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Kalhuggning och kungsörnens (Aquila chrysaetos) förökningsproduktivitet i Västerbottens län

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Abstract

The golden eagle (*Aquila chrysaetos*) is red-listed as near threatened in Sweden, but there are many basic ecological and demographical parameters important for successful management and conservation that are unknown for the Swedish golden eagle population. Forestry, and especially clearcutting (or final cutting/felling or regeneration cutting/felling), the most common harvesting system in Sweden since the 1950's, are likely important factors affecting the Swedish golden eagle population, but exactly how is largely unknown. Effects of both clearcutting and forestry in general on golden eagles and their breeding productivity may be positive, negative, direct and indirect. In this thesis I have investigated the effects of clearcutting on the breeding productivity of golden eagles between 2002 to 2016, 15 years in total, in 143 territories in Västerbotten County (each territory inventoried in at least 8 of the years of the study period). Golden eagle breeding data was provided by Kungsörn Sverige Västerbotten, and clear-cut data was provided by the Swedish Forest Agency.

Analyses were made in three groups: mountain territories, lowland territories, and all territories together (lowland + mountains). Using simple linear and 2nd order polynomial regressions in the program R, I made territory-level regressions of the average number of nestlings born per year (in three breeding productivity variables: year with territory visited by surveyors, occupied by golden eagles, and with breeding golden eagles, respectively) on the cumulatively summed area of clear-cuts weighted by territory area (in three clear-cut variables: ordinary cumulative sum, a.k.a. including clear-cuts made over the entire study period except for in 2016, thus including clear-cuts up to at least 15 years of age, and successively excluding clear-cuts when they reach 5 and 10 years, respectively). Clear-cut area was extracted from two modelled territory sizes, ca 5 km^2 and ca 30 km^2, which correspond to the minimum and maximum core area sizes of a golden eagle territory reported in a previous study. The clear-cut and breeding productivity variables were calculated over the whole study period, thus the regressions were only made on a spatial scale.

Golden eagle breeding productivity fluctuated with peak and low years and appeared to be declining in Västerbotten overall, and while the decline was not extremely steep it was also not inconsiderable. The regression results were not particularly conclusive, with many of the regressions being far from statistically significant (with statistical significance being $p \leq 0.05$) and explained very little of the variation in the breeding productivity. The only statistically significant relationships were for the breeding productivity variable nestlings per visited year in the group with all territories together. Here, significant results were found for all clear-cut variables and both territory sizes, and the relationship appeared to be positive. These models also had the highest adjusted R^2 values, but at best only 8.73% of the breeding productivity variation was explained.

However, low R^2 is not uncommon in ecological studies and even noisy, high-variability data can have a significant trend which indicates that there is something going on, which I did not consider unlikely for my significant results. Coupled with e.g. the results of previous studies and observations from golden eagle surveyors, I would say that my results are still relevant, implying that there is a relationship worth investigating here, and that it could, at least so far, be positive. That clearcutting, and forestry in general, affect golden eagles and their breeding is still considered likely, and the possibility of a significant correlation between them, possibly also to clear-cut area alone, should not be dismissed based on my results, as there are several things which should be considered when interpreting my results. For example, the relationship between golden eagle breeding productivity and clearcutting, and forestry in general, is likely very complex. There are many potential factors which could be affecting the relationship and serving as important sources of error and variance, and my methods and models were too simple and could only account for a few of these, partly due to there being restrictive gaps in both the breeding and clear-cut data. Further study is therefore highly recommended in order to more thoroughly investigate the relationship and hopefully acquire more conclusive results.

Keywords: Forestry, breeding productivity, breeding success, nestlings, breeding core home range, breeding core area

Sammanfattning

Kungsörnen (*Aquila chrysaetos*) är rödlistad som nära hotad i Sverige, men många grundläggande ekologiska och demografisk parametrar, som är viktiga för framgångsrik viltvård och artbevarande, okända för den svenska kungsörnspopulationen. Skogsbruk, och speciellt kalhuggning (eller slut- eller föryngringsavverkning), det vanligaste skogsbrukssystemet i Sverige sedan 1950-talet, är troligtvis viktiga faktorer som påverkar den svenska kungsörnspopulationen, men exakt hur är på det stora hela okänt. Både kalhuggning och skogsbruket generellt skulle kunna påverka kungsörnen och dess förökning positivt, negativt, direkt, och indirekt. I denna uppsats har jag undersökt effekterna av kalhuggning på förökningsproduktiviteten hos kungsörn mellan 2002 och 2016, 15 år totalt, i 143 revir belägna i Västerbotten Län (varje revir inventerat i åtminstone 8 av studieperiodens år). Data på kungsörnsförökning tillhandahölls av Kungsörn Sverige Västerbotten, och data på kalhyggen tillhandahölls av Skogsstyrelsen.

Analyserna gjordes i tre grupper: fjällrevir, låglandsrevir, och alla revir tillsammans (fjäll + lågland). Jag använde mig av enkellinjära och andragradspolynom regressioner i programmet R för att göra regressioner på revir-nivå av medelantalet bo-ungar födda per år (i tre förökningsvariabler: år med revir besökt av inventerare, besatt av kungsörn, och med förökning av kungsörn, var för sig) på den kumulativt summerade kalhyggesarean vägd med revirarea (i tre kalhyggesvariabler: ordinär kumulativ summa, d.v.s. inkluderande kalhyggen gjorda över hela studieperioden och därmed inkluderande upp till åtminstone 15 år gamla kalhyggen, och successivt uteslutande kalhyggen när de blivit 5 och 10 år gamla, var för sig). Kalhyggesarea extraherades från två modellerade revirstorlekar, ca 5 km^2 and ca 30 km^2, vilka motsvarar en tidigare studies minimum och maximum storlek på kärnområdet i ett kungsörnsrevir. Kalhygges- och förökningsvariablerna beräknades över hela studieperioden, och därmed blev regressionerna bara på en rumslig skala.

Kungsörnens förökningsproduktvitet fluktuerade med toppar och dalar och såg ut att minska i Västerbotten överlag, och medan minskningen inte var extremt skarp så var den ej heller obetydlig. Regressionerna var inte särskilt slutgiltiga, och många av regressionerna var långt ifrån statistiskt signifikanta (där statistisk signifikans var $p \leq 0,05$) och förklarade mycket lite av variationen i förökningsproduktivitet. De enda statistiskt signifikanta förhållandena erhölls för förökningsvariabeln bo-ungar per besökt år i gruppen alla revir tillsammans. Här erhölls signifikanta resultat för alla kalhyggesvariabler och båda revirstorlekarna, och förhållandet verkade vara positivt. Dessa modeller hade också de högsta justerade R^2 värdena, men som mest förklarades bara 8,73 % av förökningsvariationen.

Ett lågt R^2 är dock inte ovanligt i ekologiska studier, och även data med mycket variation och brus kan ha signifikanta trender som indikerar att något är på gång, vilket jag inte tycker är osannolikt för mina signifikanta resultat. Tillsammans med bl.a. resultat från tidigare studier och observationer från kungsörnsinventerare skulle jag säga att mina resultat fortfarande är relevanta, i att de antyder att det finns ett förhållande värt att undersöka här, och att det skulle kunna vara positivt, i alla fall än så länge. Att kalhuggning och skogsbruket generellt påverkar kungsörnen och dess förökning är fortfarande sannolikt, och möjligheten att det kan finnas ett signifikant förhållande dem emellan, kanske även till kalhyggesarea i sig självt, bör inte uteslutas baserat på mina resultat, då det finns flera saker att beakta när man tolkar mina resultat. Till exempel är förhållande mellan kungsörnsförökning och kalhuggning, och skogsbruket generellt, troligtvis väldigt komplext. Det finns många potentiella faktorer som kan påverka förhållandet och utgöra viktiga felkällor och källor till variation, och mina metoder och modeller var för enkla och kunde bara korrigera för några få av dem, delvis på grund av begränsande brister i både foröknings- och kalhyggesdatat. Ytterligare studier rekommenderas därför starkt för att utforska förhållandet mer utförligt och förhoppnings kunna erhålla mer slutgiltiga resultat.

Nyckelord: Skogsbruk, förökningsproduktivitet, förökningsframgång, bo-ungar, förökningskärnområde

Table of Contents

Introduction

The golden eagle (*Aquila chrysaetos*) is an aerial apex predator and a very large raptor, the second heaviest breeding eagle in North America, Europe, and Africa, and the fourth heaviest in Asia and the living eagle species with the fifth largest wingspan. Its body length and broad wings range from 66 to 102 cm and from 1.8 to 2.34 m, respectively, and it averages a weight of 3.6 kg in males and 5.1 kg in females (females are larger than males, especially in weight and wingspan) (Cornell University 2015; del Hoyo et al. 1996; Ferguson-Lees and Christie 2001; Watson 2010).

Many large carnivores and apex predators around the world are experiencing serious difficulties, threats, and declines, and many are also endangered (Cohen 2016; Ripple et al. 2014). The golden eagle is still widespread and fairly ubiquitous, and it is the most widely distributed eagle species in the world, present in sizeable stretches of Eurasia, North America, and parts of North Africa. It is additionally one of the most well-known birds of prey in the Northern Hemisphere and one of the most extensively studied raptor species in the world, especially in some parts of its range, like the Western United States and the Western Palearctic (Birdlife International 2016; Watson 2010). The species is also quite secure in some areas, and is not considered threatened or red-listed (least concern (LC)) on a global scale by the IUCN (Birdlife International 2016). However, the golden eagle used to be more widespread and it has experienced sharp population declines in many parts of its former range, now uncommon or even extirpated from some, especially where the human population has grown and spread out (Birdlife International 2016; Brown and Amadon 1986; Watson 2010). Attitudes toward the golden eagle, as towards other large predators, can also quickly shift from positive to negative and range from fascination, admiration and tolerance, to fear, hate and persecution (Artfakta 2015; Cohen 2016; Ripple et al. 2014).

The golden eagle is furthermore a slow breeder and is sensitive to adult survival rate changes, to which several interconnected characteristics contribute (Artfakta 2015; Galloway and Southern Ayrshire Biosphere 2015; Hunt et al. 1999). To start, golden eagles are fairly long-lived in natural conditions (the oldest known wild golden eagle was banded in Sweden and became 32 years old), and they are usually monogamous, forming relationships that last several years or even their entire life (if one partner dies, the other will search for a new mate, though) (Artfakta 2015; Staav and Fransson 2007). Golden eagles are also slow to mature and breed, usually becoming sexually mature at an age of 4-7 years, but successful breeding is usually not achieved until a few years after becoming sexually mature. Golden eagles are also territorial and require a territory to start breeding, and after gaining full independence (usually during the autumn of their birth year), young eagles are usually nomadic and wander widely for 4-5 years until they become sexually mature and are ready to mate, after which they usually return to the general area where they were born and start looking for somewhere to establish a territory of their own (Artfakta 2015; Hunt et al. 1999; Liguori 2004; National Eagle Center 2017; Watson 2010). Golden eagles also have relatively high rates of non-laying years, and the difference between productivity calculated per territorial pair and per laying pair can therefore be large (Southern 1970; Steenhof et al. 1997). When they do breed they only breed once per breeding year and often have low breeding success (breeding success generally seems to be greatest where prey is available in abundance) (Artfakta 2015; Burles and Frey 1981; Galloway and Southern Ayrshire Biosphere 2015; Watson 2010). Breeding outcome can also vary dramatically between different years and areas in Sweden, affected in particular by e.g. variation in prey-availability and weather in March to early May, when the eggs are laid and incubated (Artfakta 2015; Hipkiss et al. 2014; Moss et al. 2012).

The breeding season in Sweden (with earlier dates referring to south of Västerbotten County) starts in January/February with pre-breeding behaviour: courtship, nest building or maintenance, mating (40-46 days before the initial egg-laying), and display flights (which are performed as a part of courtship and to defend and establish territory boundaries, which become established or re-established during the pre-breeding phase). Eggs are laid in March/beginning of April, with incubation starting right away with the first egg if more than one is laid. The clutch size is often small: the norm is 2 egg clutches around the golden eagle's range, but in Sweden and Europe clutches of only 1 egg are most common and 3 egg clutches only occurring on rare occasions in areas of good food-availability, with 4 egg clutches being exceptional. Hatching normally occurs after 43-45 days, during the start of May, and the young usually fledge 65-90 days after hatching, in the middle to the end of July/early August, and usually become fully independent during the autumn (Artfakta 2015; Burles and Frey 1981; Moss 2015; USDA Forest Service 2016; Watson 2010).

Golden eagles often also have high juvenile mortality, with juveniles commonly having much lower survival rates than adults (partially due to them being poorer hunters than older birds) (Artfakta 2015; Burles and Frey 1981; Galloway and Southern Ayrshire Biosphere 2015; Watson 2010). In Sweden only one young tends to survive in litters larger than one, and yearly production is on average 0.5 fledglings per pair (Artfakta 2015; Hipkiss et al. 2014). In the western Rocky Mountains, 50% of golden eagles banded in the nest died by the time they were 2.5 years, and an estimated 75% had died by the time they were 5 years old (Harmata 2002). Near a wind turbine facility in west-central California, a survival rate of 78.67% was reported for non-territorial eagles (mainly based on juveniles and sub-adults, but also floaters, adults without breeding territories) (Hunt et al. 1999). In Denali National Park in Alaska, a survival rate of 19-34% was reported for migratory juveniles in their first 11 months (McIntyre et al. 2006a). Meanwhile, annual adult survival rates are usually estimated to be around 90% or higher (Bezzel and Fünfstück 1994; Hunt et al. 1999; Perrins and Birkhead 1983). Survival rates may be lower for migratory golden eagles, also adults, but especially juveniles (McIntyre et al. 2006a). Over the winter golden eagles in northern Sweden migrate to central or southern Sweden (nowadays very few leave the country for the continent, which was common around 1900), usually leaving in October and the beginning of November. Most Swedish adult golden eagles are thought to be resident (non-migratory), though, so it might be mainly juveniles and sub-adults that migrate (Artfakta 2015; Falkdalen et al. 2009; Sandgren et al. 2014; Singh et al. 2017; Tjernberg 1983b).

Golden eagles are additionally very sensitive to human disturbance, being easily disturbed by human presence and activities, more so than many other predatory bird species. They are particularly sensitive during the breeding season, especially during courtship and incubation. Golden eagles typically avoid human settlements and developed areas of any kind, from urban to agricultural, prefer remote habitats undisturbed by humans, and appear attracted to native vegetation (Artfakta 2015; Burles and Frey 1981; Moss 2015; Saav and Fransson 1991; Singh et al. 2016; The Swedish Golden Eagle Project 2016; USDA Forest Service 2016; Watson 2010). Golden eagles are also particularly sensitive in the vicinity of their nests, in particular the nest currently in use (the nest where breeding is currently ongoing), especially during the breeding season. Several studies have shown human presence and activities in many forms to adversely affect breeding success, territory occupancy, habitat use, survival, and foraging ecology in golden eagles, and causing declines in breeding productivity and population numbers. Especially rock climbing, walking, hiking, camping, recreation, tourism, use of snow-mobiles and motorized vehicles in general, mining, and skiing, disturbs and adversely affects nearby nesting golden eagles (Artfakta 2015; Bittner et al. 2011; Burles and Frey 1981; Colorado Division of Wildlife 2008; Holmes et al. 1993; Kaisanlahti-Jokimäki et al. 2008; Knight and Skagen 1988; Kochert and Steenhof 2002; LeFranc and Millsap 1984; Millar 2002; Richardson and Miller 1997; Ruddock and Whitfield 2007; Scott 1985; Steenhof et al. 2014; Steidl et al. 1993; Tjernberg 1983b; USDA Forest Service 2016; Watson 2010; Watson and Whitfield 2002; Whitfield et al. 2006). The response to aircrafts seems to be more variable and limited, though (Grubb et al. 2010).

In Sweden the golden eagle is the second largest raptor, with the average body length and wingspan being 90 cm and 1.90-2.25 m, respectively, and a weight varying between 3-6 kg depending on health and sex (with females being larger and weighing more). The golden eagle's distribution in Sweden spans almost the whole country. In 2011, known settlements were missing only from the counties Blekinge, Västra Götaland, Västmanland and Stockholm, and 860 territories were known in Sweden in total, of which ca 57% were found in the counties Västerbotten and Norrbotten County. However, with ca 50 active out of ca 60 territories known in 2011, the island Gotland had the highest golden eagle density in Sweden and one of one of the highest globally. The Swedish golden eagle population has increased in numbers by 20-30% and has significantly expanded its distribution, compared to 30 years ago. Currently, there are no apparent signs of a significant population change. However, during the 21st century there are signs of a declining reproductive rate and possibly also a population reduction in parts of northern Norrland (Västerbotten County and Norrbotten County), in the mountain golden eagle population, which in many areas has thinned out. In 2011 only ca 680 out of 860 known golden eagle territories were considered active, with the mountain population performing especially poorly, with several mountain or mountain-adjacent areas nowadays containing remarkably few breeding golden eagles. In Sweden the golden eagle has been completely protected since 1924 and red-listed as near threatened since 2000. It is further protected by the EU Bird Directive annex I, which also protects their nests and habitat, Bern convention appendix II, Bonn convention appendix II, and CITES appendix A (Artfakta 2015).

There are many factors that can affect golden eagles, but exactly how and, often, the extent of effects, both current and past, is not known. The factors behind the current population trend in Sweden are for example not known. Despite being one of the most extensively studied raptor species in the world, there are still several questions surrounding the golden eagle's ecology and population demography and biology. This is especially the case for the Swedish golden eagle population, for which several basic demographic parameters are unknown, including survival rates for different ages or life stages and the current population growth rate (Daouti 2017; Navinder Singh pers. comm. 2016). Even the current trend of the Swedish golden eagle population, if it is stable, increasing or decreasing, is uncertain, as is the population size, which ranges from 1160 to 1600 reproductive individuals (Artfakta 2015). Resolving such basic knowledge issues and understanding what affects and drives population trends is crucial for appropriate and successful management and conservation (Daouti 2017). Monitoring populations is here an important tool, crucial in assessing and predicting current and future population trends and the effects of conservation and management measures. Monitoring populations is also important in finding and understanding factors that affect populations, and is necessary for successful and appropriate management and conservation of species. Resolving such knowledge issues is often not simple, though, nor is monitoring populations or certainly assessing and predicting current and future population trends. For example, most species lack age-specific survival rates, and there is a rarity of studies providing a comprehensive picture of how multiple survival rates vary along the whole lifespan of a species. This is because collecting the necessary data requires substantial work and time, and it is difficult to monitor a sufficient amount of wild animals for a sufficiently long amount of time. Studies of birds are further complicated by birds in general being highly mobile, and in particular golden eagles, from juveniles to adults, regularly move over large distances (Sandgren et al. 2014; Singh et al. 2016; Moss et al. 2014).

Each breeding golden eagle pair maintains a territory that contains their hunting and foraging grounds and at least one nest. They show strong nest site fidelity, a.k.a. a pair often returns to the same nest site each year (Moss 2015; National Eagle Center 2017; Staav and Fransson 2007; Tjernberg 1983a; Watson 2010). Almost all established pairs build more than one nest, though (Artfakta 2015; Tjernberg 1983b; Watson 2010). In Sweden 2-4 per pair is common, and up to 6 per pair is known (Artfakta 2015). The nests of a pair can be located several kilometres from each other, up to 6.5 km stated in Norway, and are often spaced out with extreme regularity (Artfakta 2015; Tjernberg 1985; Watson and Rother 1986). Between breeding years a pair will typically alternate between its nests, although if a nest successfully produced young the pair is likely to return to it year after year (Artfakta 2015; National Eagle Center 2017; Tjernberg 1983b; Watson 2010). Should a nest prove unproductive, or otherwise unsuitable, the pair might choose a different nest or build a new one in a different area the next time they breed (National Eagle Center 2017). Nests can be used for many years, as the eagles will maintain and repair a nest whenever they use it and it is needed (Artfakta 2015; Ellis 1986; Tjernberg 1983b; Watson 2010). Territories are often used generation after generation, and some nest-trees and cliffs have been used up to 100 years. If both eagles in a pair die, a new pair will typically claim their territory (Artfakta 2015).

The terms home range, territory, and core area refer to the golden eagles' breeding grounds, where they breed and have their nests. These thus do not refer to the wintering grounds of migratory (breeding) golden eagles, which do not contain nests and are not used for breeding (Artfakta 2015). The term territory is sometimes used interchangeably with home range (in that territory is used for home range, not the other way around), and may also be used as a general term to refer to the eagles' breeding grounds, encompassing both home range, territory, and core area in their strictest definitions. The latter is how I am using the term territory in this thesis, unless otherwise specified. The home range, sometimes referred to as the entire or extended home range, is the largest partition, and encompasses the territory (in its strictest definition) and core area. It is often defined as the 95% utilization distribution of the territorial golden eagles, with exploratory movements being the remaining 5% (McGrady et al. 2002; McLeod et al. 2002; Moss et al. 2014; Singh et al. 2016; Walker et al. 2005; Watson et al. 2014). In its strictest definition the term territory refers to a somewhat smaller part of the home range used exclusively by the territorial pair for hunting, foraging, and breeding, and is actively defended against others (Hipkiss et al. 2013; McGrady et al. 2002; Moss 2015; Watson 2010). The home range can be further divided into a core area, or core home range, which is contained within the territory (in its strictest definition) and is used especially much by the territorial pair, particularly during the breeding season. The core area is usually defined as the 50% utilization distribution of the territorial golden eagles (sometimes where they spend more than 50 % of their time). The core area is most related to the location of the territorial pair's nests, especially during the breeding season, in particular to the nest/s more recently and in particular the one currently in use. The core area's location typically also coincides with the range centre (McGrady et al. 2002; McLeod et al. 2002; Moss et al. 2014; Singh et al. 2016; Watson et al. 2014). The territorial pair appears to perform most of their territorial display flights at the territory (definition uncertain) boundaries, rather than around the nest (Collopy and Edwards Jr. 1989). Territorial pairs have also been observed by surveyors in Sweden to perform display flights over nest sites as well, though. However, defence of and other individuals not breaching the territory (in its strictest sense) and especially the core area and nest site/s appears to be the primary concern for the territorial pair, more so around nests that have been used more recently, and especially so during the breeding season and around the nest currently in use (National Eagle Center 2017; Watson 2010). Surveyors in Sweden have noted that known eagles, e.g. eagles of neighbouring territories, can be allowed to pass through the outer parts of the home range, but foraging and hunting grounds are basically exclusive to the territorial pair and this year's offspring and they are not allowed too far in, especially not close to the core areas and nests, especially not during the breeding season and particularly not close to the nest currently in use. In many areas the pre-breeding phase appears to be particularly sensitive: in for example Israel (Bahat 1989), Norway (Bergo 1987), Scotland (Watson 2010), and Sweden (observed by volunteer surveyors), display flights (which also appear to be triggered by the presence of other golden eagles) and other aggressive encounters have been seen to peak from winter until just before egg-laying, and thereafter being less common. Some resident golden eagles (e.g. in Montana) appear to defend and maintain territories year-round, while in other areas, territories appear to be less strictly maintained during winter, aside from their foraging and hunting grounds, which are still basically exclusive (Harmata 1982; Watson 2010). A territorial pair can be more tolerant if it is their offspring from previous years that enters their territory, but if one would attempt to return to its birth nest to mate, then the parents would drive it away as they would any other intruding eagle (National Eagle Center 2017).

Outside of the breeding season both resident and migratory golden eagles make more far-ranging, exploratory movements, which fall outside of their home range. For instance, range size was found to increase substantially during the non-breeding season in the Columbia Plateau ecoregion, with golden eagles during the breeding season occupying ranges (home range and core area, estimated using the utilization distribution method Brownian bridge movement model with volume contours) that were less fragmented and about half as large as those used outside of the breeding season, with higher nest centricity during the breeding season, with more time being spent in the vicinity of nests, typically focused on one nest when they have settled on actually breeding in that nest that year, and the breeding season core areas and home ranges were largely contained within the core areas and home ranges used outside of the breeding season, respectively (Watson et al. 2014). Similar has been observed by volunteer surveyors in northern Sweden as well as by Moss et al. (2014) and Singh et al. (2016), where breeding golden eagles are commonly found mainly around their nests during the breeding season until summer, when their movement patterns start becoming less predictable and more far-ranging and exploratory, especially when the breeding season is over and their offspring have become independent. The size and location of the core area within the home range, and of the home range itself, thus varies depending on whether it is during the breeding season or not, and also between years, due to being most related to which nest is currently in use. A pair can therefore also have several separate core areas within their territory, which are centred around different nests and may not be cohesive or overlap, if the nests are far enough apart, and which are thus likely to be used unequally, at least during the breeding season, during the same year, depending on which nest is currently in use, as well as between years if some nests are better than others.

Golden eagles maintain some of the largest home ranges known of any bird species, but home range size, as well as territory (in its strictest definition) and core area size, can vary considerably across their range and even within countries, possibly dictated by food-availability and habitat preference (Artfakta 2015; McGrady 1997; Moss et al. 2014; Singh et al. 2016). In most of their range, home ranges can vary from 20-200 km^2 (McGrady 1997).

For example Moss et al. (2014) and Singh et al. (2016) (using utilization distribution methods) reported highly variable home range and core area sizes for adults during the breeding season (defined as beginning the 1st of March and usually ending in August, a.k.a. excluding the time of pre-breeding behaviour), the former in the northern and middle boreal zones of northern Sweden and the latter in lowland forests of northern Sweden. For Moss et al. (2014) the entire home range varied from 60-605 km^2 with an average of 226 km^2, using the minimum convex polygons (MCP's) method, and with the kernel density estimates (KDE) method, it was 70-580 km^2 with an average of 226 km^2. Singh et al. (2016) used volume contours made with the more conservative biased random bridge approach, and acquired minimum and maximum sizes of 30 and 70 km^2, respectively, for the extended home range. Core areas acquired by Moss et al. (2014) ranged in size from 2-120 km^2 with an average of 40 km^2 (MCP's), and 5-110 km^2 with an average of 41 km^2 (KDE). Meanwhile, Singh et al. (2016) acquired minimum and maximum core area sizes of 5 and 30 km^2, respectively. The average home-range sizes of Moss et al. (2014) are among the largest reported for golden eagles, which also supports the viewpoint of Tjernberg (1983b) that golden eagle home ranges in Sweden often are large and cover hundreds of square kilometres. The sizes acquired by Singh et al. (2016) have been commented as being more reliable than those acquired by Moss et al. (2014), though (Navinder Singh pers. comm. 2017).

The majority of the Swedish golden eagle population is monitored by volunteers at Kungsörn Sverige (http://www.kungsorn.se/). This is a non-profit, unaffiliated citizen science association who have been monitoring the Swedish population for a long time, with breeding records available from the 1990's. They have as a goal to coordinate golden eagle inventories all over Sweden, and also compile results from inventories of territories located above the cultivation border, "odlingsgränsen", an administrative border which separates the true mountain areas from the rest of Sweden. Territories located above the cultivation border, the mountain territories, are namely inventoried by the respective county administrative boards. In these, monitoring is done by territory, the volunteer groups divided by county, and then the results are compiled by municipality as well as county. Their work is important for the knowledge of the Swedish golden eagle population, but their monitoring methods are not strictly standardized, and all territories, both in the mountains and lowlands, have not been visited the same number of times or even years, which can be restrictive and problematic in scientific studies.

The largest numbers of golden eagles are currently found in open or semi-open mountainous regions and at high elevations, with many eagles doing a majority of their hunting and nesting on rock formations, cliffs, and rock shelves. However, they are not solely tied to such habitats, and as long as they can find sufficient amounts of food and local conditions are beneficial, golden eagles can also live and breed in the lowlands, including in lowland forests (Artfakta 2015; Burles and Frey 1981; Watson 2010). The Swedish golden eagle population predominantly ranges over the boreal and mountain regions of northern Sweden (61-69° N) (Moss 2015). While the mountains are important habitat for golden eagles also in Sweden, where they previously also used to be mainly found, and many Swedish golden eagles are cliff-nesting, a larger proportion of the population and more golden eagle territories are actually found in lowland forests than in the mountains, in particular in forests in the northern and middle boreal zone. An increasing number of scattered golden eagle populations or couples are also being established further south in Sweden, as far down as in Scania, in parts that are decidedly non-mountainous (Moss 2015). Additionally, more than half of the population nests in trees and are dependent on nest-trees (Artfakta 2015; Moss 2015;

Navinder Singh pers. comm. 2016; Saav and Fransson 1991). Golden eagle surveyors in Sweden have also noted golden eagles nesting in trees despite nesting places on for example cliffs being available near-by. Due to their large size and visual hunting style all golden eagles, also forest-dwelling ones, are best suited to hunting in open or semi-open habitat conditions and seek such habitats out all year round, as openness facilitates prey detection and capture and because it would be easier to catch prey in the absence of trees and bushes (Artfakta 2015; Balbontín 2005; Burles and Frey 1981; Soutullo et al. 2008; Tjernberg 1983b, 1985; Watson 2010). Golden eagles cannot hunt effectively in dense uninterrupted forests, and canopy closure could restrict access to and visibility of the forest floor, and inhibit detection of prey (Miller 2015; Moss et al. 2014; Singh et al. 2016). Golden eagles have also shown greater than expected use of open habitats during daytime than night-time, and given that they are known to be diurnal and usually hunt during daylight hours, this supports that they use open habitats mostly as hunting grounds (Balbontín 2005; Sandgren et al. 2014; Soutullo et al. 2008; Tjernberg 1983b; Watson 2010). Around the year, golden eagles therefore tend to search out landscapes characterized by open habitats (Watson 2010). Golden eagles in general also like habitats with steep slopes and elevations, especially southward-facing slopes, partially because their flying style also utilizes wind and thermal drafts a lot, and they particularly want to nest on elevated locations to get a good panoramic view of their territory (Artfakta 2015; Burles and Frey 1981; Moss et al. 2014; Sandgren et al. 2014; Singh et al. 2016; Watson 2010). These conditions can be sufficiently met in the lowlands and by the forests and trees there (Artfakta 2015; Burles and Frey 1981; Watson 2010). For example, golden eagles typically avoid regions with great uninterrupted stretches of dense forest, instead the forests that they inhabit are usually fairly open, fragmented, interspersed with open habitats, and/or have thin tree cover (Artfakta 2015; Burles and Frey 1981; Watson 2010). Additionally, while golden eagles hunt mostly in open grounds, forests are also important sources of prey (Forestry Comission Scotland 2017).

Forestry is very important in Sweden and affects a large proportion of the forests, especially the coniferous forests, with clearcutting (or final cutting/felling or regeneration cutting/felling, “slutavverkning” and “föryngringsavverkning” in Swedish), being the most common harvesting system. The Swedish boreal forests have been subject to intense, mainly forestry-induced landscape changes since the 1950’s, which was when the clearcutting system became dominant in Sweden, expanding the most during the 1960’s (Esseen et al. 1992, 1997; Olsson 2012; SkogsSverige 2018). Forestry and clearcutting are therefore likely affecting a large part of the Swedish golden eagle population, and effects could be significant and great; forestry is for example a likely contributing factor behind the size and quality of territories (Artfakta 2015). However, exactly how forestry affects golden eagles, in general and currently, and what the overall effect is, is not that easy to say and needs to be investigated, because the relationship is likely very complex, with many factors potentially affecting it, and there is very likely to be variation and change in space and time. Golden eagle habitat use is complex and forestry, as well as clearcutting, could affect golden eagles in many different ways, both directly, indirectly, positively, and negatively (Singh et al. 2017). Some effects are easy to predict, like how harvesting all nest-trees and trees suitable for nesting would have severe negative effects (Artfakta 2015). Others are less clear, and the overall effect may thus be hard to discern. This also appears to be an area in need of study, in particular as pertains to the effects of forestry and especially clearcutting on the breeding of golden eagles living in lowland forests. I could, for example, find no studies looking at the effects of clearcutting on golden eagle breeding productivity, and studies from Sweden on golden eagles connected to forestry and clearcutting have mainly concerned habitat selection.

The focus of this thesis is how forestry, specifically clearcutting, is currently affecting golden eagles, looking over the study period 2002 to 2016, in total 15 years, specifically their breeding productivity, looking at golden eagles in the north Swedish county Västerbotten. I chose Västerbotten County (hereafter referred to as simply Västerbotten) as my study area partly because a large part of the Swedish golden eagle population lives there and there are many known territories there, but importantly also because many of the territories in Västerbotten are also actively monitored, of which many have breeding results available for many years (Artfakta 2015). This choice is also based on the importance and extensiveness of forestry and clearcutting in Västerbotten and Swedish forests overall, especially coniferous forests, and the need for research on this topic, to be able to draw conclusions not based on inferences or parallels. I specifically chose clearcutting because I thought it likely to be the forestry-related aspect with the greatest effects on the golden eagles and their breeding, for example because clearcutting imposes a dramatic change of habitat and affects many animal and plant species, often in many different ways, which also makes it a highly relevant area of study. Although many plant and animal species are affected negatively by clearcutting in forestry, especially forest-specialists, species can also be affected positively, both, or be unaffected (Gustafsson and Fedrowitz 2015).

Research carried out in Sweden is naturally the most preferred when drawing conclusions about the Swedish golden eagle population. A caveat of more local studies is that they can be harder to reproduce in other areas, as they may depend on local conditions and variations not found in other areas. However, local studies, at least to begin with, may be necessary in this case, in order to predict how golden eagles will react to clearcutting and forestry in Sweden, or even within Sweden, because there is potential for large variations in effects of and response to clearcutting and other forestry operations and forestry-related things across the golden eagles' international range, as well as within Sweden, e.g. between populations living in considerably different habitats, such as in the mountains and lowland forests. This may be affected e.g. by how used to human presence and disturbance and forestry operations the golden eagles are, large-scale differences in prey-species composition, abundance, and dietary preferences of the golden eagles, site productivity, current and historical forestry practice in the area and the intensity and types of forestry practice (which are also probable to differ more between Sweden and other countries, than within Sweden), etc. For example, golden eagles living in Swedish lowland forests may be more used to and tolerant of humans, clearcutting, and other forestry operations and forestry-related things, than golden eagles living in the Swedish mountains, Alps, and Scottish highlands and uplands, because they live in areas rich in forest which are naturally more subjected to at least forestry operations). Nonetheless, some overarching relationship should not be impossible to find, at least between similar habitats. It is, however, important to evaluate the relationship on a more local scale first, before drawing more wide-ranging conclusions. Since clearcutting can have great effects and is likely affecting a large proportion of the Swedish golden eagle population, at least to some extent, it is important to understand the relationship, especially since the golden eagle is a red-listed species. Here, breeding productivity is one important parameter to look into.

As a starting point I explored the golden eagle breeding data to investigate spatial and temporal (time series) trends in breeding productivity in Västerbotten over my study period. Thereafter I set about to see if clearcutting could be a significant explanatory variable behind spatial trends. This could also provide information on the potential role of clearcutting in the observed temporal trend in golden eagle breeding in Sweden, which should then be investigated further and in greater detail in separate studies. I additionally wanted to look into temporal trends in golden eagle breeding productivity during my study period, because if such exist and they are significant and unrelated to temporal trends in clearcutting, they (or rather, the reasons behind them) could be confounding factors in my spatial scale analyses, which is what I used to investigate the relationship between clearcutting and golden eagle breeding productivity: I made spatial-scale, territory-level regressions, where I regressed the average number of nestlings born per year (year visited by surveyors, occupied by golden eagles, and with breeding golden eagles, respectively) in each respective territory, on the cumulatively summed area of clear-cuts, weighted by territory area (where territory area corresponds to the breeding season core area), of each respective territory (ordinary cumulative sum, a.k.a. including clear-cuts made over the entire study period (except for in 2016) and thus clear-cuts up to an age of (at least) 15 years, and excluding clear-cuts when reaching 5 and 10 years, respectively). The clear-cut sums and breeding productivity averages were calculated over the whole study period, thus the regressions were only on a spatial scale (the only temporal factor being when using clear-cut sums where clear-cuts of certain ages are excluded, but then the regressions are still on only a spatial scale). I will also look into possible effects of territories being located in the lowlands or mountains. The resulting methodology and models were simple and I did not e.g. construct prediction intervals, but given that I could not find previous studies on the effects of clearcutting on golden eagle breeding productivity, I thought it appropriate with a more basic start, as well as interesting to see whether a potential relationship could be described by simpler models. A relationship described by a simple model would among other things also be more likely to be reproducible for other data sets, e.g. data from other areas. Doing analyses such as time series regressions would also have been too complex, difficult, and time-consuming for the scope of this thesis, partially because there were gaps in the breeding and clear-cut data that would have been too restricting and complicating for such analyses.

Hypotheses and arguments behind them

My fundamental hypotheses are that clearcutting affects golden eagles and their breeding productivity, and that effects can be positive, negative, direct, and indirect, and vary both spatially and temporally, e.g. between areas and populations (like between mountains and lowlands), with clearcutting intensity, size of clear-cuts, when clearcutting is carried out during the year, characteristics of the habitat, prey and food available in an area, etc.

The golden eagle has a general range-wide association with open or semi-open habitat conditions and golden eagles have been shown to select for such in multiple studies, also including forest-dwelling eagles, as all golden eagles, as mentioned above, are best suited to hunting in open or semi-open habitat conditions (Moss et al. 2014; Watson 2010). Ground visibility, ground access, and good manoeuvre space is likely important and required especially for hunting, while foraging for carrion may be less dependent on openness. Openness would also benefit carrion foraging, though, as it is definitely harder to forage for carrion when you are spying into and trying to get to the ground in a dense, uninterrupted forest. This association and selection has been shown for example by Pedrini and Sergio (2001), who found that the nest density of golden eagles in the Alps decreased with the extent of woodland within the eagles' potential hunting range. In the Scottish highlands, Marquisse et al. (1985), Watson et al. (1987), and Watson (1992) demonstrated a link between reduced golden eagle breeding success and afforestation through commercial tree planting. The results of Whitfield et al. (2001) and in particular Whitfield et al. (2007) were more complex, but they found a similar negative relationship between forest cover and breeding productivity on a landscape scale (not on an individual territory scale, though) the former especially after canopy closure and when forest cover exceeded 10-15%.

In line with this, clearcutting ought to have positive effects as it creates open habitats in the forests, and clear-cuts could thus be attractive hunting and foraging habitat for golden eagles. Clearcutting opens up the forest and create open habitats with good hunting and foraging conditions, with the openness of clear-cuts increasing ground visibility, ground access, and manoeuvre space. Clearcutting could therefore provide access to prey and carrion found in the forests that would otherwise likely not be available outside of in wetlands, meadows, and other such open habitats, and make nesting places available that they previously could not use because they were located in large, dense, uninterrupted stretches of forest, with good hunting and foraging grounds being too far away. Clear-cuts could thus offer increased food-availability (availability of prey and carrion) by increasing the visibility of and access to, in particular, live prey, but also carrion, and providing less protection for larger prey species like hares and grouse, at least until the vegetation has grown up (Olsson 2012). For example Moss et al. (2014), Sandgren et al. (2014), Hipkiss et al. (2014), and Singh et al. (2016) have also hypothesized that clear-cuts ought to be beneficial and important habitat for golden eagles in managed forests in boreal Sweden, and that clear-cuts could increase territory quality. Moss et al. (2014), Sandgren et al. (2014), and Singh et al. (2016) also found indications of this in that they found clear-cuts to be favoured hunting habitat by golden eagles, from juveniles to adults, during the breeding season and otherwise, and have highlighted the positive effect and importance of clear-cuts in the vicinity of the eagles' territories for breeding success. Indeed, clearcutting becoming wide-spread and the dominant harvesting system in Sweden, in particular with clear-cuts of more considerable sizes increasing, could be contributing factors behind the increase in abundance and distribution of the Swedish golden eagle population seen the last 30 years. Golden eagles used to be quite rare in Sweden and were found mainly in the mountains, but this likely allowed them to expand into what was previously too dense and large stretches of uninterrupted forest. Clearcutting might be the main reason, or at least an important contributing factor, as to why the Swedish golden eagles are now so numerous and more common in the lowland forests than the mountains.

Moss et al. (2014) also found that the home range size of golden eagles in the middle and northern boreal zones of northern Sweden was inversely related to the proportion of clear-cuts within each home range (statistically significant for females but not males, perhaps because the females are larger than the males and therefore might depend more on open habitats for hunting and foraging). This could be interpreted as a high proportion of clear-cuts allowing eagles to have smaller home ranges, because their presence makes finding food easier (Moss et al. 2014). McGrady et al. (2002) found that the core areas of golden eagle territories in Argyll (Scotland) were smaller in areas where golden eagle breeding density was highest, and there was an inverse, almost entirely linear relationship between eagle density and core area size (whether significant could not be determined, though). Home-range size of golden eagles has also been shown to be closely related to food-availability in other parts of the world, being smaller where the supply is high, for example the Bale Mountains in Ethiopia by Clouet et al. (1999) and in southwestern Idaho by Marzluff et al. (1997). Nesting density of golden eagles in the Scottish highlands was found by Watson et al. (1992) to be positively affected by the amount of carrion (dead sheep and deer), and in Sweden, a low availability of small game can result in absent breeding, and 3 egg clutches only occur on rare occasions in areas of good food-availability (Artfakta 2015). It is well-established and well-documented that in raptors, including golden eagles, food supply is closely linked to and one of the most important factors behind their breeding success and breeding productivity, in particular the concurrent food supply. This is highlighted in many papers and studies, for example Moss et al. (2012), Moss (2015), Moss et al. (2014), Nyström et al. (2006), Steenhof et al. (1997), Tjernberg (1983c), and Watson et al. (1992). The breeding season, especially during egg-laying and incubation (but also later, of course, e.g. for the growth and survival of both nestlings and fledglings, which affects breeding productivity), appears to be when good food-availability is most important for the golden eagles' breeding outcome that year; for example, Moss et al. (2012) found significant correlations between different golden eagle breeding outcome variables and concurrent primary prey (small game) abundances, but not to prey abundances during the previous autumn (aside from one breeding outcome variable to the previous autumn's pooled abundance of voles, which was rather thought to be due the voles acting as an alternate food source for other predators, decreasing their predation on small game). Even if food-availability was good during the autumn and winter and the eagles are in good health when the breeding season starts again, if food levels are low during the breeding season, they will breed poorly or not try at all. However, it ought not to hurt if food-availability is good outside of the breeding season, if nothing else to ensure that the eagles survived to the next breeding season, and if food-availability is good during the breeding season, being of good health also when it starts should be advantageous. It can also be beneficial in that it may ensure that important prey populations are not low when the breeding season starts, not least by also supplying other predators with food, where an abundance of less important prey species, for the golden eagles, like voles, can also be beneficial (Artfakta 2015; Collopy 1984; Gordon 1955; Watson 2010; Moss et al. 2012).

While golden eagles are habitual scavengers and sustain themselves on carrion to some extent, they are pre-eminent hunters and appear to mainly acquire food through active hunting and killing of prey (Artfakta 2015; Watson 2010). The importance of food-availability for breeding success in golden eagles has also been shown most clearly for the amount of live prey, in particular of more important prey species, which in Sweden in general and the northern Swedish forestlands in particular, generally are small game species, including grouse species (Tetraonidae), especially western capercaillie (*Tetrao urogallus*), black grouse (*Tetrao tetrix*), and ptarmigans (mainly willow ptarmigan (*Lagopus lagopus*)), and hares (*Lepus*), especially mountain hare (*Lepus timidus*) in the north (Artfakta 2015; Moss 2015; Moss et al. 2012; Watson 2010; Watson et al. 1992). In the Swedish mountains rock ptarmigan (*Lagopus muta*) and willow ptarmigan are important, and in reindeer herding areas reindeer, especially calves, primarily as carrion but also alive, is an important food source for some golden eagle pairs during some parts of the year (Artfakta 2015). Golden eagles are opportunists, though, and virtually any animal of a reasonable size may be predated, with well over 400 different vertebrate species recorded as prey throughout its range. Small and medium-sized birds and mammals tend to be most important, though. How generalist they are also varies spatially and temporally, dependent on their need to exploit alternative food sources when and where their preferred prey species are in low numbers (Artfakta 2015; Watson 2010). Carrion can, however, also be an important food source, though mainly during winter when many prey species are in hibernation and/or are at population lows. At that time, carrion can make up a significant portion, sometimes even a majority, of the golden eagles' diet. It varies between places also during winter, though. For example, golden eagles frequently soar to scan the environment for carrion during winter in Scotland, while in the more wooded areas of Norway they tend to actively contour-hunt rather than look for carrion during autumn and winter (Watson 2010). Additionally, while Watson et al. (1992) could show that nesting density was positively correlated to the amount of carrion, breeding success was positively correlated to the amount of live prey (grouse, hares, and rabbits). Deer, moose and roe deer in particular, are likely the main sources of carrion in Sweden, especially in the lowlands; in the mountains, reindeer is likely the main source of carrion.

For clear-cuts to offer increased food-availability there also needs to be prey and/or carrion present on them. Clear-cuts, however, could also attract and increase the abundance of, most importantly, live prey, at least some species, but also other species which could become carrion. That could also lead to prey and carrion appearing in other suitable hunting habitats as well, such as wetlands and fields. Species of interest that could or have been shown to benefit from and/or select for clear-cuts include for example mountain hare (*Lepus timidus*), field hare (*Lepus lepus*), black grouse, willow ptarmigan, roe deer (*Capreolus capreolus*), moose (*Alces alces*), and several small rodent species. In particular voles have been shown to occur in high abundances on clear-cuts, in Sweden especially field vole (*Microtus agrestis*) (Andersson 2000; Artfakta 2015c; Bogdziewicz and Rafał 2014; Chapman and Flux 1990; Danell and Bergström 2010; Hansson 1971; Lewander 2012; Liberg et al. 2010; Lundrigan and Mueller 2003; Olsson 2012, 2012b, 2012c; Sullivan and Sullivan 2014; Swenson and Angelstam 1993; Wegge and Rolstad 2011; Wennberg DiGasper 2008). Benefitted or unaffected species are often common generalist species (Gustafsson and Fedrowitz 2015). For example, common species of small mammals, generalist species more consistently than e.g. forest-specialists, were found to usually increase in abundance after clearcutting, or be unaffected by this disturbance (Bogdziewicz and Rafał 2014). Clear-cuts benefit species that depend on or benefit from disturbance and open areas (many of which are generalists), and clear-cuts also typically and quickly become covered with vegetation that is attractive food for species that are prey or could be sources of carrion for the golden eagles. This also includes commercial tree plants, especially Scots pine (*Pinus sylvestris*). On clear-cuts in Sweden birch (silver birch (*Betula pendula*) and downy birch (*B. pubescens*)) and grasses typically dominate, especially the grass *Deschampsia flexuosa*, which often dominates for several years, and the birches are the most common tree species in the diameter class 0-4 cm, a.k.a. on clear-cuts, in terms of volume. After three to six growth seasons species like fireweed (*Chamerion angustifolium*) and different grasses, like *Deschampsia flexuosa*, have often increased markedly, and raspberry (*Rubus idaeus*) and broadleaf saplings also tends to be common after a couple of years. Vegetation can appear faster than that, though, already the first growth season following disturbance, like after clearcutting and scarification, and grasses can cover clear-cuts in just a year where the site productivity is good. Other attractive trees, herbs, and grasses can also appear, including e.g. Eurasian aspen (*Populus tremula*), willows (*Salix*), European rowan (*Sorbus aucuparia*), sedges, cloudberry (*Rubus chamaemorus*), horsetails (*Equisetum*), heather (*Calluna vulgaris*), and crowberry (*Empetrum nigrum*) (species and proportions depend on for example clear-cut age and site productivity) (Bergstedt and Milberg 2001; Bergstedt et al. 2008; Leijon 1999; Rytter, L. et al. 2014; von Hagen et al. 1998). Moose and roe deer have increased significantly the last decades, increasing the quickest during the 1970’s and 1980’s and peaking in the 1990’s, and today the Swedish and Norwegian moose populations are the densest in the world; in Sweden this has been connected among others to the industrialization of forest management and the clearcutting system becoming the dominant forestry practice, with pine plantations and a wide-spread abundance of clear-cuts and young forests producing a lot of food preferred by moose and other deer (especially during summer, although pine and broadleaved trees are important food also during winter, together with dwarf shrubs) (Danell and Bergström 2010; Liberg et al. 2010; Wallgren 2016; Wennberg DiGasper 2008). The roe deer population also benefitted from the red fox sarcoptic mange outbreak (Danell and Hörnfeldt 1987; Lindström et al. 1994).

The importance of voles, lemmings, and other small rodents as prey for golden eagles and their breeding success and breeding productivity is uncertain, and studies have provided mixed results (Daouti 2017; Moss 2015; Moss et al. 2012; Tjernberg 1983c). They are likely harder for golden eagles to spot and hunt for example on clear-cuts, where they more easily can hide and find cover and protection in and under the clear-cut vegetation, tree stumps, slash, etc. Moss et al. (2012), who found that vole abundance the previous autumn was positively correlated to golden eagle breeding outcome, thought that this was more likely to be because the voles acted as a buffer against other predators over the winter, decreasing their predation on more primary prey of the golden eagles, rather than the golden eagles switching to feeding on voles when they are abundant. However, golden eagles do catch small rodents, and they can occasionally comprise an important portion of their diet, especially if they are abundant and other, more important prey species are of low abundance (Watson 2010). If nothing else, when the rodents are abundant, the alternate prey hypothesis could work in favour of the golden eagles: in particular red foxes (*Vulpes vulpes*) are a competition for prey species that are generally more important for golden eagles, among others grouses and in particular hares and rabbits. However, small rodents are also an important food source for foxes, especially during the rodents’ peak years, during which the foxes often predate more on the rodents and less on the prey species that are generally more important for the golden eagles. During the rodents’ peak years, the golden eagles may therefore have more to hunt of prey species that are generally more important for them (Danell and Hörnfeldt 1987;

Lewander 2012; Lindström et al. 1994; Newey et al. 2007; Olsson 2012; Moss 2015; Moss et al. 2012).

However, clearcutting can also have direct and indirect negative effects on golden eagles and their breeding productivity. For example, Kaisanlahti-Jokimäki et al. (2008) found a significant connection between tourism and decreased golden eagle territory occupancy around tourist locations in northern Finland, but they considered it likely that both tourism and forestry had contributed (effects of forestry and prey abundance could not be tested for, however). The most obvious adverse effect relates to the availability of nest-trees. Forest-dwelling eagles are dependent on there being nest-trees, which should also preferably be surrounded by some amount of forest as to not be too exposed, e.g. to avoid detection by predators and wind-felling. The main reason for this is that golden eagles build large and heavy nests, and if the nest is in a tree, it may become so large and heavy that the supporting tree branches break, the eagles often enlarging a nest every time they maintain and repair it (Ellis 1986). Great demands are therefore put on the crown-structure of the nest-tree, and make the eagles select for massive and thick trees with wide, thick-branched crowns, preferably also with crown deformities, to build their nests in (Artfakta 2015; Burles and Frey 1981; Staav and Fransson 1991; Tjernberg 1983a). In regards to meeting these criteria, Swedish golden eagles appear to show a preference for Scots pine, with nest-trees being Scots pine in at least 95% of noted cases (Artfakta 2015). Large pines with wide crowns and thick branches tend to be old, especially in a cold climate country like Sweden, northern Sweden in particular (Artfakta 2015; Burles and Frey 1981; Staav and Fransson 1991; Tjernberg 1983a). In northern Sweden nest-trees should be at least 200 years old, in a study from 1975-1980 on 97 healthy nest-trees the average age was 311, while on Gotland average nest-tree age has been estimated to 145 years (Artfakta 2015). Golden eagles in boreal Sweden, from juveniles to adults and during the breeding season and otherwise, have in addition to clear-cuts been shown to select also for, among other things, coniferous forest, especially older pine forest (Moss et al. 2014; Sandgren et al. 2014; Singh et al. 2016). Moss et al. (2014) found a clear-cut selection specifically at an intermediate scale (between 400 and 3’240 m from the nest, thus falling within the core area), away from the nest, not closest to it. At the nest site scale (small scale, ≤400 m from the nest), they instead found a selection for rugged terrain and old forest.

It is illegal to cut down trees with golden eagle nests, but it may still happen by accident (Artfakta 2015). Cutting down a nest-tree currently in use would naturally have significant negative effects as it could result in the destruction of eggs or death of young, and may prevent the eagles from breeding successfully that year if they have no suitable alternate nest or could not finish a new nest in time to breed that year. Cutting down nest-trees not currently in use, but which are still used by the eagles, a.k.a. not abandoned (e.g. alternate nest-trees and outside of the breeding season), would also be bothersome as it forces the eagles to find a new suitable tree and build a new nest from scratch. However, while trees with nests may be protected, new suitable nest-trees also need to be continuously available in sufficient amounts to allow the population to grow, and to replace old nest-trees if they become too damaged, worn-down, or fall. Consistent forestry under a clearcutting regime results in a consistent loss of old, massive trees and old-growth forest, and thus trees which could be suitable for nesting, in particular if they are Scots pine. Old-growth forests also tend to be more open and have sparser canopy cover. This is both through such trees and forests being cut and because under a clearcutting regime, the new forests do not become particularly old by comparison (in northern Sweden coniferous forests are clear-cut after 90-120 years, in southern Sweden it can be as early as 50-70 years) (Artfakta 2015; Sandgren et al. 2014; Singh et al. 2014; Tjernberg 1983b)). Thus they never become old-growth, as old-growth forests are defined by the Swedish Nature Protection Agency as forests older than 150 years in northern Sweden and 130 years in southern Sweden, or, when defined by the National Forest Inventory, as forests older than 140 years in the boreal region and >120 years in the nemoral and boreonemoral region (Inghe 2016; Official Statistics of Sweden 2017). More than 90% of the forest is more or less affected by forestry and of low age, and the old-growth forest already constitutes a small proportion of the Swedish forest and is often fragmented into separate stands and small patches that have become more and more isolated from each other. (Artfakta 2015; Inghe 2016; Official Statistics of Sweden 2017). Only about 12% of all the forestland in Sweden is covered by forests older than 140 years, and the majority of it is found in connection to the mountains, with most of it located in northern Sweden, where it constitutes 18% and 13% of all the forestland in northern and southern Norrland, respectively. Most of the Swedish forests are of thinning age (ca 40% of the productive forestland), with 41-60 year old forests being most common (18.3% of the unprotected, productive forestland, 16.6% of all forestland) and mature and young forest decreasing (Official Statistics of Sweden 2017). If there is no or little food in an area, a lot of good nesting places are worth little, which may have the greater negative effects on breeding productivity, but breeding productivity is also decreased if there is a lot of food, but no or few good nesting places.

Forests in steep terrain typically contain more old and large trees than forests in flatter areas because due to their inaccessibility they have often been spared from cutting (Tjernberg 1983a). The old-growth forest left in northern Sweden today is also found mainly on steep slopes in connection to mountains, where tree-felling is difficult, at boulder-rich mountains, in or in connection to ravines and grabens or on mire holms (Artfakta 2015; Inghe 2016). This is both because felling and clearcutting in mountain-adjacent forest is legally more restricted, but also (perhaps in particular) because it is generally less profitable due to slow tree growth, low wood densities, difficult terrain, and cumbersome transport conditions. However, technological advances are made and market prices change, and felling and clearcutting of older, primeval-like forests was still being carried out far up towards the mountain areas in 2015. While the mature forest will naturally increase again as the thinning age forest grows older, in the interim, to satisfy the currently high wood demands more pressure might be put on the remaining, saved old-growth forest (Artfakta 2015; Tjernberg 1983a). The future of the golden eagle in Sweden is therefore considered somewhat uncertain in the longer perspective, as it could lead to a shortage of nest-trees, and it is estimated that trees suitable for nesting might become a limiting factor in the coming 30 years (Artfakta 2015). This decreasing trend in mature forest and the related possible issues might have been present also during my study period, or parts of it. A lack of nest-trees has the greatest adverse effects on the breeding productivity of forest-dwelling and tree-nesting golden eagles. More extensive cutting in old-growth forests and the above mentioned terrain types will have strong negative effects on tree-nesting and forest-dwelling golden eagles, and likely also on the whole species' persistency in Sweden. Negative effects on tree-nesting and forest-dwelling golden eagles would namely likely have negative consequences for the population and the species as a whole because they constitute a larger part of the population (Artfakta 2015). A significant loss and lack of suitable nest-trees and old-growth forest is perhaps the most important and impacting negative consequence that clearcutting could have on golden eagles and their breeding in Sweden, because it may be the most likely, far-reaching, and long-term negative effect. It takes a long time for old-growth forests and new suitable nest-trees to develop and grow old and large enough, for the purpose of good nest-trees around 200-300 years may be required in northern Sweden. However, a shorter time may be required to produce new suitable nest-trees if retention trees are saved at clearcutting, especially if they are already old and large enough (Göran Hallsby, pers. comm. 2017). The question is then if there was already a significant lack of nest-trees during my study period.

Clearcutting and subsequent scarification and planting or sowing, and forestry operations in general, also bring human disturbance, which could also have an important negative effect on golden eagle breeding productivity. The less accessible nature types mentioned above are important also because their inaccessibility decreases the risk of the golden eagles being disturbed in some way by humans there, also being sources of and providing refuges for other species including prey, in particular those sensitive to disturbance, human and otherwise. However, adverse effects on breeding are the greatest and most likely during the breeding season, when the golden eagles are most sensitive, and the closer the clearcutting is to the nests, especially the one currently in use. Adverse effects of human disturbance may therefore not be as extensive as the loss and lack of new suitable nest-trees and old-growth forest – depending on when they occur. There are a number of regulations and recommendations concerning this, for example, in addition to it being illegal to cut down trees with golden eagle nests, any disturbing activities, including clearcutting and other forestry operations, must be avoided in the vicinity of golden eagle nests between January the 1st and July the 31st south of Västerbotten, and between February the 1st and July the 31st in Västerbotten and Norrbotten County. During this time, no activities shall occur closer than 500 m to a nest. It is among other things also recommended to always save protective forest (starting at a radius of 200 m) around golden eagle nests when clearcutting, also around alternate nests (Artfakta 2015). There could still be disturbance effects, though, despite leaving buffers, like if people still walk close to the nest, especially during the breeding season. Human activities can also cause breeding failure due to eagles being prevented from hunting over part of their feeding range, as they avoid areas where people and machines are moving about (Watson 2010).

Clearcutting could also drive away and decrease the abundance of species that are prey or could be sources of carrion, at least of some species. Decreased prey-availability is raised as a concern especially in regards to clearcutting old-growth forests (Artfakta 2015). Species of interest that are known to or could be negatively affected by clearcutting are for example grey red-backed vole (*Clethrionomys rufocanus*), yellow-necked mouse (*Apodemus flavicollis*), hazel grouse (*Tetrastes bonasia*), capercaillie, mountain hare, willow ptarmigan, field vole, black grouse, moose, and roe deer (Artfakta 2015b; Baines et al. 2004; Bogdziewicz and Rafał 2014; Hörnfeldt 2014; Klaus 1991; Lakka and Kouki 2009; Lambin et al. 2001; Letser 2017; MacMillan and Marshall 2004; Miettinen et al. 2010; Mikoláš et al. 2015; Olsson 2012, 2012e, 2012f; Rueda et al. 2013; Sjöberg 1996; Storch 1993; Swenson and Angelstam 1993; Sirkiä et al. 2010; Sirkiä et al. 2011). For example, clearcutting disfavours species which dislike open areas and are sensitive to forest fragmentation and disturbance, human and otherwise, prefer or depend on varied, multi-layered, and multi-aged forests, old-growth forests and sparse natural forests, do not do well in dense production forests, and require dead wood (especially of larger dimensions), fire, or rely on species which do. Food availability may for some species also have been decreased, at least over a longer time perspective. For example, the amount of broadleaved trees, especially species other than birch (silver birch and downy birch), has been heavily decreased by forestry outside of on clear-cuts and young forests before pre-commercial thinning (today broadleaves constitute ca 20% of the standing wood on all forestland in Sweden), as most or all of the broadleaved trees used to be removed at the pre-commercial thinning stage, and were during one period also completely removed from the start using herbicides.

Forestry practice may also be the main reason why the coverage and diversity of many dwarf shrubs, including for example lingonberry (*Vaccinium vitis-idaea*) and especially bilberry (*Vaccinium myrtillus*), and the field- and ground layer in general, are declining and have been doing so for decades in the Swedish forests, in particular on productive forestland and in southern Sweden; these declines may namely be especially related to forests having become darker, in particular in southern Sweden, trends which both appear to have started in the 1980's, where darker forests may be particularly related to Norway spruce increasing and broadleaves, also Scots pine to a certain extent, decreasing (Jönsson 2015; Letser 2017; Official Statistics of Sweden 2017; Olsson 2012e). Bilberry and to a lesser extent lingonberry have also been shown to be disfavoured on clear-cuts and by clearcutting and scarification, although if they survive they can become abundant, especially lingonberry, but not on more fertile clear-cuts, because there they will be outcompeted by grasses and herbs (Atlegrim and Sjöberg 1996; Bergstedt et al. 2008; Bergstedt and Milberg 2001; von Hagen et al. 1998). A large portion of the broadleaved trees are also typically still removed at pre-commercial thinning today (using herbicides in forests is now forbidden, however), which has been brought up as a concern also in that clear-cuts can offer plenty of broadleaved trees only for a relatively short period, until they are pre-commercially thinned (Olsson 2012). Additionally, birch is the most common, well-spread-out broadleaved species (constituting ca 10-12% of the standing wood on all forestland in Sweden), both on clear-cuts and in mature forests, but it is not always the preferred broadleaved species among herbivores; for example, in Sweden deer prefer many other broadleaved species over both pine and birch, especially downy birch (the dominant birch species in northern Sweden (Rytter et al 2014)) (Letser 2017; Official Statistics of Sweden 2017; Ståhl and Berg 2013). However, deer cannot sustain themselves on only birch and pine, and dwarf shrubs appear to be very important and not replaceable for moose, at least during winter. For example, studies show that mixed forests with broadleaves are best for the health of moose (Letser 2017). Scots pine has also decreased in favour of Norway spruce, at least in central and especially in southern Sweden, where spruce dominates, while pine is dominant and slightly more dominant in northern and central Sweden, respectively. This could be related to why the condition of moose calves and the weights and reproduction estimates of moose in Sweden and Scandinavia have been declining for the last 25 years (Hjeljord et al. 2012; Letser 2017). Since the 1990's the moose and roe deer populations have decreased, and while increased hunting by humans and rebounding red fox populations may be the main reasons (so far), those may only be part of the explanation (Annika Felton pers. comm. 2018; Danell and Bergström 2010; Liberg et al. 2010; Wallgren 2016; Wennberg DiGasper 2008). Moose and roe deer may have been able to increase as much as they did during the 1970's to 1990's because at that time dwarf shrubs may still have been sufficiently present (Annika Felton pers. comm. 2018).

Other predators also benefit from the habitat conditions on clear-cuts, like how there is less protection there for species such as hares and grouse (Olsson 2012). A number of studies have shown that predation pressure increases after clearcutting, and in particular generalist predators, especially the red fox, benefit from forest fragmentation and old-growth forest being replaced by young forest, which is attributed in particular to clear-cuts increasing the abundance of voles (Borchtchevski et al. 2003; Kurki et al. 1998; Kurki and Lindén 1995; Sullivan and Sullivan 2014; Wegge and Rolstad 2011). This could also affect a number of species that are generally more important prey for the golden eagle, including hares and grouse species, like capercaillie, black grouse, and willow ptarmigan (Baines et al. 2004; Borchtchevski et al. 2003; Kurki and Lindén 1995; Kurki et al. 1997; Olsson 2012; Wegge and Rolstad 2011). For example, clearcutting and forest fragmentation has been indicated to increase predation pressure on black grouse, mountain hare, and capercaillie (Borchtchevski et al. 2003; Kurki and Lindén 1995; Olsson 2012; Wegge and Rolstad 2011). It might also affect black grouse brooding negatively (Borchtchevski et al. 2003). A study from south-eastern Norways actually indicates that predation pressure rather than habitat factors overall is the deciding factor behind both black grouse and capercaillie numbers, and no significant effects of clearcutting itself were found (Wegge and Rolstad 2011). This also connects to a potential backside of the alternate prey hypothesis: for example, small rodents can sustain other predators during the rodents' peak years, but may simultaneously increase those predator populations. Therefore, when the rodent populations crash, the predation on species which are generally more important prey for the golden eagle may increase, which in Sweden has been seen among others for red fox and mountain hare. In Sweden, the red fox has been shown to be crucial in limiting the numbers of grouse and hare species and fawns per roe deer doe, and conveying the 3-4 year fluctuation pattern of voles to small game, and the red fox switching prey when vole numbers are low is proposed to be an important factor behind mountain hare and black grouse cyclicity (Danell and Hörnfeldt 1987; Lewander 2012; Lindström et al. 1994; Moss 2015; Moss et al. 2012; Newey et al. 2007; Olsson 2012). Similarly, no connection was found between an increase in foxes and the number of hens with young of black grouse, capercaillie, hazel grouse, and willow ptarmigan in southern Finland, but was when vole numbers were low in northern Finland (Kurki et al. 1997). The red fox was decimated by an outbreak of sarcoptic mange in the early 1980's in Sweden and the rest of Scandinavia, and this has been tied to increased abundances of roe deer, grouse, and hare species, and less regular fluctuations among mountain hare from the mid-1980's and onwards (Danell and Hörnfeldt 1987; Lindström et al. 1994; Newey et al. 2007). Similarly, good food-availability outside of the breeding season can improve the condition of other predators, and allow them to reproduce more. Thus, it is also relevant to consider impacts (both positive and negative) on alternate prey/food sources that are/may be less important for the golden eagles (e.g. roe deer and voles) but could be for other predators (e.g. red fox), which compete with the golden eagles for some prey species/ food sources which are/may be more important for the golden eagles (e.g. grouses and hares).

Another relevant side-effect of clearcutting, and forestry in general, is the creation of forest roads, the network of which has increased in Sweden. This could have negative effects on golden eagles and their breeding productivity, as well as species that are prey for them or could become carrion (for example, Summers et al. (2004) found that forest roads affected capercaillie negatively), not just in the disturbance imposed when they are made and trafficked, but also in that it makes outback areas more easily accessible. This could for example facilitate and increase persecution and illegal hunting of the golden eagles as well as species that are prey for them, and also legal hunting of prey species, the ones that are game species, and the likelihood of human disturbance from outdoor activities and (Artfakta 2015).

It should also be added that the previous studies mentioned above have not actually investigated or shown whether clearcutting has a positive effect on breeding productivity (negative or positive). Positive effects are for example not a given even if golden eagles select for clear-cuts, as they may be attracted to and select for clear-cuts even if there is no or little prey, simply because they are open habitats. Sandgren et al. (2014) argued that golden eagles selected for clear-cuts because they had prominent properties as hunting grounds due to prey availability, openness, and occurrence of look-out posts, though. Questions are also raised about whether the weakening reproductive trend in the Swedish golden eagle population is due to a decline in prey-availability in the forest landscape, given the importance of food-availability for the eagles' breeding success and breeding productivity, the majority of the population residing there. It is further asked whether this could be linked to forestry and clearcutting, as the majority of Swedish forests are subjected to that (The Swedish Forest Agency 2016).

All things considered, I hypothesize that in Västerbotten the overall effect of clearcutting will be positive, that is, the positive effects of clearcutting on golden eagles and their breeding productivity will outweigh the negative effects, at least so far and in the lowlands. I based this, first of all, on the fact that golden eagle volunteer surveyors have personally not noted at least an obvious lack of nest-trees in Västerbotten. Secondly, I also got the general impression that, at least so far, the availability of important prey species should be good in northern Sweden, at least most of them and collectively, as well as of moose and roe deer. I did not think it seemed like they had been of low abundances or declined alarmingly, at least not currently and during my study period or collectively to such an extent that it would have considerable negative effects on the golden eagle population (at least not by itself). Additionally, none of the generally more important prey species nor moose and roe deer have been red-listed during my study period, nor are they currently. More of the important prey species also appeared to benefit from and select for clear-cuts and clearcutting than be disfavoured (Artfakta 2015b, 2015c, 2015d, 2015e, 2015f, 2015g, 2015h; Olsson 2012, 2012b, 2012g). Additionally, for example the capercaillie (which is typically used as a flagship for old-growth forests), might not be as dependent on old-growth forests as traditionally thought (lekking places have been found in young forests, e.g.), and it appears to be doing fine in Sweden, managing comparatively well in the modern production forests, especially in the north; the total population has remained stable for the last 15 years, and only southern and central Sweden have had decreases over a longer time scale, because the birds are moving north, likely due to increased planting of Norway spruce and decreases of Scots pine in the south (Artfakta 2015h; Jönsson 2015; Miettinen et al. 2010; Sirkiä et al. 2010; Sirkiä et al. 2011; Wegge and Rolstad 2011). Black grouse is quite consistently considered to be favoured by clearcutting, and while it has decreased considerably the last 30 years, there are currently no signs of a significant population change and the population has been relatively stable the last 15 years, even increasing the last 10 years (Artfakta 2015g; Wegge and Rolstad 2011).

There is, however, a need for research and more data on prey population sizes and trends, and reasons behind prey population changes. For example, there are indications that the mountain hare has been declining since the 1950's, or its population is expected to decline, but there is no simple answer to why and the causes are likely multiple, in addition to there being a lack of population size data, with inferences mostly being made from hunting bag statistics (Artfakta 2015e; Olsson 2012). It is common that wildlife population trends and population sizes, especially of small animals, are not certainly known. There are also no truly clear, answers to how clearcutting and forestry in general are affecting hazel grouse, black grouse, and capercaillie – the specific circumstances, levels and type of felling intensity, landscape and forest characteristics, etc., likely affect the outcome. While forestry and clearcutting often appear to be (or are expected to be) among the factors influencing wildlife population trends in Sweden, they are rarely the only influencing factors, which are often many, and not always major ones, and their specific role and importance usually need to be further investigated. For example, fragmentation and habitat loss of forest habitats in the lowland forest landscape due to clearcutting is believed to be one, not the only, important factor behind declines in grey red-backed vole, random circumstances are assumed to have caused strong decreases in rock ptarmigan and willow ptarmigan, and the rock ptarmigan is moreover not affected by forestry, as it is found too far up in the mountains (Artfakta 2015c; Artfakta 2015d; Christensen et al. 2008; Ecke et al. 2006; Ecke et al. 2010; Hörnfeldt 2004; Hörnfeldt et al. 2006). While clearcutting in forestry affects many plant and animal species negatively, especially forest-specialists, effects of clearcutting and forestry can also be complex and not straight-forward, especially the overall effect, and there are also species which are affected positively, or are unaffected. Benefitted or unaffected species are often common generalist species, and several of the species which are important for golden eagles are also generalists (Gustafsson and Fedrowitz 2015). Additionally, many species, just like the golden eagle, can be or are affected both positively and negatively by clearcutting and forestry, e.g. mountain hare, willow ptarmigan, and field vole, and then it is usually harder to predict how their populations will be affected (Artfakta 2015c; Artfakta 2015e; Lambin et al. 2001; Olsson 2012). The causes behind increases in predation, e.g. of red fox on mountain hare, are also often multiple, complex, and not straightforward (Bergström et al. 2009). The time until pre-commercial thinning can also still be considered a pretty long time, as coniferous stands in northern Sweden are usually not pre-commercially thinned until they are 20-26 years old, and sometimes later than that (Pöntynen Boström 2012). This is a long time especially from the perspective of small rodents, which rarely become older than 1 year in the wild, as well as for important prey species of the golden eagle, of which many become between 2-5 years old. This could even be considered to be the case for more long-lived species like the moose, which can live to 15-25 years old in the wild.

There are also still questions regarding the diet of golden eagles. This includes the direct and indirect (as a food source for other competing predators) importance of voles, lemmings and other small rodents (all the more relevant to know given the disruption of small rodent cyclicity), carrion, and reindeer, in particular how much the golden eagle actually actively hunts reindeer, especially calves, is uncertain. In fact, the contribution of ungulates in general to the diet of golden eagles has long been the most controversial and debated aspect of the golden eagle's whole biology (Watson 2010). Most of the knowledge of the diet of golden eagles also comes from the breeding season, based on remnants in their nests, while their diet outside of it is poorly known, but which could also be relevant. On a related note, the long-standing question remains as to why the cyclicity in voles, lemmings and other small rodent populations has dampened significantly since the 1970-80's in northern Sweden and elsewhere in Fennoscandia, in both mountains and lowlands (which has also led to decreased abundances in many of the affected species, including field vole, bank vole (*Myodes glareolus*), and especially grey red-backed vole) (Hörnfeldt 2004; Ims et al. 2008). More importantly, dampening cyclicity is also observed among small game populations, but that may be for different reasons than in small rodents (Ims et al. 2008). The disrupted cyclicity in small rodents itself may have disturbed the regularity of small game fluctuations, perhaps mainly through the alternate prey hypothesis, and the sarcoptic mange outbreak in red fox has also contributed, especially in mountain hare (Hörnfeldt 2004; Ims et al. 2008). However, so far, small game species generally do not appear to be displaying cyclicity dampening with lowered abundances. Predation pressure may therefore not have had significant effects on them, at least so far. The long-term consequences of disrupted small rodent cyclicity and how it will affect the golden eagles, in particular if it will lead to significantly more predation on small game species, and if that will be extensive enough to or if it will have negative effects on the golden eagles and their breeding, are not known, though. While golden eagles are opportunists, it is reasonable to assume that changes to the availability of more important prey species would have affect their breeding, considering that the importance of food-availability for golden eagle breeding success and breeding productivity has been shown most clearly for the amount of live prey, in particular of more important prey species. Especially if all of the more important prey species decline, should negative effects be expected. Nonetheless, it is not known if more long-term decreases in important prey species (e.g. capercaillie, black grouse, ptarmigans, mountain hare), among others through biotope-changes caused by forestry, will lead to a declining golden eagle population (Artfakta 2015).

Nature conservation measures, especially at clearcutting, have also increased in Sweden, especially since the late 1980's/early 1990's, both through legal changes, and, in particular, since the end of 1990's/early 2000's, also an increase in certification (in particular with FSC and PEFC), which may have had positive effects (Kruys et al. 2013; Svenskt Trä 2003). For example, the amount of old forest (forests older than 140 years in the boreal region and >120 years in the nemoral and boreonemoral region) has increased since the 1990's, especially in the boreal region. The amount of broadleaved trees has also increased, by 52% from 1985 to 2014 on productive, unprotected forestland, 36% for broadleaf-dominated forests (which have increased everywhere except for in northern Norrland, where it is decreasing), and there is also a slight increase in mixed broadleaf-conifer forests. The amount of broadleaf-dominated forests appears to have stabilized in Sweden overall, but broadleaved trees in general appear to be continuing to increase (Official Statistics of Sweden 2017). It is also clear that 0-10 year old stands have become structurally richer since the introduction of the retention approach in forestry, for example retention of living trees (≥15 cm diameter; single trees and trees in patches <0.02 ha) on clear-cuts has increased, reaching 1950's levels by 2007 (ca 15 trees per ha on average). The amount of large trees (diameter ≥45 cm) has also increased, in particular in Götaland and Svealand but also in northern Sweden. Amounts of dead wood have also increased, although the actual amounts are low compared to what is available in old-growth forests, especially of dead wood of larger dimensions (Kruys et al. 2013). There are additionally a number of legal protective measures, regulations and recommendations in regards to golden eagles and what do when conducting forestry and clearcutting in a golden eagle territory and close to golden eagle nests, which may also have had positive effects (Artfakta 2015).

However, how big of a difference the nature conservation in Swedish forestry has made remains to be studied in more detail, both in general and for golden eagles. For example, most of the Swedish forests are, as previously mentioned, of thinning age, and only 12% of all the forestland is covered by forests older than 140 years (albeit constituting a higher amount of the forestland in Norrland, especially northern Norrland). While there has been a more considerable increase in >140 year old forest in the boreal region, the trend there has been stabilizing lately. In total amounts broadleaved trees currently still also only constitute about 20% of. Additionally, only about 7% of the productive, unprotected forests are broadleaf-dominated. How well spread-out these broadleaved trees and forests are in the landscape is also a relevant question. The declining trends of dwarf shrubs and the field- and ground layer in general also appear to continue (Letser 2017; Official Statistics of Sweden 2017). It should also be considered that nature conservation measures have increased mainly since the 1990's, which may or may not be long enough for significant effects, especially considering that my study period started in 2002. This applies for example to if sufficient amounts of trees that are or could become suitable for nesting, and particularly if they have had time to become old and large enough to be suitable for nesting, or if they were that to begin with. They should preferably be Scots pine, and are also more valuable to the golden eagles when they are left surrounded by other trees, rather than standing alone and exposed. Leaving dead trees, high stumps, dead wood etc. may also be more common than leaving living trees, especially large and old trees, as living trees are usually left on only about 8% of the clear-cut area (Gustafsson and Fedrowitz 2015). Retention of living trees was found to have increased in 0-10 year old stands by Kruys et al. (2013), but they need be kept and survive long-term, and not be cut down at a later time or die from being left, which is more likely if they are left as spaced out singles. With pine, it can also be hard to determine how much has been left for retention, and how much is for natural regeneration, to be cut down later (Kruys et al. 2013). Nonetheless, an obvious lack of nest-trees has not been noted in Västerbotten by golden eagle surveyors, which might for example be because forests have not been clear-cut extensively enough and/or due to nature conservation measures. Legal protective measures of golden eagles, their nests and habitats may also have had positive effects, and those have lasted longer. However, the spatial distribution of potential nest-trees must also be considered. Golden eagles may for example need larger groups or areas of old trees/old-growth forest in order to find them, and it is still more common to leave single trees rather than groups scattered out on clear-cuts. Even if the eagles can find nest-trees when they are scattered out at low densities, searching them out would reasonably take longer (especially if they are rare), which could have negative consequences for their breeding.

As the amount of area clear-cut in a territory continues to increase, however, I further believe that the effects will stop being positive at a certain point, stabilize, and eventually turn negative. First, this could occur because a utilization limit is reached, based on how fast eagles can consume resources, hunt, forage, and cover an area. A very large clear-cut amount could also bring too much and consistent human disturbance, in particular increasing the likelihood that clearcutting occurs during the breeding season and too close to the nests, exposing the nests too much, or maybe even cutting them down. It can also lead to too many old trees and/or too much old forest and thus potential new nest-trees being cut down. The relationship will therefore be analysed with both simple linear and 2nd order polynomial regression models, where the 2nd order polynomial may provide a better fit than the simple linear model, with the hypothesis that the relationship starts out positive and then either stabilizes or turns negative, depending on how large the greatest clear-cut amounts are. The hypotheses are then that the simple linear relationship will be positive, while the 2nd order polynomial will start out positive and then turn negative. The relationship will realistically be more complex and not perfectly described by a 2nd order polynomial either, but higher order polynomial regressions than 2nd degree were still not made, both to avoid for example overfitting and the like, and because it was thought that a 2nd order polynomial trend would be the most dominant trend, capturing most of the relationship, and thus that a significant relationship, if such exists, could still come through.

The amount of area clear-cut would obviously be important in how great many of the potential effects of clearcutting are. Human disturbance, however, may have disproportionately negative effects in relation to clear-cut amount compared to e.g. loss of old-growth forest and creation of open hunting habitat, as a very small clear-cut amount will likely have no such significant effects because it does not confer a large enough habitat change. Effects may, however, be significant through human disturbance if clearcutting occurred e.g. close to a nest currently in use during the breeding season, or if the nest-tree is cut down. Human disturbance can also have significant effects more easily, like just by people walking or driving around, especially if by nests during the breeding season. Of course, if the clear-cut amount is very small, the likelihood of clearcutting occurring close to a nest, or even golden eagles coming across humans, is smaller.

Temporal aspects like when and how during the year clear-cuts were made, clear-cut age, how regularly clear-cutting is carried out and the area clear-cut each time, for example on a yearly scale, are also important. Effects of clear-cuts are highly unlikely to be restricted to just one year or so, and thus the effects of clear-cuts differ e.g. in regards to how many years the golden eagles have been able to use them. How many years the breeding of golden eagles has been disturbed by forestry and clearcutting operations is also relevant. The regularity with which clearcutting is carried out and the amount clear-cut each time also affects how much area is left available for more future clearcutting, and when clearcutting can be carried out again. For example, if clear-cuts are not made very often, positive effects related to hunting habitat would eventually peter out, not being "renewed" and kept more or less constant by additional clearcutting in other parts of the territory. Similarly, if a large part of a territory is clear-cut at once or in a short amount of time, there will be a long period of unfavourable habitat over a large portion of the territory, with not much area left to clear-cut until the new forest is old enough to be harvested. On the other hand, if clearcutting is consistently carried out within a territory, e.g. coming back to clear-cut each and every year, it will for example impose consistent human disturbance, which could be detrimental especially if the clearcutting consistently occurs during the breeding season.

The perhaps most important temporal aspect of clearcutting is that the quality and effects of clear-cuts change and differ with time because with time the clear-cut vegetation will grow taller, ground access, manoeuvre space, and ground visibility will decrease, and protection for prey will increase. Clear-cuts are dynamic habitats and it is likely their quality as hunting ground starts deteriorating when regrowth prevents eagles from accessing prey on the ground. In such cases individuals will be forced to abandon old, degrading hunting grounds, and move to newer clear-cuts (Moss et al. 2014). Canopy closure and forest of cover of 10-15% in particular seemed to decrease breeding success in golden eagles in Whitfield et al. (2001). In time clear-cuts will typically become new closed forest stands again, and after some point habitat effects will differ little before and after clearcutting, at least in regards to positive effects (Hipkiss et al. 2014). This is strongly tied to potential positive effects and as such they are expected to usually be more short-term. The same goes for negative effects such as abundances of prey disfavoured by open habitats. An exception would be if clearcutting increases or decreases the abundance of prey, other relevant species e.g. for the availability of carrion, and the golden eagles themselves, enough that abundances remain high and beneficial, or low, more long-term. Potential negative effects like the human disturbance aspect of clearcutting would also be short-term, at least in relation to on and close to the same clear-cut (considering that golden eagles and possibly other species could be disturbed by other clearcutting operations at a larger scale within the territory). Loss and lack of nest-trees and old-growth forest are expected to be long-term, likely the most long-term, as it takes a long time for new suitable nest-trees and old-growth forests to develop and grow old and large enough. I may not be able to see a lack of nest-trees being caused by the clearcutting during my study period, however, since a more immediate lack of nest-trees would likely require extensive amounts of clearcutting within a territory, which has not happened at least during my study period. This would likely be the case also if there should already be a lack of nest-trees, because if they are few, the likelihood of happening upon them and cutting them down would reasonably be lower, unless large amounts of forest are cut.

When clear-cuts start having effects, are of highest quality, when they start to decrease in quality, and when they are no longer used or are used very little, is harder to predict. When they stop having effects is not something which would happen sharply, but drawn out, decreasing more asymptotically in the end before they are finally not used anymore, not least, then, because there are likely both short-term and long-term effects of clearcutting, that last different amounts of time. These things likely also vary from clear-cut to clear-cut. Vegetation can show up on clear-cuts earlier than a year depending on when it was made, for example the following growth season on clear-cuts made during autumn or winter, and they can be covered by vegetation in just a couple of years, although for example grasses can cover them faster where site productivity is good . There is little vegetation right after the clear-cut is made, though, and commercial trees are not established immediately after the clearcutting (Leijon 1999). On fresh clear-cuts there is therefore likely no or little prey and carrion for the golden eagles, also e.g. because other animals are also scared away and a fresh clear-cut is too recently disturbed, by humans and otherwise, for them to have returned. More significant positive effects are therefore not expected immediately after the clear-cuts have been made, while an immediate negative effect is possible, for example related to the human disturbance. This initial lag-time in positive effects may only last a short while, and how long it lasts depend e.g. on site productivity, plant species present in the surrounding landscape, and when the clear-cut was made. The young forest stage is officially said to begin when plants reach a height of 1.3 m, lasting until they pass about 7 m in average height (SkogsSverige 2018). However, vegetation-wise, the clear-cut stage ceases, and the young forest stage thus begins, when the new forest generation starts creating a forest stand climate, when the young forest's crown layer starts to close. In a successful, planted coniferous cultivation of average site productivity in Västerbotten, this may occur 15-20 years after the clearcutting event (Göran Hallsby pers. comm. 2017). At this time the forest may be around 12-18 years, depending on when it was established (typically 2-3 years after the clear-cutting event when planting). At a height of 1.3 m, a coniferous forest is maybe 7-9 years old in northern Sweden, as small conifer plants grow about 1 dm per year in northern Sweden, and Norway spruce stands in northern Sweden were found to have an average height of 3-4.6 m at an age of 21-26 years, while in Scots pine stands aged 25-26 years the average height was 3.8-4.3 m (Pöntynen Boström 2012). At an age of 12-18 years, a coniferous forest in northern Sweden might therefore be around 2-3 m in average height. The clear-cut vegetation and tree plants might grow dense and tall enough to decrease ground, food, and live prey visibility and/or make it hard to reach food and especially catch live prey, before clear-cuts turn into young forests, though, perhaps mainly when using the vegetation-wise definition; clear-cuts might be useful for a while after the plants have reached a height of 1.3 m. Sandgren et al. (2014) suggested that areas are sufficiently open for golden eagles when the forest height is <2 m. At that point planted conifers in northern Sweden might be somewhere around 11-14 years old, to which the time until planting should also be added, typically 2-3 years, a.k.a. when the clear-cuts are 13-17 years old. Initially, most broadleaved tree species in Sweden tend to grow faster than conifers, though, especially silver birch and downy birch, which are less browsed than e.g. European rowan, Eurasian aspen, and goat willow. Birch could therefore reach that height sooner, but how densely trees are planted and stand, site productivity a.k.a. how fast the trees grow, which prey dominate and the eagles' diet in the area, etc., also matters. Small rodents like voles get cover and protection already from grass, herbs, branches, stubs, and such, though. Voles and other small rodents may be less important for golden eagles, though, at least directly as prey, and it would take longer for the vegetation to shield larger prey like hares and grouses, and small game species generally appear to be more important prey for the golden eagle. Repeated human disturbance is more negative for golden eagles than isolated occasions, and there is a possible additional human disturbance effect when the clear-cut is scarified, at which point most of the present vegetation is also removed, and planted or sown, depending on when the clearcutting, scarification and regeneration establishment occurred. Scarification typically occurs after 2-3 years if planting (the most common regeneration method in Sweden) is the chosen regeneration method, with planting usually being done directly after scarification (if scarification was done during autumn planting may not be done until spring, though, since that appears to be the safer time for planting) (Valinger 1997). After that other vegetation can show up quickly again, though. After the regeneration has been established, though, the clear-cut will again be revisited several times e.g. for regeneration inventories, possibly reinforcement planting, etc.

To try to account for some temporal aspects (clear-cut age, how regularly clear-cutting is carried out (on a yearly scale), and the area clear-cut each year), I will use cumulative rather than ordinary, non-cumulative sums of clear-cut area in the regressions, and look at three age categories: including clear-cuts that are up to (at least) 15 years old (that is, including all clear-cuts made over the study period), and excluding clear-cuts after they have become older than 5 and 10 years, respectively. Due to the variability and uncertainty of when clear-cuts "cease to be clear-cuts" and clear-cut effects start to decrease and finally vanish, three different age categories were included and the age limits had to be chosen a bit arbitrarily. Although I would instinctively say that the clear-cut variables with clear-cuts successively excluded as they become too old will perform better, it is therefore also hard to hypothesize which clear-cut variables will perform better, especially between the >5 and >10 year age limits, but even the oldest clear-cuts in my data could e.g. possibly still be useful hunting grounds for golden eagles.

I hypothesize that the relationship will perform best for the lowland territories alone, then all territories together. I think the relationship will perform the worst for the mountain territories alone, with no significant or noticeable relationship. If there is a significant or noticeable relationship in the mountains, however, it might be negative. It is unlikely that clearcutting would have any positive effects on territories in the mountains, or even any effects at all. Clearcutting has not occurred at all in a majority of the mountain territories as most of them are located at higher altitudes in mountain terrain that already contains a lot of wide open areas without forests or trees. Cliff-nesting is also more common in the mountains than the lowlands, and appears to be the dominant nesting type, especially at higher altitudes. Although not as much as at higher altitudes, this also appears to be the case in mountain territories at lower altitudes which contain more forest, which additionally still contain a lot of open areas. Clearcutting is also usually not as extensive in the forests in the mountain areas, due to accessibility issues, lower growth, regeneration difficulties, generally lower profit, and legal restrictions in the mountain-adjacent forest, thus the amount of clear-cuts is generally smaller there, and what clearcutting is carried out would not add much in respect to opening up the habitat. However, where clearcutting is carried out there could be negative effects, for example related to human disturbance, which could have significant effects on the affected individual territories, even if large amounts of clear-cuts are not made, as explained above. Mountain golden eagles may even react more negatively to clearcutting, and other forestry-related human disturbances, than golden eagles in the lowlands, because lowland golden eagles ought to happen across forestry, clearcutting, and humans and their activities more often, and might therefore be more tolerant of them. A negative relationship would, same as a positive relationship, not go on forever, but it would not turn positive after a certain point, but rather continue to decrease until a certain point is reached where it stabilizes, and, depending on the clearcutting amount, reach and remain at zero, e.g. when there is too much disturbance, too much or all the forest has been cut, etc., making the golden eagles reproduce rarely or cease reproduction altogether, or even abandon the territory. Clearcutting would affect a smaller amount of the mountain territories, though, thus the effect on the mountain territories as a group would likely not be significant.

Materials and methods

Study area

My study area was all the known golden eagle territories in the county of Västerbotten, which is located in northern Sweden, in about the middle of Norrland. All studied territories belonged to Västerbotten, and were found in all of its municipalities except for Robertsfors.

Apart from a few towns and villages Västerbotten is generally sparsely populated, with larger cities and more people found by the coast. Important land uses are forestry and reindeer husbandry. The dominating landscape type in Västerbotten is taiga, and the county is mainly located in the middle and northern boreal zones, which in Sweden are characterized by coniferous forests, mires and lakes, with elevations from 100 to 650 m.a.sl. The forests in Västerbotten are dominated by Scots pine and Norway spruce, with some elements of broadleaved trees, mainly birch (both silver birch and downy birch, but the latter dominates). Commercial forestry utilizing clearcutting affects most of the productive forest in Västerbotten, which has turned a high proportion of the forest into commercial production forest of widespread even-aged and even-layered monocultures of mainly Scots pine and Norway spruce (Esseen et al. 1997; Hipkiss et al. 2014; Sjörs 1999).

Farthest to the west mountains, which are a part of the Scandinavian Mountains, also stretch along the Norwegian-Swedish border. The Scandinavian Mountains are fells (“fjäll”), which defined by Nationalencyklopedin (2018) are mountains that rise above the climatic forest line, into the bare mountains zone (“kalfjäll”), and have been shaped by large masses of ice and glaciers and characterized by relatively flat slopes and rounded shapes. Although the cultivation border separates the true mountain areas from the rest of Sweden, the actual mountains are thus found above the forest line, and the forest line is also where the true mountain vegetation zone, the bare mountains, starts. The mountain-adjacent forest is found below the actual mountains and goes up to the forest border, and is a mix between mainly conifers (Norway spruce and Scots pine), and birch, primarily mountain-birch (*Betula pubescens* ssp. *tortuosa*). The mountain-adjacent forest includes the conifer-dominated mountain-coniferous/mountain-adjacent coniferous forest, and above it the mountain birch forest, which is dominated by mountain birch (Grundsten and Palmgren 2010; Melander 1984). Mountain-adjacent forest is found to the west of the mountain-adjacent forest border, “fjällnära skog gränsen”, an administrative border defined and established by the Swedish Forest Agency. The mountain-adjacent forest border and the cultivation border follow each other somewhat well, although they can be above and below each other.

The bare mountains are largely located in the alpine zone, a.k.a. above the tree line, and are dominated by alpine tundra. However, it begins at the forest line, and thus scattered, low-growing trees (mainly mountain-birch) are also found there, up to the tree line. The Scandinavian Mountains, including in Sweden, also contain high mountain (“högfjäll”) terrain, relatively bare mountain areas which reach far above the tree line and in the Scandinavian Mountains are found at least 1’200 meters above sea level. They are characterized by glaciers (though today they are missing in some areas), sharp peaks, large relative height differences, frost-burst rock fields, and bare rock, where only the hardiest vegetation grows, mainly mosses and lichens. The high mountains are covered by snow a large part of the year, and also during summer snow may fall and remain. By area low mountain ("lågfjäll") terrain dominates the Scandinavian Mountains, however, including in Sweden, mountains which in the Scandinavian Mountains reach no higher than 1'200 m.a.sl., but are located above the forest line. The low mountains can reach above the tree line, and the landscape consists of rounded mountains and flowing mountain plains, with an often expansive view. Occasional glacier niches can occur in the low mountain area, but only under special circumstances.

Breeding data and coordinates

The Västerbotten division of Kungsörn Sverige provided breeding data from 1995 to 2016 for all known golden eagle territories in Västerbotten, including historical territories (active in the past, but likely not anymore, or have not been active for an extended amount of time). Data was available for 193 territories, although not every year for every territory. RT90 2.5 gon W coordinates, corresponding to approximate nest locations, were available for 164 territories. Data was provided per municipality, which contained yearly territory-level information about the number of young born (denoting successful breeding) or a status which was one of the following: territory was/with a) visited (k = "kontrollerade revir" in Swedish), b) not visited (? = "ej kontrollerade"), c) occupied (b = "besatt revir"), d) unsuccessful breeding attempt (m= "misslyckad häckning"), e) visited with unknown result (o = "okänt resultat"), or f) breeding attempt with unknown result (h = "häckning"). Not all territories were visited every year. There was also data on the number of nests found in each territory (known nests), observed fledglings in the municipality each year, and more. Territories in the true mountain areas, above the cultivation border, were also divided into two classes, "F" and "O". F mountain territories have their largest part above the tree line and in high mountain terrain, while O mountain territories are located above the cultivation border but not in high mountain terrain. I used this classification to separate the territories into two groups, "mountain territories", which includes both F and O mountain territories, and "lowland territories". 70 territories, 59 with coordinates, were located in the mountains, of which 59, 51 with coordinates, were F mountain territories. For 134 territories one set of coordinates was available (51 in the mountains, of which 44 were F mountain territories). For 30 territories multiple coordinate-points (2-4, usually 2) were available (8 in the mountains, of which 7 were F mountain territories, all with two sets of coordinate points). In total, 199 nest coordinate-points were available (67 in the mountains, of which 58 were F mountain territories). Many of the territories contained more than one known nest.

Known territories, including historical (likely abandoned) territories are territories which at some point have been occupied with or without a known nest-location, alternatively a territory confirmed through an ensured nest-location without the confirmed territory having ever been observed as occupied. Newly discovered territories were new territories discovered since the last breeding report, which could also be a territory confirmed through a newly discovered but not recently built nest. Territories were visited between the 1st of January and 15th of September, and if nothing was seen, they would be noted as only visited. However, if two sub-adults or adults were observed at least 2 times separated by at least 10 days the same year from the 1st of January to the 31st of July, circling together or seen in courtship flight, and not being aggressive to one another, then the territories would be noted as occupied. They could additionally be noted as occupied with known nest/s if in addition to that at least one nest was known and at least one of the following criteria were seen: an initiated nest; two sub-adults or adults staying at a cliff with a nest or within 200 m of a nest-tree; mating; brooding; egg remnants; bad egg; dead young; successful breeding with young. Otherwise they would be noted as occupied with no known nest/s. For some of the previously mentioned criteria, territories would instead be noted as a category of breeding: breeding with unknown results, unsuccessful breeding attempt, or successful breeding attempt. Breeding with unknown results was where observations had been made of an egg, young, or a brooding bird before the 1st of June, but no revisit had been made after that point. A breeding attempt was considered unsuccessful if no young were observed in a nest where brooding was observed, a dead young was found in the nest before the 15th of July (as after this time, a young may already have fledged), egg remnants or a bad egg was found in a nest with no young before the 15th July, as well as if two dead young or one dead young and a bad egg were found regardless of date. A breeding attempt was considered successful if at least one young was present in the nest after the 1st of June, or at least one fledgling was seen flying in the territory with at least one adult bird before the 15th of September. Number of young was thus counted between the 1st of June and 15th of September, and was the estimated number of young after the last visit to the nest. If fledglings were spotted flying together with adult birds during this period, their numbers would be included in the number of nestlings, as well as recorded separately. Territories with no known nests required at least one visit during the inventory period (1st of January to 15th of September). Territories with known nests were visited more often, always at least three times: in June, to assess breeding success and, where breeding was successful, and count and ring nestlings (which at that point are usually at least 4 weeks old). Later visits before the 15th of September, when fledglings could potentially be spotted, were only occasionally carried out. Territories were also always visited to assess and confirm pre-breeding (by observing e.g. display flights, nest building/maintenance, and mating) and actual breeding (by presence of eggs, incubating adults, or nestlings), where confirmation of actual breeding was required to register territories as a category of breeding. For this, territories would usually be visited in March and May, respectively. In addition to this, territories could be visited more often, usually the case with territories of higher priority, e.g. where a new pair had been spotted, and where pre-breeding, breeding, and/or nestlings had been observed. Exceptions were commonly made, with territories being visited more rarely, some years not at all, if territories were suspected of being abandoned, at least after a certain amount of years with no observations of eagles having been made. Additionally, if in a certain year a nest had fallen down or been otherwise destroyed, that territory could be exempted from being visited the year after, as such events were considered to decrease the likelihood of occupation the next year enough to not consider the territory worth visiting the next year.

Clear-cut data

The Swedish Forest Agency's continuously updated online resource Skogsdataportalen (http://skogsdataportalen.skogsstyrelsen.se/Skogsdataportalen/, administrator Fredrik Salén) provided me with data on implemented clear-cuts, which I retrieved on 2017-02-13 for Västerbotten, 2017-02-24 for the counties Västernorrland and Jämtland, and 2017-02-27 for Norrbotten County (between these dates, no additional data had been added to the counties from which I had already retrieved data). The background map I used in ArcMap was the Overview Map (Översiktskartan) from the Swedish Land Survey department (Lantmäteriet), provided through SLU's online map resources. For every clear-cut, information was provided about the area (ha) of implemented clear-cuts, year that the application for clearcutting was registered and the date of implementation. This was provided in a vector file with clear-cuts represented by polygons, whose spatial dimensions and location were given in the reference system SWEREF99 TM. "Monitoring" of clearcutting is thus carried out and results were thus available every year for every territory.

Territories may extend over county borders, one territory is for example known to extend over three counties, and therefore data on clear-cuts was also gathered from the counties neighbouring Västerbotten, the counties Norrbotten, Västernorrland and Jämtland. Data on clear-cuts in Västerbotten was available from 1998, however the earliest years had considerably less data available than later years (1998-2000 especially, to a certain degree also 2001). Similarly, much less data was available before 2002 for the counties Norrbotten, Västernorrland and Jämtland as well. Clear-cuts in Skogsdataportalen have also been noted to be very well mapped in 2002 and forward (Per Sandström pers. comm. 2016). Therefore, data on clear-cuts, and necessarily also golden eagle breeding, was not used before 2002.

The Swedish Forest Agency registers implemented clear-cuts through differential aerial photo analyses. The date of implementation given for each clear-cut is actually the date the aerial photo was taken. These days clearcutting is carried out year-round, but the aerial photos are often taken and analysed between the end of May to September. For this reason, analyses looking specifically at the date of clearcutting were entirely avoided. It also means that clear-cuts registered for a certain year may actually have been made the previous year, during the winter, after the main aerial photo season (Fredrik Salén pers. comm. 2017). However, this will have little effect here because the clearcutting will be summarized and the analyses will be made on a spatial scale, not as a time series. It does however pose an issue in that clear-cuts made in 2016 may have been made after the last survey of the golden eagle breeding outcome (at earliest June the 1st and at latest September the 15th), or rather, specifically, after nestling production had been determined (usually in June), which is what I concerned myself with in this thesis. However, since I do not know exactly when clear-cuts were made, clear-cuts from 2016 were not included to avoid the inclusion of clear-cuts made at such a time that they could not have had an effect on the breeding data (breeding data from 2016 was included, though, as this could be affected by clear-cuts made previous years). This poses the opposite problem, though, in that potential effects on the breeding in 2016 from clearcutting in 2016 and possibly also in late 2015 will be missed. However, effects of clearcutting on breeding the same year may or may not be significant or present at all (albeit depending a lot on when and where the clearcutting occurred, e.g. during the breeding season and close to a nest or not), and it ought only affect the breeding in 2016 (clear-cuts affecting the breeding in 2015 ought to all be included). The effect of excluding clear-cuts registered in 2016 is therefore assumed to be negligible. Thus the data used in the analyses is clear-cuts made in

2002 to in 2015 (which applies to all four included counties) and golden eagle breeding in 2002 to in 2016.

Additional definitions

Breeding productivity for golden eagles can be defined in many ways, but it involves the outcome of breeding in some manner, beyond just breeding success. It is usually defined as the number of young reaching the minimum acceptable age for breeding success reported, commonly, per territorial pair or per occupied territory in a particular year (Southern 1970; Steenhof et al. 1997; Steenhof and Newton 2007). Breeding success is then typically defined as producing young that survived to fledge (a.k.a. fledglings, young that have become fully-feathered and voluntarily left the nest for the first time and flown at least once, but remain in the care of its parents, still being largely dependent on the nest and the parents for food (Burles and Frey 1981; National Eagle Center 2017; Southern 1970; Steenhof et al. 1997)) (Southern 1970; Steenhof et al. 1997; Steenhof and Newton 2007). However, in the golden eagle monitoring program from which I got my data territories were only occasionally visited at times when fledgling numbers could be assessed, while visits were always made in June, when young are nestlings (a.k.a. young which are not fully-feathered or able to fly, that are entirely dependent on the nest and its parents' care and food (Burles and Frey 1981; National Eagle Center 2017; Southern 1970; Steenhof et al. 1997)). Fledglings were therefore not counted as often as nestlings. Fledgling data was also only available per year for each municipality, not territory, and was also not available for every year. I have therefore only calculated measures of breeding productivity based on the nestling data. The situation was the same for e.g. Hipkiss et al. (2014) and Moss et al. (2012), who got their data from the same source as me and also opted to use the relatively early date (the time of nestling ringing) as an indication of breeding productivity. Moss et al. (2012) furthermore used for example nestlings per occupied territory and nestlings per breeding territory, while Hipkiss et al. (2014) used the total number of nestlings born over the study period.

I calculated breeding productivity on a basis of territory rather than territorial pair, as data was not available on for example when a territory became abandoned by one pair and taken by another. However, in difference to Hipkiss et al. (2014), I did not think it appropriate to use total number of nestlings as a measure of breeding productivity. I was concerned about bias, for example when comparing breeding productivity between territories, or groups of territories, and when analysing breeding productivity relationships. This was because not all territories were visited the same number of years (and not just because some were discovered later than others), and therefore the breeding productivity of less visited territories may be under- or overestimated using total number of nestlings. In all my analyses I therefore used breeding productivity calculated as an average, the total number of nestlings born in a territory over the study period averaged by the number of years during the study period that that territory was 1. visited by surveyors (status k, m, b, number (nestlings born that year) the highest possible number), 2. occupied by golden eagles (b, m, number), and 3. with breeding golden eagles (m, and number, thus including both years of successful and unsuccessful breeding), respectively. Years with a status of o and h, a.k.a. visited and breeding but with unknown results, respectively, were not included because they lacked data on resulting number of nestlings that year, so including them when calculating the breeding productivity averages could result in underestimation. Still, even when averaging by year, if territories had not been visited very often their breeding productivity may still be under- or overestimated, and comparing them to territories that had been visited more often would be unfair. Either way breeding productivity of less visited territories would be founded on too little data to be certain. To be included in analyses territories therefore first of all needed to have been visited in a certain amount of years of the study period, where half of the study period was deemed sufficient for acceptable breeding productivity error margins. Thus territories needed to have been visited in at least 8 of the years of the study period to be included in analyses (technically 7.5 years with my study period of 15 years, but there are no “half-year visits” – either a territory was visited one year, or it was not). This left 152 territories, and excluded the municipalities Nordmaling and Vännäs. Of these 143 had coordinates, and of those 54 located in the mountains and 47 were F mountain territories. An exception was made in purely descriptive analyses, where the total number of nestlings born in territories was presented both excluding and including territories visited in less than 8 years, respectively, for the purpose of giving a full account of the known reproductive outcome of golden eagles in Västerbotten.

The different breeding productivity averages incorporate different aspects of the territories’ breeding productivity in addition to the average number of nestlings born per successful breeding year, except for in cases where the number of nestlings born is 0. Breeding productivity is affected by how often territories are occupied and how often eagles breed and breed successfully, which could all be affected by clearcutting. Nestlings/visited year does not appear to be a commonly used measure of breeding productivity in golden eagles, but this also accounts for how often territories were occupied, which is something that could be affected by clearcutting and is thus relevant to include. Nestlings/occupied year incorporates how often breeding occurs when territories are occupied, and nestling/breeding year incorporates the breeding success rate. Nestlings/successful breeding year is the average litter size, and was not used, which was mainly because, while it is also affected by outside factors, it may be more influenced by individual-based factors such as fecundity. Nestlings/successful year also varied much less between territories than the other breeding productivity variables, which would make potential trends and relationship harder to see and obtain because all clear-cut variables varied a lot between territories.

In this thesis, mountain territories are defined as territories located above the cultivation border, a.k.a. F and O mountain territories are added together, and thus there are territories which are located in or extend below the forest border and mountain-adjacent forest border. F and O territories were added together as O territories were still assumed to have more similar habitat conditions to the F territories than the lowland territories, as they are still close to and contain a lot of open areas. F mountain territories can also be close to and/or contain trees and forest. Cliff-nesting is also more common in both the F and O territories compared to the lowland territories, and appears to be the dominant nesting type in both, although considerably more so in the F territories. Golden eagle surveyors have also noted that golden eagles in the mountains seem to often stick to the mountain-adjacent forest, and quite a lot of mountain eagles also do have tree-nests (even when there are cliff-sites available, which has also been seen in the lowlands), also among the F territories (but more so in the O category). The amounts of tree-nesting and cliff-nesting are additionally closer between the O and F territories than between the O and lowland territories. Most of the mountain territories were in the F category anyway.

Data processing, simulations, and analyses

Using ArcMap Ver. 10.4, I mapped the clear-cut data and territory coordinate-points. This included reference system conversion for the territory coordinates, which were in RT90 2.5 gon W, to SWEREF99 TM, as that was the coordinate system of the clear-cut data. Next, I simulated non-overlapping territories using circles as an approximation of their real size and extension (this method chosen due to restrictions in time and available data). First, I constructed circular buffer zones with sizes corresponding to core areas around the coordinate-points, which were dissolved if intersecting with another territory's buffer zone. Given how much the size of golden eagle home ranges, territories, and core areas can vary, both across the golden eagle's international range as well as within Sweden, on both a smaller and larger scale, I wanted to base my models on as local data as possible, and simulate more than one territory size. I therefore simulated two territory sizes, using buffer zones with radii 1.2616 and 3.0902 km, corresponding to the maximum and minimum core area sizes estimated by Singh et al. (2016) for adult golden eagles in lowland forests in northern Sweden during the breeding season, 5 km^2 and 30 km^2, respectively. Secondly, I constructed Thiessen polygons for each coordinate-point and intersected them with the buffer polygons previously constructed, which produced non-overlapping territories. The territories ended up being of varying sizes and shapes, as coordinate-points for separate territories could be closer to each other than 2.5232 and 6.1804 km (for 5 km^2 and 30 km^2 buffers, respectively) and because there were territories with multiple coordinate-points, and the buffer zone areas of the coordinate-points of the same territory were added together and could also touch each other and form a single cohesive area. It was not necessary for all coordinate-points in the same territory to touch, though, as golden eagles can have several separate core areas in their territory, which are centred around different nests and not cohesive to each other if the nests are far enough apart. All coordinate-points were simulated for territories with multiple points, despite the fact that different points might represent the same nest, as I thought that this might increase the likelihood of catching actually relevant clear-cuts, since exact nest- or core area locations were unknown. Lastly, I extracted data on the clear-cuts which were intersected by the simulated territories in the two size classes. Only the clear-cut area which fell within the territory was extracted (calculated by the GIS-program), as including remaining area of intersected clear-cuts outside of the territory buffer might result in overlap between territories (which also would have complicated the analyses). This intersected area was calculated by the GIS-program. In the case of territories with multiple coordinate-points, the clear-cut area from all coordinate-points in the same territory was added together.

Given that the core area (and other home range sizes) acquired by Singh et al. (2016) had been commented as being more reliable than those acquired by Moss et al. (2014), I chose to use the former's core area sizes rather than the latter's. Singh et al. (2016) defined their breeding season as starting the 1st of March, a.k.a. excluding the pre-breeding part, a time which is also relevant to consider, especially in terms of human disturbance during courtship. However, the core area ought not vary or change much or significantly depending on whether it was estimated from when the pre-breeding starts (usually in February) or from the 1st of March. Areas simulated were (by necessity) assumed to sufficiently correspond to the actual location and extension of the core area (despite e.g. coordinate-points only being approximate nest locations, and coordinate-points not being available for all nests in all territories). The main reason for simulating sizes based on breeding season core areas (as the ones from Singh et al. (2016) were) was to more reliably assume no overlap between territories, as overlap would violate the assumption of independence. It should be valid to assume that the core areas of different territories do not overlap between my territories, considering that more territorial displays and defence of territory borders are made already further away from the core, and the core and nest site/s, especially the nest currently in use, are of highest priority for the territorial pair not to be breached by intruders (which may be why more of the defence and displays are made further away, to decrease the risk of a breach further in), and they spend the most time there, and are thus present and ready to defend it a lot of the time. This is especially the case during the breeding season and for the core area used during that time, since golden eagles typically exhibit higher nest centricity then, spending more time in the vicinity of nests, typically focusing on one nest when they have settled on actually breeding in that nest that year, and making the breeding core area smaller than the core area used outside of the breeding season.

The breeding season is the period of interest here, and the breeding core area and its characteristics are assumed to be the most important for the golden eagles' breeding productivity (both for breeding productivity defined by nestlings as well as by fledglings), especially the food-availability and thus the habitat and potentially clear-cut amounts there. The food-availability during the breeding season, especially during egg-laying and incubation, is the food-availability that appears to be most important for the golden eagles' breeding success and breeding productivity that same year. Since the parents typically spend more time and are more restricted to staying in the vicinity of the nest where they are breeding, especially when they have eggs or nestlings, and thus making the breeding core area smaller, the breeding core area's characteristics, especially food-availability, are therefore likely particularly important for breeding productivity. Both the male and female help with brooding and caring for the young (thus one parent could stay in the nest while the other goes to hunt and forage) (Artfakta 2015), but having good food-availability and good hunting and foraging areas closer to the nest would nonetheless be advantageous, for example reducing the area and energy needed to be covered in the search for food and decreasing the time and distance away from the nest, good e.g. if the core, nest, and eggs or young need defending, where having both parents present is advantageous. It is also beneficial when the fledglings are learning to fly, hunt, and forage on their own, since they will not be able to travel very far at first. Golden eagles also prefer to have their nests close to their hunting and foraging grounds, and have also been found to have a high intensity of both flight and perch use in the core area (Artfakta 2015; Burles and Frey 1981; Watson et al. 2014; Watson 2010). They are also central place foragers, which means that when they are breeding they are expected to remain and hunt and forage (mainly) in the vicinity of their nest, since they spend more time there then. This does not apply to golden eagles that were unsuccessful in their breeding, though, as they then have no obligations to remain around the nest, instead favouring expanding their breeding home range post-breeding, something which was also observed in Moss et al. (2014) (Marzluff et al. 1997; Moss et al. 2014; Watson 2010). Additionally, while only approximate nest locations were known, core areas are particularly related to the location of the nest/s (especially during the breeding season and to nest/s used more recently and in particular the one currently in use) and tend to coincide with the range centre.

Using Microsoft Excel 2010, I processed and organized the extracted clear-cuts' areas, and then made sums for each territory of the clear-cut area made in each respective territory. The clear-cut sums were made both cumulatively and in the ordinary, non-cumulative way, where in the latter case I simply summed the area of the clear-cuts made in 2002 to in 2015. Three cumulative sums were made, using only clear-cuts registered as being made in 2002 to in 2015, but extending the accumulation throughout the entire study period, a.k.a. also to 2016, summing cumulatively both in the ordinary way, a.k.a. accumulating the area of all clear-cuts made in 2002 to in 2015 throughout the study period, as well as excluding clear-cuts from adding further to the cumulative sum when they had become older than 5 and 10 years, respectively. Thus, for a 5 year example, the area of clear-cuts made in 2002 was not included in the accumulated sum in 2008 and forward. The accumulation was extended to include 2016 because although I did not include clear-cuts made that year, there are clear-cuts present in 2016 made in previous years which are potentially affecting the breeding in 2016.

Thereafter I used Excel to organize, process, and explore the golden eagle breeding data, calculate breeding productivities, and make graphs showing spatial and temporal trends in breeding productivity in Västerbotten over my study period. First the total number of nestlings born in a territory over the entire study period was calculated for each territory. Thereafter I calculated the breeding productivity averages (nestlings per visited, occupied, and breeding year, respectively) for each territory, albeit only for those visited in at least 8 of the years of the study period, as this was done to be able to compare territories without bias from how often they had been visited. The averages were calculated by dividing the total number of nestlings born in a territory over the study period by the number of years during the study period that that territory was, respectively, visited by surveyors, occupied by golden eagles, and contained breeding golden eagles.

Spatial trends in breeding productivity were shown by making graphs of the territories' breeding productivity averages, as well as of total nestlings born. In the graphs of total nestlings both territories visited in at least 8 of the years of the study period, and territories visited in less than 8 of the years of the study period, respectively, were included. The less visited territories were marked out, to show their characteristics and numbers. To get some sense of how golden eagle breeding has looked over time in Västerbotten during my study period, I additionally made temporal trends of breeding productivity, the total number of nestlings born each year, and nestlings born per territory each year, in the former case for the county as a whole and for each municipality, while in the latter case only for each municipality (making them on a territory-scale would be too time-consuming for the scope of this thesis). The municipality-scale breeding productivity averages were calculated by dividing the total number of nestlings born in a certain year by the number of territories visited, occupied, and breeding that year territory, respectively, in each municipality respectively. The averages were made in order to compare the different municipalities' trends without bias, since some municipalities had more territories and, again, since not all territories were visited the same number of years. For the averages I thus also excluded territories which had been visited in less than 8 of the years of the study period. This excluded the municipalities Nordmaling and Vännäs because they had only one territory each and it was visited in less than 8 of the years of the study period, and they thus also had the same trend of nestlings born per territory as total nestlings. For the temporal trends of total nestlings, all territories were included, however, also those visited in less than 8 of the years of the study period. In all the spatial and temporal trends territories were included regardless of whether they had coordinates or not. This, as well as making spatial and temporal trends of total number of nestlings, was done to show and get a total account and complete sense of the golden eagle breeding in Västerbotten over my study period, as far as what was known.

In the regressions, naturally, only territories with coordinates could be included, as data on clear-cuts could be extracted only from them. Using R Ver. 3.3.3, I made territory-level regressions of the territories' breeding productivity averages (response variables) on the territories' cumulative clear-cut sums (predictor variables), only using territories visited at least 8 years, with statistical significance being p-value ≤ 0.05. Thus the three following predictor variables were used in the regressions: nestlings/visited year, nestlings/occupied year, and nestlings/breeding year, and thus the six following response variables were used: three cumulative clear-cut sums (ordinary cumulative sum, cumulative sum excluding clear-cuts when older than 5, and cumulative sum excluding clear-cuts when older than 10 years) based on clear-cut area extracted from two territory sizes (ca 5 km^2 and ca 30 km^2). One predictor variable was regressed on one response variable at a time. However, before the regressions were made the clear-cut sums were weighted by the respective territory area. This was because not all territories were the same size, due to some territories having more than one coordinate-point, and some lying close enough to overlap. Thus some territories may have obtained a greater clear-cut area simply because they wound up a larger size, and vice versa, thus introducing bias and confounding the relationship. While the territories vary in size in real life, I do not know which are actually larger than others, nor the actual sizes, and in such a situation treating the territories equally felt preferable. Additionally, weighing by territory area also accounts for the possibility of the same amount of clear-cut area affecting territories differently depending on their size, as the cumulative clear-cut sum is proportional to territory area (the accumulated clear-cut proportion of territory area – not, however, the actual proportion; thus, the weighted clear-cut sum can be greater than one, which then does not mean that more than the territory size has been clear-cut). It is reasonable to assume that the same clear-cut amount could affect territories differently depending on territory size, because the proportion of the territory affected would differ, which ought to matter at least in terms of e.g. human disturbance and loss of potential nest-trees. That is, for example, in a large territory a certain amount of clearcutting may not impose a significant amount of disturbance or loss of nest-trees, but in a small territory, it does. Positive effects may be of similar magnitude regardless of whether it is proportional or not, though. Simply averaging the total clear-cut area between the multiple points also felt inappropriate, as all multiple coordinate points may have affected the breeding, and might be related to different nests (something which was not known), and overlapping could also cause the multiple points to have different sizes. Thus, regressions were only made on a spatial scale.

I made both simple linear and 2nd order polynomial regressions, using the lm() and glm() functions, for the polynomials additionally using the poly() function, using the default setting with raw = FALSE to get orthogonal polynomials and avoid correlation between the variables. Both lm() and glm() were used (same formula) because the former directly provided R^2 and adjusted R^2 values as well as the F-statistic and p-value for overall polynomial models, while the latter directly provided the models' AIC values. I made correlations for three groups: mountain territories alone, lowland territories alone, and lowland and mountain territories together. The resulting sample sizes were thus 143 with lowland and mountain territories together, 54 for the mountain territories alone, and 89 for the lowland territories alone. Compared to the known total sizes of these groups and with a confidence level of 95% (significance level 0.05), these group sizes would result in a margin of error of ca 5% for all territories together, ca 6% for the lowland territories alone, and ca 7% for the mountain territories alone, all of which are considered acceptable margins of error. Thus, while there are more lowland than mountain territories, I assume that this will not significantly affect how well the models of the different groups will perform. The correlations with lowland and mountain territories separated were made to account for the hypothesized difference in the relationship between lowlands and mountains.

At least some of the regressions' residuals appeared non-normally distributed, to varying degrees, indicated by their QQ-plots and density plots. This was clearly the case for the mountain regressions, but looked pretty acceptable and not too deviant for the lowland regressions, while the regressions with all territories were a bit more dubious (there was no big difference between the simple linear and polynomial regressions). Either way, normality is a less important assumption of regressions when the purpose is estimating the regression line (compared to predicting individual data points and prediction intervals), in which case the assumption of normality is barely important at all (Frost 2014; Gelman and Hill 2006). With a sample size of at least 15 (which was well exceeded by all groups in my analyses), test results from simple and multiple linear regressions (the latter under which polynomial regression is also considered to fall) are usually also reliable for distributions with non-normal residuals (Frost 2014). It is by comparison more important that the error terms have a constant variance and are independent. This was also considered to be the case, based on interpretation of scale-location plots of the regressions' residuals and Durbin-Watson and Goldfeld-Quandt tests on the regressions.

For the territories used in the regressions, I also calculated the coefficient of variation (CV) of the different breeding productivity averages, as well as of the number of years a territory was visited, occupied, and breeding, which was done across territories, to see how much these variables varied between the territories. For this I therefore calculated the average and standard deviation of each breeding productivity variable across all territories, and then divided the standard deviation by the average.

Lastly, I performed two-tailed Wilcoxon rank sum tests (with continuity correction) in R to test whether the territory-level breeding productivity averages and clear-cut sums (same as those used in the regressions, but also including the ordinary, non-cumulative sum of the area of clear-cuts made in 2002 to in 2015, which was also weighted by territory area) differed significantly between mountain versus lowland territories. It was obvious from the raw data and maps that there were far more clear-cuts in the lowland territories than in the mountain territories (as well as in the lowlands than the mountains overall, see figure 4) – the majority of the mountain territories were located where there were little or no clear-cuts or forest, and all of the territories with no clear-cuts were located in the mountains at the larger buffer zone size, and almost all of them at the smaller buffer zone size. A formal comparison was nonetheless made, for the sake of formal confirmation. the same reasons as for the regressions, this comparison was only made on a spatial scale, with territory-area weighted clear-cut sums, and only looking at territories which had been visited at least 8 years during the study period. Additionally, to directly compare the results of the two Wilcoxon tests, both were made only on territories for which coordinates were available. That is, the sample sizes of the two Wilcoxon tests were the same as for the regressions, 143 territories. The average, standard deviation, and median of the breeding productivity of these territories were also calculated respectively for the lowlands and mountains. Histograms, QQ-plots and Shapiro-Wilk tests indicated that some variables were non-normally distributed, which is why a non-parametric test was chosen. The distance between the closest mountain and lowland territory points was approximately 16.6 km, which given previously acquired home range and core area sizes for golden eagles in boreal Sweden was considered enough to assume independence between the two groups (something which is also relevant for the regressions). It was also a small proportion of mountain and lowland territory points that neighbour each other.

Results

Trends in golden eagle reproduction in Västerbotten

In 2016 the total number of known territories (including historical ones) in Västerbotten County was 193, 152 when excluding territories visited in less than 8 of the years of the study period. Per Västerbotten municipality, the total number of known territories ((including historical ones) was 33 in Vilhelmina, 31 in Åsele and Sorsele each, 28 in Storuman, 22 in Lycksele, 12 in Skellefteå, 9 in Malå, 8 in Vindeln and Dorotea each, 4 in Norsjö, 3 in Bjurholm, 2 in Umeå, and 1 in Vännäs and Nordmaling each. Mountain territories were found in Dorotea (7, of which 4 were F mountain territories), Sorsele (20, 19 F mountain territories), Storuman (20, 18 F mountain territories) and Vilhelmina (22, 20 F mountain territories)). When excluding territories visited in less than 8 of the years of the study period 28 territories were located in Vilhelmina and Åsele each, 22 in Sorsele, 20 in Storuman, 17 in Lycksele, 10 in Skellefteå, 7 in Vindeln and Malå each, 6 in Dorotea, 3 in Norsjö and Bjurholm each, and 1 in Umeå, and the municipalities Nordmaling and Vännäs became excluded. The number of mountain territories in each municipality was then 5 in Dorotea (3 F mountain territories), 15 each in Sorsele and Storuman (14 and 13 F mountain territories, respectively), and 19 in Vilhelmina (17 F mountain territories).

Golden eagle breeding productivity showed a fluctuating trend with peak and low years, on average separated by 2 years, during the study period in Västerbotten as a whole, on a county level (Fig. 1), as well as on a municipality level for all measures of breeding productivity analysed (Appendix I, Figures I-IV). The amplitude of the fluctuations varied between municipalities, though. Looking at Västerbotten as a whole, there appears to be a declining trend, which while not extremely steep was also not inconsiderable. From 2006 and forward the declining trend appeared to be more related to less productive peak years rather than further lowered productivities during the low years.

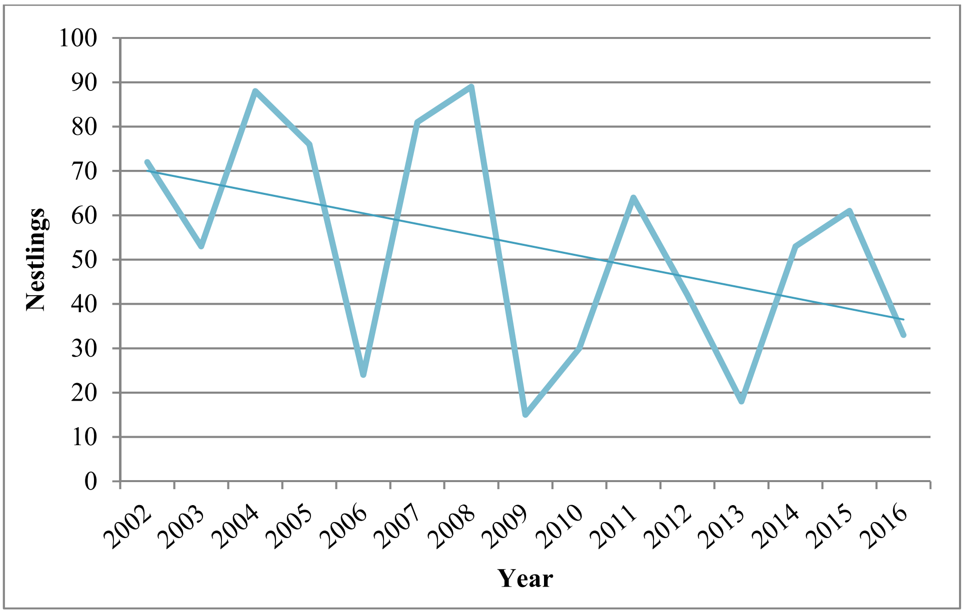

Figure 1. Temporal trend of the known total number of nestlings born in all known territories in Västerbotten County over the study period.

For all breeding productivity variables declining overall trends were also seen in most of the municipalities, although how steep they were varied between municipalities, and for some the overall trends were more stable, or even increasing slightly. It could be seen in all the breeding productivity variables that some of the declining municipalities had similar overall trends to on the county level, declining not extremely steeply but also not inconsiderably, while others had slighter overall declining trends. All municipalities with mountain territories showed signs of having overall declining trends in breeding productivity, and while some of the municipalities with only lowland territories also showed declining trends, there were also lowland municipalities that appeared to have overall increasing or fairly stable trends. Looking at total number of nestlings (Fig. I) mostly overall declining trends were seen, although for some the overall trend was more stable, and Skellefteå appeared to have a slight overall increase. Looking at nestlings/visited territory (Fig. II), overall trends were mostly declining, or more or less stable. Nestlings/occupied territory (Fig. III) fluctuated more than nestlings/visited territory, but municipalities again showed mostly declining overall trends, although some were more stable. A few municipalities had overall trends that appeared to be increasing slightly, though, most notably Skellefteå. In nestlings/breeding territory (Fig. IIII) patterns were less clear, outside of breeding productivity fluctuating between years, with fluctuations in some municipalities appearing more random and most municipalities appearing to have overall stable trends. Signs of overall declining trends could be discerned in some of the municipalities, but only Vilhelmina, Vindeln, and Åsele had overall trends which more clearly appeared to be declining.

There was a large variation in breeding productivity between the territories, and the territories with a high breeding productivity constituted a small portion of them (Fig. 2 and 3), as was also found by Hipkiss et al. (2014). This was seen especially when looking at total number of nestlings born over the study period (Fig. 2).

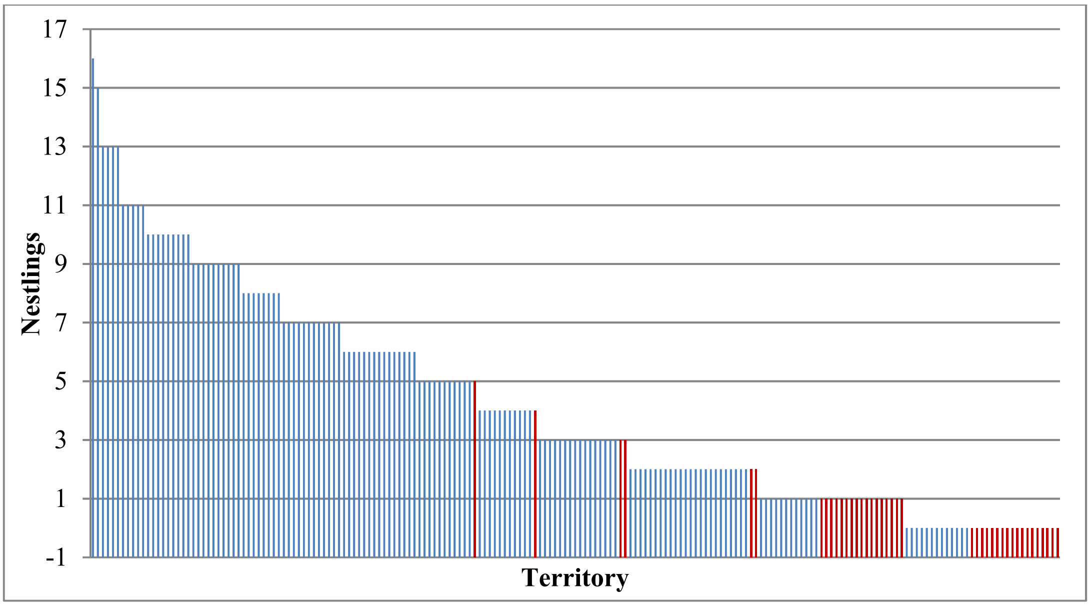

Figure 2. Known total number of nestlings born over the study period for each territory, n = 193 territories in total. Blue bars are territories visited in at least 8 of the years of that period (n = 152 territories), and red bars are territories visited in less than 8 of the years of that period (n = 41) (the y-axis (nestlings) starts at -1 to show territories with 0 nestlings).

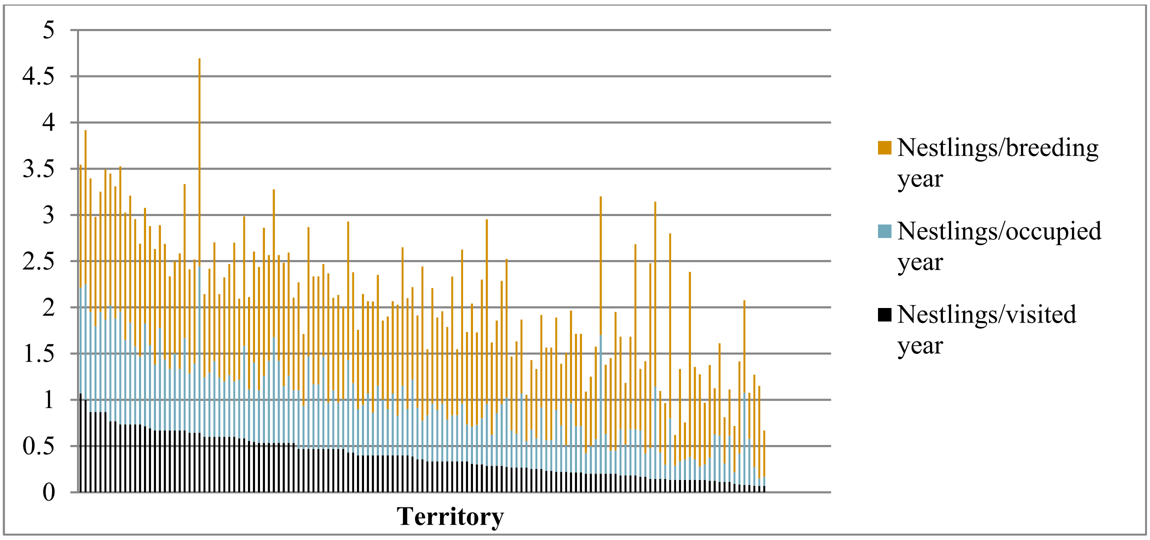

Figure 3. Breeding productivity averages (nestlings per visited, occupied, and breeding year, respectively) for each territory, averaged over the study period, for territories visited in at least 8 of the years of that period. n = 152 territories.

Table 1. Average breeding productivity (nestlings per visited, occupied, and breeding year, respectively) of the territories used in the regressions (territories with coordinates that had been visited in at least 8 of the years of that period), and standard deviation (SD) and coefficient of variation (CV, given in %) thereof. n = 143 territories.

	Years visited	Years occupied	Years breeding	Nestlings/ visited year	Nestlings/ occupied year	Nestlings/ breeding year
Average	13.601	8.748	4.692	0.377	0.588	1.074
SD	2.018	3.83	2.735	0.237	0.323	0.424
CV	14.837	43.78	58.294	62.824	54.987	39.527

Table 2. Average ± standard deviation (SD) and median golden eagle breeding productivity (nestlings per visited, occupied, and breeding year) of the mountain and lowland territories, calculated over the study period using territories with coordinates that had been visited in at least 8 of the years of that period. n = 143 territories.

		Nestlings/visited yr	Nestlings/occupied yr	Nestlings/breed. yr
Average ± SD	Mountain	0.264 ± 0.209	0.523 ± 0.372	1.01 ± 0.552
	Lowland	0.445 ± 0.227	0.627 ± 0.285	1.113 ± 0.321
Median	Mountain	0.214	0.5	1
	Lowland	0.467	0.636	1.125

Table 3. W-statistic, difference in location and p-values from two-tailed Wilcoxon rank sum tests of whether golden eagle breeding productivity (nestlings per visited, occupied, and breeding year, respectively) differs between territories in the mountains and lowlands. Territories included had been visited in at least 8 of the years of the study period and had coordinates. On all accounts there was a negative difference in location (non-significant for nestlings/breeding year), which indicates that the breeding productivity is higher in territories in the lowlands than in the mountains. n = 143 territories.

	Nestlings/visited yr	Nestlings/occupied yr	Nestlings/breed. yr
W-statistic	1285	1836	2050
Difference in location	-0.2	-0.136	-0.107
p-value	< 0.001	0.018	0.137

Table 4. W-statistic, difference in location and p-values from two-tailed Wilcoxon rank sum tests of whether there were significant differences between golden eagle territories in the lowlands and mountains in regards to clear-cut area made in 2002 to in 2015 summed in an ordinary fashion (Ordinary sum), ordinary cumulative sum of the area of clear-cuts made over the study period (not including clear-cuts made in 2016) (All years), and cumulative sums excluding clear-cuts when >5 years old (Excl. >5) and >10 years old (Excl. >10), respectively. All sums of clear-cut area were weighted by territory area and based on clear-cuts extracted from both territories simulated to a size of ca 5 km^2 as well as ca 30 km^2. Territories included had been visited in at least 8 of the years of the study period. There was a significant negative difference in location in all cases, which meant that lowland territories were indicated to have significantly higher clear-cut amounts than the mountain territories. n = 143 territories.

		Ordinary sum	All years	Excl. >5	Excl. >10
W-statistic	5 km^2	393	410	412	412
	30 km^2	85.5	103	100	102
Difference in location	5 km^2	-0.056	-0.516	-0.23	-0.454
	30 km^2	-0.062	-0.533	-0.325	-0.482
p-value	5 km^2	< 0.001	< 0.001	< 0.001	< 0.001
	30 km^2	< 0.001	< 0.001	< 0.001	< 0.001

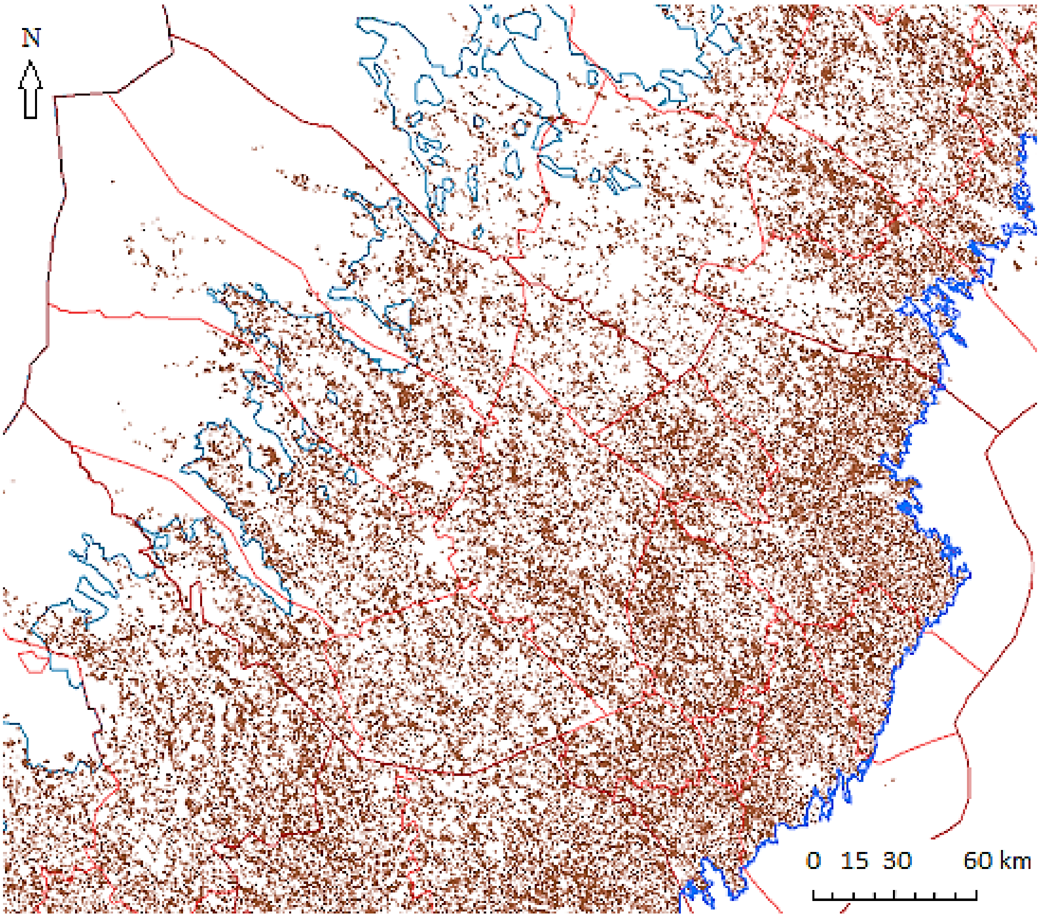

Figure 4. Clear-cuts (brown) made in 2002 to in 2016 in the counties Västerbotten, Norrbotten, Jämtland, and Västernorrland, overall. Thin red lines delineated municipalities while thick dark red lines delineate counties. The bright blue line to the east marks the coast. The dark blue line to the west is the border for mountain-adjacent forest. Note: Clear-cuts that appear to be “floating in the sea” are found on islands not contained in the underlying map.

Results of the regressions

No obvious or strong relationships between the breeding productivity and clear-cut variables, or other patterns, could be visually discerned, with the data being highly dispersed. The only regressions that were statistically significant were nestlings per visited year with all territories included in the analysis (table 5; for non-significant models see appendix II, table I). All significant models had positive adjusted R^2's and always explained more of the variation in the response (breeding productivity), a.k.a. they always had higher adjusted R^2, than the non-significant models (p-value and adjusted R^2 were usually positively correlated in the models, a.k.a. a model with a low p-value usually also had a (comparatively) high adjusted R^2, but not always). The model explaining the most variation (Fig. 5, the polynomial model of all territories together with nestlings/visited year and the >5 year clear-cut age limit, with clear-cuts extracted from the larger (ca 30 km^2) buffer zone size) still only explained 8.73%, however.

AIC differed very little between the corresponding simple linear and polynomial regression models, at most 2 units between the corresponding significant models, and usually less between the non-significant models, most commonly below a difference of 1 unit.
In the models with all territories together nestlings/visited year always performed the best (the only significant models were of all territories together with nestlings/visited year), then nestlings/occupied year, and last nestlings/breeding year. While this was seen in some other models as well, it was nothing entirely consistent across different groups, and among the remaining models there were generally no really consistent patterns of how the breeding productivity variables related to each other, and sometimes the difference between the measures was small. Models with clear-cut amounts based on the larger buffer zone size almost always performed better than ones based on the smaller buffer zone size (ca 5 km^2), often by much, being more significant and having adjusted R^2's higher by several percent. If the smaller buffer zone size performed better, it was only by a small difference. This was always the case for the significant models and the models of mountain territories alone, where the larger buffer zone size always performed considerably better. It was also common in the remaining models, but there the difference was sometimes not very large. Simple linear models were generally more significant than the corresponding polynomial models, also reflected when looking at the p-values for the coefficients of the polynomials, where the 1st order term would usually be more significant than the 2nd order term. That is, the added polynomial term generally did not improve the regression in terms of p-value. This was always the case for the significant models (although the difference was very small at the larger buffer zone size), and for the majority of the non-significant models. In the significant polynomial models the linear term was always the one with the significant p-value, while the quadratic term never had a significant p-value. In the occasions where the quadratic term had a lower p-value (seen in a few non-significant models), the difference was always still very small. In contrast, in the significant models, almost all corresponding polynomial models had higher adjusted R^2's (the difference was minor at the smaller buffer zone size, though). In difference to the significant models, the simple linear mountain territory models explained more variation than the polynomial models, and in the remaining non-significant models polynomials always performed worse, in both p-value and adjusted R^2.

The significant simple linear models showed an increase in breeding productivity with increasing clear-cut amount. The same was the case for the significant polynomial regression models, up to a point, after which breeding productivity started to decrease with increasing clear-cut amount. Among the significant models more variation was explained and the p-value was smaller when using the clear-cuts sums where clear-cuts were successively excluded as they became too old, usually most for the >5 years age limit (such was the model with the highest adjusted R^2). The model with the highest significance (Fig. 6), however, was the simple linear model of all territories together with nestlings/visited year and the >10 year clear-cut age limit, with clear-cuts extracted from the larger buffer zone size. However, the difference in p-value was not that great between the clear-cut variables when comparing the >5 year age limit models and the models where no clear-cuts were successively excluded to the >10 year age limit, respectively, and the same was the case when comparing adjusted R^2. The differences were very small between all clear-cut variables, even more so, at the larger buffer zone size, where the difference in adjusted R^2 was at most around 1%, when comparing between the clear-cut variables in each respective group, and all significant models had a very small p-value, which thus did not differ greatly in magnitude between either of them.

While more of the non-significant models where clear-cuts were successively excluded when they became too old performed better, it was far from a considerable majority, and often with only a small difference; there were really no clear or consistent patterns in the non-significant models regarding the clear-cut age factor, aside from the clear-cut variable where no clear-cuts were successively excluded as they aged, and then almost always the >10 year clear-cut age limit, performing the best in the large buffer zone size mountain territory models.
After the significant models the ones of mountain territories alone usually performed the best, generally having the lowest p-values and highest adjusted R^2's, which was the case e.g. in the nestlings/visited year group. As the clear-cut amount increased breeding productivity always decreased in the simple linear mountain models, and the polynomials always started with a decrease. They usually still had fairly high p-values and very low adjusted R^2's, though, which were often negative, and the negative trends had to be related to a smaller portion of the territories, as many mountain territories had zero clear-cuts. Many of the remaining non-significant simple linear models were positive and many polynomials started positive, but quite a few were negative and started negative, especially among the lowland territory models. The remaining non-significant models were usually of very low statistical significance and adjusted R^2's were always negative, especially for models of lowland territories alone. Between the non-significant models of lowland territories alone and lowland and mountain territories together, one type did not consistently perform better than the other.

Table 5. Significant (p-value ≤0.05) simple linear and 2nd order polynomial regression results, which were only acquired for the group with all territories together (lowland + mountains) with the breeding productivity variable nestlings per visited year. Within this group, significant results were acquired for all clear-cut variables (All years = ordinary cumulative sum of the area of clear-cuts made over the study period (not including clear-cuts made in 2016), >5 years = same but excluding clear-cuts from the accumulation when >5 years, >10 yrs = same but excluding clear-cuts from the accumulation when >10 years) and both buffer zone sizes (clear-cuts extracted from ca 5 km^2 and ca 30 km^2 buffer zones, respectively). Std. err. = standard error, p = p-value (which was the same for the F- and t-test, just one more digit provided for the F-test), R^2 adj. = adjusted R^2 (given in%), F = F-statistic. For simple linear regressions, t = t-value, Est. = Regression coefficient. For polynomials, Est. 1st = 1st order regression coefficient, Est. 2nd = 2nd order regression coefficient; p-value and F-statistic are for the overall regression. n = 143 territories for each combination. All clear-cut sums were weighted by territory area.

Simple linear		**All yrs**		**>5 yrs**		**>10 yrs**
5 km^2, All, Visit	Est.	0.08559	Est.	0.15681	Est.	0.09781
	Std. err.	0.03437	Std. err.	0.05532	Std. err.	0.03731
	t	2.49	t	2.835	t	2.621
	F	6.201	F	8.036	F	6.871
	p	0.014	p	0.005	p	0.01
	Adj. R^2	3.533	Adj. R^2	4.721	Adj. R^2	3.97
	AIC	-7.305	AIC	-9.0768	AIC	-7.9542
30 km^2, All, Visit	Est.	0.17151	Est.	0.28732	Est.	0.19244
	Std. err.	0.04858	Std. err.	0.08065	Std. err.	0.05355
	t	3.53	t	3.563	t	3.593
	F	12.46	F	12.69	F	12.91
	p	<0.001	p	<0.001	p	<0.001
	Adj. R^2	7.469	Adj. R^2	7.607	Adj. R^2	7.74
	AIC	-13.262	AIC	-13.476	AIC	-13.681
Polynomial		**All yrs**		**>5 yrs**		**>10 yrs**
5 km^2, All, Visit	Est. 1st Est. 2nd	0.57923 -0.27251	Est. 1st Est. 2nd	0.65532 -0.20947	Est. 1st Est. 2nd	0.60832 -0.25272
	Std. err.	0.23229	Std. err.	0.23132	Std. err.	0.23192
	F	3.797	F	4.423	F	4.034
	p	0.025	p	0.014	p	0.02
	Adj. R^2	3.79	Adj. R^2	4.599	Adj. R^2	4.098
	AIC	-6.7039	AIC	-7.9119	AIC	-7.1619
30 km^2, All, Visit	Est. 1st Est. 2nd	0.80421 -0.34295	Est. 1st Est. 2nd	0.81098 -0.37382	Est. 1st Est. 2nd	0.81741 -0.35102
	Std. err.	0.22678	Std. err.	0.22626	Std. err.	0.22635
	F	7.432	F	7.789	F	7.723
	p	<0.001	p	<0.001	p	<0.001
	Adj. R^2	8.306	Adj. R^2	8.727	Adj. R^2	8.65
	AIC	-13.579	AIC	-14.237	AIC	-14.116

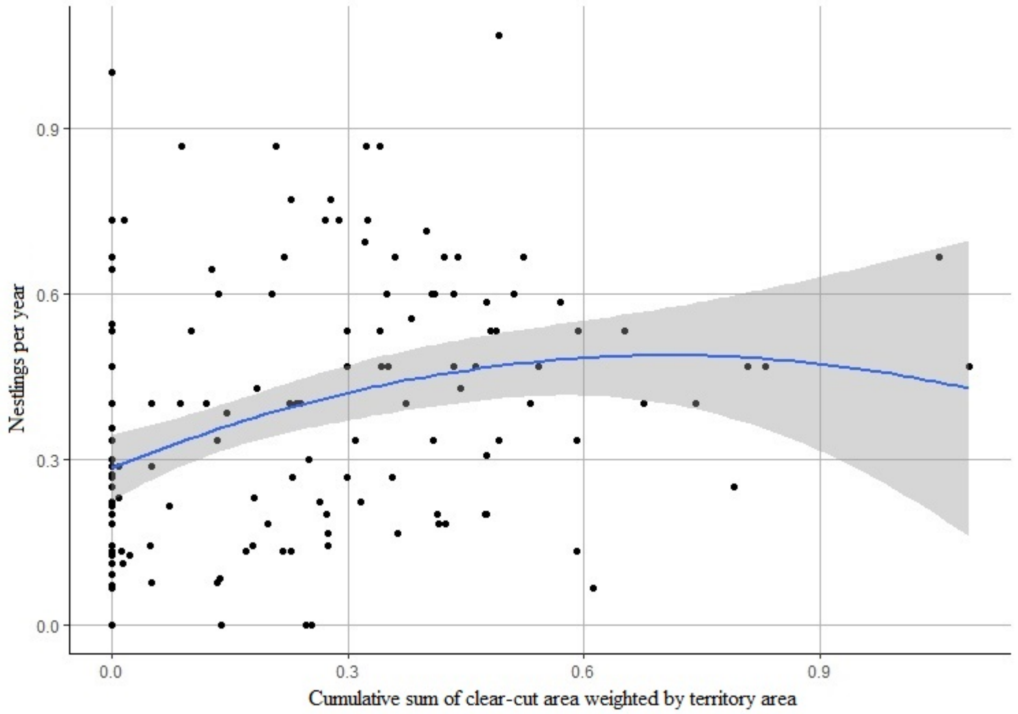

Figure 5. The model explaining the most variation (highest adjusted R^2), the polynomial regression model of all territories (mountain and lowland territories together) with the >5 year clear-cut age limit, with clear-cuts extracted from the larger (ca 30 km^2) buffer zone size, and nestlings averaged by the number of years the territory was visited by surveyors from 2002 to 2016 (n = 143 territories, p = <0.001, adj. R^2 = 8.727, AIC = -14.237).

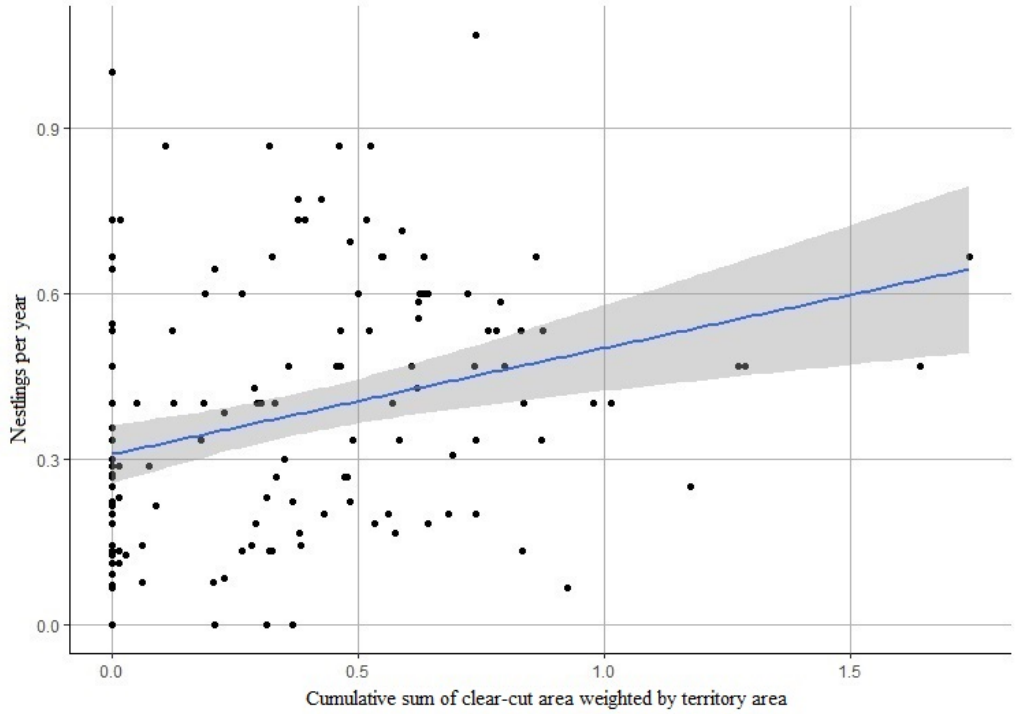

Figure 6. The model with the highest statistical significance, the simple linear regression model of all territories (mountain and lowland territories together) with the >10 year clear-cut age limit, with clear-cuts extracted from the larger (ca 30 km^2) buffer zone size, and nestlings averaged by the number of years the territory was visited by surveyors from 2002 to 2016 (n = 143 territories, p = <0.001, adj. R^2 = 7.74, AIC = -13.681).

Discussion

Breeding productivity and clearcutting in the lowlands and mountains

The breeding productivity in the lowland territories was higher than in territories in the mountains for all breeding productivity variables, although statistically significant for nestlings/visited year and nestlings/occupied year, with a bigger difference and higher significance for nestlings/visited year. Possibly related to this was how all of the municipalities with mountain territories showed overall declining temporal trends in breeding productivity, while, although some municipalities with only lowland territories also showed overall declining trends, there were lowland municipalities that appeared to have overall increasing or fairly stable trends.

An important reason behind this might be that over the last 10-20 years an intensified persecution has been noted in several areas along the whole Swedish mountain range as well as in the mountain-adjacent forests. Meanwhile, it appears like persecution of golden eagles in the lowland forests of northern Sweden has decreased to some extent compared to the situation during the 1970's and early 1980's (Artfakta 2015). It might also be related to food-availability, in which case food-availability might be lower in the mountains than in the lowland forests, possibly then of live prey in particular considering that has been shown to be more important for breeding success and breeding productivity. While the mountains contain more and larger open areas, the lowland forests have obviously become sufficiently accessible and might, at least so far, offer territories of higher quality than in the mountains (as also indicated by the greater number of golden eagles living in lowland forests in Sweden today). Vegetation and consequently animal biomass, as well as species richness and abundance, tend to be higher in lowlands than mountain regions, mainly because the weather and climatic conditions are more favourable in the lowlands. Thus, food could be more abundant and of higher availability in the lowland forests, made accessible to the golden eagles through clearcutting.

In all analyses the territories in the lowlands also had statistically more clear-cuts, as was entirely expected, considering that the majority of the mountain territories were located where there were little or no clear-cuts or forest (all of the territories with no clear-cuts were located in the mountains at the larger buffer zone size, and almost all of them at the smaller buffer zone size). Thus clearcutting is unlikely to be a significant factor behind the observed difference in breeding productivity between mountain and lowland territories, aside from clearcutting providing the golden eagles access to the lowland forests.

Results of the regressions and regarding the methodology and models – sources of error and variance, and points to improve

The data was highly dispersed with no visually obvious or strong relationships between the breeding productivity and clear-cut variables (or other patterns), even in the significant models. However, even noisy, high-variability data can have significant trends, and I did nonetheless detect some statistically significant results. On one hand, the more data and/or variables you have, the greater the likelihood of finding a statistically significant trend simply through a statistical effect; on the other hand, it also still means that the predictor variable nonetheless provides statistically significant information about the response even though data points fall far from the regression line (Frost 2014b). I also did not have an over-abundance of variables nor were my sample sizes abnormally large. Additionally, the territory group with the largest sample size (all territories together) did not perform the best outside of in the significant models; in fact, after the significant models, the smallest sample size (mountain territories alone) generally performed the best. The sample sizes of all groups were also considered sufficiently large compared to the known total populations sizes. As expected due to the high dispersion of the data, the percentage of the breeding productivity variation explained by the model was still low, though. However, this is a study on an ecological relationship, and ecology is a multi-causal world where many factors influence a system simultaneously, and this relationship is no different. A low R^2 is therefore not uncommon in published ecological studies, even as low as 2-5% (McGill 2012).

Most of the polynomial models explained more variation than the corresponding simple linear models, probably because the polynomial trendline was more fitted to the data. This can be interpreted as the relationship being better described by a 2nd degree polynomial than simple linear model, which is in accordance with my hypotheses. However, the simple linear models almost always had more significant p-values, both in statistically significant and non-significant models, and in the polynomial models the polynomial term generally did not improve the regression in terms of p-value. Graphs of the regressions' residuals vs fitted values also did not show signs of any obvious non-linear patterns, which would otherwise indicate a non-linear relationship, unequal error variances, and/or outliers (where the first would be a confounding factor when using simple linear regressions and the latter two being generally confounding factors). However, the differences were not very substantial between the significant models, especially in regards to the R^2 value, and AIC also differed very little between the corresponding simple linear and polynomial regression models. To say that one regression type decidedly performed better than the other is therefore difficult, and I can therefore also not conclusively state that an overall positive effect of clearcutting stabilizes and turns negative as the clearcutting amount increases and starts to cover highly extensive amounts of the territory. I would, however, still say that it is most realistic to expect that. I would therefore rather say that I cannot conclusively state whether clearcutting levels have been captured where effects are starting to stabilize or turn negative.

In the models of all territories together nestlings/visited year performed the best (the only significant models), then nestlings/occupied year, and last nestlings/breeding year. This was seen in some of the other models as well, but it was nothing entirely consistent across different groups. Generally, among the non-significant models, there were no really consistent patterns of how the breeding productivity variables related to each other, and sometimes the difference between the measures was small. This could be taken to indicate that the specific breeding productivity variable used was not so important, at least on its own, that it always had an impact and caused the same pattern. Neither did it appear to be connected to how well the model performed; for example, nestlings/visited year did not always perform best among the mountain territory models (which generally performed the best among the non-significant models).

On the whole, all territories together performed better than the lowland models, however among the non-significant models one of these did not consistently perform better than the other, and mountain territories alone generally performed better than both. This was surprising, considering how I expected relationships modelled for the lowland territories alone to perform the best and mountain territories alone the worst, with lowland and mountain territories together in between. In fact, while not statistically significant, the mountain models more consistently performed better as a group, while the other territory groups did not. These results imply a more consistent relationship in the mountains, which, while there were other models performing better, could imply that the relationship is stronger there. Meanwhile, it was the weakest and most inconsistent when looking only at the lowland territories. One possible explanation for this could be that there is more variation in how golden eagles in the lowlands respond to clearcutting, while golden eagles in the mountains respond in a more similar way. It could also be that where clearcutting does occur in the mountains, the effect is more profound because it is still not as common as in the lowlands, so the golden eagles living there are still less used to human presence and forestry than lowland eagles, and thus react more strongly to it, enough that the effect is reflected across all breeding productivity and clear-cutting variables. However, because so few mountain territories were located where clearcutting occurs, it is still not enough to confer a significant relationship or explain much of the breeding productivity variation. The observed negative trend also did appear to be related to few territories.

Fitting with my hypotheses, the significant models where clear-cuts were successively excluded as they became too old performed better. In the non-significant models, however, these patterns were not entirely consistent or always seen. This indicates that the temporal aspects of clearcutting I could account for (clear-cut age, how regularly clear-cutting is carried out (on a yearly scale), and the area clear-cut each year), at least as they are accounted for here, are not statistically significant factors. Even if one considers only the significant models or considers them more, as one perhaps should, the effect is not very pronounced, because significant results were still acquired for all clear-cut variables and the difference in p-value and adjusted R^2 were not that great when comparing the >5 year age limit models and the models where no clear-cuts were successively excluded to the >10 year age limit, respectively, and the differences were very small, even more so, between all clear-cut variables at the larger buffer zone size. However, an obvious flaw in accounting for the temporal aspects in this way is that if the clear-cut amounts are too similar between the clear-cut variables, not least because they were also weighted by territory area, then the results will not differ significantly between them, even if there actually are differences. Because new clear-cuts are continuously being made in the landscape, and golden eagle territories are large so all the forest in them will not be harvested at once, thus many different habitat types can exist in them at once, when one clear-cut becomes less and less useful, new clear-cuts may have appeared that the golden eagles switch to or are already utilizing. Thus, different clear-cuts of different ages and development stages can be affecting breeding at the same time. Even if I have successively excluded clear-cuts from my cumulative sums as they become too old, they have still been present and could have been affecting the breeding. To be able to see a difference between the clear-cut variables thus hinges on their effects on breeding being of significantly different strengths, e.g. with breeding being affected significantly more by clear-cuts of certain ages, and that I have grouped the clear-cuts appropriately to capture this. It additionally requires that if there are opposing effects at different ages, one kind is stronger (its effects would still be weaker compared to if one could isolate the effects of clear-cuts of a certain age). Otherwise, if clear-cuts of different ages have significantly different, opposing effects of similar strength, the overall relationship may become weak and non-significant. It may also be that there is no clear or great difference between clear-cuts of the specific age limits I used here, and if that is the case a longer study period than mine would be needed, in order to adjust the age limits in the clear-cut variables and capture clear-cuts of such ages that differences are being seen. It may also be that I have not appropriately or sufficiently accounted for the temporal aspects of clear-cut age, how regularly clear-cutting is carried out (on a yearly scale), and the area clear-cut each year. Because, obviously, clear-cut age will at some point make a significant difference, as the forest grows back up on the clear-cuts (except, then, for on those grounds were forest regeneration is unsuccessful, at least in the short term).

Just like for the clear-cut variables, there were significant results for both the small and large buffer zone sizes. However, there was a clear difference in performance between them, with the large buffer zone size performing notably better. There was also a greater difference between the buffer zone sizes compared to between the different clear-cut variables, when comparing the clear-cut variables between the buffer zone sizes, despite them still being weighted by territory area. This was often also the case among the non-significant models. Indeed, models at the larger buffer zone size almost always performed better than models at the smaller buffer zone size, and often by much (and if the smaller buffer zone size performed better, it was only by a small difference). Although this was much more pronounced and consistent in the significant models, as well as in the models of mountain territories alone, this consistency indicates that buffer zone size is more important and influential than the other variables, which did not show such consistency across groups. It could be interpreted as implying that, while clear-cuts close to the nest are important and have effects strong enough to confer significant results when only including them, clear-cuts found at a larger scale are also important, and including them is more important than just including the clear-cuts found closest to the nest. These results, and how the larger buffer zone size is based on the maximum core area size in Singh et al. (2016), could also possibly indicate that breeding productivity is significantly affected by clear-cuts on a larger scale than what was simulated, outside the core area, both the breeding core area and possibly the core area in general. But, regardless, buffer size on its own did not confer statistical significance or higher adjusted R^2.

In all, my results indicate that whether the regressions performed well (in regards to p-value and adjusted R^2) was due to the combination of both which specific breeding productivity variable was used, as well as which territories were included in the model, which then needed to be nestlings/visited year and all territories together. Nestlings/visited year and grouping all territories together were clearly not strong enough factors on their own in determining whether the outcome was statistically significant. When combining them, it apparently was enough, resulting in a correlation strong enough to confer statistical significance. This breeding productivity variable and this territory group thus may have possessed some characteristics which, while not apparent on their own, when combined came through and gave them an “advantage” over the other variables and groups. One characteristic of nestlings/visited year which might be important here is that it was the breeding productivity variable that varied the most between territories (had the largest CV value), followed by nestlings/occupied year with a smaller difference between nestlings/visited year and nestlings/occupied year than between nestlings/occupied year and nestlings/breeding year. The clear-cut variables varied a lot between territories, and it therefore stands to reason that if a breeding productivity variable varies little between territories, there will not be a strong connection, or none at all, between the clearcutting and breeding productivity variables. This could also explain the different breeding variables’ performances in the Wilcoxon rank sum test of breeding productivity in the mountain versus lowland territories). That the breeding productivity variables had these CV value could for example be because, while the number of times a territory was breeding varied most, then how many times it was occupied, and last how many times it was visited, there was still a greater potential for variation in how many times a territory could be visited compared to occupied and especially breeding. That is, the golden eagles never bred or even occupied their territory every year of the study period, but a territory could be visited every year. That the other breeding productivity variables did not seem to be significantly correlated to the clear-cut variables could imply that when looking at the breeding outcome on a basis of when territories are occupied or breeding, other factors, such as weather and individual characteristics like fecundity and age (hunting and foraging experience), matter more than clearcutting for the breeding outcome, while clearcutting has significant effects on a "larger scale", where how often golden eagles occupy their territory is also factored in. This thus also implies that clearcutting might have the strongest effects in how often the eagles occupy their territory.

It is harder to speculate why it was specifically all territories together that was needed. One possibility is because the sample size is larger. However, the sample size of all territories together is, as previously mentioned, not so large that I feel it should incur some purely statistical effect, and the sample size should additionally be sufficiently large for the lowland and mountain groups alone that it ought not make such a big difference. That the relationship is positive, though, might be because the positive trend seen in lowlands alone for nestlings/visited year is stronger than the negative trend seen in mountain territories alone for nestlings/visited year, which might be because only a few territories in the mountains carry the negative relationship, while more lowland territories carry the positive relationship. Still, in terms of significance and adjusted R^2, based on the individual results of the lowland and mountain territories individually, one would assume that all territories together would perform somewhere in between, a.k.a., in the case of nestlings/visited year, worse than the mountains group but better than the lowlands group.

The inexplicability of this makes it feel like it was some random effect related to the data being so dispersed that made this particular combination significant, at least in regards to it being the all territories group. That it conferred significance for all clear-cut variables and both buffer zone sizes could be because weighing by territory area has decreased whatever differences there may have been between them so much that they differ too little to make a difference, and possibly because there was no clear or great difference between clear-cuts of the specific age limits I used here. Patterns being less consistent in the models that performed worse is also to be expected – obviously, if there for example is no relationship between clearcutting and breeding productivity, factors like clear-cut age and buffer zone size would have no effect. However, if which models became significant should be just random, I would still not have expected the consistency with which specific model combination it was that became significant, nor the consistency that was still seen in some patterns, especially the one related to buffer zone size. Nonetheless, this possibility and the inconsistent patterns of which breeding productivity and clear-cut variables performed the best across all models together with the fact that many models were not statistically significant, having high p-values, and explained very little of the variation, even having negative adjusted R^2's, could be taken as an indication of there not being a significant (statistical or otherwise) relationship between clear-cut amount and breeding productivity overall, at least as described here, or at least not a strong, consistent one.

However, these results were perhaps not so surprising, because the relationship is likely complex with many potential affecting factors and sources of error and variance, both related and unrelated to clearcutting. The methods and models I used were simple, and while this was in some ways preferable, they did not account for many of the potential affecting factors and potential sources of error and variance, and may also not have appropriately or sufficiently accounted for the temporal aspects clear-cut age, how regularly clear-cutting is carried out (on a yearly scale), and the area clear-cut each year. That is, these results may be caused by my methods and models being too simple and undetailed, and may indicate that a different approach altogether is needed. Factors not related to clearcutting as described here that have significant effects and are not unaccounted for can be confounding sources of error and variance if they are too great in magnitude. If there are both positive and negative effects of clearcutting, also as described here, that are of more equal weight at play, it would result in an overall neutral or weakly positive/negative relationship. While this is a completely valid result, it could also make it seem like clearcutting has no effects whatsoever, which is unlikely. It is also of interest to find out things such as when positive and negative effects appear and what their individual strengths. Similarly, accounting for other factors affecting breeding productivity is relevant in order to see what the relationship looks like, and not just find out how much of the breeding variance clearcutting on its own can explain. If there are significant effects of clearcutting not related to or accounted for by my clear-cut variables, however, for example if there are long-term negative effects of clear-cuts from the past that are not included in my variables, or if there are completely unrelated factors significantly influencing golden eagle breeding productivity, they would need to be disentangled, or they could be confounding and obscuring any relationship present. The same goes for if there was an unrelated, significant population and/or reproductive decline – there is, after all, a temporal decline in golden eagle breeding productivity in Västerbotten, which while not extremely steep was also not inconsiderable. Doing analyses like here, on a spatial scale, averaging or summing and weighing variables, can smooth out irrelevant noise, deal with inequalities, bias, and lessen effects of e.g. clear-cuts not included. Backsides to this are, among other things, that it is harder to account for some of the potential unaccounted affecting factors and sources of error and variance, and temporal trends and variations in both clearcutting and breeding that could be relevant are lost or diminished and not accounted for. As already mentioned, weighing the clear-cut amounts by territory area also diminishes differences between the clear-cut variables and buffer size groups, while the breeding productivity remains unchanged, and summing the area clear-cut over years makes it harder to account for temporal aspects of clearcutting, which are important to account.

One very important thing not accounted for is that one clear-cut is not exactly the same as another, and therefore all clear-cuts will not have the same effects. For example site productivity, the size of individual clear-cuts, the time of the year that the clearcutting was carried out, prey species present in the area, which food sources and prey species golden eagles mainly feed on in the area, surrounding habitat, and habitat characteristics before clearcutting, could influence what the effects of clearcutting are and how long they last, affecting e.g. how fast the vegetation grows, and which vegetation appears, which in turn affects and is affected by which prey species appear, both of which influences how soon prey is disguised by the vegetation, and also the number of suitable nest-trees and how fast trees grow to become suitable for nesting. Clear-cuts can additionally vary in their effects both in how fast they age, but also within the different development stages, e.g. affected by species composition in the landscape and on the clear-cuts of plants and prey. Related factors likely to be relevant are for example forest age, amount of young, mature and old-growth forest, tree and plant species composition, forest denseness and patchiness, amount of old trees and how regularly they are spaced out, and competition from other predators. This thus also makes it hard to e.g. group clear-cuts by appropriate age limits. How connected disturbance effects are to clear-cut area is also a point which could be confounding, and is something which needs to be investigated in greater detail.

Another important thing to point out is that breeding productivity and variation therein may be related to individual quality rather than territory habitat and quality, for example lower fecundity and breeding productivity due to being too old, while too young individuals may be too inexperienced at hunting and building nests. Additionally, while golden eagles are monogamous, if one partner dies, it will usually be replaced by a new individual (Artfakta 2015). A sudden temporal change in territory breeding productivity may be habitat-related, but also for example because old eagles died and were replaced, either one partner or the whole pair, and the new and old eagles breed differently well, something which could confound a relationship between breeding productivity and a habitat-related factor like clearcutting. Naturally, golden eagle breeding productivity is affected by many other factors not accounted for here, forestry as well as non-forestry related, where in particular weather and climate, especially when the eggs are laid and incubated, are known to be especially important for their breeding success, in addition to food-availability. Weather and climate in turn also affect for example food-availability, predation pressure, as well as forestry and clearcutting (Artfakta 2015; Kaisanlahti-Jokimäki et al. 2008; Moss et al. 2012; Tjernberg 1983c; Wegge and Rolstad 2011). Other forestry operations, indirect effects of forestry, like the creation of forest roads, and other human activities naturally also affect golden eagles, for example through human disturbance.

There are other weaknesses in the methodology which could be confounding, one primary being that the core areas were simulated in a very simplified manner. Most importantly, minimum and maximum core area sizes were used as the basis for all territories, and territory sizes, including breeding core area size, have been shown to vary considerably just within the lowland forests of northern Sweden, so in all likelihood some territory sizes have been underestimated and some have been overestimated. The core areas were additionally based on only approximate nest locations, and while it was assumed that they would be close enough to sufficiently estimate the location of the core areas, this may not be the case. Furthermore, it is unlikely that the core areas are perfectly circular, and animals rarely keep entirely static territory borders, which is also true for the golden eagle. It was also not entirely clear whether multiple coordinate points corresponded to the same nest or different nests. For many territories coordinates were probably not available for all its known nests anyway, with many territories having only one set of coordinates despite having more than one known nest. Since the core area location depends most on which nest is used for breeding, all potentially relevant clear-cuts around the nests without coordinates are very likely not included. Different clear-cuts can also be of differing importance, e.g. based on how many years a certain nest is used for breeding. It was also not known when different nests where made or discovered, or when and how many years they were used. As mentioned briefly above, there are also the potential effects of clear-cuts at a larger scale, outside both the breeding core area and the core area in general, that needs to be considered. The accuracy with which the territories are simulated is important in order to capture the clear-cuts that are actually located in the territory, in particular in the breeding core area, and thus could be affecting the golden eagles and their breeding. Otherwise, the clear-cut amounts will be too far off from the amount of clear-cuts potentially affecting the golden eagles' breeding productivity, and one would not be able to find a relationship, even if such exists, or only a weak, non-significant one.

One might also look into how appropriate this way of grouping territories into mountain and lowland territories is, and whether there is a need for an intermediary habitat group. One might also look into the need of handlings historical, potentially abandoned territories differently (in the cases where they were visited enough to still be included), as they should maybe only be included up until they stopped being active. Otherwise, the clear-cut variables could include clear-cuts which has had no effect on the territory's breeding productivity, because they were made after the territory was abandoned. They should be included to some extent, though, because why they stopped being active could be related to clearcutting.

Additionally, in all likelihood the clear-cut sums do not include all clear-cuts potentially affecting breeding also because there is a lack of data on clearcutting before 2002. This would be relevant especially for the beginning of the study period (although clear-cuts made in the years closer to 2002 might affect breeding during my entire study period, or large parts of it, depending on e.g. how quickly the clear-cuts become overgrown), at least in terms of effects likely to be noticed more immediately and thus during my study period, such as human disturbance and improved hunting habitat, and not possible consequences such as loss of old-growth forest and nest-trees, which would naturally be more long-term. Several assumptions must also be correct, including that of independence between the territories, the clear-cut registry being complete, and that the observations of the golden eagle surveyors are true about there not being at least an obvious lack of nest-trees. While there should be no overlap in habitat use between territories in regards to the core area, there is nonetheless a possibility of territories that lie close together affecting each other in regards to the eagles' movements and habitat use, as for example McLeod et al. (2002) found eagle locations to generally be closer to the range centre when other territories were immediately adjacent. How common such situations and how significant the effects thereof may be is relevant to investigate in greater depth as this affects the assumption of independence. If there is a lack of nest-trees during my study period, it would likely be caused by clearcutting in the past, and not so much the clearcutting of my study period, which, as previously mentioned, could obscure other effects that are likely to be noticed more immediately following clearcutting and thus during my study period. That potentially relevant clear-cuts made in 2016 were not included should not make that big of a difference, though. They would only have made a difference for the breeding in the year 2016 (since the clear-cuts made during my study period potentially affecting breeding in 2015 should all be included in my variables), and then likely only significantly in regards to potential negative effects related to the disturbance clearcutting imposes, and so only the clear-cuts made up until the nestling production that year had been determined would be relevant. This should not affect the outcome of my regression significantly. Nonetheless, in hindsight, I could have included clear-cuts made in 2016 that had been registered up to the end of May or maybe June, since these could only be clear-cuts made up to that point, and thus potentially relevant clear-cuts. Aerial photos were mainly taken from the end of May to September, so a lot of the clear-cuts made during the breeding season might therefore still not be caught, but it would at least not erroneously include irrelevant clear-cuts.

It is important to include territories of low breeding productivity because the reason they perform poorly may be due to clearcutting, but many such territories did not have any coordinates or had been visited very few times, or often both (thus their apparent low breeding productivity is based on sparse records), so they could not be included in either case. Territories of low breeding productivity may therefore be underrepresented, and this could bias tests of this relationship. This presents a disadvantage to using data collected through citizen science, because territories may have been visited less specifically because they had low breeding productivity, and were thus less interesting to visit. For scientific studies such as this to be as robust and have as many models and tools available to analyse the data as possible, it is necessary that the data has been gathered objectively and with the same amount of effort is invested in each area of study. Otherwise, it will introduce bias which can confound subsequent analyses of the data, e.g. leaving out important parts of a relationship and/or producing results which are non-representative for the entire population.

There are both pros and cons to using data collected from not strictly scientific experiments or sources and data not collected by oneself, such as citizen science and government agency sources like here, but one must be aware of the restrictions of such sources and ideally, they should at least be complemented by data collected through more rigorous scientific experiments or monitoring projects. One drawback is the greater likelihood for non-standardized methods and varying degrees of effort, particularly in long-term monitoring projects, and greater difficulties in accounting for such sources of error and variance. Variability of e.g. surveyor effort is an important point to assess, as well as for example the rate of territory discovery and whether there is a connection between clearcutting and habitat changes, and the number of territories being discovered, or whether it is related to surveyor effort. One is generally more restricted when working with data not gathered by oneself, as the specific methods of data collection and what data is gathered cannot be controlled, and additional information needed for certain analyses may be hard to get, unavailable, or non-existent. This may particularly be the case when the data is openly available to the public and managed by larger organizations, governmental or otherwise. In such cases it may be hard to get in contact with the people in charge of the inventories, or to get all information required. Issues like these were present in both the breeding and clear-cut data.

Conclusions

Summarily, the results of my regressions are not particularly conclusive and do not consistently or conclusively confirm or disprove my hypotheses when considering them in their entirety. They could be interpreted as being indicative of there not being a significant (statistical or otherwise) relationship between clear-cut amount and breeding productivity overall, at least not as defined and calculated here, or at least not a strong, consistent one. However, they could also be interpreted as simply indicating the complexity of the relationship, and that my methods and models are too simple and undetailed, and that a different approach altogether is needed. The relationship between golden eagles and clearcutting is very likely complex, as is golden eagle habitat use, and there are many potential affecting factors and sources of error and variance (both for forestry in general, clearcutting, and clear-cut area specifically), which are expected to change and vary in both time and space, not accounted for here. There are also many things to consider when interpreting the results, as well as additional questions and data gaps that need to be answered and filled.

Ecological studies often have a low R^2, and even noisy, high-variability data can have a significant trend, showing that the predictor variable nonetheless provides statistically significant information about the response. In this case, I believe that it is not just a statistical effect of e.g. a very large sample size and/or many variables, which I do not think my data or models have. And while many of my models were not significant, having high p-values, and had very low adjusted R^2's, and many patterns were inconsistent, I would therefore still say that my results are relevant at least in that they, based in particular on my significant results and the more consistent patterns that were found, coupled with the results of previous studies on related subjects like golden eagle habitat selection, could be taken as an indication of something being there and implying that there is a relationship worth investigating here. Either way I would definitely not say that clearcutting is not affecting golden eagles and their breeding in Västerbotten, and I also would not dismiss the possibility of clearcutting having strong effects on its own, regardless of how one interprets my results. I would, however, at least conclude that in all likelihood the methods and models I used here are too simple and undetailed and to analyse this relationship you need to use more complex and detailed methods and models (despite the risk of such potentially making it harder to reproduce results for other data sets, e.g. data from other areas). Several improvements can be made just to my models and the underlying data. This includes for example accounting for more factors and sources of error and variance affecting golden eagle breeding productivity (related to clearcutting or not), and having more certain, accurate territory locations, shapes, and sizes. There are improvements to be made in how the clear-cut and breeding data was collected, shortcomings which aside from leading to gaps in the data may also be sources of error. However, it became apparent during my study that in all likelihood an altogether different approach is needed, especially to describe clearcutting and account for the temporal aspects thereof differently. Time series analyses are likely better at accounting for several of the here unaccounted potential affecting factors and sources of error and variance, as well as to catch and analyse temporal trends and variations in both breeding and clearcutting. Time series analyses are probably the best way to account for the temporal aspects of clearcutting, and may provide more conclusive results. With time series analyses you could also look into whether there is a connection between clearcutting and the number of territories being discovered, or whether it is related to surveyor effort, something which is not possible when averaging breeding productivity by year. Using such more complex and perhaps more appropriate models might reveal a stronger relationship between clearcutting and golden eagle breeding productivity, but most importantly, they would hopefully yield more conclusive results.

With time series analyses you can also look more closely into whether clearcutting, or forestry in general, is a significant factor behind the indicated declining reproductive trends in Västerbotten and Sweden as a whole, as well the possible population reduction in parts of northern Sweden. First of all, though, it should be mentioned that it is important to perform formal statistical analyses to ascertain whether these trends are both statistically as well as biologically significant. In my significant models a positive relationship (up to a point in the polynomial models) was seen, which was also the case in several non-significant regression models of lowland territories and all territories together (albeit not a clear majority). Based on this together with the results of previous studies on related subjects like golden eagle habitat selection, the observations of the golden eagle surveyors in Västerbotten regarding nest-tree availability, and my conclusions regarding abundances of prey and other relevant species, e.g. for the availability of carrion, the relationship implied by my results and previous habitat selection studies could be positive, at least so far in the lowlands in Västerbotten. I would therefore also say that clearcutting ought not be tied to the declining trend in nestling production in Västerbotten, at least so far. However, if there IS a lack of nest-trees, prey, negative effects of clearcutting carried out further back in time, or such, in the lowland forests, I might amend this opinion. Clearcutting could be negative overall in the mountains, but since the majority of the mountain territories contained little or no clear-cuts or forest, other factors than clearcutting, and forestry in general, are more likely to be behind declining reproductive and population trends in the golden eagles in the mountains. An obvious lack of nest-trees had not been noted by golden eagle surveyors in Västerbotten, but it has been brought up for example by surveyors in other parts of Sweden, as a possible reason for the declining reproductive trend in golden eagles, with intensive forestry being suggested as the cause. It is therefore important to properly investigate the availability of nesting places, in particular then nest-trees, to confirm the Västerbotten surveyors' observations, as is the abundances of prey and carrion. Before drawing conclusions about the overall effect of clearcutting and forestry in general on the golden eagle population and its breeding in

Sweden as a whole, studies must also be made on the relationship in other parts of Sweden, since it and the response of golden eagles to clearcutting and forestry in general could vary, depending on several factors. Because the relationship could also change and vary in time, and thus results could be harder to reproduce for other data sets if they are separated by enough time, the relationship should preferably also be investigated on several occasions in time. Related to carrion is for example to investigate the status of the four other large predators in Sweden (brown bear (*Ursus arctos*), gray wolf (*Canis lupus*), wolverine (*Gulo gulo*), and Eurasian lynx (*Lynx lynx*)), which are likely important for the supply of carrion for golden eagles, probably more so than human hunters, at least periodically. A highly relevant area of study concerns the occurrence and severity of lead poisoning in golden eagles, and here hunting leftovers from humans could be playing an important role.

If clearcutting is overall positive a lack of clear-cuts in the territories could be an issue. The forest landscape in Sweden is dynamic and in continual change, e.g. with new clear-cuts being made and young forests becoming mature forests that are harvested again and become clear-cuts once more (Hipkiss et al. 2014). Clearcutting has been and is still continuously being carried out every year throughout the forest landscape in Västerbotten, but to ascertain whether a lack of clear-cuts in the territories is an issue, clearcutting trends must be investigated in-depth at a territory-level (also outside the breeding core area and core area in general). Because, looking briefly at the trends in clearcutting in the breeding core area as defined here, clearcutting was not carried out every year in every territory, especially not at the smaller buffer zone size, where several territories also did not have clearcutting occur particularly regularly, which was also the case for some at the larger buffer zone scale (most of those were mountain territories, though).

However, simplification was necessary also due to restrictions in time and the data and knowledge available. For example, the necessary information was not available to account for things such as when different nests where made, used, and discovered, whether territories were abandoned or not (even if one could guess in some cases), if a territory was abandoned because the golden eagles had left the it (for some reason) or died, if and when one or both of the golden eagles in a territory's pair were replaced, etc. Disentangling individual and territorial (habitat-related) types of variation in ecological studies is also difficult (territorial and individual variation often covariate, though, because high-quality individuals usually claim the best territories (Fretwell and Lucas 1970)) (Balbontín and Ferrer 2008; Carrete et al. 2006). Additionally, estimating territory/core area size, shape, and location more accurately through GPS-tracking would not have been possible for a lot of territories, as all active territories in Västerbotten do not have eagles with GPS-trackers, especially not both in a pair, and it would not have been practically or economically possible to outfit enough golden eagles from enough territories. It would also have taken too much time for the scope of this thesis to capture enough golden eagles and territories, estimate core areas, capture the relevant clear-cuts, and then proceed with further analyses. Territory borders, including those of the breeding core area, are also not static, but change and vary between years, and so does the location of the breeding core area e.g. depending on prey- and food-availability, and the nest being used in specific years for breeding, which might change even within the same year, if breeding is disturbed and the eagles have time to move to an alternate nest (Moss et al. 2012; Tjernberg 1983b).

Time series analyses are also complex and difficult to do; for example, it is not sufficient to correlate nestlings born the same year to clear-cuts made that year considering clearcutting in all likelihood has effects that span several years, and all potential effects are unlikely to be seen at the same time. Golden eagle habitat use is also complex, changing in both space and time, and the forest landscape changes continually, with new clear-cuts continuously being made and the clear-cuts themselves changing and varying in time and space, and the golden eagles in all likelihood switching between clear-cuts e.g. as they age. The same factors of variance that can affect golden eagle breeding and the relationship are present regardless of whether spatial or time series analyses are used, and they can also change in time and space, from on a landscape scale to on the clear-cut itself, e.g. food- and prey-availability, prey species composition, abundance, and their relative importance as prey. However, data on the all these possible factors is not always easy to come by, especially on a territory scale, which is the most preferable, if not necessary, for example prey-availability. Similarly, several of the difficulties faced by my spatial analyses would be relevant and troublesome also for time series analyses, such as the gaps in the breeding and clearcutting data and how all territories were not visited the same amount of years (even when accounting for all territories not being discovered at the same). A particular issue with this data-set is that there are years which lack data, and some temporal models do not work with that. While one method to account for gaps in the data is to extrapolate, this is usually done for continuous variables and does not work well when only working with a few discrete variables, as is the case here, with the number of young born each year in a territory varying between 0 and 3 and usually being 0 or 1. This fact could even make it hard to see trends in the data when looking at breeding productivity temporally, at least if one constructs time series on a yearly scale. This might be dealt with if one were to construct interval time series, where breeding and clearcutting is summarized within intervals. However, this would likely require longer time series than what was available to me. It can additionally be useful to look into how clearcutting is carried out within the year, such as how many times clearcutting has been carried out during a year and how much was carried out during the breeding season. To account for all of this, very complex models, possibly longer study periods than mine, and data without inequalities and gaps in how often territories were visited, are required. An experimental setup where clear-cuts are created and the golden eagles' response to and use of them are followed in time would be the ideal setup (use of previously existing clear-cuts could be accounted for by ascertaining their age and monitoring them as well). However, such a setup would be very hard to do, importantly because the eagles will in all likelihood move back and forth between clear-cuts, especially as the clear-cuts age, and one would have to monitor all clear-cuts being made in the territory, especially the breeding core area, but also in the territory's vicinity, in particular if the golden eagles are found using them. This would become a very large-scale and expensive project, with many golden eagles needing to be GPS-tracked and followed for a long time over a large area, not least because golden eagles can move over very large areas, just the breeding core areas can be very large, and clearcutting is continuously being carried out throughout the forest landscape. Additionally, when estimating core area size, the sex of the eagle should also be considered, since female golden eagles appear to spend more time on nest maintenance and do most of the incubation (Collopy 1984; Gordon 1955; Watson 2010; Watson et al. 2014).

Much of the relevant and required data for analyses like these is hard to find at sufficient detail both spatially and temporally, or it is very labour-intensive and time-consuming to collect and not practically or economically viable. This is also a common caveat of more complex models that utilize more variables, in that more time and resources must be spent on data collection, as well as making sure that all the data was gathered correctly. Care must also be taken so that one does not apply models and methods that are too complex and advanced, as that will risk for example overfitting and a relationship highly unlikely to be reproducible for other data set. Using too complex models with too many variables and different data sets can also for example obscure relationships that are there, and increase the risk of something going wrong and there being flaws in the data, e.g. upon collection, and thus they would not provide more conclusive results.

There are both pros and cons to using data collected from not strictly scientific experiments or sources and data not collected by oneself, such as citizen science and government agency sources like here, and ideally, they should at least be complemented by data collected through more rigorous scientific experiments or monitoring projects. Utilizing sources like these can, however, be a great way to quickly acquire data from a large area and e.g. access the experience of long-time dedicated ornithologists, and the work of Kungsörn Sverige is still very important for the knowledge of the Swedish golden eagle population, among other things because they monitor the majority of it and have been doing so for a long time. It is usually the case when dealing with studies on animals in the wild that it is very hard to control and account for all factors and sources of error and variance, but especially so for birds, which in general are highly mobile, and especially far-ranging ones like the golden eagle. However, for future analyses, in particular if time series analyses are to be used, the breeding and clear-cut data should ideally be improved. This would include for example collecting the data in a more standardized way, try to account for individual variables like fecundity and age of the golden eagles, at least by trying to record things like when territories are abandoned and eagles die and are replaced, and outfitting more eagles with GPS-trackers, including data on clearcutting further back in time, possibly having a longer study period than mine (depending e.g. on the type of study to carry out, but also on when one might start to see effects of clear-cuts, and likely required to catch effects on nest-tree availability), and getting information on when during the year clear-cuts were made.

Thus, further study is highly recommended, primarily to get more conclusive results, but also because there is a dearth and need for research on this topic, and because of the large proportion of the Swedish golden eagle population lives in lowland forests and nests in trees combined with the importance and great presence of forestry and clearcutting in Swedish forests. One should also expand the research to look at the effects of other forestry operations and forestry in general, because while clearcutting instinctively feels like it should carry the greatest effects and determine how forestry affects golden eagles and their breeding overall, there may be important and significant effects of other forestry operations for example related to human disturbance and food-availability. It is especially important to have a good understanding of this since we are dealing with a red-listed species. There are, of course, many relevant and related research areas for future studies to look into, some already mentioned above, but one additional topic particularly relevant to address is the effect of clearcutting and forestry in general on young beyond the age of both nestlings and fledglings, as well as on the golden eagle population as a whole, like population size. It must be remembered that I based my breeding productivity on nestlings, which is not reflective of the recruitment to the breeding population, which is typically much lower, also compared to fledgling production. Recruitment is very important for assessing and predicting the stability and trends of current and future populations; having produced many nestlings or fledglings matters little if none survive to breed, for example. Any shortfalls due to nestling mortality after ringing ought not substantially affect the overall territory rankings, at least, as argued by Hipkiss et al. (2014).

The future of the golden eagle is dependent on a lot of factors, and in Sweden forestry, especially clearcutting, likely plays an important role, in particular in food- and nest-availability. Clearcutting might currently have an overall positive effect on the breeding productivity of golden eagles as defined by nestlings, at least in lowlands of Västerbotten, but if this translate to an overall positive effect of forestry on the golden eagle population as whole must be investigated, and whether it will persist depends on many factors. Here, the development of the forests, forestry practice, and the role of and trends in nature conservation measures within the forestry sector are particularly important to monitor and evaluate, in particular to evaluate how much of a difference the current levels of nature conservation make, if and what improvements need to be made, and whether previously saved trees and forest-patches are saved also in the next rotations. To monitor the stability in the trends of clearcutting and forest age classes is also relevant, especially regarding if there will be more dips in the amount mature forest and whether this will increase clearcutting of old-growth forests. The importance of open habitats must not be overlooked, however, and here continuous clearcutting, well-spread out through the landscape, could play an important role in the long-term for the lowland forest golden eagles, and thus for the Swedish golden eagle population in general – if combined with appropriate measures being taken by the forestry sector for example to ensure the long-term supply of prey, carrion, and new nest-sites, in particular nest-trees, and that they are well-distributed throughout the landscape, protection of already established nest-sites, and minimization of human disturbance in golden eagle territories, at least during the breeding season and close to nests. Beneficial is also to allow for there to be areas, as well-distributed throughout the landscape as possible, that are undisturbed or at least not subjected to large-scale human activities like forestry, with focus on those that are already less affected by human activities, like areas with difficult terrain, in particular mountains and steep slopes and hills. The golden eagle needs continuity on a landscape scale, but a landscape mosaic of older forest and open areas, such as clear-cuts, could be favourable for the golden eagle, as suggested by Sandgren et al. (2014).

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Appendix I

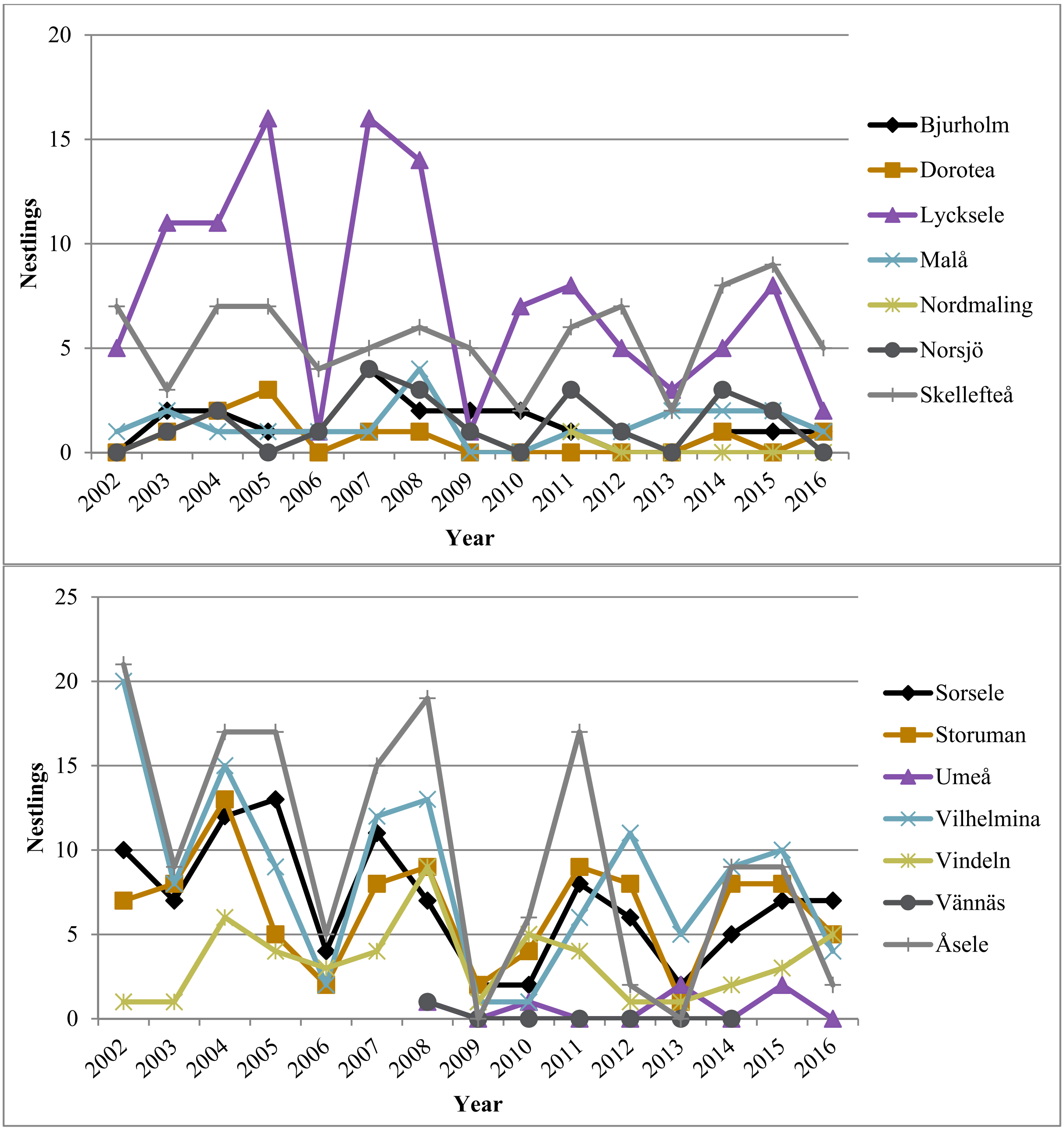

Figure I. Temporal trends of the known total number of nestlings born in each municipality in Västerbotten County over the study period (including territories visited in less than 8 of the years of that period).

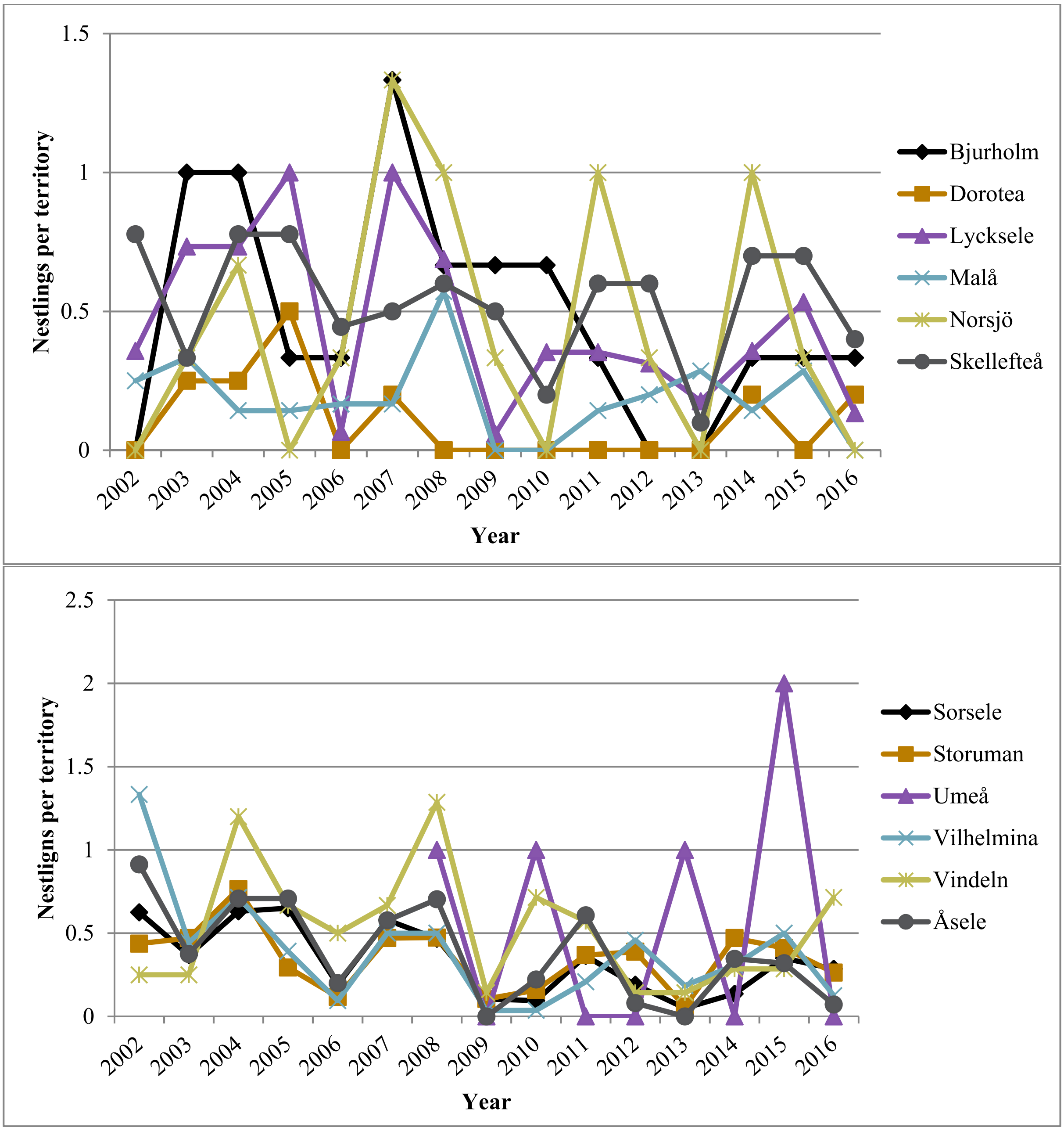

Figure II. Nestlings per visited territory in each municipality in Västerbotten County over the study period (excluding territories visited in less than 8 of the years of that period).

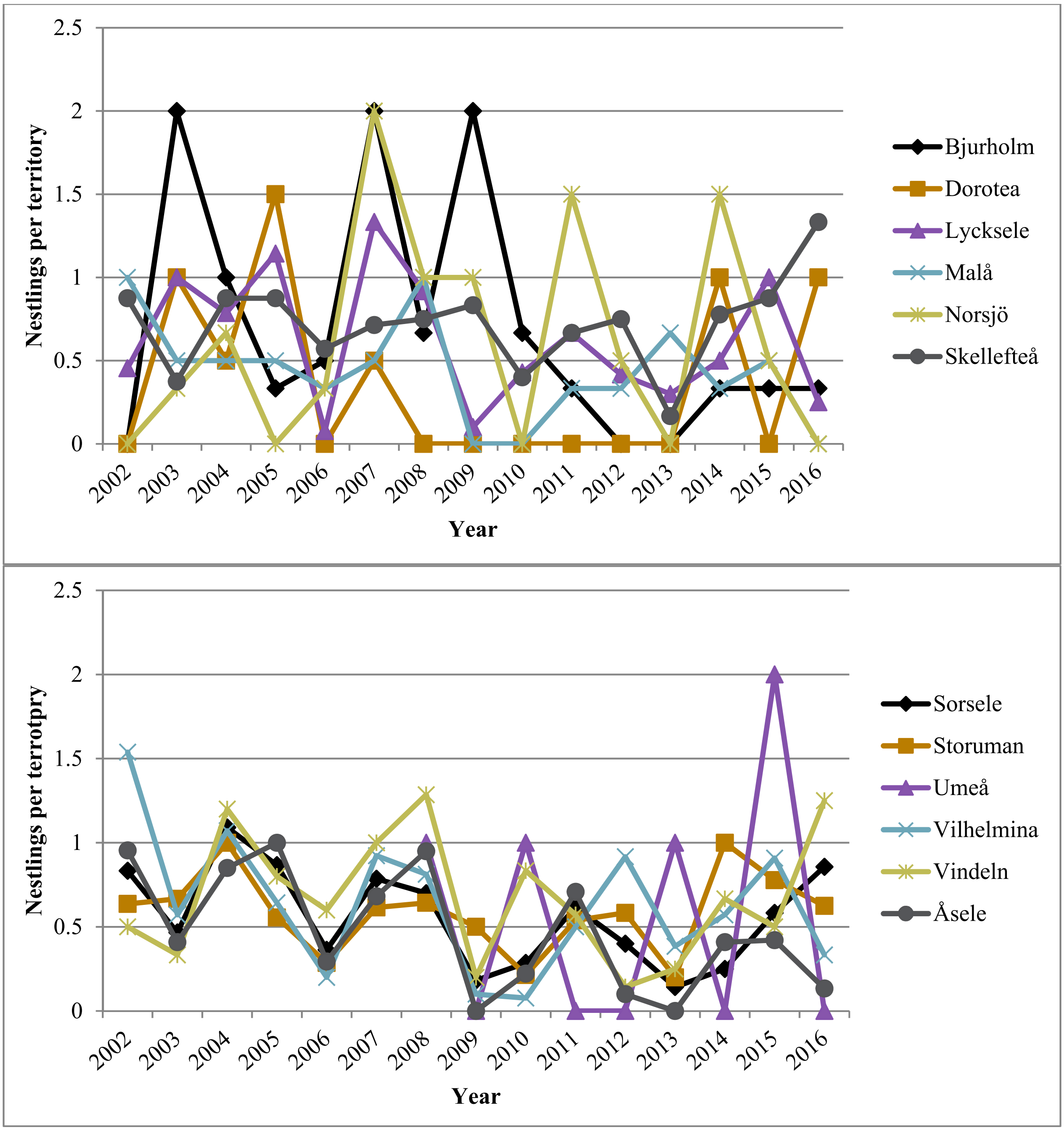

Figure III. Nestlings per occupied territory in each municipality in Västerbotten County over the study period (excluding territories visited in less than 8 of the years of that period).

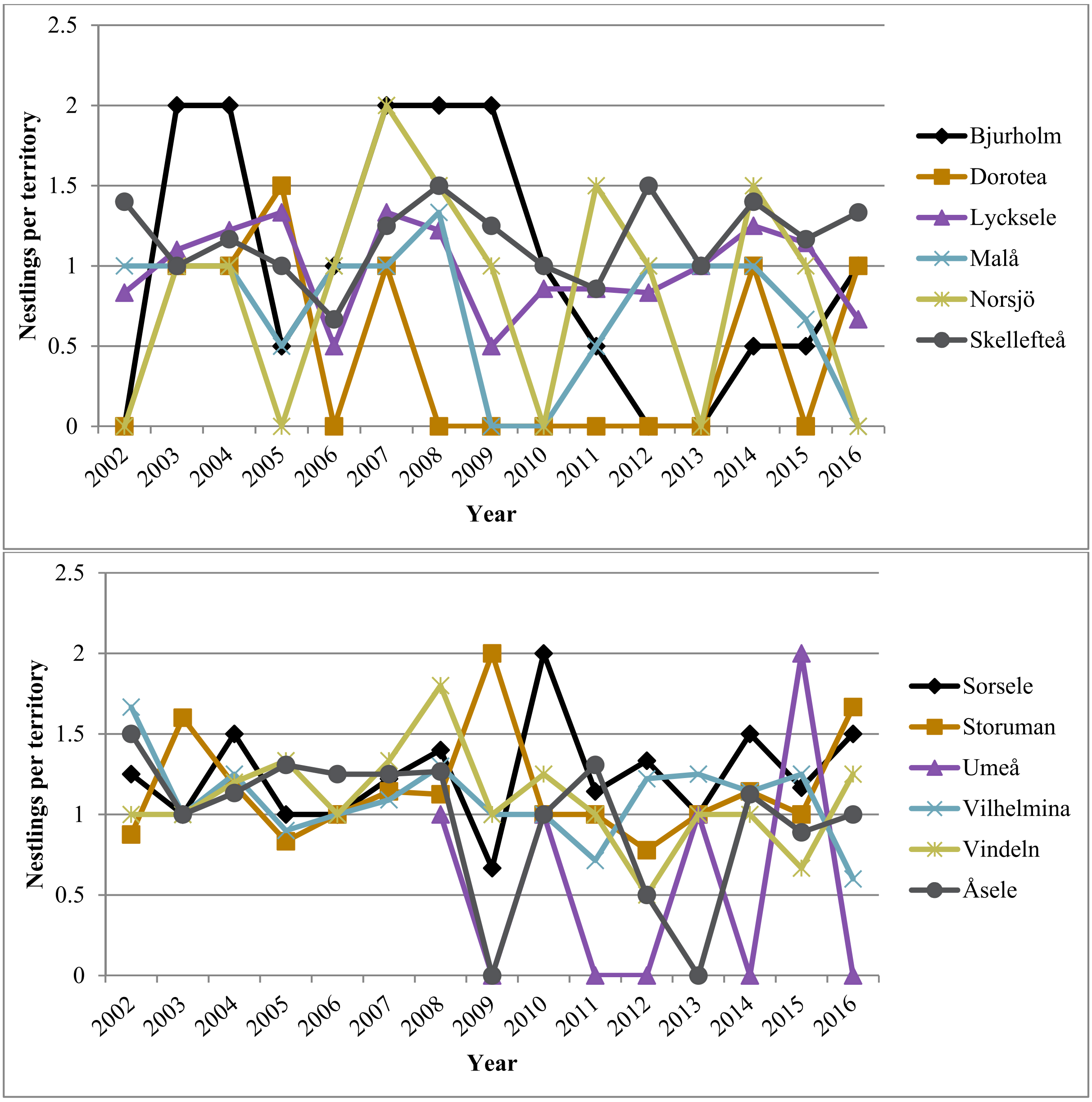

Figure IV. Nestlings per breeding territory in each municipality in Västerbotten County over the study period (excluding territories visited in less than 8 of the years of that period).

Appendix II

Table I. Results of non-significant (a.k.a. had p-values >0.05) simple linear and polynomial regressions between between the following breeding productivity and clear-cut variables (with clear-cuts extracted from ca 5 km^2 and ca 30 km^2 buffer zone sizes: Visit = nestlings per visited year, Occ = nestlings per occupied year, Breed = nestlings per breeding year, All years = ordinary cumulative sum of the area of clear-cuts made over the study period (not including clear-cuts made in 2016), >5 years = cumulative sum of clear-cut area excluding clear-cuts when >5 yrs, >10 yrs = same as the last but when clear-cuts >10 years. All clear-cut sums were weighted by territory area. Territory groups were all territories (lowland + mountains), only lowlands territories (Low) and only mountain territories (Mount). Std. err. = standard error, p = p-value (which was the same for the F- and t-test, just one more digit provided for the F-test), R^2 adj. = adjusted R^2 (given in%), F = F-statistic. For simple linear regressions, t = t-value, Est. = Regression coefficient. For polynomials, Est. 1st = 1st order regression coefficient, Est. 2nd = 2nd order regression coefficient; p-value and F-statistic are for the overall regression. n = 143 territories for each combination.

Simple linear models						
5 km^2, Low, Visit		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	0.01749	Est.	0.05255	Est.	0.02719
	Std. err.	0.0404	Std. err.	0.06524	Std. err.	0.04386
	t	0.433	t	0.805	t	0.62
	F	0.1874	F	0.6487	F	0.3843
	p	0.666	p	0.423	p	0.537
	Adj. R^2	-0.932	Adj. R^2	-0.401	Adj. R^2	-0.705
	AIC	-6.446	AIC	-6.915	AIC	-6.647
5 km^2, Mount, Visit		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.13006	Est.	-0.23667	Est.	-0.13620
	Std. err.	0.14847	Std. err.	0.25623	Std. err.	0.15583
	t	-0.876	t	-0.924	t	-0.874
	F	0.7674	F	0.8532	F	0.7639
	p	0.385	p	0.36	p	0.386
	Adj. R^2	-0.441	Adj. R^2	-0.278	Adj. R^2	-0.448
	AIC	-11.462	AIC	-11.55	AIC	-11.458
30 km^2, Low, Visit		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	0.04967	Est.	0.07581	Est.	0.05954
	Std. err.	0.06953	Std. err.	0.11908	Std. err.	0.07741
	t	0.714	t	0.637	t	0.769
	F	0.5103	F	0.4053	F	0.5915
	p	0.477	p	0.526	p	0.444
	Adj. R^2	-0.56	Adj. R^2	-0.68	Adj. R^2	-0.466
	AIC	-6.775	AIC	-6.668	AIC	-6.857
30 km^2, Mount, Visit		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.42662	Est.	-0.63752	Est.	-0.44498
	Std. err.	0.29768	Std. err.	0.48201	Std. err.	0.32015

	t	-1.433	t	-1.323	t	-1.39
	F	2.054	F	1.749	F	1.932
	p	0.158	p	0.192	p	0.17
	Adj. R^2	1.95	Adj. R^2	1.394	Adj. R^2	1.728
	AIC	-12.763	AIC	-12.457	AIC	-12.641
5 km^2, All, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	0.02617	Est.	0.05928	Est.	0.03266
	Std. err.	0.04790	Std. err.	07748	Std. err.	0.05210
	t	0.546	t	0.765	t	0.627
	F	0.2986	F	0.5853	F	0.3929
	p	0.586	p	0.446	p	0.532
	Adj. R^2	-0.496	Adj. R^2	-0.293	Adj. R^2	-0.429
	AIC	87.603	AIC	87.313	AIC	87.507
5 km^2, Low, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.01134	Est.	0.005393	Est.	-0.004897
	Std. err.	0.05068	Std. err.	0.082066	Std. err.	0.055084
	t	-0.224	t	0.066	t	-0.089
	F	0.05011	F	0.004	F	0.007904
	p	0.823	p	0.948	p	0.929
	Adj. R^2	-1.091	Adj. R^2	-1.144	Adj. R^2	-1.14
	AIC	33.869	AIC	33.916	AIC	33.912
5 km^2, Mount, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.25754	Est.	-0.48350	Est.	-0.27184
	Std. err.	0.26376	Std. err.	0.45479	Std. err.	0.27679
	t	-0.976	t	-1.063	t	-0.982
	F	0.9534	F	1.13	F	0.9645
	p	0.333	p	0.293	p	0.331
	Adj. R^2	-0.088	Adj. R^2	0.245	Adj. R^2	-0.067
	AIC	50.597	AIC	50.417	AIC	50.586
30 km^2, All, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	0.05121	Est.	0.09045	Est.	0.05884
	Std. err.	0.06904	Std. err.	0.11467	Std. err.	0.07620
	t	0.742	t	0.789	t	0.772
	F	0.55	F	0.6222	F	0.5961
	p	0.459	p	0.432	p	0.441
	Adj. R^2	-0.318	Adj. R^2	-0.267	Adj. R^2	-0.285
	AIC	87.242	AIC	87.169	AIC	87.196
30 km^2, Low, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.04013	Est.	-0.07105	Est.	-0.04190
	Std. err.	0.08722	Std. err.	0.14926	Std. err.	0.09716
	t	-0.46	t	-0.476	t	-0.431
	F	0.2117	F	0.2266	F	0.186
	p	0.647	p	0.635	p	0.667

	Adj. R^2	-0.904	Adj. R^2	-0.887	Adj. R^2	-0.934
	AIC	33.553	AIC	33.538	AIC	33.58
30 km^2, Mount, Occ		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.86542	Est.	-1.29604	Est.	-0.90362
	Std. err.	0.52660	Std. err.	0.85336	Std. err.	0.56653
	t	-1.643	t	-1.519	t	-1.595
	F	2.701	F	2.307	F	2.544
	p	0.106	p	0.135	p	0.117
	Adj. R^2	3.109	Adj. R^2	2.406	Adj. R^2	2.831
	AIC	48.844	AIC	49.235	AIC	48.999
5 km^2, All, Breed		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.007185	Est.	0.003573	Est.	-0.004416
	Std. err.	0.062937	Std. err.	0.101926	Std. err.	0.068485
	t	-0.114	t	0.035	t	-0.064
	F	0.01303	F	0.001	F	0.004158
	p	0.909	p	0.972	p	0.949
	Adj. R^2	-0.7	Adj. R^2	-0.708	Adj. R^2	-0.706
	AIC	165.71	AIC	165.72	AIC	165.72
5 km^2, Low, Breed		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.05788	Est.	-0.06889	Est.	-0.05642
	Std. err.	0.05690	Std. err.	0.09237	Std. err.	0.06191
	t	-1.017	t	-0.746	t	-0.911
	F	1.035	F	0.5562	F	0.8307
	p	0.312	p	0.458	p	0.365
	Adj. R^2	0.039	Adj. R^2	-0.507	Adj. R^2	-0.193
	AIC	54.486	AIC	54.971	AIC	54.692
5 km^2, Mount, Breed		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-0.27035	Est.	-0.56977	Est.	-0.28622
	Std. err.	0.39249	Std. err.	0.67638	Std. err.	0.41190
	t	-0.689	t	-0.842	t	-0.695
	F	0.4745	F	0.7096	F	0.4828
	p	0.494	p	0.403	p	0.49
	Adj. R^2	-1.002	Adj. R^2	-0.551	Adj. R^2	-0.985
	AIC	93.527	AIC	93.285	AIC	93.518
30 km^2, All, Breed		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	0.05305	Est.	0.08036	Est.	0.05969
	Std. err.	0.09073	Std. err.	0.15076	Std. err.	0.10016
	t	0.585	t	0.533	t	0.596
	F	0.3419	F	0.2841	F	0.3551
	p	0.56	p	0.595	p	0.552
	Adj. R^2	-0.466	Adj. R^2	-0.507	Adj. R^2	-0.456
	AIC	165.38	AIC	165.44	AIC	165.37
30 km^2, Low, Breed		**All yrs**		**>5 yrs**		**>10 yrs**

	Est.	-0.01383	Est.	-0.05288	Est.	-0.01592
	Std. err.	0.09867	Std. err.	0.16880	Std. err.	0.10990
	t	-0.14	t	-0.313	t	-0.145
	F	0.02	F	0.09815	F	0.02099
	p	0.889	p	0.755	p	0.885
	Adj. R^2	-1.127	Adj. R^2	-1.035	Adj. R^2	-1.125
	AIC	55.518	AIC	55.438	AIC	55.517
30 km^2, Mount, Breed		**All yrs**		**>5 yrs**		**>10 yrs**
	Est.	-1.32335	Est.	-2.02010	Est.	-1.35916
	Std. err.	0.77875	Std. err.	1.26112	Std. err.	0.83859
	t	-1.699	t	-1.602	t	-1.621
	F	2.888	F	2.566	F	2.627
	p	0.095	p	0.115	p	0.111
	Adj. R^2	3.439	Adj. R^2	2.87	Adj. R^2	2.978
	AIC	91.099	AIC	91.416	AIC	91.356
Polynomial models						
5 km^2, Low, Visit		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	0.09879 -0.00510	Est. 1st Est. 2nd	0.18333 0.05516	Est. 1st Est. 2nd	0.14131 0.00876
	Std. err.	0.22953	Std. err.	0.22885	Std. err.	0.22927
	F	0.09287	F	0.3499	F	0.1907
	p	0.911	p	0.706	p	0.827
	Adj. R^2	-2.105	Adj. R^2	-1.5	Adj. R^2	-1.874
	AIC	-4.446	AIC	-4.976	AIC	-4.648
5 km^2, Mount, Visit		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.18376 0.15792	Est. 1st Est. 2nd	-0.19360 0.17543	Est. 1st Est. 2nd	-0.18334 0.16027
	Std. err.	0.21066	Std. err.	0.21021	Std. err.	0.21063
	F	0.6614	F	0.7723	F	0.6683
	p	0.521	p	0.467	p	0.517
	Adj. R^2	-1.294	Adj. R^2	-0.867	Adj. R^2	-1.267
	AIC	-10.054	AIC	-10.282	AIC	-10.068
30 km^2, Low, Visit		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	0.16272 -0.01200	Est. 1st Est. 2nd	0.14510 -0.06674	Est. 1st Est. 2nd	0.17511 -0.04295
	Std. err.	0.22910	Std. err.	0.22913	Std. err.	0.22895
	F	0.2536	F	0.2429	F	0.3101
	p	0.777	p	0.785	p	0.734
	Adj. R^2	-1.726	Adj. R^2	-1.751	Adj. R^2	-1.593
	AIC	-4.778	AIC	-4.756	AIC	-4.894
30 km^2, Mount, Visit		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.297033 0.003209	Est. 1st Est. 2nd	-0.27490 -0.02390	Est. 1st Est. 2nd	-0.28839 0.01133

	Std. err.	0.209278	Std. err.	0.20984	Std. err.	0.20951
	F	1.007	F	0.8646	F	0.9489
	p	0.372	p	0.427	p	0.394
	Adj. R^2	0.028	Adj. R^2	-0.514	Adj. R^2	-0.193
	AIC	-10.763	AIC	-10.471	AIC	-10.644
5 km^2, All, Occ		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	0.17714 -0.05117	Est. 1st Est. 2nd	0.24774 -0.04591	Est. 1st Est. 2nd	0.20311 -0.04688
	Std. err.	0.32527	Std. err.	0.32495	Std. err.	0.32517
	F	0.1607	F	0.3006	F	0.206
	p	0.852	p	0.741	p	0.815
	Adj. R^2	-1.196	Adj. R^2	-0.995	Adj. R^2	-1.132
	AIC	89.577	AIC	89.292	AIC	89.486

5 km^2, Low, Occ		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.06407 0.08980	Est. 1st Est. 2nd	0.01882 0.06769	Est. 1st Est. 2nd	-0.02545 0.08483
	Std. err.	0.28771	Std. err.	0.28786	Std. err.	0.28780
	F	0.0735	F	0.02979	F	0.04735
	p	0.9292	p	0.9707	p	0.9538
	Adj. R^2	-2.151	Adj. R^2	-2.255	Adj. R^2	-2.213
	AIC	35.768	AIC	35.859	AIC	35.822
5 km^2, Mount, Occ		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.36386 0.18678	Est. 1st Est. 2nd	-0.39551 0.22859	Est. 1st Est. 2nd	-0.36593 0.19676
	Std. err.	0.37537	Std. err.	0.37429	Std. err.	0.37523
	F	0.5936	F	0.7448	F	0.613
	p	0.556	p	0.48	p	0.546
	Adj. R^2	-1.557	Adj. R^2	-0.972	Adj. R^2	-1.482
	AIC	52.336	AIC	52.024	AIC	52.296
30 km^2, All, Occ		**All yrs**		**<5 yrs**		**<10 yrs**

	Est. 1st Est. 2nd	0.24012 -0.11683	Est. 1st Est. 2nd	0.25529 -0.15193	Est. 1st Est. 2nd	0.24991 -0.13762
	Std. err.	0.32474	Std. err.	0.32455	Std. err.	0.32463
	F	0.3381	F	0.4189	F	0.3862
	p	0.714	p	0.659	p	0.68
	Adj. R^2	-0.941	Adj. R^2	-0.825	Adj. R^2	-0.872
	AIC	89.11	AIC	88.946	AIC	89.012
30 km^2, Low, Occ		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.13147 0.14289	Est. 1st Est. 2nd	-0.13599 0.09328	Est. 1st Est. 2nd	-0.12324 0.10271
	Std. err.	0.28695	Std. err.	0.28717	Std. err.	0.28719
	F	0.2289	F	0.1649	F	0.156
	p	0.796	p	0.848	p	0.856
	Adj. R^2	-1.784	Adj. R^2	-1.935	Adj. R^2	-1.956
	AIC	35.297	AIC	35.429	AIC	35.447
30 km^2, Mount, Occ		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.60254 -0.11000	Est. 1st Est. 2nd	-0.55886 -0.17956	Est. 1st Est. 2nd	-0.58564 -0.10038
	Std. err.	0.36990	Std. err.	0.37071	Std. err.	0.37049
	F	1.371	F	1.254	F	1.286
	p	0.263	p	0.294	p	0.285
	Adj. R^2	1.38	Adj. R^2	0.948	Adj. R^2	1.068
	AIC	50.751	AIC	50.987	AIC	50.922
5 km^2, All, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.04863 0.04975	Est. 1st Est. 2nd	0.01493 0.07885	Est. 1st Est. 2nd	-0.02747 0.05046
	Std. err.	0.42744	Std. err.	0.42742	Std. err.	0.42745
	F	0.01324	F	0.01763	F	0.00903
	p	0.987	p	0.983	p	0.991
	Adj. R^2	-1.409	Adj. R^2	-1.403	Adj. R^2	-1.415
	AIC	167.7	AIC	167.69	AIC	167.71
5 km^2, Low, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.32689 0.26090	Est. 1st Est. 2nd	-0.24033 0.25547	Est. 1st Est. 2nd	-0.29324 0.25320
	Std. err.	0.32200	Std. err.	0.32294	Std. err.	0.32245
	F	0.8435	F	0.5898	F	0.7218
	p	0.4337	p	0.557	p	0.489
	Adj. R^2	-0.357	Adj. R^2	-0.941	Adj. R^2	-0.636
	AIC	55.809	AIC	56.326	AIC	56.057
5 km^2, Mount, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.38196 0.25143	Est. 1st Est. 2nd	-0.46608 0.35234	Est. 1st Est. 2nd	-0.38530 0.26700
	Std. err.	0.55883	Std. err.	0.55651	Std. err.	0.55864

	F	0.3348	F	0.5511	F	0.3521
	p	0.717	p	0.58	p	0.705
	Adj. R^2	-2.575	Adj. R^2	-1.723	Adj. R^2	-2.506
	AIC	95.313	AIC	94.862	AIC	95.277
30 km^2, All, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	0.24876 -0.12644	Est. 1st Est. 2nd	0.2268 -0.1223	Est. 1st Est. 2nd	0.25353 -0.14138
	Std. err.	0.42683	Std. err.	0.4269	Std. err.	0.42677
	F	0.2137	F	0.1822	F	0.2313
	p	0.808	p	0.834	p	0.794
	Adj. R^2	-1.12	Adj. R^2	-1.165	Adj. R^2	-1.094
	AIC	167.29	AIC	167.35	AIC	167.25
30 km^2, Low, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.04529 -0.02560	Est. 1st Est. 2nd	-0.101217 0.006582	Est. 1st Est. 2nd	-0.04682 -0.04992
	Std. err.	0.32509	Std. err.	0.324959	Std. err.	0.32506
	F	0.01281	F	0.04871	F	0.02217
	p	0.987	p	0.953	p	0.978
	Adj. R^2	-2.295	Adj. R^2	-2.221	Adj. R^2	-2.273
	AIC	57.512	AIC	57.437	AIC	57.492
30 km^2, Mount, Breed		**All yrs**		**<5 yrs**		**<10 yrs**
	Est. 1st Est. 2nd	-0.92138 -0.21822	Est. 1st Est. 2nd	-0.87107 -0.26525	Est. 1st Est. 2nd	-0.88087 -0.15502
	Std. err.	0.54664	Std. err.	0.54785	Std. err.	0.54837
	F	1.5	F	1.381	F	1.33
	p	0.233	p	0.261	p	0.274
	Adj. R^2	1.853	Adj. R^2	1.418	Adj. R^2	1.231
	AIC	92.93	AIC	93.169	AIC	93.271

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