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Master thesis
Predation on Artificial nests; can it predict actual nest loss in
capercaillie *Tetrao Urogallus*?

Master in Applied Ecology

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Summary

1 Declining populations of alpine and subalpine species are thought to be a result of one or more reasons; (1) abiotic and climatic drivers, (2) change in land use, (3) invasive predatory species, or (4) increased population of predators and alternative prey hypothesis. In recent years capercaillie and black grouse populations have decreased and is evident in struggling reproductive success. Up to 70% of reproductive failure is credited to nest predation, which stresses the importance of knowledge about nest mortality on capercaillie nests.

2 As a method of gaining knowledge about nest survival, artificial nests have been debated the last few decades. Uncertain estimates and bias towards predominantly avian predators have lead to discussions about whether the method gives representative results. Artificial nests are used since obtaining data on real capercaillie nests are difficult, time consuming and very dependent on population levels to ensure sufficient data.

3 This paper tries to evaluate the three most common distribution methods used in artificial nest studies; Grid pattern with short distance between nests, random distribution with medium distance between nests, and transect with long distance between nests. Additionally, I used a pair-wise setup parallel to each real capercaillie nest found in 2015 to directly compare survival between real and artificial nests placed in proximity to each other. Further, I examined if nest variables such as nest cover, forest visibility, distance to habitat edge, number of eggs, forest type, forest age and vegetation types impacted the daily survival rate of artificial nests. I used real capercaillie nest data from 2009 - 2015 to compare daily nest survival against the survival of artificial nest, to reveal if artificial nest gives similar daily survival rate. I treated the artificial nests as a productivity gradient from low to high productivity. Three study areas in Norway founded the low productive end of the gradient, where three study areas in Sweden formed the high productive end of the gradient.

4 I found that grid distribution with short distance between nest did not have significantly different daily survival rate as the mean daily survival rate for real capercaillie nests between 2009 and 2015. Pairwise artificial and real capercaillie nest within the same year and in close proximity, had significantly different daily survival rate. Further, I found that the interaction between distance to habitat edge and nest cover impacted daily nest survival for artificial nests the most. Also, avian predators revealed to be the major predatory group depredating artificial nests, in contradiction to real capercaillie nests where mammalian predators were the major predatory group. Lastly, I found no tendency towards a productivity-dependency in the gradient, suggesting that there were relatively equal predation along the gradient.

Sammendrag (Summary in Norwegian)

1 Reduserte bestander av alpine og subalpine arter antas å være et resultat fra en eller flere mulige årsaker; (1) abiotiske og klimatiske drivere, (2) endring i arealbruk, (3) introduserte predatorer, eller (4) økt predatorbestand og «alternativ bytte hypotese». I senere tid har både storfugl og orrfuglbestander gått tilbake noe som har vært tydelig i en årlige nedgang i reproduksjonen. Så mye som 70% av reproduksjonssvikten kan skyldes reirpredasjon, noe som belyser viktigheten av kunnskap og økt forståelse om hvordan dødligheten er på storfugl reir.

2 En ofte brukt metode for å få økt kunnskap om reiroverlevelse, har vært bruk av kunstreir, men metoden har vært mye debattert de siste tiårene. Usikre estimater og en skjevfordeling i retning av høy predasjon fra kråkefugl har ledet frem til diskusjonen om kunstreir i det hele tatt gir ett representativt resultat. Kunstreir er benyttet grunnet innsamling av reirdata på storfugl er vanskelig, tidkrevende og svært avhengig av bestandsnivået hos storfugl det inneværende år.

3 Denne oppgaven forsøker å evaluere de tre vanligste metodene brukt i eksperimenter med kunstreir; rutenett fordeling med kort avstand mellom reir, tilfeldig fordeling med medium avstand mellom reir, og transektlinjer med lang avstand mellom hvert reir. I tillegg til de tre metodene benyttet jeg meg av ett parvist oppsett, hvor ett kunstreir ble plassert parallelt til hvert ekte storfugl reir som ble funnet i 2015, for å illustrere den direkte forskjellen i reiroverlevelse mellom ekte og kunstige reir. Det ble også sett nærmere på hvilke habitatfaktorer som påvirker den daglige reiroverlevelsen på kunstreir. Disse faktorene var; reirdekning (nest cover), skogtettheten (forest visibility), avstand til habitatkant (distance to habitat edge), antall egg (number of eggs), skogtype (forest type), hogstklasse (forest age) og vegetasjonstyper (vegetation type). Jeg brukte ekte reir på storfugl fra 2009 til 2015 for å sammenligne daglig reiroverlevelse mellom ekte og kunstige reir, samt om kunstreir kunne oppnå lignende daglig reiroverlevelse som ekte reir avhengig av hvilke metode som ble brukt. Kunstreiområdene ble behandlet i en gradient fra fattig til rik sett på habitat. De tre studieområdene i Norge ble sett på som den fattige enden av gradienten, hvor områdene i Sverige ble behandlet som meget rikt.

4 Jeg fant at rutenettmetoden med kort avstand mellom reir hadde samme daglige reiroverlevelse som den gjennomsnittlige daglige reiroverlevelsen for ekte storfuglreir i perioden 2009 - 2015. Det parvise oppsettet med ekte og kunstige reir som lå i nærheten av hverandre, hadde signifikant forskjellig daglig reiroverlevelse. Videre fant jeg at interaksjonen mellom avstand til habitatkant og reirdekning påvirket den daglige reiroverlevelsen til kunstreir. Den viktigste predatorgruppen for kunstreir viste seg å være kråkefugl, i motsetning til de ekte storfuglreirene som ble predatert i hovedsak av pattedyr. Jeg fant ingen sammenheng i fattig-rik gradienten, som foreslår at det var en relativ lik predasjon langs hele gradienten.

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1. Introduction

Alpine and subalpine bird species are declining in northern Europe (Lehikoinen et al. 2013; Lindström et al. 2013), but have received less attention compared to farmland species (Hanski, 2005; Gregory et al. 2005). Several climatic and other environmental drivers have been identified to increase the risk of extinction (Sekercioglu et al. 2008; Moss, 2001; Elmhagen et al. 2015), with evidence of range shifts in both poleward and uphill expansion in alpine and forest species (Thomas, 2010; Thomas & Lennon, 1999). Evident in willow grouse (*Lagopus lagopus*) and rock ptarmigan (*Lagopus muta*) which have been added as threatened species in Norway from 2015 (Henriksen & Hilmo, 2015). Forest species such as capercaillie (*Tetrao urogallus*; abbreviated CAP hereafter) are susceptible for stochastic and environmental drivers leading to reduced populations or increased yearly reproductive failure. Revealed in both CAP and black grouse (*Tetrao tetrix*) in recent years with struggling reproductive success (Proctor & Summers, 2002; Saniga, 2002; Kurki et al. 1997; Wegge & Kastdalen, 2007; Wegge & Rolstad, 2011). Several potential drivers have been identified that may cause alterations in the population of CAP, such as;

(1) changes caused by abiotic or climatic factors such as temperature related stress, alteration of habitat by changes in weather conditions or changes of temperature leading to a shift in habitat preference by adapted species (Lehikoinen et al. 2013; Huntley et al. 2007; Gonzalez et al. 2010; Ludwig et al. 2010). (2) change in land use. Increased habitat fragmentation and degradation of suitable habitat negatively impacting CAP populations (Mikolas et al. 2015; Sirkia et al. 2010; Caizergues et al. 2003). (3) invasive predatory species. Such predators may impose a large risk to native prey species as the native species are not familiar with these new predators, and thereby not adapted with an efficient anti predator behaviour (Sugiura, 2016). Such as the potential threat from the invasive raccoon dog (*Nyctereutes procyonoides*) on tetraonidae populations (Kauhala & Kowalczyk, 2011). (4) increased population of predators and the effect of the alternative prey hypothesis (Støen et al. 2010; Selås & Vik, 2006) as predators shift focus from one prey species to another because of declining availability of primary prey (Kjellander & Nordstrom, 2003; Støen et al. 2010; Selås & Vik, 2006).

This change in prey availability may be due to several reasons, but results in increased pressure on alternative prey species that may be easier to catch and more abundant (Støen et

al. 2010; Selås & Vik, 2006). Evident in the cyclic population crashes in vole species affecting CAP by increased predation as a result of prey-switching (Sundell et al. 2003). CAP as well as rock ptarmigans and willow grouse are being pressured by red fox (*Vulpes vulpes*), as the red fox have become more numerous in the mountain ranges of Scandinavia compared to previous decades as a result of increased population (Steen & Haugvold, 2009; Støen et al. 2010). Generalist predators such as red fox and pine martens (*Martes martes*) are more capable of switching to secondary available prey compared to the specialist predators (Dell'Arte et al. 2007; Henden et al. 2010). This impact on CAP by red fox and pine marten have been attributed to reduced hunting pressure on both red fox and pine marten in recent years, more available food all year round, and mesopredator release (Selås & Vik, 2006; Selås, 1998; Wegge & Rolstad, 2011).

Mortality due to predation affects CAP on several stages during its lifespan, from the nest to adulthood (Steen & Haugvold, 2009; Linden, 1981; Wegge & Kastdalen, 2007; 2008). Mortality of subadults are higher than for adult birds, but with seasonal variation in how prone adults are for predation and which predatory species that poses the largest potential danger (Borchtchevski & Kostin, 2014; Storaas et al. 1999; Wegge et al. 2005; Pekkola et al. 2014). For example, in winter when the CAP are primarily feeding on pine needles (*Pinus spp*) the majority of time during a day is spent in conifer trees, avian predators poses the largest threat (Tornberg et al. 2013; Linden, 1988). Hence in early autumn the majority of feeding-time is spent on the ground, mammalian predators poses a large threat (Pulliainen, 1979; Wegge & Kastdalen, 2008). Meaning that different predatory groups will have different impact on the CAP according to different seasons, foraging behaviour and life stage (Wiebe & Martin, 1998; Widen, 1987; Tornberg, 1997; Borchtchevski & Kostin, 2014). Recent studies have identified that red fox and pine marten have a big impact on the CAP population, in particular nest predation (Wegge & Rolstad, 2011; Jahren, 2012).

Predation on nests comprises the majority of mortality for CAP (Steen & Haugvold, 2009; Kurki et al., 1997; 2000; Wegge & Rolstad, 2011; Selås & Kålås, 2007), and as much as 70% of reproductive failure in different bird species can be credited to nest predation (Ricklefs, 1969), though this will differ according to species, depending on whether the species is a ground- or a tree nesting bird (Ricklefs, 1969; Kleindorfer et al. 2003). Species nesting in trees may be unavailable for most mammalian predators, whereas avian predators have access to both ground- and tree nesting birds (Ricklefs, 1969). However, predation rates on nests also depend on types of habitat and surrounding factors, as well as type of predators,

nest type, nesting species and nest cover (Colombelli-Negrel & Kleindorfer, 2008; Kleindorfer et al. 2003; 2005; Remes, 2005a). Nest cover are determined by the potential predators. As top-cover of the nest is more prone to protect the nest from avian predation (Remes, 2005b), ground cover is important to prevent predation from mammalian, reptilian and other ground based predators (Kleindorfer et al. 2003). However, nest cover and its importance, can vary depending on time period. For species such as CAP who only the female incubate and cares for the chicks after hatching, predation on the adult females results in the death of the entire clutch (Wiebe & Martin, 1998). Nests in incubation will have different attraction possibilities than already hatched chicks that emits more scent and sound (Rangen et al. 1999; 2000; Remes, 2005b). This also differs according to which species, such as songbirds who will care for their chicks in the nest until they can fly, whereas CAP will wander off with the clutch immediately after the chicks are hatched. Bird nests are vulnerable in comparison to already hatched chicks or subadults, since the nest is stationary in one location for an substantial length of time, and when the predator detects a nest - all eggs are usually depredated (Remes, 2005a; 2005b). To identify which predators that depredate nests and which factors that influences the probability of predation; the most commonly used method is artificial nests.

Predation on bird nests by using artificial nests have been used as a surrogate for real nests in several studies done in the last 30 years (Robinson et al. 2005; Moore & Robinson, 2004; Michalski & Norris, 2014; Melville et al. 2014; Haegen et al. 2002; Angelstam, 1986; Storaas, 1988; Pedersen et al. 2009; Seibold et al. 2013; Söderström, 1999; Suvorov et al. 2014; Summers et al. 2004; Klausen et al. 2009). However, there are debates about whether or not artificial nests are an accurate or a poor method to measure predation on nests (Major & Kendal, 1996; Lambrechts et al. 2010; Paton, 1994; King et al. 1999; Robinson et al. 2005; Moore & Robinson 2004; Willebrand & Marström, 1988). The use of artificial nests is a result of alleviating the difficulties, and for some species, the near impossibility to get sufficient data on real nests. Some species are difficult to find in the nesting season such as willow grouse, other species are found in low numbers and therefore difficult to obtain adequate number of observations complicating statistical analysis, or species nesting in areas where the terrain and vegetation makes it difficult (King et al. 1999; Paton, 1994). On the other hand, positive reasons for using artificial nests are no limits on sample size and spatial distribution of nests. Therefore artificial nests have been a substitute for real nests in several nest studies, but with varying results (Major & Kendal, 1996; Haegen et al. 2002; King et al.

1999; Paton, 1994). Some articles have evaluated the efficiency of artificial nest with focus on which species that comprises the large part of the predators on artificial nest, such as in the paper of Willebrand & Marcström (1988). Other studies have raised the question whether the actual eggs in the nests are the prey of choice, since the female CAP appear to be the main incentive that draws the predator to the nest (Willebrand & Marcström, 1988; Storaas, 1988; Swanson et al. 2012). By contrast, chicken eggs commonly used in artificial nests, will emit a lot less scent as a real CAP nest will do (Storaas & Wegge, 1987). Later years, Jahren (2012) have worked extensively on CAP and black grouse nests using camera traps placed on real nests reported in by forestry workers, volunteers and hikers. His results state that the red fox and pine marten are the major predators on both CAP and black grouse nests. In contradiction, Storaas (1988) and Willebrand & Marcström, (1988) found that avian predators where the major cause of artificial nest loss.

Hence in my study, I have focused on examining the most commonly used methods and designs in artificial nest experiments. I wanted to see if it is possible to use a nest-design that reflects similar nest survival and predation rate as real CAP nests. Additionally, examine if artificial nests is an accurate method, and if it is still a viable option to use. In this study, I compared the daily nest survival on artificial nests with the daily survival on real CAP nests, within, and between the years of 2009 - 2015. To examine if it was possible to optimize the design to reflect similar results, I used artificial nests in three areas with different design and distance between nests. To test how the surrounding factors and different habitat affected the survival rate of artificial nests, I collected several habitat parameters for analysis. To see if the number of eggs in the nest would make any differences in the predation rate, I varied the number of eggs in the artificial nests. Lastly, I made a design to illustrate the direct difference between artificial and real nests, by placing an artificial nest parallel to each real CAP nest. To include a larger area, more diversity and observations from another year, I also included a dataset from a study done on artificial nests in Sweden collected in 2010.

Hence, I made several predictions; (I) there is a difference in daily survival rate between artificial and real nests in the pairwise setup, (II) random nest distribution reflects the most accurate and comparable results to real CAP nests, (III) forest visibility and the amount of eggs are important variables affecting daily nest survival for artificial nests, (IV) avian predators would be the major predatory group on artificial nests. Lastly, I expected that (V) there would be a difference in daily nest survival along the gradient or latitude, with more predation in the south than in the north.

2. Methods

2.1 Study area

Scandinavia forms a peninsula containing vast open mountain ranges and deep valleys covered in boreal forests. Scandinavian vegetations zones are defined by both latitude and altitude (Fremstad, 1997). The alpine zone is found in the northern parts of the peninsula, but also extends south at high altitude in the mountain ranges of both Norway and Sweden in both latitude and altitude (Fremstad, 1997; Ostlund et al. 1997; Hickler et al. 2012).

Table 1: Vegetation zones found in Scandinavia, from the north to south with primarily dominating tree species with each of the study areas, and which vegetation zone they were situated in.

Vegetation zone	Region of the penninsula	Dominating Tree species	Study area
Southern Arctic	Northernmost	Dwarf birch	-
Alpine	North and high altitude	Dwarf birch, birch	-
Northern Boreal	start of landscape w/trees	Birch and Spruce	Imsdalen
Middle Boreal	confier forest	Pine and Spruce	Braatalia, Evenstadlia
Southern Boreal	confier forest	Pine and Spruce	Garpenberg
Boreo-nemoral	conifer and decidous	Spruce, pine & deciduous	Dyltabruk, Kolmården
Nemoral zone	Southernmost	Deciduous	-

Both southern arctic zone and alpine zone is characterized for a treeless landscape, except for dwarf birch (*Betula nana*), whereas the following zone, northern boreal zone is where forest starts to become dominant (Ostlund et al. 1997; Hickler et al. 2012). Northern boreal zone ranges from having birch trees (*Betula spp.*) at the tree-limit just below alpine areas, to denser forest of Norway spruce (*Picea abies*). In the middle boreal forest the Scots pine (*Pinus sylvestris*) becomes more abundant than the previous zone, however not being as dominating as in the southern boreal forest. The middle and southern boreal zones is mainly dominated by Scots pine and Norway spruce, but also other deciduous species occur more frequently such as rowan (*Sorbus aucuparia*), common aspen (*Populus tremula*) and willow (*Salix spp*) (Ostlund et al, 1997; Hickler et al. 2012). In Boreo-nemoral and nemoral vegetation zones is where there is a shift from the more dominating boreal forests to more deciduous forest, with addition of species such as oak (*Quercus robur*) and elm (*Ulmus glabra*; Fremstad, 1997).

All of the study areas formed a gradient regarding both latitude and altitude, but also most importantly; how fertile, productive and proportion of agricultural lands each area had. Thus the gradient goes from lush and fertile in the southeast to more barren and low productive in the northwest. The south has more agricultural lands than the northern end of the gradient. In addition the study areas were grouped into two

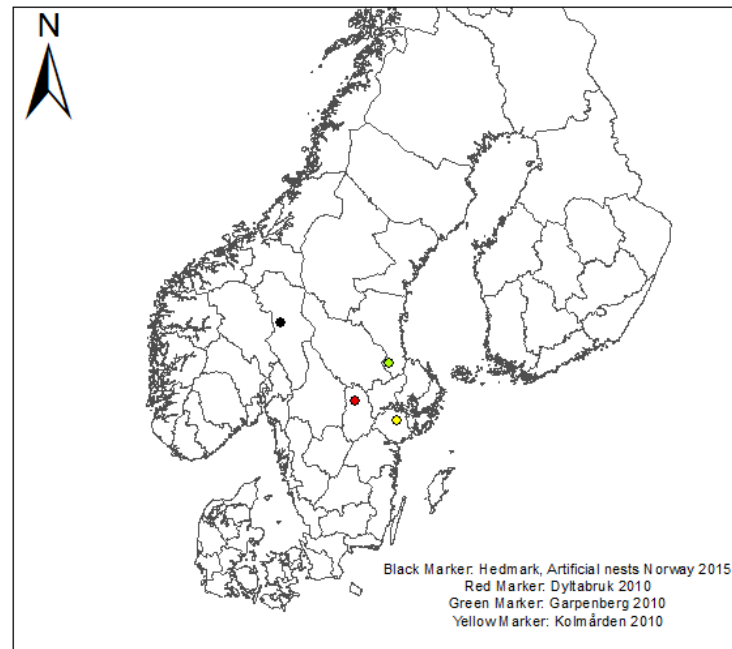


Figure 1: Map showing Scandinavia with points marking the study areas where artificial nests were used.

separate groups with a large distance between them (three in Norway, three in Sweden; hence referred to as low production and high production, figure 1). The most productive study areas was Dyltabruk in the southeast which has a longer growth season and a larger diversity of deciduous tree species. Whereas the most barren and low productive was Imsdalen in the northwest, dominated by mainly spruce and birch. Additionally, the remaining study areas were called Bråtaia, Evenstadlia, Garpenberg and Kolmården (figure 1), and follows the gradient respectively from low to high production areas. Bråtaia and Evenstadlia, has a similar growth season as Imsdalen, but they are situated at lower altitude and in a different vegetation zone (middle boreal zone). Whereas, Garpenberg and Kolmården has different growth season than Dyltabruk, and Garpenberg is situated in a different vegetation zone than Kolmården (Southern boreal zone). Lastly, real CAP nests were found throughout the counties of Hedmark and Nord-Trøndelag, Norway, primarily in the same vegetation zones as represented in Imsdalen, Bråtaia and Evenstadlia.

Potential nest predators along the productivity gradient are represented both in avian and mammalian predators. The most common avian predators are hooded crow (*Corvus cornix*), common raven (*Corvus corax*), magpie (*Pica pica*) and Eurasian jay (*Garrulus glandarius*), but also golden eagle (*Aquila chrysaetos*) have been known to depredate CAP and black grouse nest, but to an uncertain extent. Mammalian predators are represented by red fox,

pine marten, badger (*Meles meles*) and ermine (*Mustela erminea*), found along the entire gradient. In addition, also wild boar (*Sus scrofa*) is present in Kolmården and Dyltabruk. Within this gradient wolf (*Canis lupus*), brown bear (*Ursus arctos*), lynx (*Lynx lynx*) and wolverine (*Gulo gulo*) are also represented, but at lower densities and more specific distributions than the small mammalian- and avian predators, though it is unknown to which extent these species contributes to nest depredation. This study was done as a part of a collaboration project between Hedmark university college and the Nord University. Data on real CAP nests were supplied by the collaboration project.

2.2 Artificial nests

Low productivity - Imsdalen, Bråtaalia & Evenstadlia

The artificial nest survey in Norway was conducted between 23rd of May and 20th of July, 2015. To resemble the CAP incubation period, all artificial nests were left for a minimum of 28 days. For the artificial nest study I used 600 brown chicken eggs divided on 158 nests. I also used a randomly varying number of eggs per nest on two designs. Due to the amount of available brown eggs, which was hard to come by, I used random number of eggs in only one area. In Evenstadlia I used a random egg-count between 3 and 7, this to see if number of eggs in the nest affected the detection probability and thus daily survival rate (table 2). Each area was given a different nest-design to investigate survival rates, those being;

Grid

This design was conducted in Braataalia, Hedmark county in a small area measuring 500 meters x 250 meters with a grid system of 50 meters between each nest and the lowest average distance between nests of 66 meters.

Random

This design was done in Evenstadlia, Hedmark county. The distance between nests ranged from 14 meters to 2,1 kilometres, and had the medium average distance between nests of 217 meters.

Transect

In Imsdalen, Hedmark county, the deployment was done in a transect design. Four transects, split 300 meters apart, deployed 200 meters between nests on each transect. The average distance between nests was 286 meters.

Pairwise

Artificial nests were deployed pairwise in combination with real CAP nests found by the CAP project in the spring of 2015. Artificial nests were deployed 400 meters away from the real nest in a random cardinal direction. In order to mimic the habitat of the real nest, we deployed a corresponding number of eggs within a 50-meter radius of the 400-meter point. This design was confined to CAP nests found in Hedmark County. Intuitively, this design should resemble survival rates for real CAP nest the most.

Table 2: The table shows the study areas with each distribution accordingly. In addition it shows Pairwise which was on a larger scale dispersed around Hedmark county. Number of nests is for each area and the eggs per nest is; eggs per nest in that area. (* Method of monitoring nests. Number of chicken eggs was the same as the real CAP nest placed close to)**

Area	Design	Number of nests	Eggs per nest	Nest sensors*	Camera traps*
Hedmark	Random	50	3-7	15	0
Hedmark	Grid	50	3	15	0
Hedmark	Transect	50	3	15	0
Hedmark	Pairwise	8	Same as pairwise real nest**	0	8

High productivity - Garpenberg, Kolmården & Dyltabruk

The artificial nest study in Sweden was conducted between May and June in 2010. This was also to ensure that the artificial nests was placed in the field as the same time the CAP start incubating. One of the main goal in the study in Sweden was to estimate how, and to which degree, wild boar depredates CAP nests. The three areas were divided according to whether there were wild boar in the area (table 3). In the same areas there was a study going on looking at population levels of voles through trapping lines, so the artificial nests were placed along the same transects as the vole traps.

Table 3: Shows study areas in Sweden with the population level of wild boar, and the number of artificial nest used in each area. Survey method is what kind of predator identifier used on the nest, this was automatic camera traps.

Areas	Wild boar population	N. Artificial nests	Nest survey method
Dyltabruk	High	48	Camera
Kolmården	Low	60	Camera
Garpenberg	None	60	Camera

I set up nests at premade GPS positions on each transect line. When arriving at the GPS position I had the opportunity to position the artificial nest within a 100 x 100 meter area. This was to ensure that the nest was positioned, or created as a real CAP nest would be. Then

I set a new GPS position for the newly established nest, this being the correct position of the artificial nest. The survey in Sweden was conducted in a different way than the survey in Norway, thus needing more eggs. For the survey in Sweden it was used approximately 1500 chicken eggs, 3 eggs in each nest equally in all study areas.

2.3 Nest survival

Low productivity - Imsdalen, Bråta, Evenstadlia & Pairwise

To monitor nest survival on the artificial nests and real nests in Norway, I used two methods; 8 nests were monitored with automatic camera traps, which I used on the pairwise design of artificial nests and on all real CAP nests. The second method was nest sensors, made to monitor the moment of predation (see Appendix I for details).

Automatic camera traps

The camera traps were of the type HCO Scoutguard SG550 with motion sensor and infra red blitz, and used only on the pairwise setup and real CAP nests. When mounting the automatic camera traps it is important that there are no obstacles in the line of view and positioned within 5 meters from the nest object. Preferably with a clear view of the eggs, but at least no obstacles that will trigger the motion sensor, or hinder the motion sensor to trigger when a predator shows up at the nest. The goal with automatic camera traps was to identify the predator on both real CAP and artificial nests and to identify time of failure or success. I used a total of 16 camera traps in this study, 8 on real nests and 8 on artificial nests.

Nest sensors

A common challenge in artificial nest studies is to identify time of nest failure. Often, nests are visited periodically and failure dates are often pooled in time-periods and have thus low resolution. To work around this problem and reduce human activity around the nest sites, I used sensors to accurately estimate time of nest failure for artificial nests in the three different designs used. I created nest sensors from alarm clocks and mini lever switches to work when an egg was removed from the holder the circuit was complete and the alarm clock start counting (Appendix I). The alarm clock was put into a plastic container with two holes leading the positive and the negative electrical cord out to the mini lever switch mounted on a wooden plug. The mini lever switch was turned off when the lever was depressed and the circuit was incomplete, therefore when the lever was released (egg removed) the circuit became complete, initiating the alarm clock to start counting from the

pre-set time. At the end of the lever I mounted a iron-thread into a circular shape that would be able to carry the weight of an egg and also depress the lever when the egg was in place (Appendix I). The goal with the nest sensor was not to identify the predator, rather to estimate the time of failure of the artificial nests without using camera traps. I produced 47 nest sensors, but used a total of 45 nest sensors divided on the three study areas, giving 15 in each area. I saved two nest sensors as backup in case some malfunctioned whilst I was deploying the artificial nests.

High productivity - Garpenberg, Kolmården & Dyltabruk

In the survey conducted in Sweden, I used automatic camera traps on the artificial nests to identify the predator and date of failure. I did not have enough camera traps to cover all artificial nests, instead this was dealt with by assigning camera traps randomly. The camera traps were Scoutguard 550530 with infra red blitz, motion sensor and removable memory card.

2.4 Habitat parameters and Nest variables

Low productivity - Imsdalen, Bråtaia & Evenstadlia

On each nest site I collected several parameters based on the same parameters sampled on the real CAP nests. Since there were only nest sensors on artificial nests, the collection method were slightly different, since time-of-day was not important to collect on real CAP nests as it were on artificial nests (Appendix I).

Habitat parameters

I measured habitat characteristics immediately surrounding the nest site. I categorized the nest site to vegetation types according to Fremstad (1997). I also registered dominating tree species; pine, spruce or birch (table 4). Surrounding the nests site, the dominating vegetation type was measured on a large scale.

Table 4: The table shows a selection of Norwegian vegetation types recorded in this study with description and tree species, according to Fremstad (1997).

Code	Vegetation	Common tree species
A1	Dry, some Heather, dominated by lichens.	Pine
A2	Dry, several other species of heather, such as crowberry	Pine
A3	Heather and bog bilberry dominating species, moss common	Pine and Spruce
A4	Blilberry, more moist	Pine and Spruce
B1	Dry, but calcium rich. Small perennials and herbs.	Pine and Spruce
C2	Wet, lot of shade. Large perennials and herbs. Lush and green	Spruce
E1	Very wet, swamp-forest. Green, but lot of moss and Wood-horsetail	Spruce
J1	Dry bog, some small trees. Grass- and moss species	Pine
J3	Very wet bog, moss and some grass species	None

Finally, I assigned each nest site into forest stand felling class. Felling class consists of 5 classes, the first is clear-cut, with no regeneration (class 1). The second class is from the regeneration starts and until the forest has reached 2-3 meters in height (class 2). The third class is from 2-3 meters to 5-8 meters. Felling class 3 is where thinning take place (class 3). Class 4 and 5 is older, climax stands. Usually, final logging is conducted in felling class 5. This was estimated subjectively on-site, and I did not drill for tree-ring counts or use other equipment to establish age.

Nest cover

The nest cover is an important factor to record on each nest surveyed. Both regarding mammalian- and avian predators. If the nest is situated on a rock or a protruding element in the forest, it is more likely to be seen by passing predators, and therefore it was important to find a way to measure nest cover. As a measure of cover I used a chess board (30 x 30cm) with a 100 squares of 3 x 3cm (similar to Jahren, 2012 & Summers et al., 2010; Appendix II picture 7). I placed the chessboard upright in the middle of the nest and stood 5 meters away and counted all of the squares I could see that was not covered by vegetation, then subtracting them from the total count of 100 squares, giving me the amount of squares covered by vegetation. If a grass straw or other kinds of vegetation was passing "trough" or covering a square it was considered as *covered* and therefore added on the count of squares covered by vegetation. I stood in the nest looking in four directions; North, South, East and West. In addition, I also put the chess board flat on the ground where the nest where and counted any squares that was covered by vegetation when standing and looking down on the

chessboard. This adds to 5 values; North, South, East, West and top-down, with a maximum value of 500 (100 squares per compass direction and 100 from top-down), with 500 being absolute coverage (not able to see the chess board from any direction, even top-down). Hence, a value of 0 relates to full visibility of the chess board and all its squares, from all compass directions and top-down (See; Jähren, 2012; Appendix II picture 7).

Forest visibility

I estimated forest visibility by standing in the middle of the nest site and looking outwards in four cardinal directions, similar to the nest-cover method. When standing in the nest, I estimated how much of an imaginary horizontal line, 10 cm in width and 15 meters in length, I could see. I estimated how much of the imaginary horizontal line I could see in head-height in percentage. With a maximum value of a 100 % and four cardinal direction, gives a total of 400. This value corresponds to the density of the forest, a total value of 400 is open area without any canopy. Due to the difficulty of getting accurate percentage estimations it is a product of heaping, so no values were recorded as 92% or 47%, but rather heaped into 10-20%, giving whole values in the total estimation.

Tree Count

I estimated the density of different tree species. This was done by having a rope that was cut at 1.78 meters, mounted on a stick placed in the middle of the nest. The length of the rope was then the radius in a circle with the nest as centre point. All trees inside the circle above knee-height was counted. 1.78 meter radius gives a circle with area of $\sim 10\text{m}^2$. Multiplying number of trees with 100 gives trees per decare (1000m^2). The dominating tree species recorded were pine, spruce and birch.

Distance habitat edge

To reveal potential edge effect on nest survival, I measured distances to nearest habitat edge. Distance to habitat edge was then defined as the shortest distance to where nesting habitat transitioned into a different forest stand, or other change in the landscape. To estimate the distance to habitat edges I measured the shortest distance from the nest to the habitat edge using the GPS. This is not as accurate as it is with a measuring tape, but measuring error should occur randomly.

High productivity - Garpenberg, Kolmården & Dyltabruk

In Sweden I did not collect any habitat parameters, mainly because the goal with the study was only to identify which predators that depredates artificial nests, and if wild boar contributes to predation of CAP nests.

2.5 Deployment and collection**Low productivity - Imsdalen, Bråtaia & Evenstadlia**

In Evenstadlia study area I assigned the nest sensors by random on the artificial nests. In Imsdalen I set the nest sensors on every fourth artificial nest, thus not being a perfect fit, so I had to adjust it so it was as equally distributed on the four lines as possible. In Braataia I was easier to distribute the nest sensors equally in the grid, since it contained of five lines with 10 nest positions 50 meters apart. I positioned nest sensor on the first nest on the line, the fifth and then on the 10th equally on all lines. I mounted the nest sensors so that it was not possible to see them, even when crouching down besides the nest (Appendix I). I covered the nest sensor and the electrical cords going out to the lever switch, and further covering the lever switch with vegetation making only the eggs and a small piece of iron-thread visual (Appendix I). I used latex gloves when handling the eggs and the nest sensors in the field, to avoid adding additional unnecessary human scent on the nest site.

When collecting the nest, if there were a nest sensor that was activated, the first and most important thing to do first was to write down the present time (the actual time of day I arrived at the nest) and then the time displayed on the nest sensor, so it would be possible to estimate time of nest failure accurately.

High productivity - Garpenberg, Kolmården & Dyltabruk

In the field study in 2015 I deployed the nests and then collected the data/nest after a minimum of 28 days. In Sweden 2010 on the other hand, I checked the nest 5 days after it was deployed, and if the nest was depredated I added 3 new eggs in the nest. Then after a new 5 day period I checked the nests again, if depredated I added new eggs. After a new period of 10 days I checked the nest for the last time and collected all of the automatic camera traps. This adds up to a time period of 20 days per nest.

2.6 Real capercaillie nests

Data from real CAP nest was collected from 2009 to 2015 in Hedmark and Nord- Trøndelag county, and comprised 224 nests with 152 and 72 nest in each county respectively. I used the daily survival rate of real CAP nests to compare with artificial nests to estimate which type of artificial nest design resulted in similar daily survival rate as CAP nests. Real nest were located using three different methods; (1) advertisement through media and other relevant magazines, (2) active search with pointing dogs and (3) in contact with forestry workers who do logging in spring. Real nests were treated as they were not found by random, since they were found where people are. To see more information on how real CAP nest were found, see paper of Jahren (2012).

2.7 Statistical analyses

I used Excel (Microsoft corporation, Redmond, Washington, USA 2007) to create and systemize all data collected after field study. For the statistical analyses I used R statistical tool (R Development Core team, 2016) with the cran package R MARK with nest survival models. The analysing process was divided into three parts; first being analysing the habitat variables, then analysing the distribution methods (*Areas*) and then between the areas in Sweden and Norway (gradient), and lastly analysing the data from real CAP nests collected between 2009 and 2015. Habitat variables consisting of; Vegetation Type (*Vtype*), Forest Type (*Ftype*), Age Forest (*Age*) and Number of Eggs (*Neggs*) were categorical and treated as such. The other habitat variables were Nest cover (*NestCov*), Forest Visibility (*ForestVis*) and Distance to Habitat Edge (*DistEdge*) and was continuous. Additionally, Spruce-, Pine- and Birch per area (*spruceArea*, *pineArea* and *birchArea*) were used as continuous variables. Further, Year was used as a categorical variable, same as Method (*Area*). To fulfil statistical assumptions and to test for normality and distribution, I tested all variables using initial histograms and Shapiro tests. After checking all variables I found that *Vtype*, *ForestVis* and *NestCov* did not meet the assumption of normal distribution. However, after testing different transformations none made the variables become closer to the normal distribution, rather worse. Therefore I chose to use the variables un-transformed, and each variable had equal distribution within in each area (nest-design area). *ForestVis* and *NestCov* were close to normal distribution, except for *Vtype* that differentiated the most from normal distribution with majority of observations in one vegetation category (see table 4). However, when

running the variables I chose to remove Vtype from the models, because the lack of normality influenced the models to a large extent. All analyses were run as nest survival models and therefore the dataset had to be set up in a specific order, see table 5.

Table 5: Setup of the first six columns in the datasets needed to estimate daily nest survival.

ID	FirstFound	LastPresent	LastChecked	Fate	Freq
/*1*/	1	12	31	1	1
/*2*/	1	16	31	1	6

When selecting the best model from models selection, I used Akaike's Information Criterion (AIC; Akaike, 1973). the best model was selected based on the lowest DeltaAIC and supported by the Weight. To estimate the hatching success (How many nests will survive until it hatches), I calculated daily survival rate (abbreviated DSR) raised with 28 (days of incubation), abbreviated as $DSR^{\text{days of incubation}}$. Difference between avian and mammalian predators were tested by Chi-squared tabular test. The two summary tables (6 and 7 results) was analysed with a test of variance on all DSR for artificial nests and real CAP nests from both tables.

When analysing effect of habitat factors I pooled the artificial nests, removing the effect of area to ensure I only detected the effect each variable had on artificial nests regardless of area. Real CAP nests was used without any transformation or treatment of the data, and did not contain any habitat parameters similar to the variables for artificial nests. Due to low population of CAP in 2015, I obtained few observation and resulted in large variation. Random points for placing artificial nests in Evenstadlia, creating maps and calculating average distance between nests in each area was done in ArcGIS (ESRI, 2016). Lastly, I used R statistical tool to produce plots from the model selection and Excel to produce graphs and figures of descriptive illustration included in this paper.

3. Results

3.1 Daily nest survival: comparing artificial- and real nests

Hatching success ($DSR^{\text{days of incubation}}$) after 28 days of incubation showed large variation in real CAP nests. The lowest hatching success was 8,4% after 28 days of incubation (Hedmark, 2012), while the highest hatching success was 59% in 2015 (Hedmark, 2015).

Table 6: Summary of daily nest survival of CAP nests from both counties between 2009 and 2015.

Year	County	Daily survival rate	SE	L CI	U CI
2012	Hedmark	0.915	0.018	0.871	0.945
2012	Nord Trøndelag	0.925	0.024	0.862	0.960
2009	Hedmark	0.938	0.019	0.885	0.968
2011	Hedmark	0.955	0.009	0.933	0.971
2010	Hedmark	0.956	0.008	0.936	0.970
2013	Hedmark	0.957	0.012	0.923	0.976
2011	Nord Trøndelag	0.961	0.010	0.934	0.977
2010	Nord Trøndelag	0.961	0.010	0.936	0.977
2014	Hedmark	0.962	0.009	0.939	0.976
2013	Nord Trøndelag	0.962	0.011	0.931	0.979
2014	Nord Trøndelag	0.966	0.011	0.936	0.983
2015	Hedmark	0.981	0.013	0.928	0.991

Braatalia and Dyltabruk were the two areas with the lowest DSR, 0.94 and 0.92 respectively. Evenstadlia was following with a DSR of 0.98 (table 7). The remaining areas had fairly high DSR varying around 0.99. Estimated hatching success for artificial nests ranged from 8,9% in Dyltabruk, to 93,4% success in the pairwise setup after 28 days of incubation (theoretical incubation). Test of variance between the DSR in both tables (6 and 7) revealed insignificant result ($p=0.093$), hence no difference in variance between artificial and real CAP nests.

Table 7: Summary of daily survival rate of artificial nest in all study areas in 2010 and 2015.

Year	Area	Daily survival rate	SE	L CI	U CI
2010	Dyltabruk	0.917	0.003	0.911	0.923
2015	Grid/Braatalia	0.938	0.002	0.933	0.943
2015	Random/Evenstadlia	0.981	0.001	0.978	0.983
2015	Transect/Imsdalen	0.990	0.0001	0.988	0.991
2010	Garpenberg	0.995	0.0001	0.994	0.996
2015	Pairwise/Hedmark	0.997	0.001	0.993	0.999
2010	Kolmården	0.998	0.0002	0.997	0.998

Pairwise setup illustrates the direct difference in survival between artificial nest and real CAP nests located 400 meters apart (hence pairwise). Even if the DSR estimated for CAP nests in 2015 had a large variation due to few observations (DSR=0.981, 95% CI=0.9284914 - 0.9913401; table 6), there was a difference between the DSR for CAP nests in 2015 and pairwise setup of artificial nests (DSR=0.997, 95% CI=0.9935826 - 0.9992254). I compared the mean DSR of CAP nests from both counties against the DSR for each of the three designs, and found significant differences between the four different artificial nest designs when comparing with the mean DSR for real CAP nests (figure 2).

The pairwise setup was significantly different (non-overlapping confidence intervals) from transect design, where transect design were significantly different from random design. Grid design was then significantly different from random design (figure 2). However, grid design (*Braatalia*; figure 2) were significantly different other nest-designs, but not significantly different from the two mean DSR of CAP nests (*CAP Hedmark*, *CAP Nord-Trøndelag*; figure 2). Artificial nests deployed in grid-design produced similar DSR to what was measured in real nests of CAP.

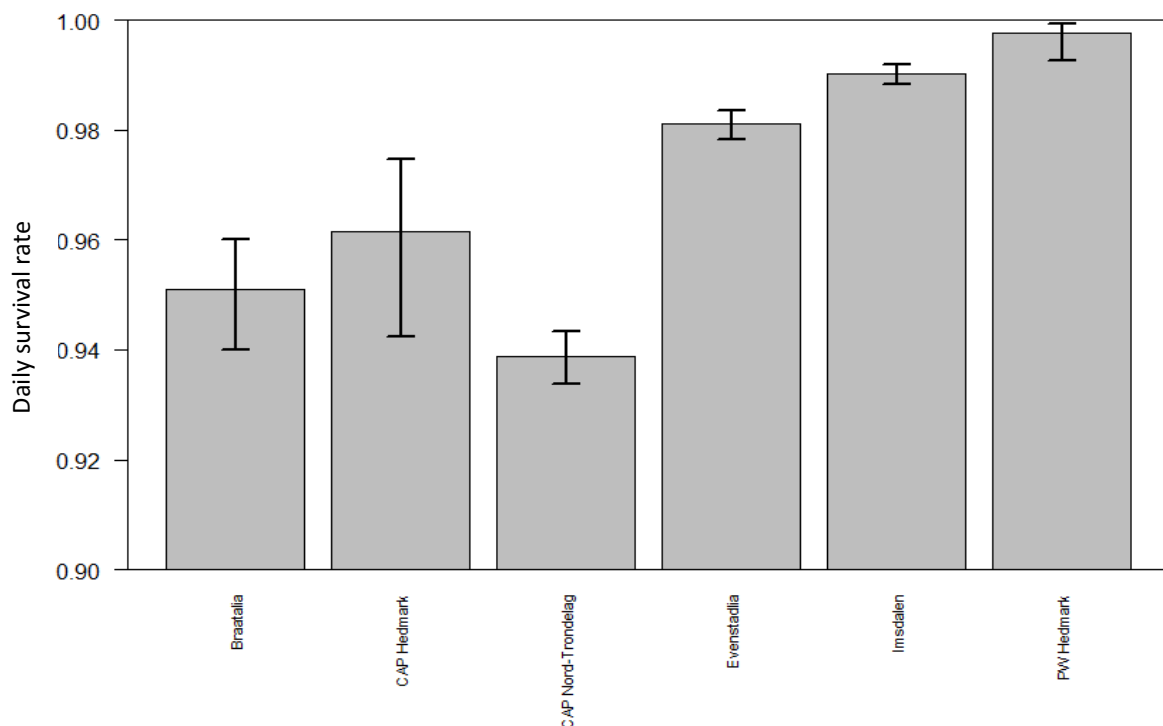


Figure 2: Mean DSR for the CAP nests in Hedmark and Nord-Trøndelag (CAP HM and CAP N-T). Grid- (Braatalia), random- (Evenstadlia), transect- (Imsdalen) and pairwise distribution (PW Hedmark) for the artificial nests.

3.2 Habitat variables in artificial nests

To test for effect of certain variables affecting the outcome of nest survival in artificial nest, I analysed habitat variables for the four artificial nest designs (Areas; *Evenstadlia*, *Imsdalen*, *Braatalia* and pairwise) pooled into one group. There were 50 (= n) nest in *Evenstadlia*, *Imsdalen* and *Braatalia* respectively, and 8 (= n) in the pairwise (*PW Hedmark*) setup adding up to a total of 158 artificial nests. I found an interaction between Distance to habitat edge (*DistEdge*) and Nest cover (*NestCov*) on the DSR for artificial nests (figure 3) when running model selection by use of AIC (Akaike, 1973).

Table 8: Model selection presenting the three best models (total models = 28; R mark analysis).

	Models	AICc	DeltaAIC	Weight
1	S (~DistEdge + NestCov + DistEdge:NestCov)	3733	0.000	9.66
2	S (~DistEdge + ForestVis + DistEdge:ForestVis)	3741	7.575	2.18
3	S (~vtype + SpruceArea + vtype:SpruceArea)	3742.	8.872	1.14

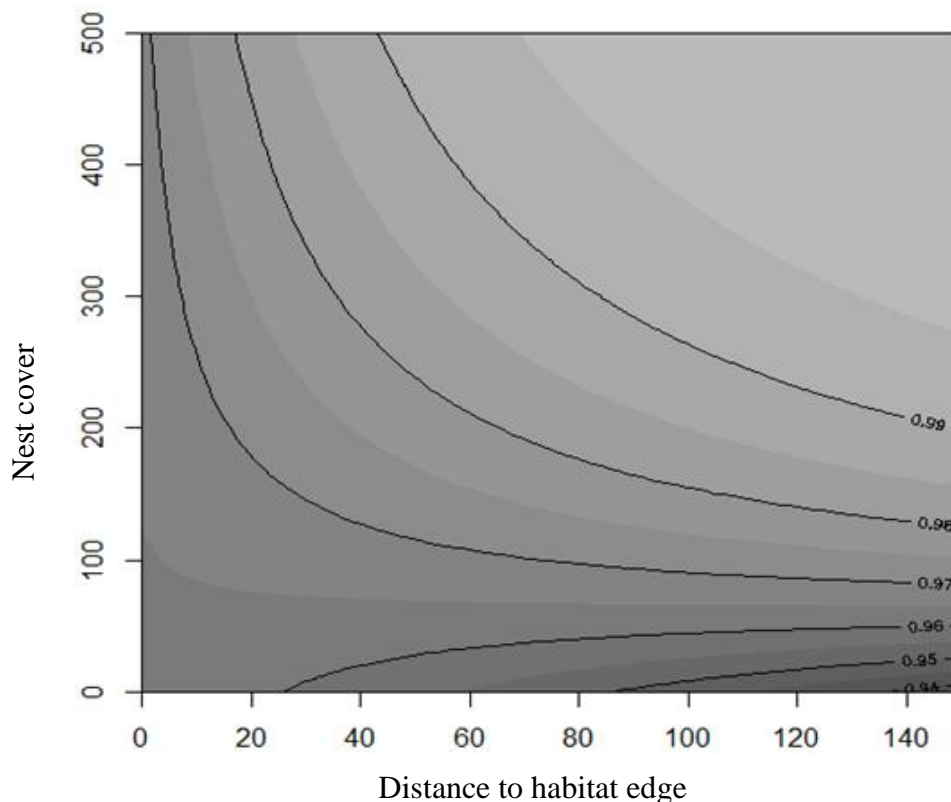


Figure 3: Contour plot showing the interaction between Distance to Edge and Nest cover. Shade of colour and isolines indicates DSR for the pooled group of all artificial nest. Darkest shade: low DSR, light shade: high DSR. Nest cover is presented in a scale from 0 till 500 (see methods) and Distance to edge is scaled in meters from the nest to habitat edge.

However, for forest visibility (*ForestVis*), forest type (*ftype*), type of conifer cover (*spruce or pine*), the tree count of the most common species (*spruce, pine or birch*) and vegetation type (*vtype*), I found no significant effect on DSR of the artificial nests. Additionally there were no significant effect of number of eggs placed in the artificial nest in the two areas with random egg count (between 3-7 eggs) and pairwise with equal amount of eggs as real adjacent CAP nest (3-8 eggs).

3.3 Nest sensors, Time of day and it's predators

Artificial nests in 2015 was primarily fitted with nest sensors, but artificial nests in the pairwise setup had camera traps. Nest sensors produced a date and time at the actual predation moment, and therefore could estimate the survival of the nest in days, hours and minutes. The efficiency of nest sensors were uncertain before deployment, but revealed to function properly and reliably throughout the field study. Out of 45 nest sensors 2 did not function for the duration in the field, giving nest sensors a success rate of 95,6% during the entire period. However, even though it could not produce proof of predators such as pictures, it was possible to get data at which hour, or time of day, the artificial nests were depredated.

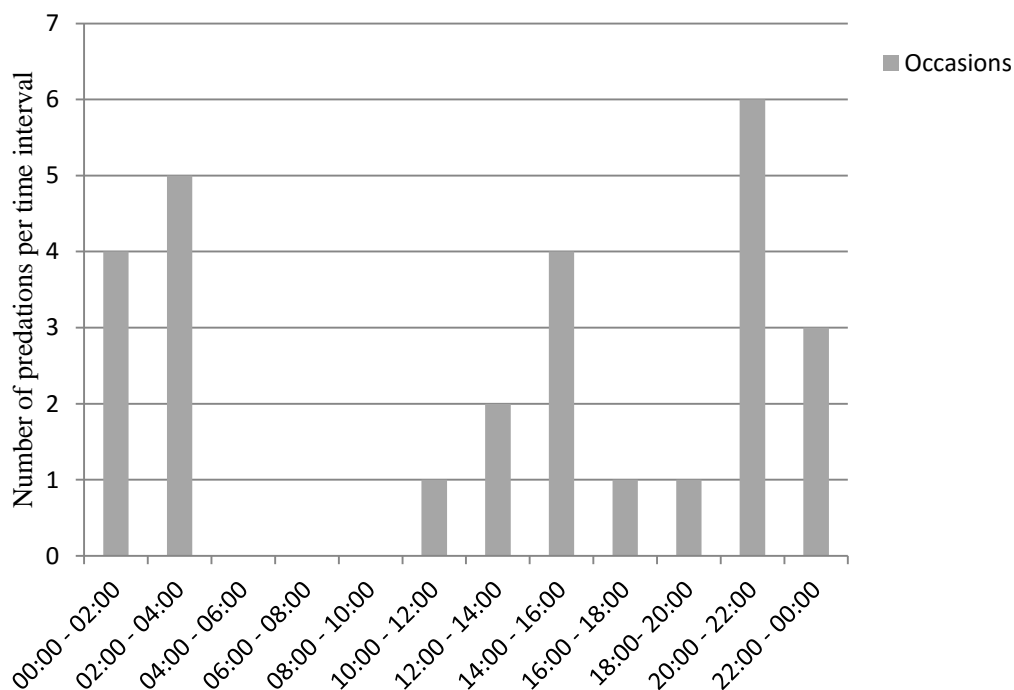


Figure 4: Graph illustrating predation at different time of day during the entire study period from artificial nests with nest sensors (No camera traps included). Number of occasions on the Y axis.

The time-of-day the predation happened revealed that between the 03:00 AM and 11:30 AM there were no predation of the artificial nest with nest sensors (figure 4). During that time of year (June & July) the length of day and the short night is confined to darkness between 00:00 AM and 03:00 AM, however not becoming entirely dark. The sun is up from approximately 03:00 AM until 23:00 at night. One group in the left of the graph (figure 4) is within the dark hours of the day, whereas the rest were depredated when it was daylight (group to the right in the graph, second group; figure 4).

Between 2009 and 2015 camera traps were used to identify predators on real CAP nests. To compare this result with artificial nests I used camera trap results from artificial nests in 2010 (see methods). I grouped the species into mammalian and avian predators.

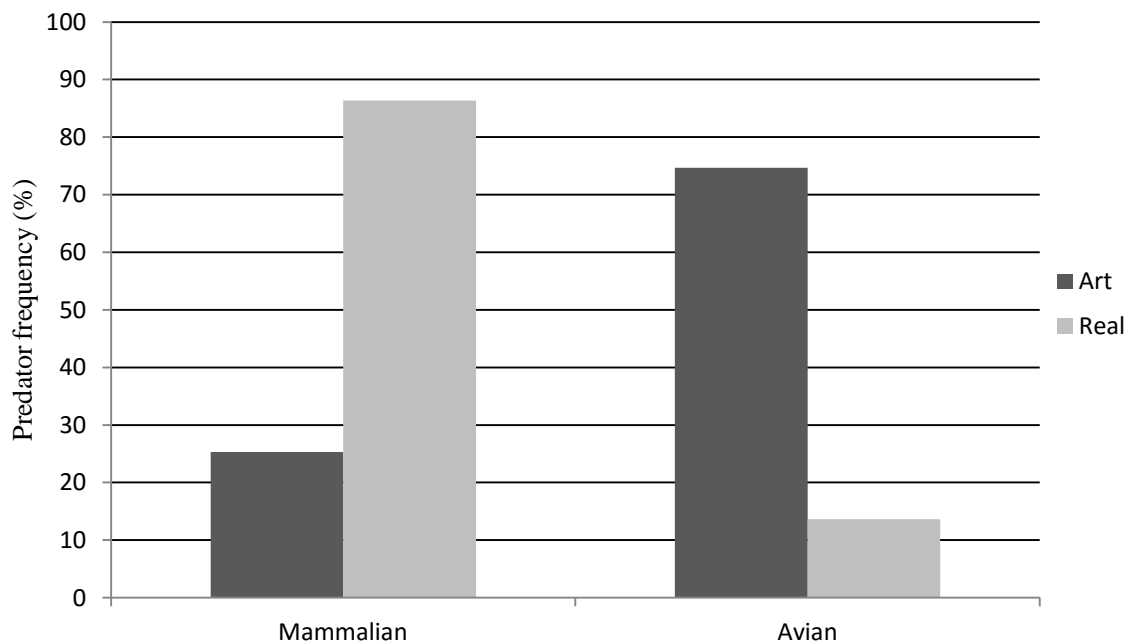


Figure 5: Graph presenting mammalian and avian distribution between real CAP nests (Real) and artificial nests (Art) in percentage from identified predators in front of camera traps in 2010 for artificial nests and between 2009 and 2015 for real CAP nests.

When examining the predator frequency it revealed a difference in type of predators between artificial nests and real CAP nest (figure 5). For CAP nests there were 38 mammalian and 6 avian predators, whereas there were 20 mammalian- and 59 avian predators in the artificial nest study from 2010 (figure 5). Additionally I found a significant difference in

representation of predator groups between real CAP nests and artificial nests ($\chi^2 = 1.32$, $df = 1$, $p < 0.0127$).

Real CAP nests was mainly depredated by red fox ($n_{\text{real}} = 26$ vs. $n_{\text{art}} = 1$) and pine marten ($n_{\text{real}} = 24$ vs. $n_{\text{art}} = 9$), while hooded crow showed a higher predation rate on artificial nests ($n_{\text{real}} = 2$ vs. $n_{\text{art}} = 22$) as also did the common raven ($n_{\text{real}} = 2$ vs. $n_{\text{art}} = 12$) Lastly, wild boar contributed with 3 ($n=3$) predations on artificial nests, whereas there were no predation by wild boar on real CAP nests in my study (figure 6).

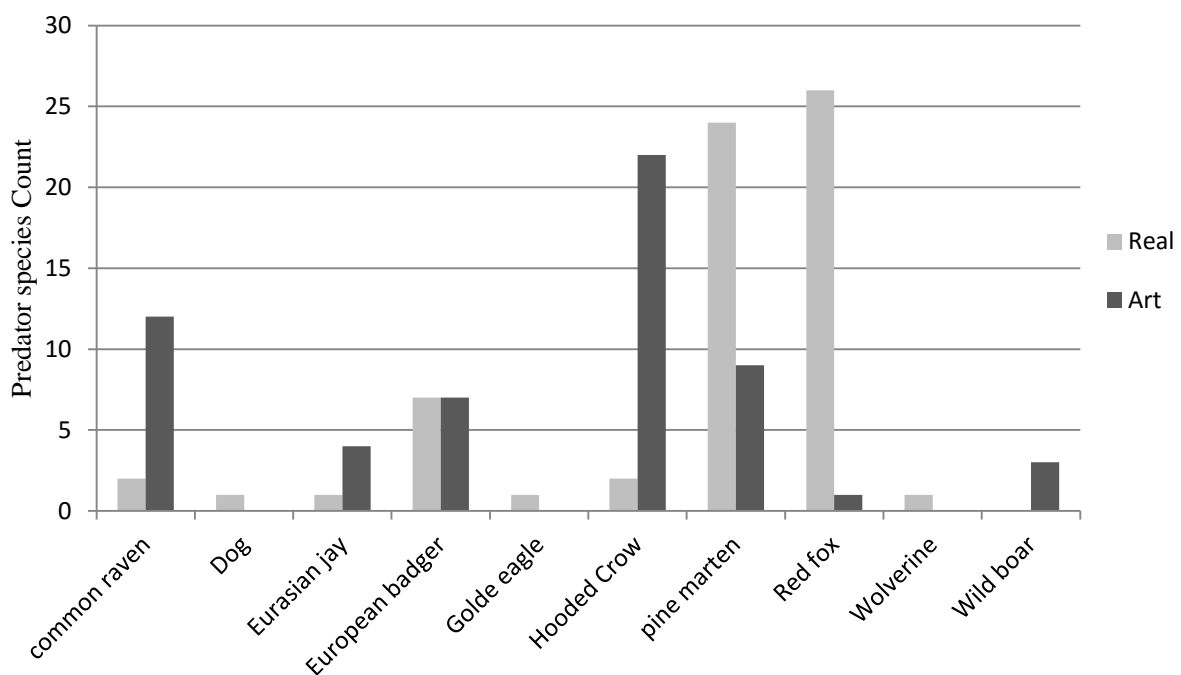


Figure 6: Descriptive representation of species observed by camera traps depredate both artificial and CAP nests in 2010 and between 2009 -2015, respectively. Total predation; 79 (=N) artificial nests, 44 (=N) CAP nests.

3.4 Regional effects

I combined the field study from 2010 and 2015 to examine if there were any influence of productivity (richness and productivity gradient). Southern regions of the peninsula contains larger areas with agricultural land, mixed with higher annual average temperatures and is expected to yield a higher population of predators due to higher productivity, and therefore have a low DSR. Whilst the northern areas in the gradient would have a lower population of

predators, reflected by the highest DSR rate along the gradient. However, I found no tendency towards a productivity-dependent gradient, revealed in the DSR between low and high productive areas (figure 7).

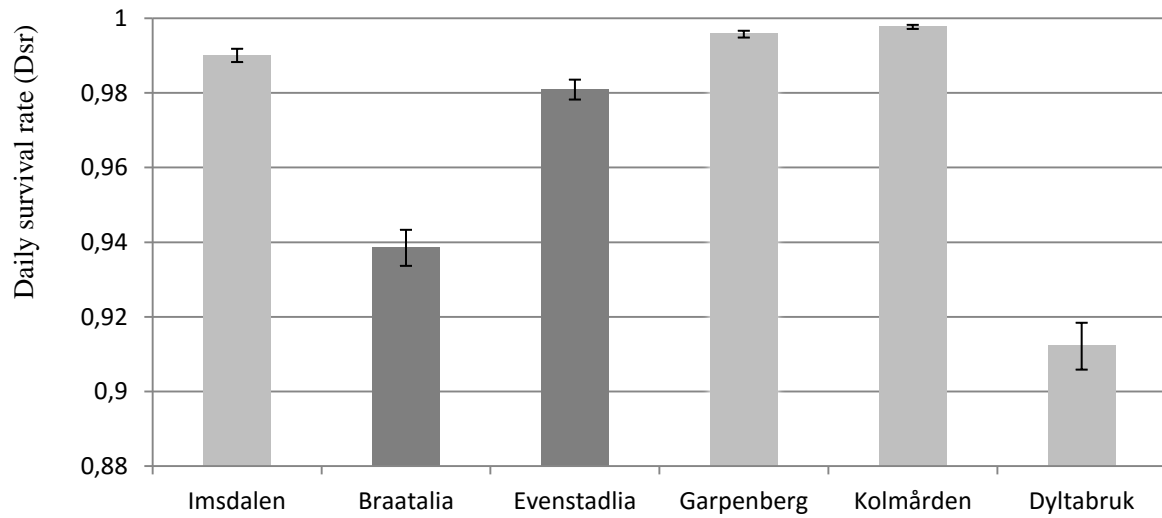


Figure 7: Daily nest survival for all artificial nest areas in the study, from Imsdalen that had the lowest productivity to Dyltabruk that showed the highest productivity (95% CI). Each colour gradient represent different distribution pattern. Dark grey: Grid and random method, light grey: transect method.

4. Discussion

I found no difference in total variation in the results between artificial and real CAP nests, suggesting potentially similar temporal predation patterns. I found that artificial nests in the pairwise setup had higher DSR than real capercaillie nests in 2015. Three out of four artificial nest designs I used, had higher nest survival than real CAP nests. However, grid design obtained similar DSR as the mean DSR for real CAP nests between 2009 and 2015. I found that the interaction between nest cover and distance to habitat edge affected the DSR of artificial nests. Avian predators were identified to be the predator group that affected artificial nests the most, whereas mammalian predators had the largest impact on real CAP nests. Interestingly, time-of-predation data from nest sensors revealed two distinct predation patterns. With few predations during the dark hours of the night, no predation in the morning, and the majority of predation during daylight. Lastly, I found no tendency towards a productivity-dependency in the gradient, with similar nest survival along the gradient.

CAP nest in all habitats that they normally use and no features of nest site selection has been identified (Storaas & Wegge 1987). Thus, the designs with most resemblance to the spatial distribution of CAP nests were therefore pairwise and random deployment of artificial nests, which both had higher survival estimates than mean DSR for real CAP nests. This may be a consequence of differences in detection probabilities between CAP nests and artificial nests, different suite of nest predators or that artificial nests deter predators from eating the eggs.

Studies such as Burke et al. (2004) and Seibold et al. (2013) found a tendency of artificial nests having lower nest survival compared to real nests. In contrast, I found that three out of four (transect, random and pairwise) nest designs had higher DSR than mean DSR of real CAP nests. The DSR for artificial nests in grid design was not different from the mean DSR of real CAP nests. Grid design bears little resemblance to the spatial distribution of real nests of any species in the boreal forest. The grid design had 400 nest per square km whilst CAP nests occur at much lower densities. In contrast, King et al. (1999) found that the survival rates for artificial nest were significantly lower than for real nests of house sparrows (*Passer domesticus*). They used a similar deployment to my pairwise design, aiming to place the artificial nest in similar habitats as the house sparrow would use. For the house sparrow study, this suggest either higher detection rates in artificial than real nests or that predator efficiency upon detection was higher at artificial nests.

Contrary to King et al. (1999), my pairwise design comparing the artificial nests and real capercaillie nests within the same year (2015) revealed that artificial nests had higher DSR. Even when placed in close proximity of each other and in similar habitats, it still resulted in different nest survival between the two sets of nests. In general, one obvious difference between real nests of any kind of species and artificial nests is the parental care exhibited by the incubating bird at the real nest, which may attract or divert predators whilst artificial nests are easily accessible (King et al. 1999).

Several causes of nest failure exists in real CAP nests that do not exist in artificial nests. A number of studies, such as Thompson & Burhans, (2004), Guyn & Clark (1997), Burke et al. (2004) and Buler & Hamilton (2000) warn against extrapolating nest survival patterns from artificial nests to real nests because of differences in important mechanisms. Artificial nests have potentially two outcomes that determines nest survival, predation or no predation. Real capercaillie nests on the other hand, are susceptible to several nest fates. The incubating female can desert the nest due to low body condition or stress. Or as documented in 2015, a female dying whilst incubating the eggs. The female is also vulnerable to predation when she is foraging between sessions of incubation, all of which may result in nest failure.

Storaas & Wegge (1987) hypothesized that the primary goal for mammalian predators when detecting nests is the female incubating the nest, and the eggs becomes secondary prey if the female is flushed. if the predator is unable to catch the female. Clark & Wobeser's (1997) findings supports this, where they made an experiment with treatment and control nests for mallard (*Anas platyrhynchos*) and added scent from mallard faeces, pond water and feathers to the nests. Those nest with scent added had lower survival than those without. Equally, removing the hen from the nest, effectively removes the majority of olfactory cues. The remaining means of finding the nest will then be accidental stumbling on to the nest, or by detecting the nests visually, from the air or perch trees. Storaas (1988) and Willebrand & Marcstrøm (1988) suspected that avian predators were the primary predators of artificial nests. In my study, distance from habitat edge and nest cover affected the DSR of artificial nests. Distance to habitat edge indicates that predators search for food along more predictable routes in the landscape. Additionally, edges between different types of vegetation or forest stands, contain trees that differs in size and makes good vantage points for corvids, similarly found in Rolstad et al. (1991) with birds of prey hunting in fragmented forests. In addition, mammalian predators in Storaas et al. (1999) were found to use habitat edges when searching for prey. The importance of nest cover in the apparent DSR for artificial nest

indicates that vision may be the primary sense when predators detect artificial nests. If there was no effect of nest cover it would be more plausible that scent could play a larger role in the detection probability of artificial nests.

According to Willebrand & Marcström (1988) avian predators were the primary predator on artificial nests, I found similar results. Avian predators were significantly more present on artificial nest than real CAP nests. I found that mammalian predators contributed to the largest predation on CAP nests. This supports the results found in the nest cover and distance from habitat edge, indicating the importance of vision. Indication towards two distinct groups of predators affecting artificial nest during the 24 hours a day was revealed by nest sensors. Most of the predations were interpreted as species active during daylight. Fewest predations were observed between 00:00 AM and 03:00 AM - which was the hours with darkness, thus interpreted as mammalian predators. The majority of predation that were observed between 12:00 PM and 23:00, where primarily interpreted as avian predators. Even though several predation events occurred during nights, this does not exclude corvids because of lack of darkness during summer. In early spring and summer, when the nights are short, mammalian predators such as red fox and pine marten are usually most active during the darkest hours of the night. However, activity of red fox and pine marten will still occur in early evenings and in early mornings when it is still daylight. In the middle of the day, they will be primarily inactive and stationary in comparison with avian predators. Interestingly, between 03:00 AM and 11:00 AM however, there were not documented any predation in any of the artificial designs. One probable cause this lack of predation between 03:00 AM - 11:00 AM, may be that initial food search of corvids are related to feeding the fledglings before finding food for themselves. First half of the day, corvids may be retrieving food items for their chicks, and not moving too far away from the nest. Whilst later in the day searching for food or prey for themselves makes them search further away from the nest and coming into the study areas where the artificial nests placed.

Nest sensors were developed as a method to estimate time of failure in artificial nests since automatic camera traps are costly and it were uncertain how many camera traps were available before the experiment started. It is a low-cost and effective way to produce a large amount of sensors used for artificial nests. For artificial nests, it was effective, and proved to be durable in the field. Obviously, it did not produce any form of identification of the predators, but is a valuable tool for calculating DSR estimates in artificial nests. Nest sensors are not suitable for using on real bird nests, mainly because the bird rotate and shifts eggs

around during incubation. Instead, I used automatic camera traps to identify predators on real CAP nests and artificial nests in the pairwise setup and artificial nests in 2010. However, I observed in the artificial nest study collected in 2010 that predators took notice of the camera traps and it seemed that some species, such as wild boar were attracted to the camera traps. On the other hand, it seemed as the camera traps deterred the red fox. This can probably vary depending on camera trap type and model, since some field studies have not encountered the same problem (Meek & Pittet, 2012; Rovero et al. 2013). Additionally, red fox can exhibit different behaviour according to regions or areas. In some areas, the red fox can avoid automatic camera traps, where in some areas the red fox takes no notice in the equipment.

Within the productivity gradient, I expected that the nest survival would be higher in the northern, low productive areas. Whereas the high productive end of the gradient was expected to have a low nest survival. Although Dyltabruk (high productivity) had the lowest DSR, Braatalia (low productivity) had a similar DSR. Garpenberg (high productivity) and Kolmården (high productivity) both had higher DSR than Imsdalen (low productivity) and Evenstadlia (low productivity), showing no pattern towards a productivity-dependent gradient. Density of artificial nests were primarily the same in all areas, and the same number of nest within each areas. However, Dyltabruk had a high density of wild boar. The same dataset have been used to examine the effect of wild boar on nest survival of artificial nest in a different study. However, wild boar contributed with only 6% of the total predation of artificial nests in 2010, where avian predators were interpreted to be the main predators (Gjertsen & Hörnell-Willebrand unpubl.). Nest survival in the areas situated in the high productive end of the gradient were correlated to population level of wild boar. Wild boar-related supplementary feeding stations has probably an indirect effect on nest survival and remains of offal after hunting may lead to increased population of mesopredators. Supported by Oja et al. (2015) who found that nest survival was correlated to wild boar feeding stations and mesopredators increasing consequently.

The lack of any tendency towards a productivity-dependency in the gradient can be a result of comparing two large areas (high and low productive) between years. Prey populations fluctuate and populations of predators fluctuate accordingly. Effect of predation tends to be similar on a quite large scale (Moran 1953). However, removing the effect of year and only considering the productivity of the gradient may as well reveal lower nest survival in the high productive end of the gradient. Alternatively, the traditional view of a south-north

gradient in productivity and thus predator densities may not be as evident as previously suspected.

One potential improvement of this study is to repeat the study with a rotation of deployment-designs. Although area-effects among the different deployment-designs should be small due to spatial proximity, it is unclear to which extent area affects the results, and by comparing between two consecutive years- and different nest designs it is perhaps possible to obtain better accuracy. Additionally, it would be possible to see the effect of potential differences in predator population between years. One possibility that I was not able to account for, was if grid design (Braatalia) was situated in the home range of e.g. a nesting pair of corvids. Potentially, a pair of corvids could develop a search image for artificial nests or their probability of detecting a nest would simply increase by time. The drawback of adding camera traps or other kinds of equipment to artificial or real nests, is that it is unsure to what extent it deters or attract predators. Equally, nest sensors can impact the results, by emitting scent from humans, plastic or tape. Alternatively, it can act as a visual cue for predators (Picozzi, 1975), but an observational comparison of the two methods, nest sensors were usually more concealed than camera traps. Due to difficulties obtaining sufficient amounts of brown chicken eggs and a limited time frame, the variation in number of eggs per nest became too small. Finding no effect of number of eggs in the nest is something to consider to do once more to obtain better accuracy.

4.1 Conclusions:

Using artificial nests as a substitute for real nests when estimating nest survival in CAP are not recommendable for a number of reasons. Estimations of nest survival based on data from artificial nests, lacks the main mechanisms found to be important in the relationship between CAP nests and the predators predated the nests. Several factors affect nest survival in CAP, which do not exist in artificial nests, such as the female abandoning the nest due to low body condition. Although, grid design revealed to be the best method in this study, it raises concerns about the empirical value of data derived from artificial nests. Since the number of nests per square kilometre are exceedingly high in comparison to naturally occurring capercaillie nests and location of the artificial nest grid may play an important role. High densities of artificial nest can probably result in two outcomes; either the grid is detected by predators and most nests are predated, or the grid remains undetected. Additionally, with the

apparent difference in predators affecting artificial and real CAP nests, it strengthens the conclusion that artificial nests will not reveal any mechanisms believed to act upon real CAP nests. I suggest that even if it requires a lot more work and efforts, using real bird nests will provide the accurate and correct results needed to understand mechanism driving nest survival.

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7. Appendix I

Production of Nest sensors

Nest sensors were produced accordingly to (Borgo & Conover, 2009), with some adjustments since, the paper was published in the United states, and some parts were not obtainable in Norway. The nest sensors work in the same way described in that paper, just with some other components and a slightly different design.

Materials needed for the production of 45 nest sensors:

- *Wooden plugs*, (See picture 5) 45 pieces

The wooden plugs must have a minimum length of 15 cm because one must take into account the mounting of the sensor on top, and vegetation when sticking it in the soil. Also it must be flat, or the mounting of lever switches can become unstable.

- *Electrical cords*, 135 meters (2x 1,5 meter per nest sensor box, minimum)

I recommend that you get the thinnest wire possible without compromising too much on strength, since it is going to be soldered and that high thickness of the wire leads to higher tension on the soldering when the wire is being moved around. Get electrical cords that are brown or black, green is also preferable as long it is not reflective.

- *Mini lever switch*, 45 pieces.

Hard to obtain due to different names on that kind of switch, my recommendation is to get those with premade screw wholes. Makes it a lot easier to mount them on the wooden plug.

- *Alarm clocks*, 45 pieces

Find a cheap alarm clock that displays date, month and time on a digital display. Check that it restarts at the same time every time the clock is powered up (very important!).

- *Tupperware boxes/ Plastic containers*, 45 pieces

Get some plastic containers that has a good sealing to avoid water entering the box (very important!). should be transparent, because it makes it a lot easier to check if the nest sensor works when you mount it.

- *Glue*, one tube

Get a hold of a good glue, should be water resistant and strong and preferably pliant so it can withstand tension.

- *Iron thread*, the more the merrier

I recommend that you get a iron thread that is thin enough to be easy to work with, but can still hold the weight of an egg when suspended at the end of the lever switch.

- *High grade tape*, 3 pieces

Get a black or brown tape to use on the cords, plastic containers and when securing the lever switch to the wooden plug.

- *AAA batteries* (depending on alarm clock), 100 pieces (10 in backup)

Step 1: The alarm clock

Start by preparing all the plastic containers. Remove all kind of stickers that has bright colours, then drill two holes on one side of the container. The wholes should be the same diameter as the electrical cords. If desired, it is possible to paint all the plastic containers, but remember that they will need to be left alone and unusable until the smell of paint is reduces or removed.

Than prepare all the electrical cords, cut them into 1,5 meter lengths. This is a minimum, I recommend that the cords are at least 2 meters in length (Then remember to buy more electrical cord than mentioned above).

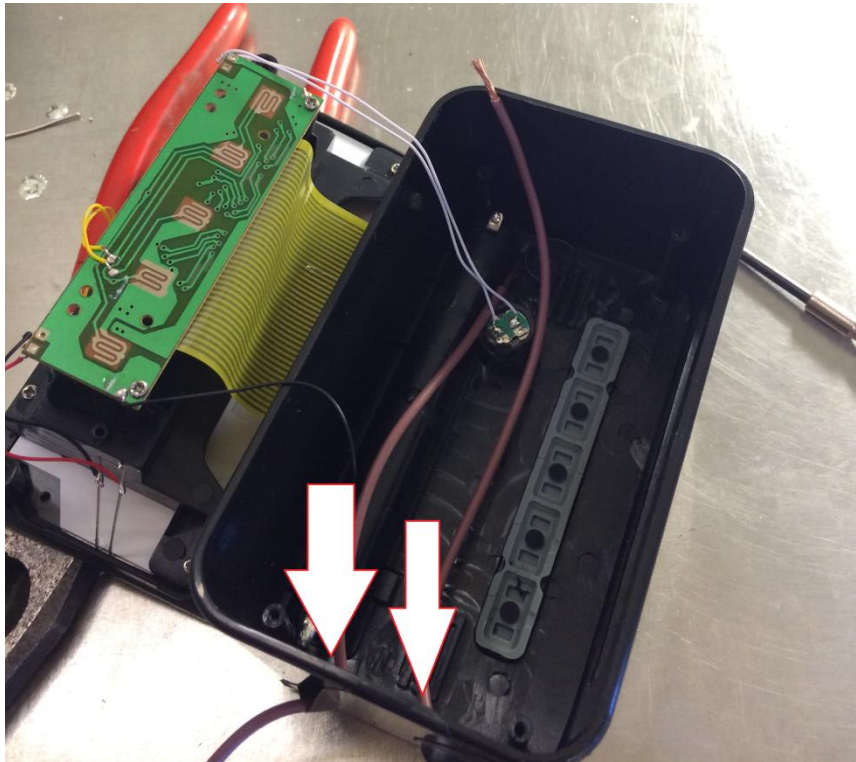
Step 2:

Start by checking if all of the alarm clocks work, it is too bad if some of them do not work when you are finished soldering and mounting them in the plastic container.

Step 3:

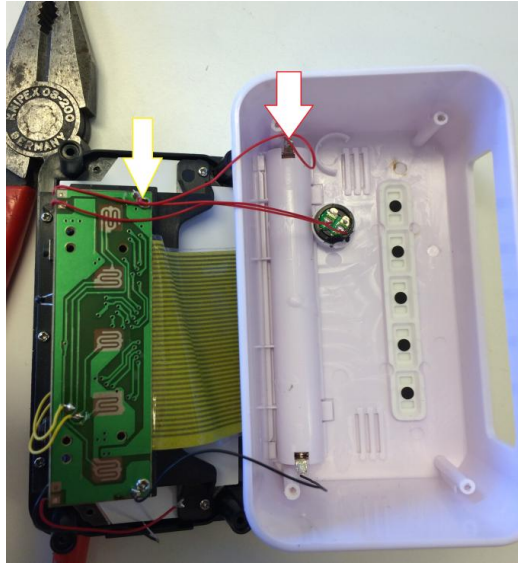
Start to disassemble the alarm clocks, I would suggest doing a couple at a time. Use a soldering iron of good quality, since the points where you should solder is tiny and difficult to work with if the soldering iron is not producing enough heat.

Then, make wholes or cut out a piece of the side on the alarm clock, so it is space enough that the electrical cords can exit the alarm clock when assembling it again. Be careful not to damage the digital screen of the alarm clock, see picture 1.



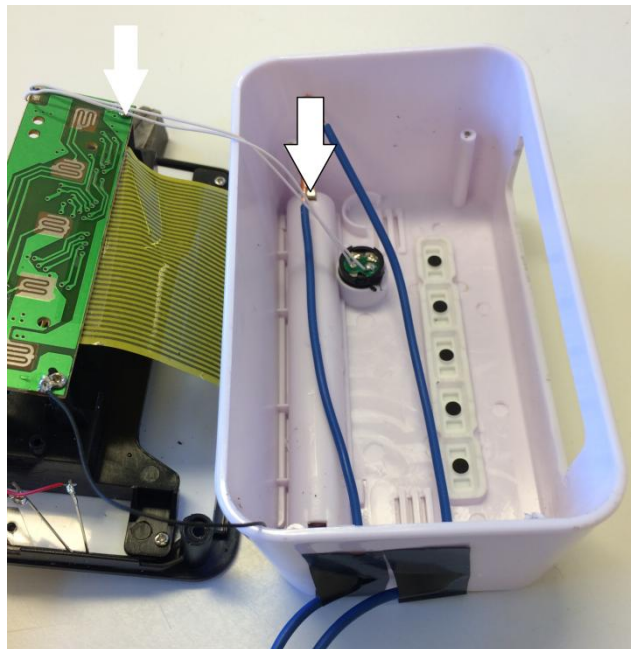
Picture 1: Arrows mark where to drill or cut through the plastic to insert the electrical cords.

When disassembled, cut the cords going from the circuit board and to the positive pole where it connects to the battery holder, See picture under.



Picture 2: Cut the electrical cord indicated between the yellow and red arrow, remove the cord at the mounting spots also showed by the arrows.

Then insert the electrical cords through the newly drilled holes, measure so they reach the opposite side of the alarm clock and of sufficient length that they can be soldered in place. The cords are inserted at the opposite side because of tension when the cords are being bent. Cords mounted through the side where I soldered tend to break in the soldering spots when assembling the alarm clock.



Picture 3: Blue electrical cord on the left is soldered where the white bordering arrow is marked, the right cord is soldered where the black bordered arrow is marked (positive battery pole). Be careful with the soldering angle.

Step 4:

Then assemble the alarm clock with the newly added electrical cords, be careful when assembling it so that the soldering points do not break (Still possible to put a lot of tension on the soldering points). Afterwards, insert new batteries and hold the ends of the electrical cords together to see if the electrical circuit is complete and the alarm clock powers up. If not, disassemble and check if some of the soldering points have broken in the process of assembling the alarm clock.

Step 5:

If all of the alarms are working, then start mount them in the plastic containers. Remember to insert the batteries before mounting them. I would advise from gluing the alarm clock to the plastic container when it creates a problem if you need to change batteries.

When assembling the alarm clocks into the plastic containers, make sure that there are enough electrical cord inside the container so it is possible to twist and turn the alarm clock without putting too much tension of both soldering points and the glue. When in place, glue the electrical cords in place and make sure that the glue covers all around making it as water proof as possible, see picture underneath. Leave the nest sensor to rest until the glue has hardened.

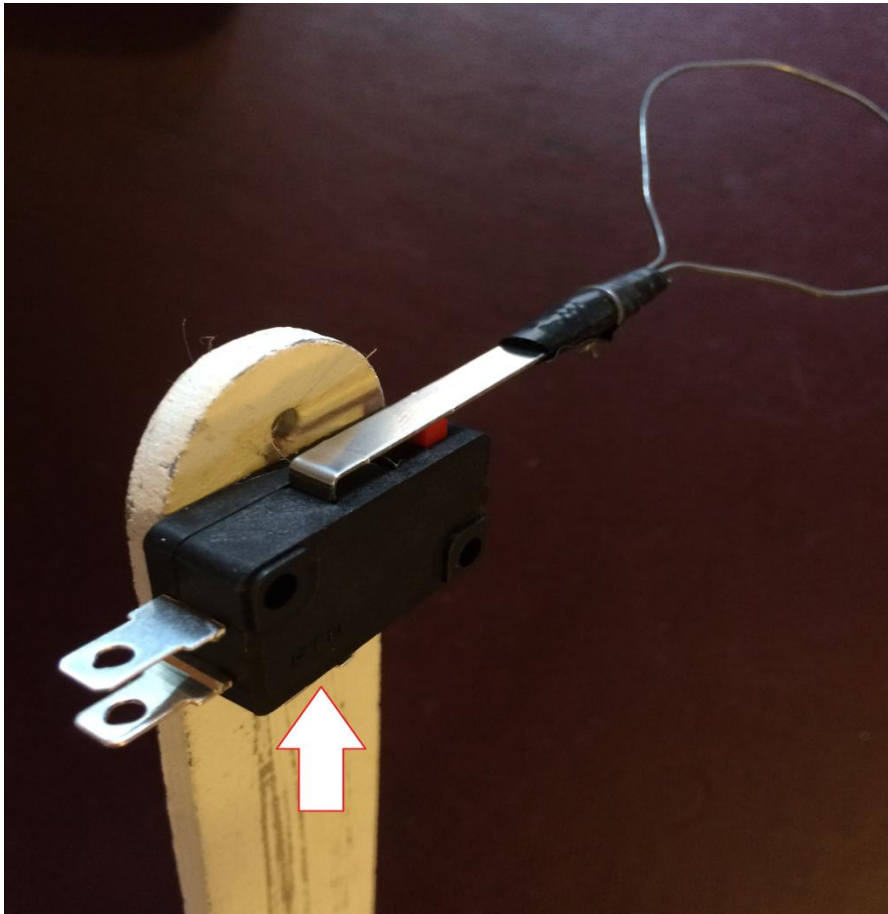


Picture 4: Three alarm clock mounted inside plastic containers showing the electrical cords exiting the side of the container. Glue around the cords, both inside and outside.

Step 6: The lever switch

If there are any paint on the wooden plugs, start by removing the paint where the lever switch is going to be mounted. In addition, use some sandpaper to make the surface more rough and easier for the glue to stick on.

Then, start gluing the mini lever switches onto the wooden plugs, also secure it with some high grade tape. This makes shelters the glue from sunlight that can in some instances be detrimental for the glue, also it makes the switch stick better to the wooden plug. As mentioned earlier, I would recommend getting wooden plugs and mini lever switches that can be screwed on instead of glue.



Picture 5: Mini lever switch mounted on the wooden plug (Paint not removed, had to be re-done after picture was taken). The white arrow indicates where the third electrical connection is located (underneath the lever switch, not visible in picture).

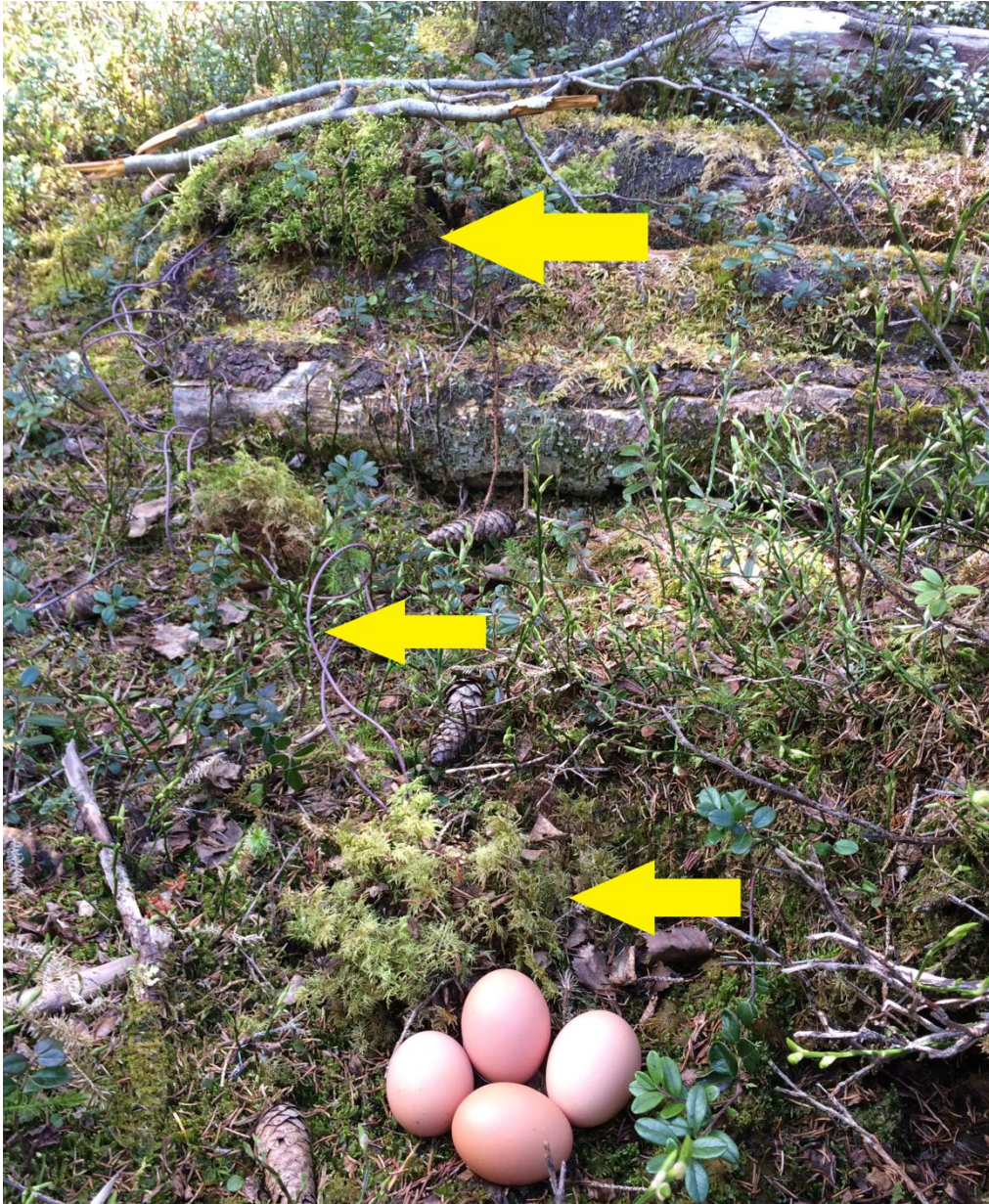
With the lever switch mounted and glue hardened, start by making the egg-holder with steel wire. Try not to make it so that it becomes too long, the hoop should start to form immediately after going past the end of the lever switch (See picture 5). This to ensure that

the wire do not bend or that the angle becomes too steep and the egg falls out of place. Fasten the wire hoop with epoxy glue, and add a steel wire tensioned firmly around the lever switch and the wire hoop, see picture above. I added the tape because that end will be visible when arranging the nest and can influence the detection possibility when there are a reflective component in the nest.

Step 7:

Now that both the wooden plug with the lever switch is hardened and the alarm clock is ready, start to check all of the components. Check if the alarm clocks is still working and none of the soldering points have broken, and that the lever switch is thoroughly fastened to the plug, then connect the components to see if it works as a whole. Fasten the first electrical cord on the top connection (see picture 5) and then the last electrical cord on the connection under the lever switch (picture 5, marked with white arrow). If you connect both of the electrical cords on the two visible connections on picture 5, it will not work as we want. Then when the lever is depressed the electrical circuit is complete, we want the other way around. Fasten the last electrical cord under the lever switch and the electrical circuit is complete when the lever is not depressed. Therefore working as a nest sensor, since when the egg is removed the lever release back to original position and the circuit is complete and the alarm clock powers up.

If everything is connected properly and working, then you have produced working nest sensors!



Picture 6: Shows a functioning nest sensor deployed in the field. Arrow on top shows where the alarm clock in the plastic container is concealed. The middle arrow shows the electrical cords going out from the plastic container and to the lever switch. Lastly, the bottom arrow shows the lever switch on the wooden plug arranged with one of the four eggs in the wire loop, and the switch is concealed with moss

All of the nest sensors did not take any damage from water or battery was depletion during the time in the field, one was destroyed by a moose stepping on it, and one had a faulty electrical cord. Still the success rate of all nest sensors was 95,6% during a time frame of one and a half month.

8. Appendix II



Figure 7: Chessboard used for calculating Nest cover on artificial nests.



Picture 8: Chicken eggs in an artificial nest depredated