birch (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
SLU Forest Map: kNN-data	Volume oak (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
SLU Forest Map: kNN-data	Volume pine (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
SLU Forest Map: kNN-data	Volume spruce (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
SLU Forest Map: kNN-data	Volume deciduous (m^3sk/ha)	Raster	25 x 25	2010	RT90 2,5 gon V	Dept. of Forest Resource Management, SLU
Laser-data	dBW: basal area weighted mean diameter (cm)	Raster	12,5 x 12,5	2009 – 2013	Sweref99TM	Swedish Forest Agency and Section of Forest Remote Sensing, SLU
Border of counties	County Subdivision Sweden	Vector	1:1 000 000	2012	Sweref99TM	© Lantmäteriet, i2014/764
Road Map	Roads and Railways	Vector	1: 100 000	2007	Sweref99TM	© Lantmäteriet, i2014/764
GSD-Land and Vegetation Cover (Svensk Marktäckedata)	Forest, disturbance objects and watercourses	Raster	25 x 25	2013	Sweref99TM	© Lantmäteriet, i2014/764

Appendix 2

Table 5. Disturbance objects, roads and railways considered to be avoided by the black stork.

Settlement or other type of disturbance	Infrastructure elements
High populated city	Motorway, arterial (main) road
District with more than 200 inhabitants and small areas of gardens and green areas	Motor-traffic road, arterial (main) road
District with more than 200 inhabitants and larger areas of gardens and green areas	Public road under construction, non-arterial (main) road
District vid less than 200 inhabitants	Motorway, non-arterial (main) road
Industry, trading area, public service or military camp	Motor-traffic road, arterial (main) road
Dock area	Public road under construction, arterial (main) road
Airport	Public road > 7 m, arterial (main) road
Gravel- and sand pit	Public road > 7 m, non-arterial (main) road
Other mineral-extraction places	Public road 5 – 7 m, arterial (main) road
Refuse dump	Public road 5 – 7 m, non- arterial (main) road
Building site	Public road < 5m, arterial (main) road
Urban green areas	Public road < 5 m , non- arterial (main) road
Sport centre, shooting gallery, racing track, horse racing facility and dog-racing arena	Exit road
Airfield (grass)	Exit road, arterial (main) road
Ski slope	Street
Golf green	Bigger street
Non-urban park	Better road
Camping site and leisure area	

Appendix 3.

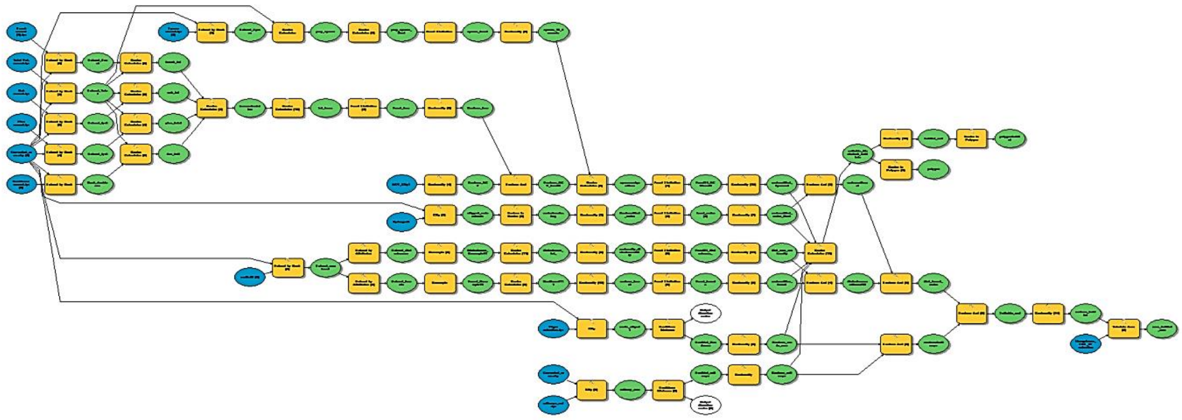

Figure 6. The complete model with all tools used in the analysis, step by step. The blue oval boxes represent input data, the yellow rectangular boxes containing tools for a specific function and the green oval boxes are the output of a specific function.

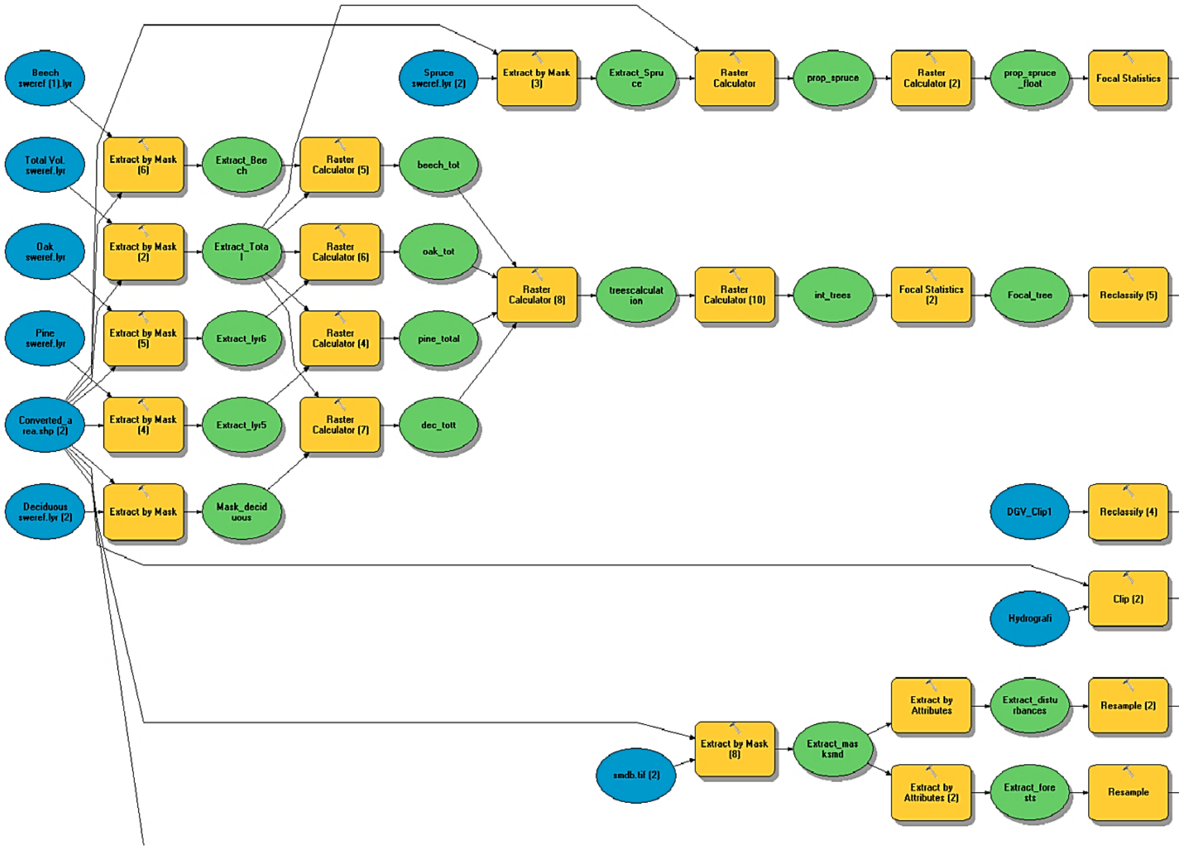

Figure 7. The first part of the in zoomed model. The blue oval boxes represent input data, the yellow rectangular boxes containing tools for a specific function and the green oval boxes are the output of a specific function.

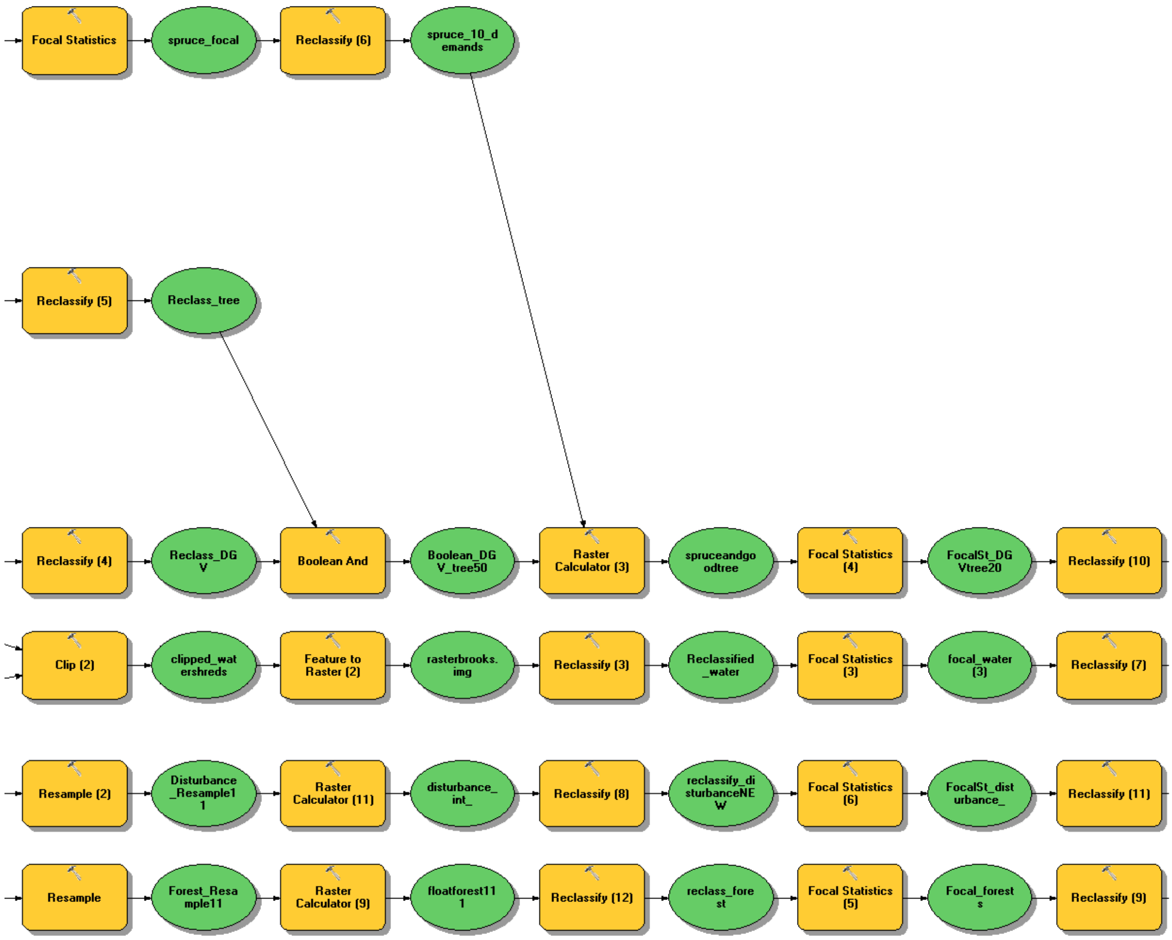

Figure 8. The second, upper part of the in zoomed model. The blue oval boxes represent input data, the yellow rectangular boxes containing tools for a specific function and the green oval boxes are the output of a specific function.

Figure 9. The second, lower part of the in zoomed model. The blue oval boxes represent input data, the yellow rectangular boxes containing tools for a specific function and the green oval boxes are the output of a specific function.

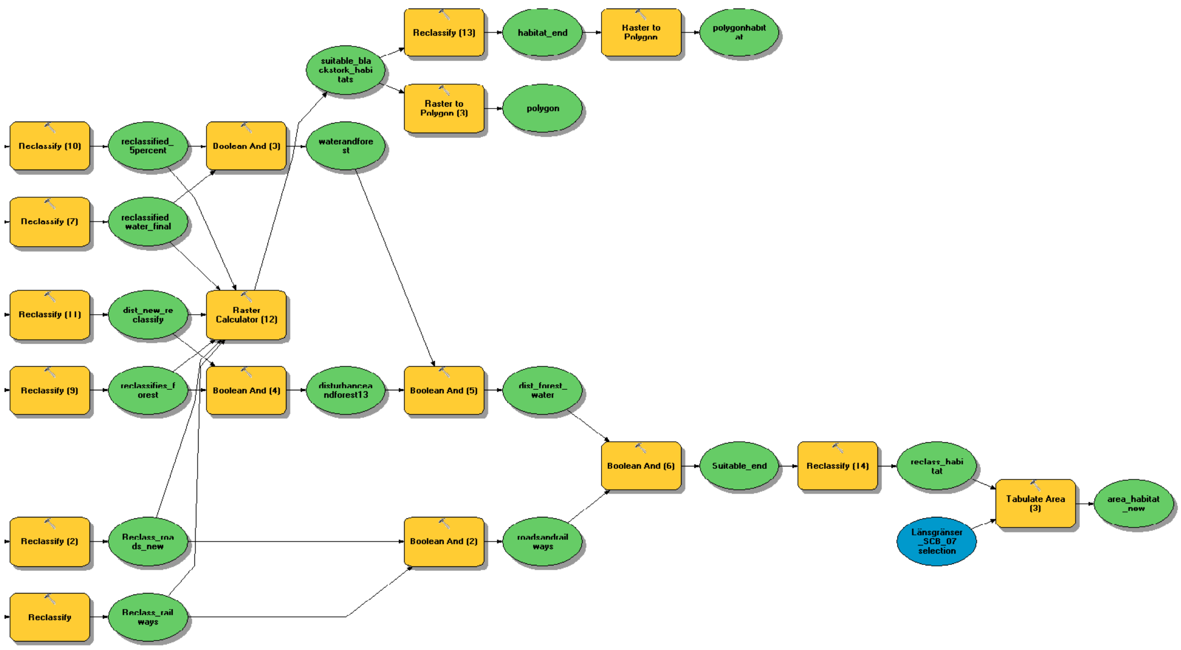

Figure 10. The last part of the in zoomed model. The blue oval boxes represent input data, the yellow rectangular boxes containing tools for a specific function and the green oval boxes are the output of a specific function.

Appendix 4.

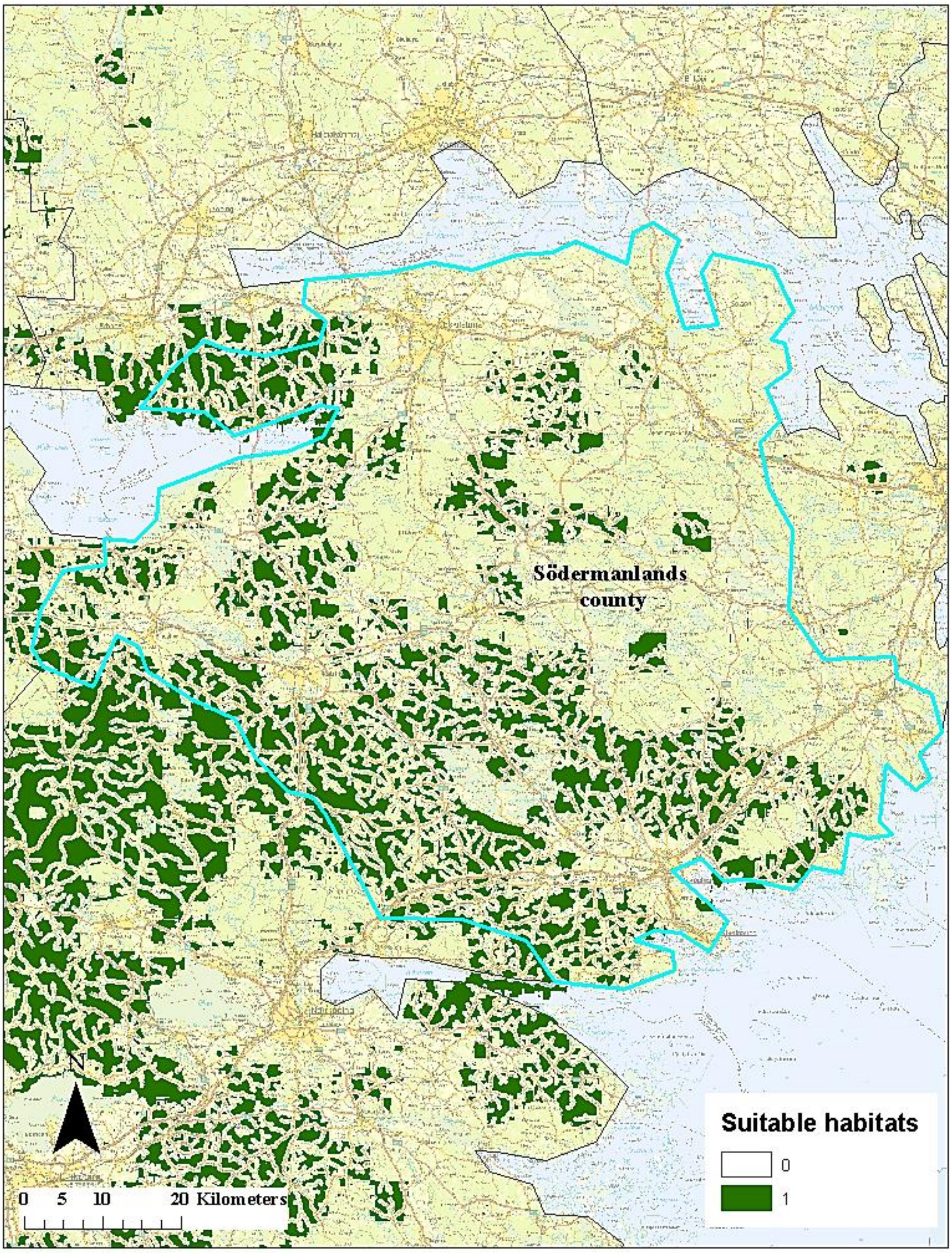

Figure 11. Södermanlands county with 18.5 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

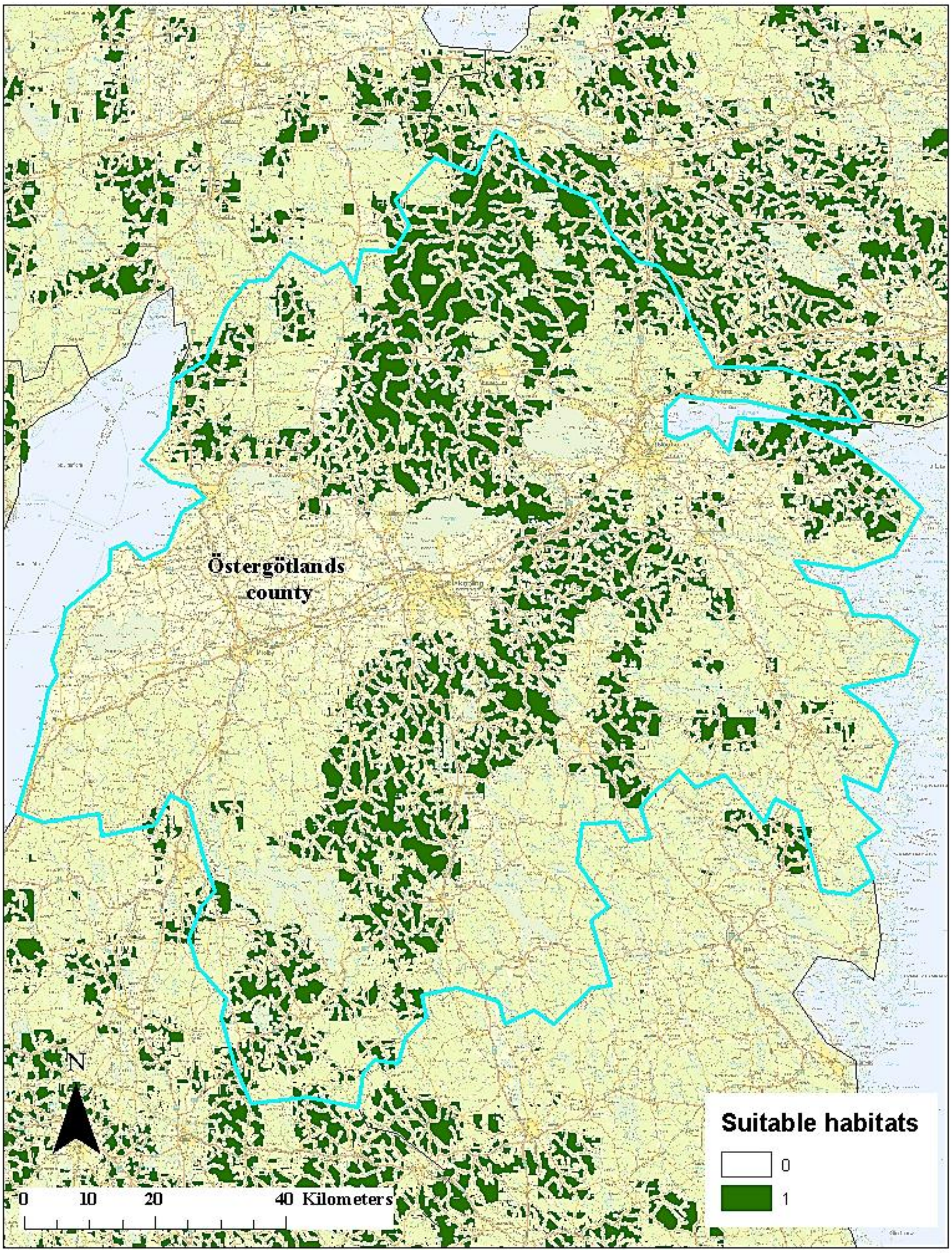

Figure 12. Östergötlands county with 19.6 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

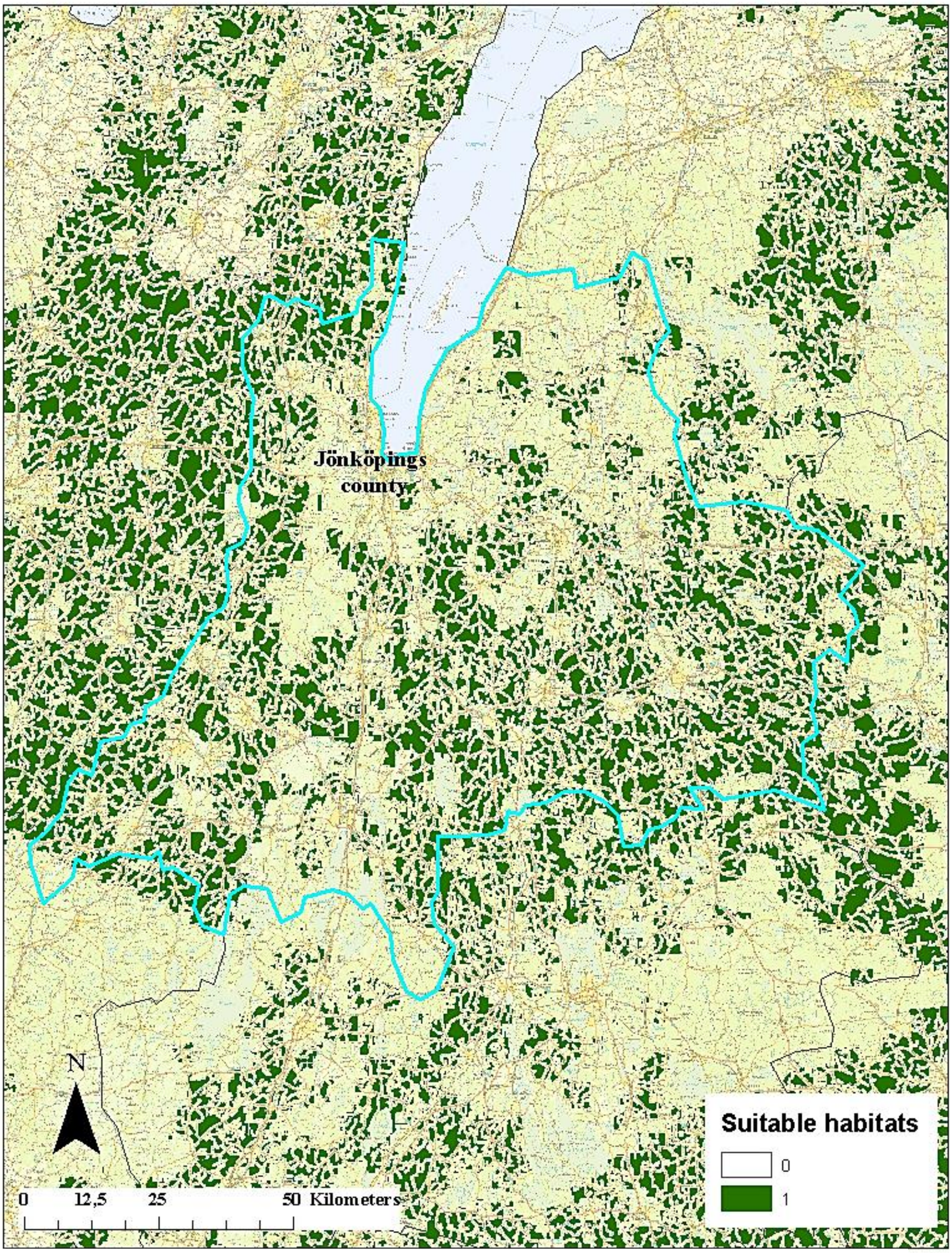

Figure 13. Jönköpings county with 25.8 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

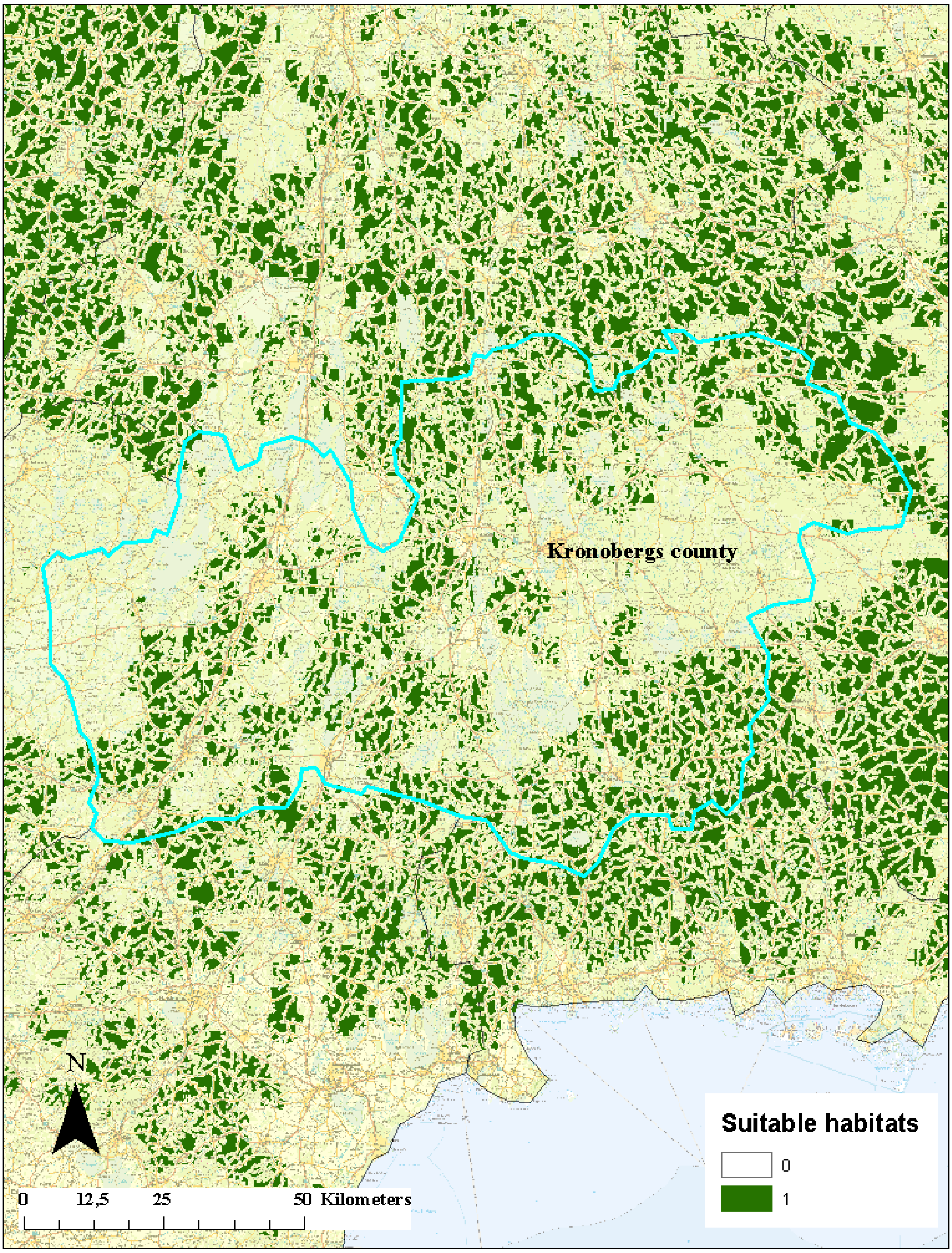

Figure 14. Kronobergs county with 20.7 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

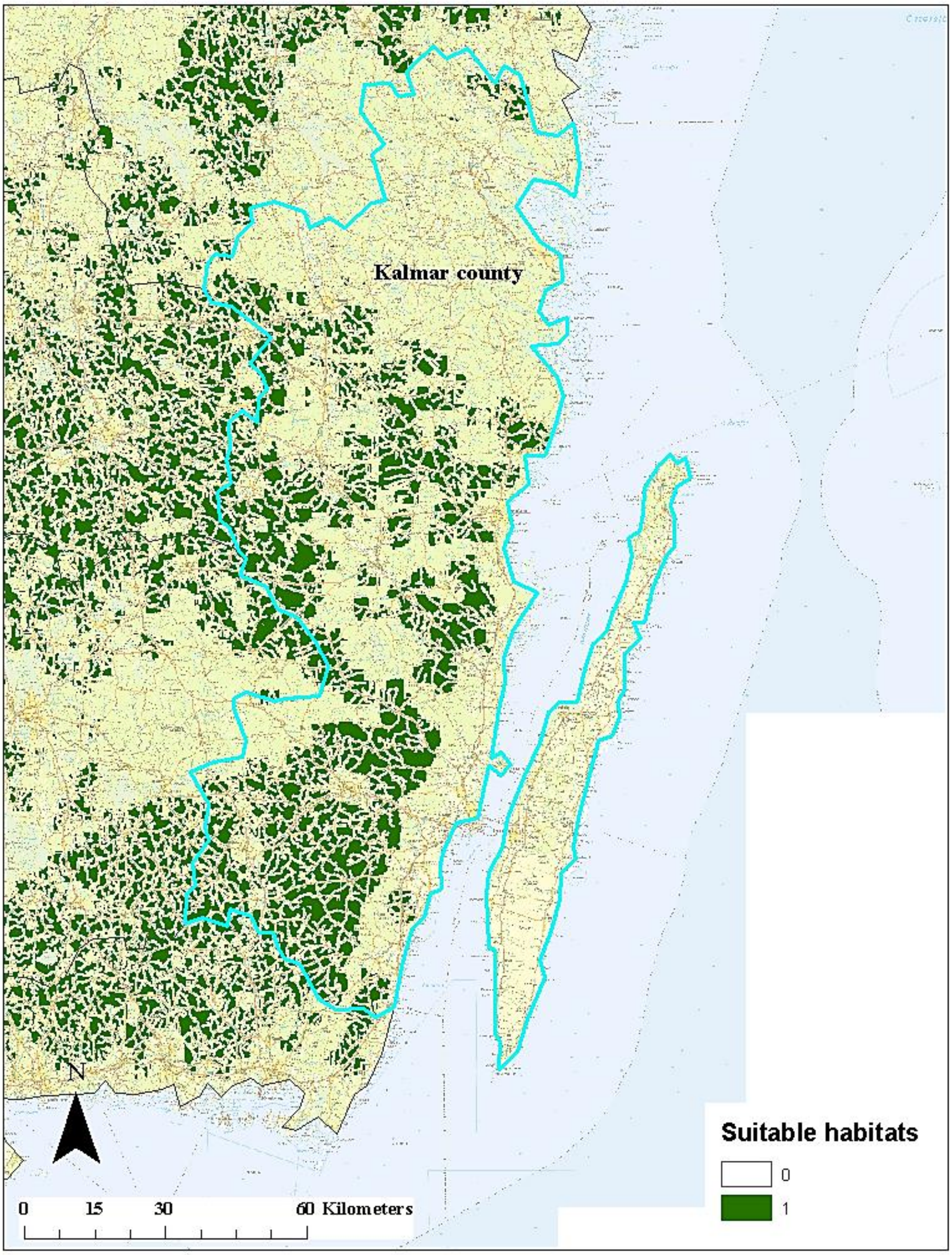

Figure 15. Kalmar county with 18.9 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

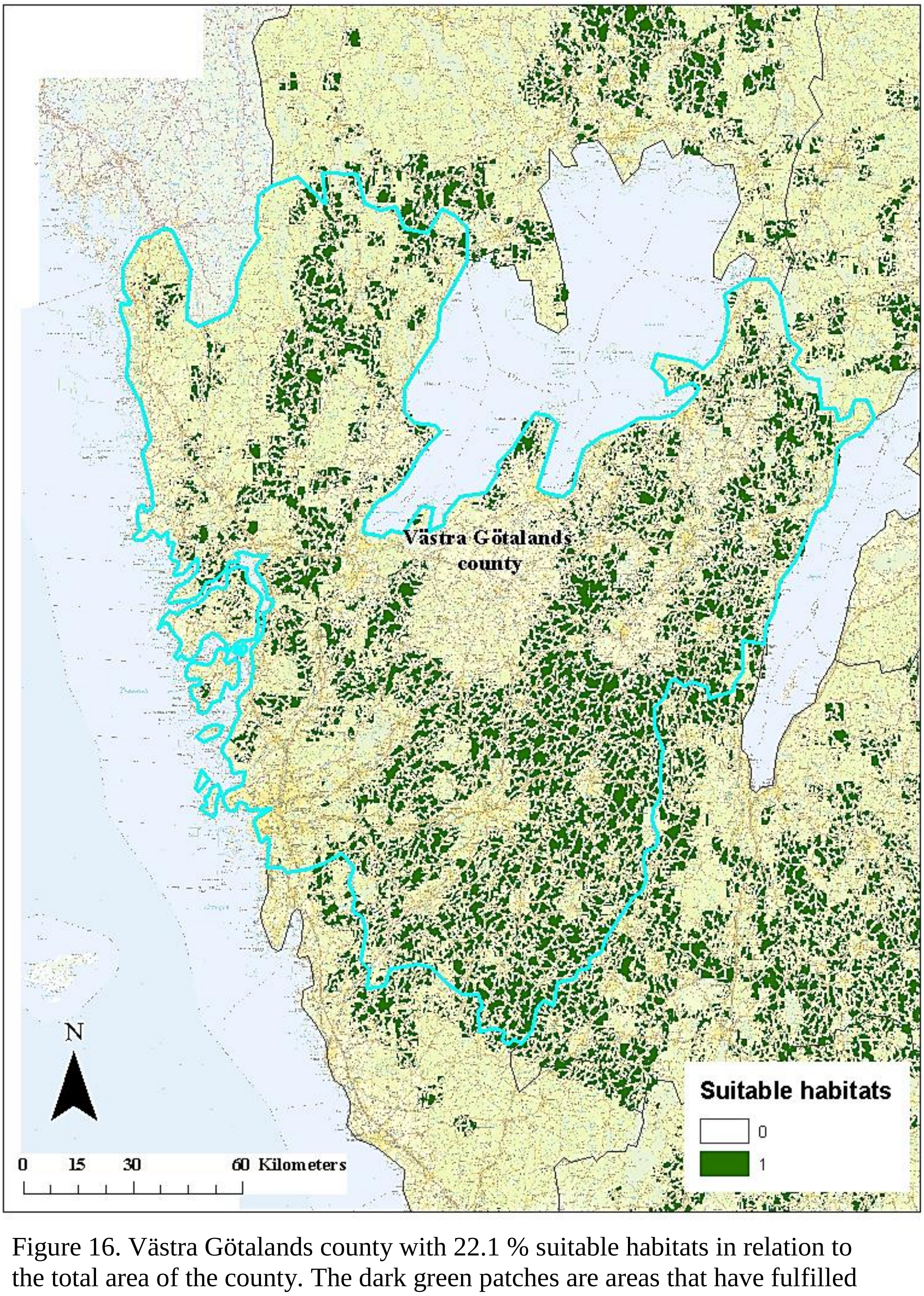

Figure 16. Västra Götalands county with 22.1 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

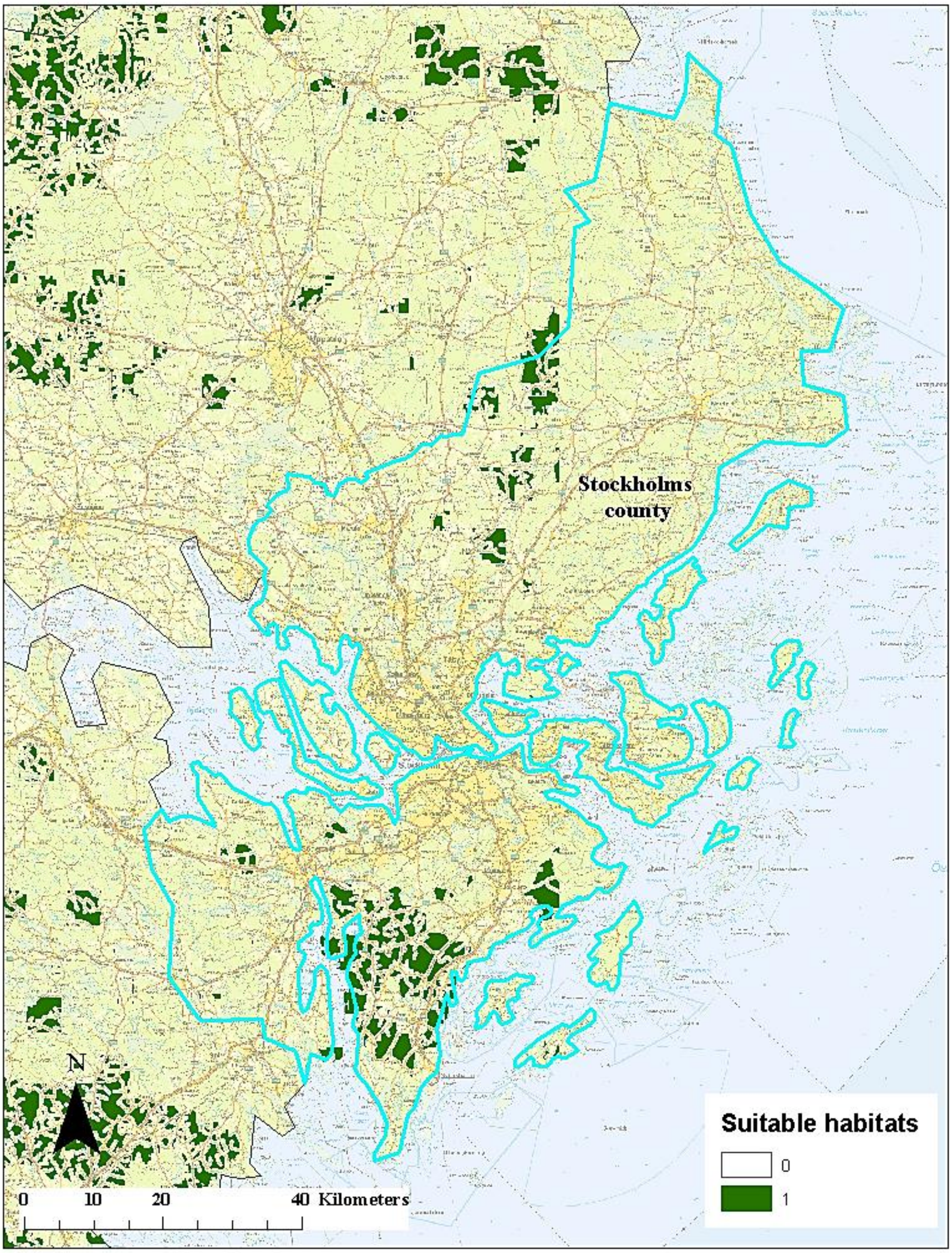

Figure 17. Stockholms county with 3.2 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

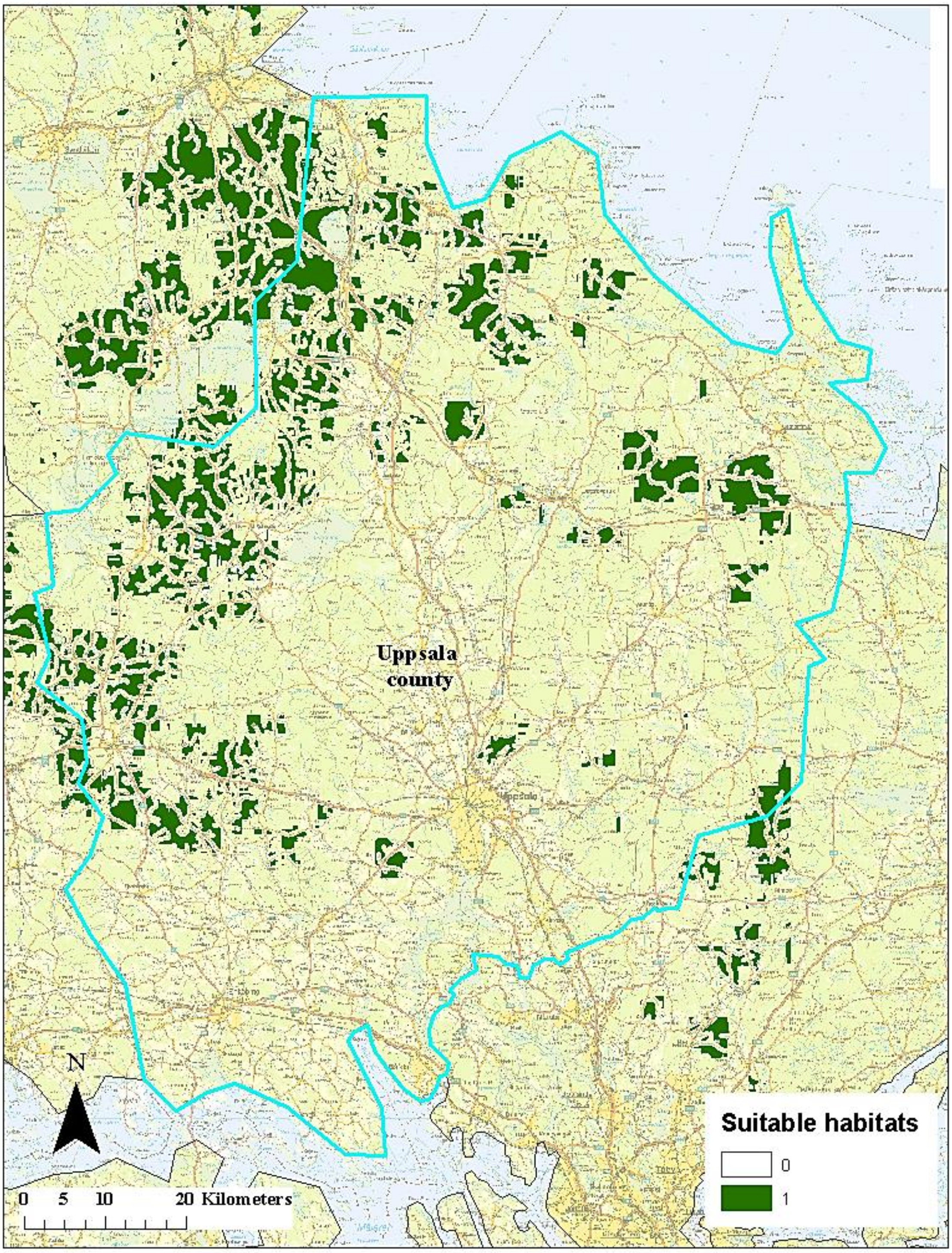

Figure 18. Uppsala county with 8.3 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. **© Lantmäteriet, i2014/764.**

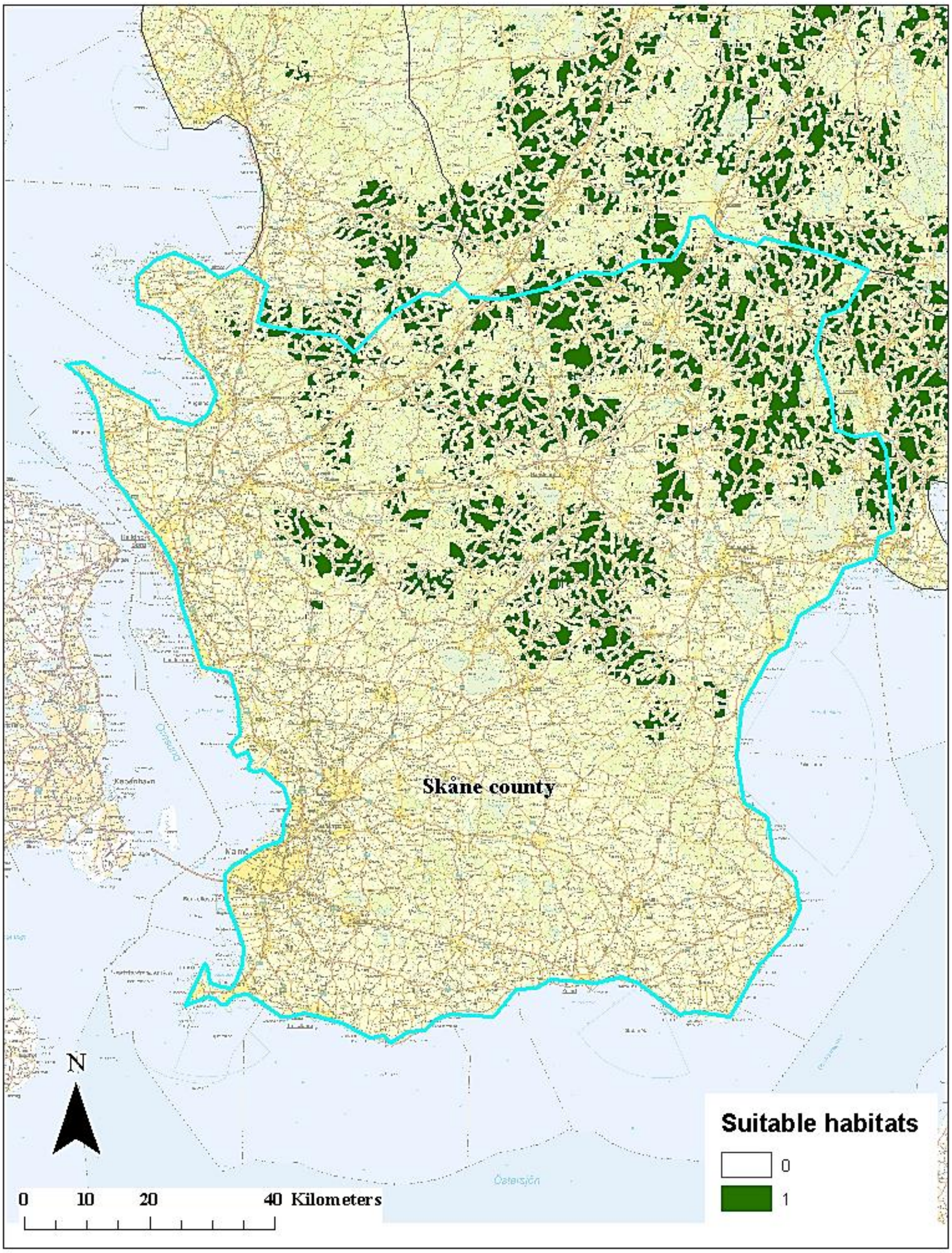

Figure 19. Skåne county with 9.1 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

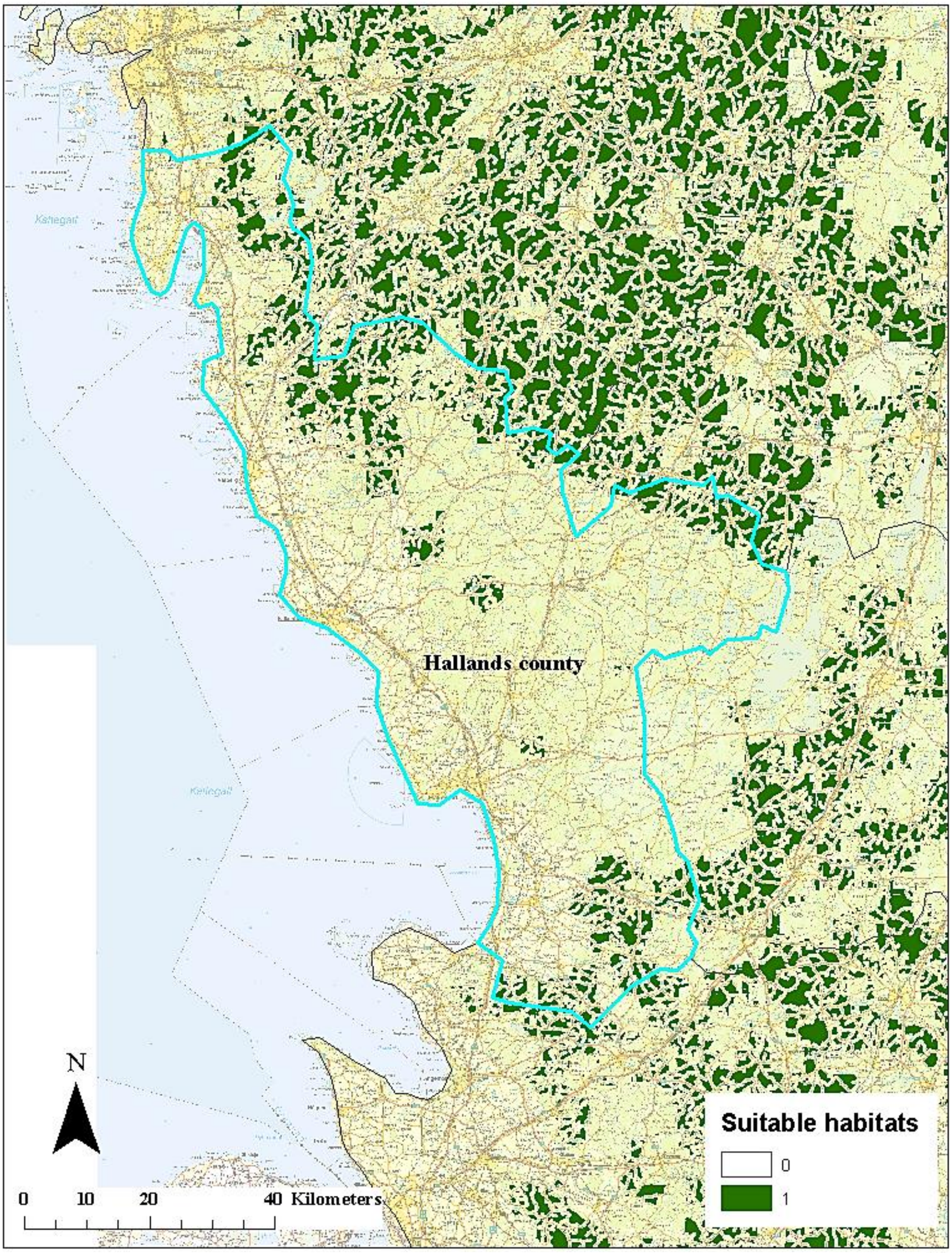

Figure 20. Hallands county with 8.9 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

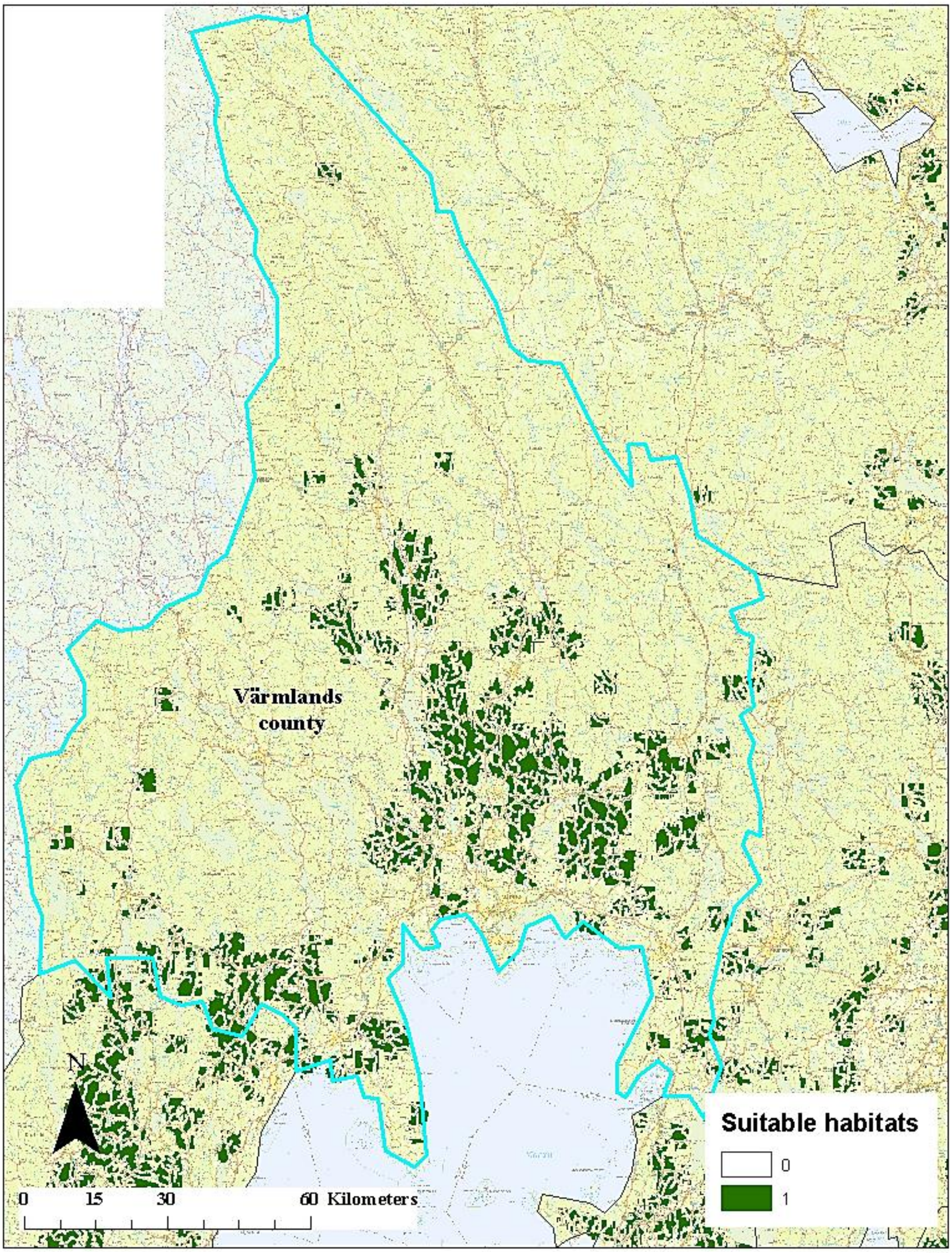

Figure 21. Värmlands county with 8.4 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

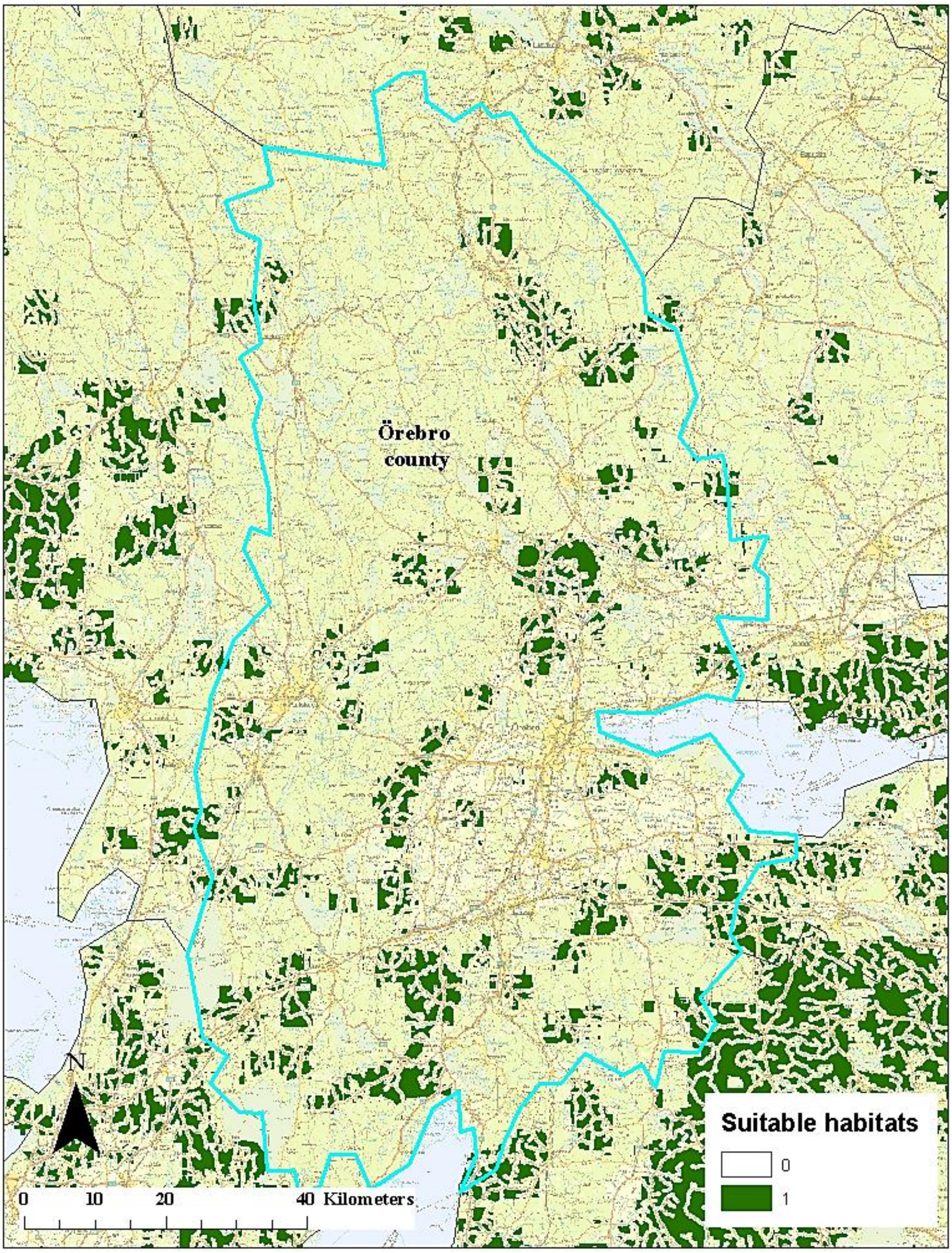

Figure 22. Örebro county with 8.1 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

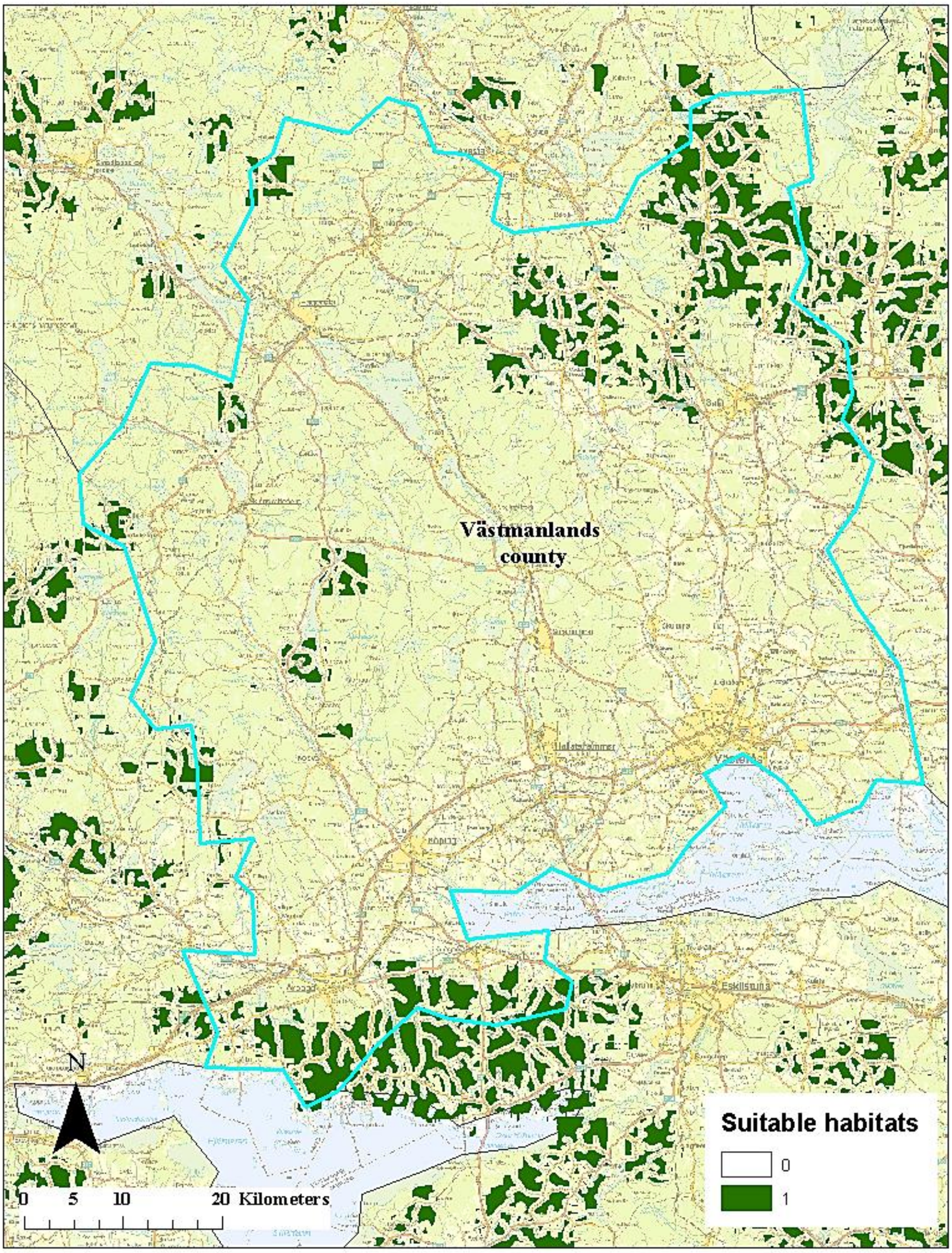

Figure 23. Västmanlands county with 6.0 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

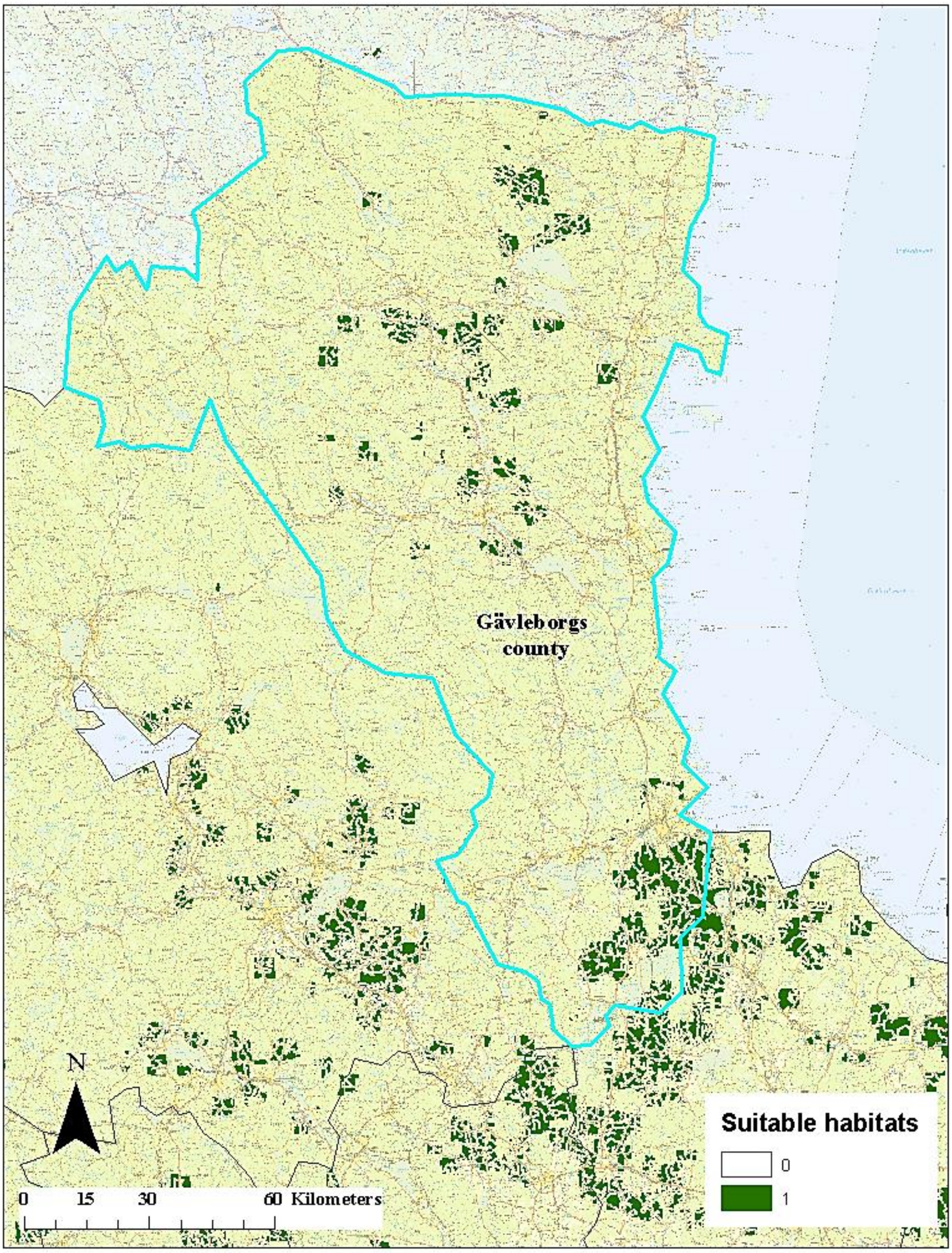

Figure 24. Gävleborgs county with 3.3 % suitable habitats in relation to the total area of the county. The dark green patches are areas that have fulfilled all the variables in Table 1. © **Lantmäteriet, i2014/764.**

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