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Name / Candidate no:
Christopher Reppe / 1

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Effects of urbanization on nesting sites of rooks (*Corvus frugilegus*)

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Preface

This thesis's is written as the final work of my master's degree at Nord University. With this task, I complete my master in terrestrial ecology and nature management.

First and foremost, I would like to thank my helpful and committed supervisor Sam Steyaert at Nord University, for his help with the statistical analysis, the writing and for sharing knowledge and ideas with me.

I also want to thank Eivin Røskaft at NTNU for helping me understand the data, Morten Haugen at the environmental department in the municipality of Trondheim for providing me with the historical data, Kristian Overskaug at "DKNVS" for keeping me motivated and Geir Lasse Aune for help with the fieldwork.

I also want to send a special thanks to my family for helping me with the writing, and a special thank you to my fellow students, Chris Brostrøm and Oddbjørn Larsen, thank you for the cooperation and friendship during the writing process and to my wife, Monica Hoff, thank you for your patience.

«*Kornkråka er lik en smokingkledd spradebass med kvit snipp*» - «*Fakta ark 33*» source from Trondheim kommune.

Christopher Reppe

Trondheim, May 2020

Abstract

Rooks (*Corvus frugilegus*) in Trondheim have shown a decrease in numbers, the last couple of decades. Urbanization is affecting the wildlife in and around towns, and research shows that rooks are losing important breeding habitats and being persecuted by humans all over Europe. This study aims to map rookeries in Trondheim municipality and investigate what kind of habitats that are important for rooks when they are building rookeries.

Rookeries were mapped between February and May by using the same method that has been used by Trondheim municipality on previous occasions, this combined with an online survey. By using logistic regression, the occurrence of presence /abundances was modelled to various spatial scales, with relation to landscape classes (development, farming, pasture, forest, and open area).

Three unknown locations for rookeries were discovered due to the online survey. There was no correlation between presence/abundance on a coarse scale. Looking within the home range of rooks, both presence/abundance of rookeries, responded negatively to the landscape type "development". By investigating the colony sites and how it relates to land cover types at various spatial scales, I found that pasture influenced the presence (< 300 meter-buffer) positively. Investigating at the coarse-scale (< 600 meter-buffer), the forest was correlated negatively. The rooks seemed to build rookeries in the proximity of pasture and avoided areas with dense forest patches.

The results show that pasture is an important habitat class for rookeries. Most likely because they provide suitable access to important foods for chicks, like the earthworm *(Lumbricidae)*. Furthermore, the removal of breeding trees has an essential impact on rookeries. Further research on the topic should implement the use of more detailed geospatial maps and investigate how the biological restrictions may affect the local population in Trondheim.

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1. Introduction

1.1 Urbanization and its ecological effects

The change of nature into cultivated landscapes started thousands of years ago when humans become sedentary. Agriculture is a significant contributor to this (Feare, Dunnet, & Patterson, 1974; Taylor, 2014; Warton, Lyons, Stoklosa, & Ives, 2016), as deforestation and the cultivation of farmland were changing the landscape(Pedersen, Schnedler-Meyer, Ekberg, & Tøttrup, 2018). Urbanization and modernization of agriculture reduced important wildlife habitats such as semi-natural grasslands, woodlands, water areas, and pastures, which have disappeared in several regions throughout the world (Forman, 2014; Tietze, 2018). Urbanization is the process that includes human-induced soil modifications, microclimate and landscape change, and biodiversity loss (Forman, 2014). This pattern of habitat loss is often conspicuous; however, the demographic implications of such habitat loss can be more subtle (Fryxell, Sinclair, & Caughley, 2014; MacArthur, 1984). One example of this is the scrub-jay *(Aphelocoma californica)* that lives in Florida (Forman, 2014; Stith, Fitzpatrick, Woolfenden, & Pranty, 1996). It is a relatively large bird that lives in a social group (families) in a unique habitat of thinly forested scrub oak stands on infertile soils. Scrub Jay will defend their territory that is about 10 ha, against other families. The increase of the human population in Florida has resulted in the rapid loss of Scrub-Jays habitat. Each decade, the population of Scrub-Jays is decreasing by 25-50 % due to habitat loss (Coulon, Fitzpatrick, Bowman, & Lovette, 2010; Stith et al., 1996). A large number of field studies show that both local and entire populations of species can significantly decrease in densities due to habitat change (Fryxell et al., 2014).

Urban areas are more than just big cities and metropoles, and they also include the surrounding regions around cities. The term “urban area” is not very precisely defined in the literature, but is characterized by having a high density of people, houses, commercial buildings, and infrastructure (Rodrigues, Borges-Martins, & Zilio, 2018). It is estimated that over 65% of the human population in the world will reside in urban areas by the year 2025, and this urban population will grow to four billion people by 2030 (Bradley & Altizer, 2007)**.** The increasing population growth in the world is affecting wildlife communities in (semi)natural habitats, agricultural landscapes, as well as in urban areas (Dirzo et al., 2014;

McKinney, 2002). The loss of biodiversity is a profound global challenge and some scientists have applied the term “defaunation” to describe the issue (Dirzo et al., 2014). Human impacts on Earth have now reached such profound levels that it leaves a permanent geological signature on the planet and thereby demarks a new geological period: *the Anthropocene* (Young, McCauley, Galetti, & Dirzo, 2016). Annually, the planet is losing 11-58 000 species (mostly in the tropics), and just since the 1500s, 385 vertebrate species have become extinct (Dirzo et al., 2014; Young et al., 2016).

Typical urban areas can be classified into different sections (Forman, 2014). The inner part of modern cities is often characterized by dense developments and tall buildings, roads, and concrete. Moving away from the city center, commercial areas and apartment blocks prevail. These areas often contain green spaces, small forest stands or parks, and private gardens. Moving further away from the urban core, the suburban area appears (Forman, 2014; Rodrigues et al., 2018), which is dominated by a residential community consisting of detached and semi-detached houses with mid-sized gardens, more and larger green spaces, and occasionally small agricultural fields. In this master thesis, urban areas are defined as buildings, parks, recreational areas and roads (Forman, 2014; Jokimäki et al., 2011). Urbanization destroys natural habitats, but also creates new habitat, and species of natural habitat can be replaced with a species that are better adapted to the urban environment (Forman, 2014). With the rapid expansion of urban and suburban development and the associated habitat modifications, the importance of understanding the relationship between wildlife and the process that involves urbanization can be a crucial factor for improved management of biodiversity in the future. Understanding how species can be affected by the anthropogenic change in the landscape (including farmlands and deforestation in sparsely populated areas) may be a proper way to manage species that are affected in vulnerable areas (Dirzo et al., 2014; Forman, 2014). Conservation and management of populations of animals require information on where they are, why they are there, and where else they could be (Fryxell et al., 2014).

Species that flourish in cities and take advantage of human resources to such a degree that they can maintain a stable population are known as urban adapters (Synurbization) (Tietze, 2018). Urban birds are known for having high rates of feeding innovation (new ways of acquiring food) (Gil & Brumm, 2013). Being omnivorous is favourable in urban areas where human activities mass-produce novel food resources such as garbage, whereas insectivores can be at a disadvantage (Croci, Butet, & Clergeau, 2008; Jokimäki et al., 2011).

The Corvidae genus comprises a large taxonomic group, including 120 species, and they are found throughout the world, except for the southernmost tip of America and the Polar caps (Clayton & Emery, 2005). Corvids have a large brain, adapted for learning compared with other bird species (e.g., Clark's nutcrackers (*Nucifraga Columbiana)* that bury over 30 000 pinecone seeds and recover them after months), and Corvids are social birds (Clayton & Emery, 2005; Taylor, 2014). Corvids chicks have an extensive developmental period in which they are dependent on their parents (Gil & Brumm, 2013; Røskaft 1983). They show a high propensity to find innovative solutions to novel problems, and can use tools for foraging (e.g., the Caledonian crow (*Corvus moneduloides),* uses barbed edges of screwpine (*Pandanus spp)* leaves to pull grubs from within tree trunks) (Boire, Nicolakakis, & Lefebvre, 2002; Hunt & Gray, 2004). The Corvidae family is one of the intelligent families of birds and is sometimes referred to as 'fearless problem solvers in the urban habitat (Worall, 2018). Some Corvids have learned to use urban landscapes to their advantage. For example, in Sendai, Japan, the Carrion crow (*Corvus corone*) is frequently observed using the tires of cars as nutcrackers (Nihei & Higuchi, 2001). There, crows used roads with intersection or where cars drive slowly (e.g., sharp bends) to position unbroken walnuts. They even move walnuts centimetres if much time has passed without being cracked by car tires (Nihei & Higuchi, 2001).

1.2 Focal species: the rook

The rook *(Corvus frugilegus*) is one of eight different crows found in Norway and Trondheim (Svensson, 1999). An adult rook weighs around 400-550 grams and has a wingspan between 81 and 94 cm (Svensson, 1999). It is a bird that builds twig nests in spruce (*Picea*) or pine (*Pinus*) trees, often in the vicinity of farms and in cities (Kitowski, 2011). The nest is like hooded crow's (*Corvus cornix*) nest, but seems to be built looser (Hermansen & Schandy, 2017). There are often several nests in the same tree. Both sexes collect nest material and participate in the construction (Røskaft 1983), and the same nest can be used in many multiple breeding seasons. Like most corvids, the rook is monogamous and pair bond is lifelong, but sometimes pairs separate (Svensson, 1999). It is a colonial bird that often is observed in cultivated fields along trench edges and pastures, often along with jackdaws (C*oloeus monedula*). Rooks establish nests in colonies in March (Svensson, 1999). In this thesis, a colony is referred to as a group of birds and breeding nests rookies. Incubation usually starts at the end of March or early April. The incubation period is up to 20 days (Hermansen &

Schandy, 2017; Røskaft, 1980). The young leave the nest after 4-5 weeks (Svensson, 1999). Rooks are omnivorous and feed on insects, earthworms (*Lumbricidae*), and small mammals (e.g., mice), as well as on seeds and other plant material (Clayton & Emery, 2005; Svensson, 1999). The rook has a completely black suit that can glitter reddish when observed from certain angles. Adults have a greyish-white skin around the nebula, and juveniles are often mistaken for crows because of the lack of development in distinctive colour around the root of the beak (Svensson, 1999).

The rook is widespread in Europe and Asia (Alerstam, 1993). Some birds migrate to warmer regions for overwintering, but some colonies are resident throughout the year (e.g., Spain and England) (Alerstam, 1993). In Norway, the rook is associated with agricultural landscapes (Bangjord, 1986; Bollingmo, 1973; Røskaft, 1980). There are only three places in Norway where the rook has successfully established colonies, in Trondheim, Rogaland, and by lake Mjøsa. The Mjøsa and the Rogaland colonies migrate out of Norway before winter, whereas the Trondheim colony is stationary (Bollingmo, 1973; Røskaft, 1980).

1.3 The rook in Trondheim

In the Trondheim municipality, there was a considerable loss of pastures and meadows during the 20th century (Overskaug, 2004). Those areas declined from about 9000 ha too little as 2000 ha and were replaced by housing, industry, and agriculture (Overskaug, 2004). This change in the landscape benefited corvids and especially the rook because of the creation of agricultural fields, parks and green spaces within urban areas favoured this bird (Overskaug, 2004). During the 1970s, rooks were associated with farmland outside Trondheim city (Bollingmo, 1973). However, not before 1972, rookeries (N = 42) were also discovered at Reitgjerdet in Trondheim and in 1978, the rookeries increased to a total number of 70-80 (Bangjord, 1986; Størkersen, 1990). The same year, a new colony was established at Tunga. After 1980, several colonies were established in Trondheim, and by the '90s, 10-12 additional colonies were discovered (Bangjord, 1986). Most of the population resided in the areas of Lade, Tunga, Jakobsli, and Charlottenlund (Bangjord, 1986; Størkersen & Sandvik, 1988). In 2001, 311 breeding pairs were observed in Trondheim. Since 2001, however, a decline in the rook population occurred being as low as 76 breeding pairs. In Norway, it is on the IUNC red list listed as near extinct (Gjershaug & Haugskott, 1994). Most of the population that is located in Norway is located in Trondheim and the municipality has made the rook as one of their “key species” to follow up in years to come (Trondheim kommune, 2014).

This decrease in rookeries is a trend that is also observed in Fennoscandia (Røskaft, 1980) and in Europe (Rytkönen, Koivula, & Lindgren, 1993). In many of the cities in Europe, the rook has been under much pressure, due to persecution and habitat loss (Kitowski, 2011; Orłowski & CZapulak, 2007). The loss of pasture and meadows is affecting the population of rooks negatively (Griffin, 1998; Kasprzykowski, 2003, 2007; Kitowski, 2011). Is the anthropogenic change of the landscape affecting the rook population in Trondheim as in Chełm (eastern Poland)? There, smaller rookeries tend to disappear over time. Alternatively, as in County Durham (UK), does the lack of pasture have affected the rook colonies (Griffinn & Thomas, 2000; Kitowski, 2011).

1.4. Research objective

Why has there been a decline in observations of rookeries since 2001 in Trondheim? To find out, I modelled the presence/absence and abundances of rookeries within Trondheim municipality and combined the observations with geospatial data. My goal was to 1) combine the observations of rookeries done by the Trondheim municipality with statistical land-cover data to investigate how land cover on the coarse-scale changed in Trondheim and if it has affected rookeries; 2) combine the observations of rookeries done by Trondheim municipality with geospatial data to investigate if there was any relationship between colony occurrence and size and land cover types;3) Use all known locations of rookeries to look at how the relative probability of nesting at a colony site relates to land cover types at different spatial scales. Overall, I predict that i) rookeries occur more frequently in areas with proportionally high cover of farmland (pastures) ii) the landcover type development within the home range, is affecting the presence and abundances of rookeries negatively iii) increasing the spatial scale, pasture will influence the rookeries more increasingly.

2. Methods

2.1 Study area

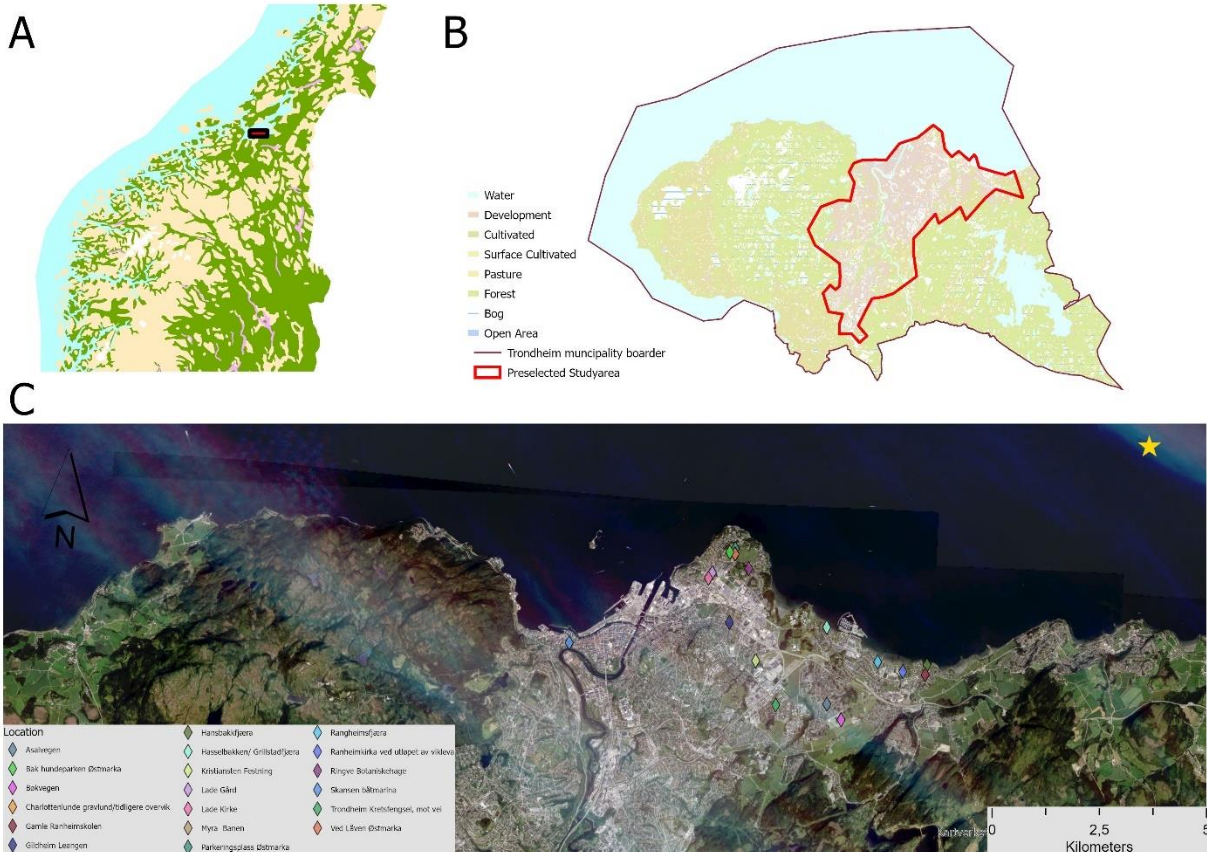

Figure 1: A) An overview map over Trondheim, and location of Trondheim municipality in Norway. **B)** An overview of the distribution of landcover classes in Trondheim and area restriction for the RSF model. **C)** All of the known rookeries in the period 2009-2019. The star in map C shows the solar interference that made the reclassification difficult.

Trondheim (Latitude**:** 63.446827, Longitude: 10.421906) has a population of almost 200 000 people and is located in the middle part of Norway (Rosvold, 2019). Trondheim is a municipality in the Trøndelag County and comprises off 342 km^2. Of this, 65.5 km^2 (19.1 %) is agriculture land, 32.4 km^2 (9.5 %) is urban development , and 165.8 km2 (48.5%) is forest (Rosvold, 2019). In Trondheim, five larger nature areas exist Estenstadmarka, Bymarka, Tillermarka, the coastal zone along the Trondheim fjord, and the Nidelva corridor (Appendix A). Also, eight natural regions (Appendix A) and one botanical nature monument are being protected under the Nature Conservation Act (now replaced by Diversity Act 2009) (Backer, 2009; Naturmangfoldloven, 2009). In total, the protected area amounts to over 13 000 acres or approximately 4% of the municipality's area. Trondheim has short summers and long winter (November to March) (Mamen, 2020), the annual rainfall is about 1000-1200 mm and the average monthly temperature is between 0 – 15 degrees (Overskaug, 2004). The temperature during the winter is mild, and since it is a municipality by the coast, there is little snow in the winter (Røskaft 1985).

2.2 Rook data

The location of colonies and the number of active rookeries within each colony in Trondheim were determined during surveys (1991- 2018) by the environmental department of Trondheim municipality. They used volunteers that were interested in ornithologically to conduct the fieldwork. Each year during early spring/summer, the colonies were visited, and the number of nests counted. As in the study design of Griffin (1998), a new colony was defined as a group of nests more than 50 meters away from other rookeries (Griffin, 1998). Rookeries that were within a 50 m radius were merged as one colony in this study design (i.e., Tunga Kretsfengsel). All known rookery locations were revisited in the municipality between February to May 2019, to examine the presence of active rookeries. For 2019, I relied on the information available from the municipality but also used “citizen science” to locate potential additional nesting sites.

Citizen science is a collective term for methods where one engages volunteers, who often do not have a research background, to collect data (Bonney et al., 2009). This method makes it possible to engage participants in global and continental data-gathering networks (Bonney et al., 2009). Citizen science is a research method that has become increasingly important and has contributed to new scientific discoveries (Cooper, Shirk, & Zuckerberg, 2014). In cooperation with Trondheim municipality, we wanted to inform the public about rooks, assess their attitudes (in a parallel project) towards the rook use citizen knowledge to map potential new breeding sites for the bird. We used SurveyMonkey, a web-based platform for conducting surveys (Waclawski, 2012) for the survey, which consisted of 5 main parts:

1) In the first part, we presented basic information about rook appearance, ecology, and distribution on an information page. This page served as an introduction, as well as informing the public about the project.

2) In the second part, the participants would report if they had seen rooks in Trondheim and in what area, general habitat type, number of observations and what time of day they saw the rooks. If the participant had not observed rooks in Trondheim, they were directed to the attitude questions (part 4).

3) In the third part of the survey, the question was whether participants had observed nesting Rooks. Participants could also indicate the date of observation and the location of the rookery.

4) In the fourth part, participants were questioned about the management of the rook in Norway, and their attitude towards the response was given on a five-point Likert scale (from strongly disagree to strongly agree) (Bonney et al., 2009). The full questionnaire is included as supplementary material (Appendix B).

5) In the fifth and final part of the survey, the participants could provide their sociodemographic data and where they had heard about the survey.

In this thesis, I only used information about parts 2 and 3 of the survey. The other data was beyond the scope of the thesis. Reported rookeries by participants were validated against already known sites. Unknown sites were checked to see if these contained new rookeries.

The rooks from each location were monitored two times each day with a total of 40 inspections, distributed over 20 days of fieldwork. Breeding pairs at each site were surveyed at regular time intervals, once at 0600 and again in the late afternoon 1800, using binoculars (*Diamondback HD 8x42*, *binoculars, STD*) and a powerful zoom camera (Nikon COOLPIX P1000, 125x optical zoom, equivalent to the entire 24-3000 mm). Just in the study of Rawat & Rao (2020), the camera was used to take pictures of each colony (Rawat & Rao, 2020). At the end of each observation day, camera images and observations were controlled for the right number. Since the camera had a powerful zoom, it was also possible to see if the rooks were sitting on nests. Each location had a fixed point (Appendix C) that was marked using a handheld GPS (Garmin Gpsmap 64sx, GPS, STD), and this was the vantage point at each location (Rawat & Rao, 2020). The horizontal distance between the rookeries and the observation point was never more than 25-50 meters so that the observer could detect birds by sight and sound. Number off nesting rooks was counted for each observation for 20 minutes, at every rookery location (figure 1C).

2.3 Land cover data

To investigate how land cover affected the presence/absence and abundance of rooks on a municipality level, areal statics was downloaded from Statistics Norway (Statistisk sentralbyrå, SSB) in the period 2011-2019 (Bye, Aarstad, Løvberget, & Høie, 2013). This map is continuously updated using data from cadastre that contains information on land properties, addresses and buildings and digital real estate mapping (Engelien & Schøning, 1999; Steinnes, 2014). Area statistics of Trondheim contained six classes, and these were development, forest, open area, bog, barren mountains (gravel/blocks) and freshwater (Appendix D). The map has a scale of 1: 10 000 and the municipality are responsible for the map being updated (Steinnes, 2014).

To look in more detail at the home range level, what kind of land cover types affect rook nesting, AR5 land resource map was applied (Arealressurskart) (Bjørdal & Bjørkelo, 2006). Ar5 is a part of the standard Norwegian map database (FKB, Felles kartbase) and is maintained by the Norwegian Institute of Bioeconomic (Norsk institutt for Bioøkonomi) and were provided by the planning department of Trondheim Municipality (Appendix E). AR5 is a national classification system for land cover types, with an emphasis on the suitability of land for plant cultivation and natural plant products, and is commonly used within land planning and agriculture (Bjørdal & Bjørkelo, 2006). AR5 maps are based on interpretation from aerial images and field validation. The classification of AR5 divides land surfaces into polygons of specific land cover types, forest habitats, tree species, and soil conditions. The main subdivision is based on criteria for vegetation, natural drainages, and cultural inheritance (Bjørdal & Bjørkelo, 2006). The smallest polygon size is generally about two acres. The map has a scale of 1: 5000 and the municipality are again responsible for the map being updated. All spatial data processing was done in ArcMap Pro, using model builder (version 2.5) (Appendix F).

Kasprzykowsk (2007) and Griffin (1999) determined that the vast majority of rooks foraged between 300-1000 meters from the nest (Griffin, 1999; Kasprzykowski, 2007). Therefore, I created a buffer on 1 km around each location for observed rookeries and extracted the proportion of each land cover type for all the rookery locations.

RapidEye satellite data from (25.07.2019, the spectral band in RGB and NIR) were downloaded from planet explorer using the API tool, to assess how rooks selected their nesting sites in very high spatial detail in 2019 (Mishra, Stumpf, & Meredith, 2019). Satellite images with minimal cloud cover (< 5%) and within the months of June to August when the vegetation is lush were selected (Aksnes, 2019). A supervised classification algorithm in ArcGIS pro was applied the RapidEye data, with ground truth based on orthophotos from 'Norge I Bilder' *(www.norgeibilder.no)* to classify the satellite image into the following land cover types: water, development, forest, bog, planted/cultivated and Herbaceous (Appendix

G). The land cover types were determined using a spectral profile and the classification I did (Appendix H), was based on the procedural route develop by J.R. Jensen (Liu & Yang, 2015). To control the classification, a thematic accuracy assessment was applied, using a stratified random sampling on the final classified map (Liu & Yang, 2015). Unfortunately, the reclassification (77 %) did not meet good enough standards to include in this thesis (figure 1C) (Appendix I). Hence, 2019 AR5 data was applied to analyze nest site selection, as described earlier.

A resource selection function (RSF) was applied, to determine where in the landscape rooks select their nesting sites (Boyce, Vernier, Nielsen, & Schmiegelow, 2002). An RSF model is a habitat selection model and is used to find important habitat features for animals by combining known occurrences with random sites (wherein the landscape no occurrences have been observed, i.e., a pseudo-absence), to evaluate the likelihood of that animal utilizing a specific resource in the environment (Boyce et al., 2002). In the period 2009-2019, all known GPS locations over rookeries were combined. With the definition of the urban core area (figure 1B), 100 random points were created using ArcGIS Pro. For each random and known rookery location, I then extracted proportional land cover in buffers with increasing radius from 100 meters to 1000 meters in 100-meter intervals, to see if there was any nest selection scale dependent within this range.

2.4 Statistical tests.

All of the datasets for the statistical analyses were prepared first in Microsoft Excel and then imported into statistical software R studio, version 3.6.3 (R Core Team, 2020). Statistical significance thresholds were set at $\alpha = 0.05$. The data that was downloaded from SSB consisted of 8 classes and was turned into proportions. Annual observation data of rookeries was linked with the SSB data over Trondheim. Locations with no observation within the period 2011-2019, were removed from the dataset (Kristiansten Festning).

This was also applied for the home range data. The Ar5 spatial data consisted of 9 different classes. Data was extracted within a predefined buffer, many of these were represented by very low proportions. Several classes were merged, resulting in fewer categories (i.e., development with roads, surface cultivated soil with cultivated land (renamed as farming), and open area with bog) to run statistical tests (Appendix E).

Generalized linear mixed effect models (GLMER) were applied to the SSB and geospatial data as my response variables were i) (1) presence /absence (0) (family = binomial) and ii) the abundance of birds at rookeries during a given year (family = poisson) (Harrison et al., 2018). Because of repeated measures in space (rookery location) and time (years), the models always included year and location as a random effect on the intercept. The library lm4e was used to fit the models (Bates & Bolker, 2015; Duxbury & Chapman, 2019).

To generate the best model for each GLMER, the dredge function of the MuMIn package was applied to each full model (Barton, 2019), i.e., a model with the proportion of land cover types within a predefined buffer as additive explanatory variables. This function runs all possible model combinations based on the full model, which results in an optimal model that is ranked after the AIC_C (sample size corrected Akaike Information Criterion), a likelihood-based metric for model selection (Akaike, 1998; Symonds & Moussalli, 2011). The most parsimonious model that was within the range of ΔAIC_C 0-2 (i.e., the difference in AIC value between the first ranked model and the other candidate models) was chosen (Akaike, 1998; Johnson & Omland, 2004). The final model was then checked for overdispersion, using the dispersion_glmer function from the Blmeco package (Korner-Nievergelt et al., 2015; Pedersen et al., 2018). This validates the fit of the model for the data within an acceptable range between 0.7 -1.4.

To analyze the relationship between the selected landcover type and the presence of rookeries withing the 100-1000 m buffer, using Generalized Linear Models (GLM) (Hosmer & Lemeshow, 2000) that were fitted to the data using a binomial distribution, since the response variable was presence/absent of rookeries (0-1) (Warton et al., 2016). Using random selector in r on the 100 random points, 53 random points were selected and merged with the known locations of rookeries (106 points each buffer). AIC based model selection for each buffer distance following the method described earlier. Each buffer model was checked for model robustness by using residual deviance over degrees of freedom.

3. Results

Trondheim had 19 locations with rookeries from 2007-2019. Some locations such as parkeringsplassen Østmarka, Tunge Kretsfengsel and Låven Østmarka had nesting rooks during almost all study years (Appendix C). The lowest counted number of rookeries was in 2014 (n=76) and the highest was in 2009 (n= 195). From March to July 2019, I registered 130 rookeries in the Trondheim municipality, three new locations were found around the part of Lade (Bak hundeparken Lade, Ladekirke and Ladegård). These nest sites were located using citizen science (the online survey).

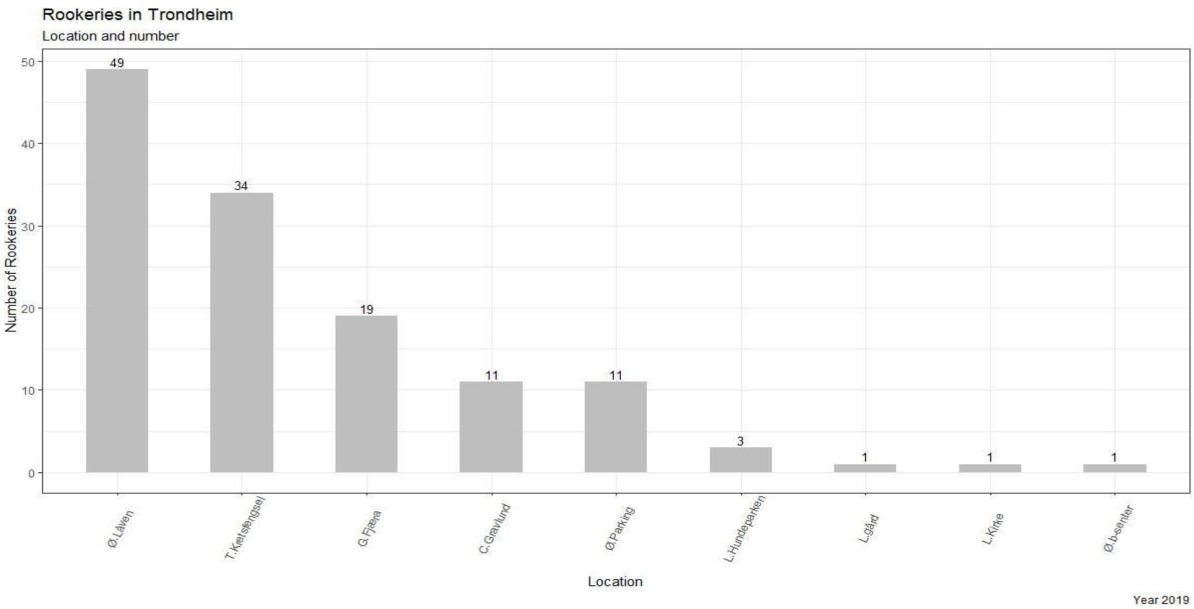

Figure 2: The number of rookeries per location detected in Trondheim municipality in 2019 (Ø=Østmarka, T=Tunga, G=Grillstad, C= Charlottenlund, L= Lade)

3.1 Presence and abundance of rookeries on the municipality scale

On the municipality scale, landcover types did not appear to affect the presence/absence of rookeries at colony sites or the abundance of rookeries, as the null model was selected as the most parsimonious for both analyses. The dredge tool for the presence/absence model showed that only the null model was within the ΔAICc 0 – 2 range (ΔAICc = 0, w_i = 0.160) and with dispersion 0.94).

For rookery abundance per location, three models were within the range of ΔAICc 0 – 2 (table 1). Since I aimed to select the most parsimonious model (i.e., the model with fewest parameters) that were within the range of ΔAICC 0-2, the null model was selected as the most parsimonious.

Table 1: Model selection table showing the abundance models within a range of ΔAICc 0 – 2 on the municipality level. The marked model was the null model and was selected as the most parsimonious. This model had a dispersion of 0.79. Df = degrees of freedom.

Model	*Farming*	*Forest*	*Df*	*AIC_c*	*ΔAIC_c*	*w_i*
Model Null			3	107.4	0	0.280
Model 3	✓		4	1071.8	0.48	0.220
Model 2		✓	4	1072.6	1.28	0.148

Note: ✓ Shows with model that was chosen.

3.2 Presence and abundance of rookeries on the home range scale

Out of all possible model combinations produced by the dredge tool within the 1000m radius (home range) around colony locations for the presence/absence of rookeries, four models were within the range of ΔAICc 0 – 2 (table 2). The top-ranked model only included the proportion of development (ΔAICc = 0.99, w_i = 0.136). The most parsimonious model shows that there was a significant negative relationship (estimate: -0.04, standard. error: 0.02, p-value: = 0.049) between the presence of rookeries and the proportion of development around colony sites (figure 3).

Table 2: Model selection for assessing rookery occurrence at colony sites in relation to land cover types at the home range scale s within an ΔAICc 0 – 2 range. The model with the lowest Dfs was chosen as the best model. The null model is also included in the table (ΔAICc:2.87, w_i: 0.053). The top-ranked model had a dispersion parameter of 0.93.

Model	*Development*	*Farming*	*Pasture*	*Df*	*AIC_c*	*ΔAIC_c*	**w_i**
Model 2	✓			5	18.70	0.99	0.136
Model 10	✓		✓	6	179.70	0	0.223
Model 12	✓	✓	✓	7	181.60	1.87	0.136
Model 9			✓	5	181.60	1.91	0.850
Model Null				4	182.6	2.87	0.053

Looking at the abundances of rookeries within a 1000 m radius around a colony site gave similar results, with the top-ranked model only including the proportion of development around colony sites (ΔAICc:0.55, $w_{i:}$ 0.169). The dredge produced four models within the range of ΔAICc 0-2 (table 3). The most parsimonious model shows that there was a significant negative relationship (β: -0,07, se: 0,03, p = 0.02**)** between the abundance of rookeries and the proportion of development around colony sites (figure 3).

Table 3: Model selection for presence/absent for the GLMER within an ΔAICc 0 –2 on a home scale range. The model with less Df was chosen as the best explanatory model. Model Null is also included in the table (ΔAICc:3.68, w_i: 0.035). The top-ranked model had a dispersion of 0.82.

Model	*Development*	*Farming*	*Pasture*	*Forest*	*Df*	*AIC$_c$*	*ΔAIC$_C$*	w_i
Model 2	✓				5	597.6	0.55	0.169
Model 10	✓		✓		6	597.0	0	0.222
Model 12	✓	✓		✓	7	598.8	1.77	0.092
Model 6	✓	✓			6	599.0	1.98	0.082
Model Null					4	600.7	3.68	0.035

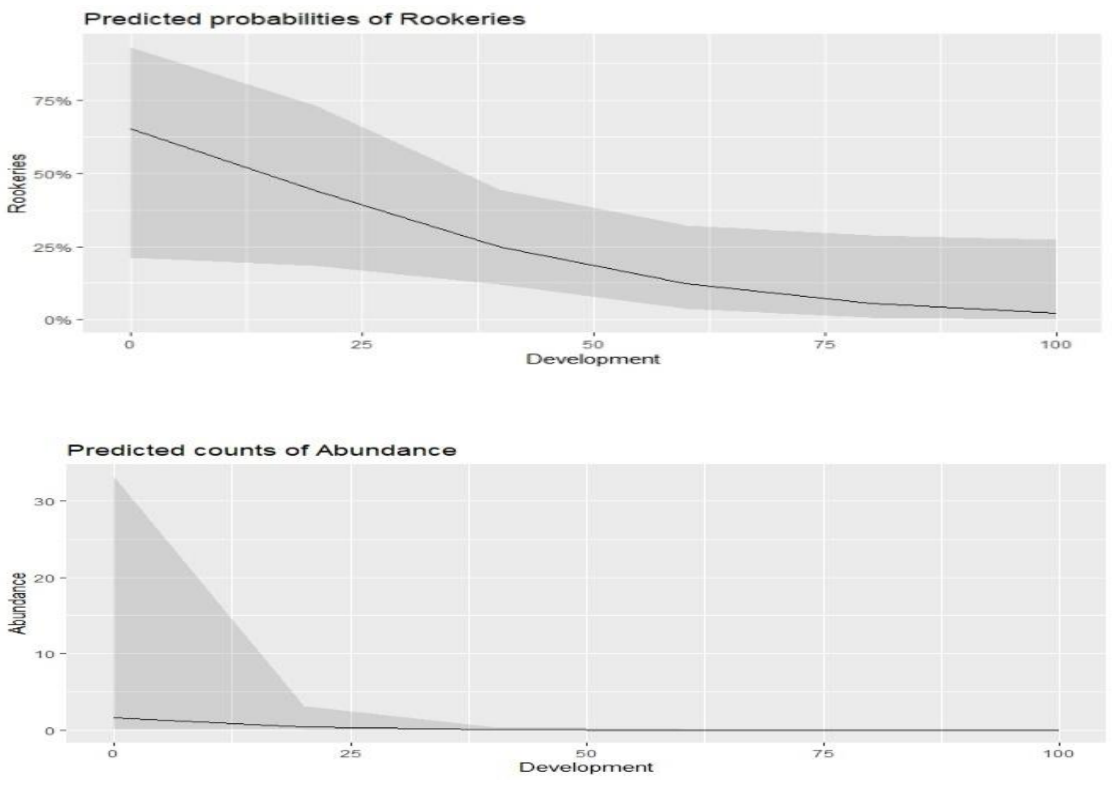

Figure 3: Development negatively affected the predicted probability of rookery occurrence at colony sites (upper panel) and their abundances (lower panel). The light grey areas represent the 95 % confidence interval and the black line is the regression line.

3.3 Presence of rookeries within different spatial scales

I used a multiscale approach to investigate how landscape variables affected rookeries and examined ten different scales (100-1000 meter-buffer). Different patterns were emerging at various spatial scales. Results from prior spatial models supported our predictions that pasture would affect the presence of rookeries. The model selection yielded very similar models within a buffer of < 500 meters, showing that rookeries are in areas with the landcover type; pasture and development (table 5). The best-fitting model for the 100m-buffer ($\Delta AICc = 1.46$, $w_i = 0.179$) showed that rookery selection was negatively related to proportion of development (estimate β: -0.02, standard error se: 0.01, $p < 0.001$) and farming land (β: -0.08, se: 0.03, $p = 0.02$) (fig 3). The best fit model for the 200m-buffer ($\Delta AICc = 0.54$, $w_i = 0.094$) showed that rookeries were positively associated with pastures (β: 0.07, se: 0.05, $p = 0.01$). The best fit model for the 300m-buffer ($\Delta AICc = 0.96$, $w_i = 0.174$) however showed that both development (β: 0.03, se: 0.01, $p < 0.001$) and pastures (β: 0.22, se: 0.07, $p = 0.01$) were positively associated with rookeries (fig 3).

This was the same result was found for the 400m- buffer ($\Delta AICc$:0.68, w_i: 0.206), showing that rookeries had a significant positive relationship with pasture (β: 0.19, se: 0.10, $p = 0.01$), but negative relationship with forest (β: -0.08, se: 0.02, $p < 0.001$) (fig 3).

The top ranked model for the 500-meter-buffer ($\Delta AICc$:0.0, w_i: 0.305), however there was no significant relationship between pasture and rookeries (β: 0.06, se: 0.01, $p = 0.055$).

From 600 m and further, the forest was the only land cover type that affected rookery site selection (table 4). The top-ranked model for 600 meter-buffer ($\Delta AICc$:0.68, w_i: 0.258), had no significant relationship between forest and rookeries (β: -0.17, se: 0.11, $p = 0.13$). The models from 700 meter-buffer and were all significantly negatively correlated with forest and rookeries (Appendix K).

Table 4: *Model selection table showing all the top-ranked models for the 100-1000 m buffer, the top-ranked model was chosen after DF. Notice how the forest is the dominant land type from 600 m and up.*

Buffer Model	Development	Farming	Pasture	Forest	Df	AIC_C	ΔAIC_C	w_i
Model_100	✓	✓			3	135.8	1.46	0.179
Model_200			✓		2	147.8	0.54	0.094
Model_300	✓		✓		3	139.5	0.96	0.174
Model_400			✓	✓	3	139.5	0.68	0.206
Model_500			✓		2	143.7	0	0.305
Model_600				✓	2	143.3	0	0.258
Model_700				✓	2	142.3	0	0.365
Model_800				✓	2	136.1	0	0.378
Model_900				✓	2	135.4	0	0.305
Model_1000				✓	2	137.1	0	0.285

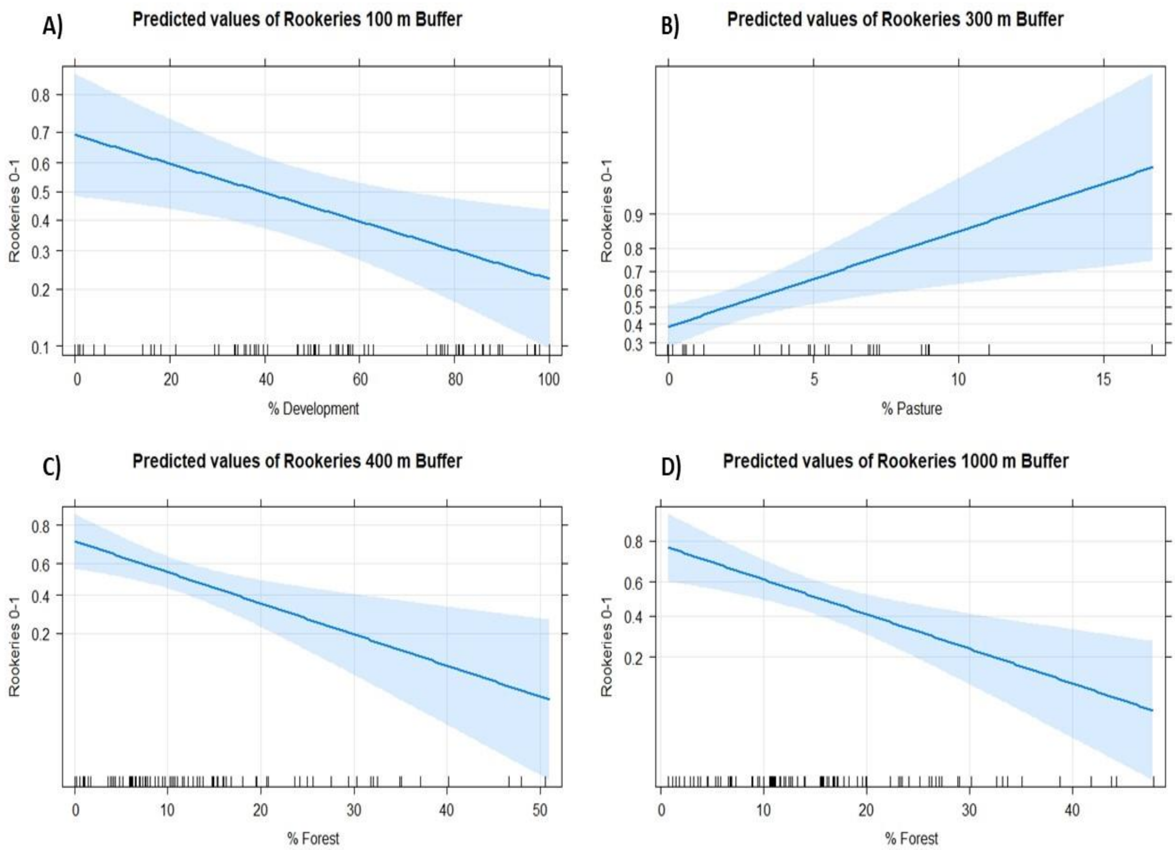

Figure 4: The predicted probabilities of the GLM of a selected buffer. The light blue areas represent the 95 % confidence interval and the blue line is the regression line. **A)** Development from the 100-meter-buffer (β: -0.08, p = <0.001) had a negative effect on rookeries. **B)** Within a buffer of 300-meter, the proportion of pasture positively affected (β:0.22, p = 0.013) rookery site selection. **C)** Within a buffer of 400-meter, the proportion forest negatively affected (β: -0.08, p = < 0.001) rookery site selection and **D)** Within a buffer of 1000-meter, the proportion forest negatively affected (β: -0.08, p < 0.001) rookery site selection.

4. Discussion

This study investigates how urbanization affects rookeries. During my fieldwork, I found 130 rookeries and mapped three previously unknown locations (Lade kirke, lade gård and Hundeparken Lade) of rookeries in Trondheim, with the public's help. Using SSB data and looking at the coarse-scale of rookeries (P1), I found no relationship between land cover types and the presence and abundance of rookeries.

As I predicted, there was a negative correlation between presence and abundance of rookeries and the landcover type 'development' (P2) when investigating rookery presence and abundance within a 1000-meter buffer area around known colony sites. The persecution of rooks has been a problem in Trondheim, with poisoning, removal of the rookeries, and shooting (Størkersen, 1990). Removal of nesting trees in parks and home gardens have had the most significant influence on the rook population in Poland (Kitowski, 2011).

My prediction that the landcover type 'pasture' would influence the presence of rookeries across the landscape was partially confirmed (P3). The spatial distribution of rookery sites appears to be associated with serval landscape variables for each 100-meter-buffer, not only pasture. However, agricultural landcover types were included in all models (< 500 meters) when comparing rookery sites with random locations. I found that there was a positive correlation between the presence of rookeries towards what Trondheim municipality had mapped as pasture. The coarse models of the multiscale analysis (> 600 meters) showed that the forest was negatively correlated with rookeries, and this could be a factor of predation pressure.

4.1 Scale

There was no association between the landscape classes and the presence and abundance of rookeries in Trondheim using the SSB data. However, different land cover classes were affecting the presence/abundances when looking at a finer scale. In ecology, the scale is often referred to as grain or extent, where grain is the finest spatial resolution, and extent size could be in this case the study area (Thompson & McGarigal, 2002). In a study from Levin (1992), the author pointed out that the levels of scales are correlated; when increasing the scale, the logical extent is also increasing (Levin, 1992; Thompson & McGarigal, 2002).

However, it is an important consideration to be aware of, that as one changes the scale, the observed ecological pattern can also change. These differences could be biological interactions (i.e., predation, intra/inter competition, available nesting sites) and abiotic (temperature, geodiversity) (Griffinn & Thomas, 2000; Levin, 1992). A study done by Anderson et al. (2005) looked at how the elk *(Cervus elaphus nelsoni)* used summer habitat in Wisconsin, using different scale sizes (Anderson et al., 2005). They found a similarity in both grain and extent scales, that the elk would select areas that were far from wolf territories (Anderson et al., 2005). However, in the coarse-scale, they found that elks would avoid human structures such as roads, but on a grain scale analysis, the elk selected areas near roads. They found that grass biomass was higher around development, and the elk avoided woody-browse (Anderson et al., 2005).

The use of coarse-scale data could result in losing valuable information regarding where the rooks are breeding. The data from SSB showed that 19.1 % of all areal in Trondheim was defined as farming land in general (Rosvold, 2019). In contrast, the FKB-AR5 data differentiates farming into more detailed classes, including surface-, cultivated and pasture landscape types (Bjørdal & Bjørkelo, 2006). The coarse data could give a misleading picture of the heterogeneity between different landscape types in Trondheim (Newman, Kennedy, Falk, & McKenzie, 2019). A study done by Thompson and McGarigal (2002) on bald eagles (*Haliaeetus leucocephalus),* found that multiple choices drove the eagle's habitats selection at different spatial scales (Thompson & McGarigal, 2002). They pointed out how critical thresholds in variation in landscape structure could produce relatively large changes in ecological responses (Thompson & McGarigal, 2002). Wiens (1989) described that within a range of scaling thresholds, organisms could display some pattern of selection (Thompson & McGarigal, 2002; Wiens, 1989). Rooks are often associated with being in close vicinity areas with meadow and pastures (Griffin, 1998; Kasprzykowski, 2007; Kitowski, 2011; Svensson, 1999), which was also reflected by my results: when looking at the buffer (< 500- meter), pasture was the dominating type.

4.2 The ecological effects of urbanization

Urbanization may be a homogenizing force, producing landscapes and ecosystems that are more similar to each other than the natural ecosystems that they have replaced (Forman, 2014; Turner & Gardner, 2015). The changes that come with the city growth include destroying natural habitats and creating new ones, and native species are being replaced with a few species that are more suitable to live in the urban environment (Rodrigues et al., 2018). Studies around the world show that animals display phenotypic differences between nonurban and urban counterparts (Tietze, 2018). These phenotypic contrasts have been reported in a wide range of forms, from physiology to morphology, with potential impacts on life-history characteristics and fitness (Rodrigues et al., 2018). It is not easy to identify the drivers for the phenotypic changes and whereas these changes are caused by "non-genetic" phenotypic plasticity or genetic divergence (Tietze, 2018). A study done by Heiss et al. (2009) on American crow (*Corvus brachyrhynchos*), showed there were phenotypical differences between rural and suburban crows (Heiss, Clark, & McGowan, 2009). Rooks in urban areas are often observed in garden and parks, foraging for earthworms, while rural rooks forage in meadows and pastures (Orłowski & CZapulak, 2007). It is possible that these two populations can be phenotypically different from each other.

With the increasing population growth, landscape ecology has been more and more influenced by humans (patterns and process) (Fryxell et al., 2014). The human disturbances (i.e., alternation of natural disturbance regimes) can have long-lasting ecological effects on a species (Forman, 2014). The European hedgehog (*Erinaceus europaeus),* for example, - is a mammal that is disappearing in rural and urban areas due to an increased level of human disturbance in its natural habitat (Hof, 2009). During hibernation, if it is disturbed, it will wake up and try to find a new suitable den (Hof, 2009). Looking for a new den, the hedgehog will burn unnecessary fat reserves, resulting in a weakening in their physical condition. Ultimately this could lead to death during hibernation, due to starvation (Hof, 2009). Due to the intensive fragmentation of their habitats with roads, more hedgehogs are being killed annually by traffic (Hof, 2009). Similar to the hedgehog, the rook has been under much pressure in Europe (Orłowski & CZapulak, 2007; Richardson, Patterson, & Dunnet, 1979). The rapid loss of agricultural land, the use of toxins, and the persecution of people are affecting the rook population negatively (Kitowski, 2011). Studies from Poland show that one of the main reasons for the decline in rookeries, is that good nesting trees are being cut down (Kitowski, 2011). A study by Kitowski (2013) showed that the rookeries were systematically removed from parks using pyrotechnics or by guns, or knocking rookeries out of trees and poisoning the birds (Kitowski, 2013). In Poland, an interview with local people showed that (>100) colonies have disappeared due to human disturbances in a 30-year-old period (Kitowski, 2013). There have been many examples of human disturbance in Trondheim

(Bangjord, 1986), including the destruction of the colony in 1986 at Tungaskogen by cutting down nesting trees for rooks for building the new E6 road (Bangjord, 1986; Størkersen, 1990). The same year, there were registered 150 fewer rookeries in Trondheim compared to the previous year. The following year, a new colony was discovered at Moholt Cemetery with 27 new rookeries, but all the rookeries disappeared the year after (Størkersen, 1990). The author points out that the rookeries at Moholt were systematically removed by flushing the trees with water (Størkersen, 1990). Studies done by Griffin (1999), showed that the nesting distribution was linked together with the availability of suitable nesting trees for the rook (Griffin, 1999). Many see the rook as a troublemaker and a bird that messes up garbage depots (Orłowski & CZapulak, 2007). In British mammal fauna, there have been a shift in attitudes towards wildlife due to conservation campaigns, and books (Morris 1987). Attitudes towards urban wildlife have changed during the last century and more people are more aware of vulnerable species (Morris 1987). The online survey mapped how Trondheim perceives the rook, with the background of problems people had with the bird in the past (Appendix B) (Størkersen, 1990). Results from the survey show that there are overall positive attitudes towards the rooks in Trondheim (Appendix L & Appendix K). When it comes to attitudinal questions, it shows that women responded slightly less positively than men regarding the intelligence and appearance of the bird (Appendix L). However, the Mann - Whitney U test, showed no correlation between sexes. Younger participants responded more positively than people over 70 years (Appendix K). The Kruskal-Wallis Test that was run on age showed that the question:” Do you think that the municipality has a responsibility for the species?” showed that there was a differences inn opinion between age classes. This could confirm what Morris (1987) suggested, there is a generational change going on (Morris 1987).

With the increasing population growth in and around cities, more wildlife habitat is disappearing (Harveson, Lopez, Collier, & Silvy, 2007). For example, the key deer (*Odocoileus virginianus clavium*) is an endangered species in Florida (Harveson et al., 2007). In the last 30 years, there has been a rapid human population growth that has sized more and more of the key deer habitat (Harveson et al., 2007). Changes have forced the key deer to utilize more of the urban habitat than compared to 30 years ago. This adaptation has increased the lower survivability for young key deer males, due to lack of knowledge about the urban risk factors (e.g., swimming pools, roads, fences). Rooks are often associated with farming, but new research shows that rooks in the cities have adapted to an urban habitat (Orłowski & CZapulak, 2007). Researchers noticed that rooks that lived in the city were not only observed in gardens and other urban habitats foraging for earthworms. However, this was not confirmed in my study, as open habitat was not an important factor for the presence of an abundance of rookeries in Trondheim. Orłowski and Czapulak (2007) suggest that the decline in the rookery population was due to a rapid change in farming. An example of this was when Poland was free from communism in 1989, and the food market in Poland opened (Orłowski & CZapulak, 2007). This rapid change in crop structure in Poland has affected the rook population negatively. More mechanical harvesting is disturbing rooks when they are foraging for earthworms (Orłowski & CZapulak, 2007). Due to a more slow change in agriculture over 20-30 years, western rook populations have produced more stable populations (Orłowski & CZapulak, 2007).

The Anthropogenic climate disruption is changing conditions for many species, altering their timing of lifecycles (e.g., hibernation, breeding, migration) (Dirzo et al., 2014; Young et al., 2016). With the changes that come with climatic disruption, an organism can either: 1) evolve and speciate in response to the changing climate, 2) disperse and migrate track suitable habitat, or 3) species can go extinct (Turner & Gardner, 2015). Rooks can raise two young from a clutch of 4-5 eggs, and the bird will have a high degree of parental investment in the chicks (Røskaft 1985). In Trondheim, Røskaft (1983), noticed that the rooks had a long post-hatching period, that resulted in their physical condition decreased (Røskaft 1983). Weaken condition after breeding, is also something observed on rooks in Finland (Rytkönen et al., 1993). First breeders tend to breed earlier than older rooks, when the ground is still frozen and the availability of earthworms is sparse (Rytkönen et al., 1993). It is only after that the frost melts that; the rooks can feed on earthworms. Climate change is producing higher average temperatures each year (Tietze, 2018; Young et al., 2016), and this can affect the availability of earthworms for rooks (Rytkönen et al., 1993). In Trondheim, there has been a steady decrease in observations of rookeries since 2001. There is a probability that this could have been related to climate change (e.g., dry soil) that makes the worm dig deeper (Røskaft 1983). The winter of 2013 – 2014 was the warmest in Norway, with 0.6 °C above the 1971–2000 mean (Howe, 2018). In 2014, there were only 76 active rookeries in Trondheim. Rooks in Trondheim do not migrate during the winter, and this is mostly because of the mild climate with little snow (Røskaft, 1980). Another reason for being stationary in Trondheim is that in contrast to many other birds, rooks have a strong association with their nesting rookeries throughout the year (Griffin, 1999). There could be a possibility, that the rook in Trondheim is ecological trapped, and Rytkönen et al., (1993), stated that the Rook is not well adapted to northern conditions. Factors such as mild climate, high abundances of winter food, a strong association with their nesting rookeries, is attracting the rook to be stationary (Jokimäki et al., 2011). Suggesting that a species is ecological trapped, are still controversial. More information regarding rooks mortality rate and breeding success is needed, over a more extended period (Jokimäki et al., 2011).

From 2007 to 2019, there have been 19 known locations with rookeries in Trondheim. The colony at parkeringsplassen Østmarka, låven Østmarka and Tunga Krestfengsel, have had almost continuous observations in this period. Looking at the random effects for the generalized linear models, these locations had the most impact, on the models for both the binomial and poisson distribution within the home range (Appendix J). Other locations in Trondheim have disappeared and then reappeared (Størkersen & Sandvik, 1988). Kitowski (2011), found that small colonies (> 15 rookeries) had a three times higher chance for disappearing than large colonies and disappeared after some years with activity (Kitowski, 2011).

4.3 Rookeries in the landscape

The rook's selection for colony sites was driven by multiple landscape classes (development, farming, pasture, and forest) at various spatial scales. Forman (2014) proposed that the grain size of an area provided a unique insight into an ecological process (Forman, 2014). In ecology, these zones are known as critical thresholds (Turner & Gardner, 2015). For example, how the scrub-jay is decreasing in number due to anthropogenic destruction and alteration of their habitat (Coulon et al., 2010; Stith et al., 1996). With more fragmented areas, their effective dispersal decreases with the proportion of their habitat that becomes lost. Looking at a large scale, the researchers found that the scrub-jay may disperse further as fragmentation increases, but their success for breeding goes down (Coulon et al., 2010; Stith et al., 1996). The multiscale model observed several threshold-like patterns for habitat selection for rookeries. The definition of AR5 farming is a polygon that has attributes such as, ordinary ploughing depth and is mostly cleared for mechanical harvesting (Bjørdal & Bjørkelo, 2006). In Poland, rooks were often associated with small-scale farming, picking up earthworms after the ploughing. Due to an intensification of the agriculture and small patches are being merged into larger farming areas, rooks are rarely observed in these habitats (Orłowski & CZapulak, 2007; Turner & Gardner, 2015).

Development had a negative impact on the presence of rooks, and as mention earlier, this could be a result of human disturbances and the destruction of nesting trees (Griffinn & Thomas, 2000; Kitowski, 2011). However, buffer size 300-meter showed that development correlated positively to the presence of rookeries. In the methods, roads were represented by very low proportions and merged with development. Proximity to roads may also be important in this aspect, although both may provide scavenging opportunities (Svensson, 1999).

Both buffer size 200-, 300-, and 400-meter buffer showed that there was a positive correlation between the presence of rookeries and the proportion of pastures in the buffer. Studies from Scotland suggested that the availability of grassland was necessary for chick development when rooks are dependent on invertebrates (Gimona & Brewer, 2006). Most of the rookeries found in Trondheim are in the vicinity of human habitations and surrounded primarily of arable land (Bangjord, 1986). Previous studies show that pasture and meadows are important habitat classes for rooks, and the disappearance of these classes is affecting the presence of rookeries (Griffin, 1999; Kasprzykowski, 2007; Kitowski, 2011). The incubation period for rooks usually starts at the end of March /April (Svensson, 1999). Studies from Orłowski et al. (2009) showed that adult rooks preferable feed the chicks earthworms (Orłowski, Kasprzykowski, Zawada, & Kopij, 2009). The nestling mortality is highest during the first third of the nestling period, and the most likely cause for high mortality is starvation. Rook chicks have an average weight gain during the ten days after hatching, of about 35 % (Rytkönen et al., 1993).

One of the main advantages of being in a colony is its defence against predators (Tietze, 2018). Studies show that the location of the rookeries is primarily connected to the reduction of nest predation (Kasprzykowski, 2008). In colonial breeding, a large number of rookeries constructed in a small area can attract predators. When choosing a rookery location in a tree, the most dominant bird in the colony will choose higher roosting places in trees than subordinates or younger individuals (Kasprzykowski, 2008). The proportion of forest within each scale affected the presence of rookeries negatively. A possible explanation for this can be the predation pressure of chicks and eggs (Kasprzykowski, 2008). One of the most frequent mammal predators of rookeries is the red squirrel *(Sciurus vulgaris)* *(*Kasprzykowski, *2008).* Studies from André and Lemnell (1992) show that the highest density of red squirrel is located in the old spruce forest (Andrén & Lemnell, 1992). Random and known points for rookeries were all located in areas in arable land (figure 1b). When increasing the buffer for each point, more forest was being included in the spatial data (Appendix N). It is mainly during the reproductive period when the squirrel needs high protein food. It is often then squirrel are observed robbing eggs and chicks from rookeries (Kasprzykowski, 2008). The rookeries that were located lower than the roosting point was most exposed to predation from squirrels. In the later years, more tracks of the European pine marten (*Martes martes*), have been registered by Geir Lasse Aune in Trondheim (Personal communication, 05 May 2020).

4.5 Limitations to the study

Fieldwork was based on the same method that Trondheim municipality had done in the period 2007-2018. All previously known locations for rookeries were revisited, and all the responses regarding new rookeries from the survey monkey were controlled for rookeries.
Most of all, the fieldwork was based on the sites in the North-Eastern part of Trondheim. Historical texts from Trondheim, which talk about rookeries around Byåsen and Kolstad, were investigated in the first part of the fieldwork. During the fieldwork, three unknown sites for rookeries were discovered, so it is quite possible that areas such as Byåsen (Størkersen, 1990), had a successful nesting of rookeries, but were not included in the study. Just looking in one part of Trondheim may make the number of rooks inconsistent and can give an incorrect picture of the rook population. However, during my fieldwork, the online survey was used to find unknown locations of rookeries. Since the online survey was operational throughout 2019 (still operational), it is quite possible that all colonies were registered.

Regarding the use of RSF modelling, it is difficult to demonstrate if the random points, do not contain any rookeries (Boyce et al., 2002; Morris, Proffitt, & Blackburn, 2016). RSF modelling can cause a bias in the results because I am sure that the present points are used, but less certain about the random points could contain rookeries. Hence, these points should be perceived as 'pseudo absence' and not as true absences (Morris et al., 2016).

Using the AR5 data could give a misleading picture of the importance of forest trees, for rooks on a grain scale. The definition of the forest by the AR5 classification is an area with at least six trees per acre (Appendix E). Due to this, the forest is not being mapped at all rookery locations in Trondheim (e.g., Tunga krestfengsel, Overvik) (Appendix N). This could give a misleading picture of the importance of good nesting trees for rooks in Trondheim.

5. Conclusion

In general, my study shows the importance of understanding the habitat selection patterns for rookeries in Trondheim. Using a multiscale approach shows that different landscape variables affect the rookeries in Trondheim. In many countries in Europe, there has been a decline of rookeries, and factors such as human disturbance (persecution) and habit loss (pasture and meadows) are affecting the rook population negatively. Although the rook population is consider as not endangered, the intensification of agriculture could have an impact on the population in Central Europe.

Given that urbanization is expanding rapidly, some rooks have adapted to a life in cities. Instead of seeking out habitats such as pasture and meadows, rooks are observed in gardens and parks, foraging for earthworms. The rooks that are found in the cities may be phenotypically different from rook found in the rural gradient.

The rook has their physical condition decreased due to a long post-hatching period and combined with a high mortality risk on chicks, gives a decrease in rookeries each year. Studies from Europa show the importance of good nesting trees for rookeries, and for further land planning, this must be accounted for if we are to preserve rooks in Trondheim.

For further analyses, I will recommend using more detailed maps, perhaps include substrate analyses (what kind of trees it builds a rookery in) and a more consistent method for mapping rookeries in Trondheim. Continuous monitoring of rooks and investigating the biological restrictions for rooks in Trondheim would make it easier to understand the mechanisms and reason behind the reduced number of rookeries.

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Appendix

A. Protected areas

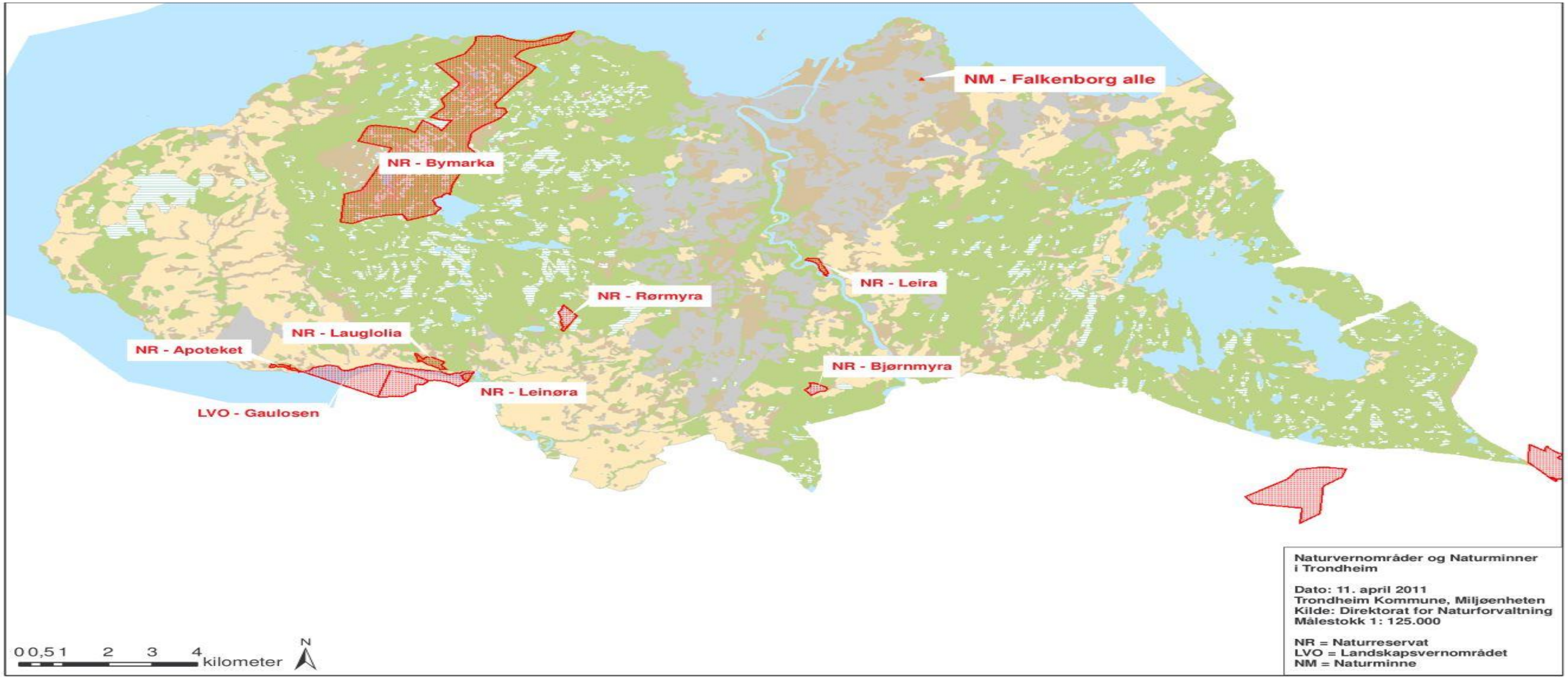


Figure S1: Shows the eight natural regions and the botanical nature monument that is protected by the diversity act. The environmental department approves the use of this map. The map from https://www.trondheim.kommune.no/naturvernomraader/

Note: S = supplementary

B. Survey Monkey

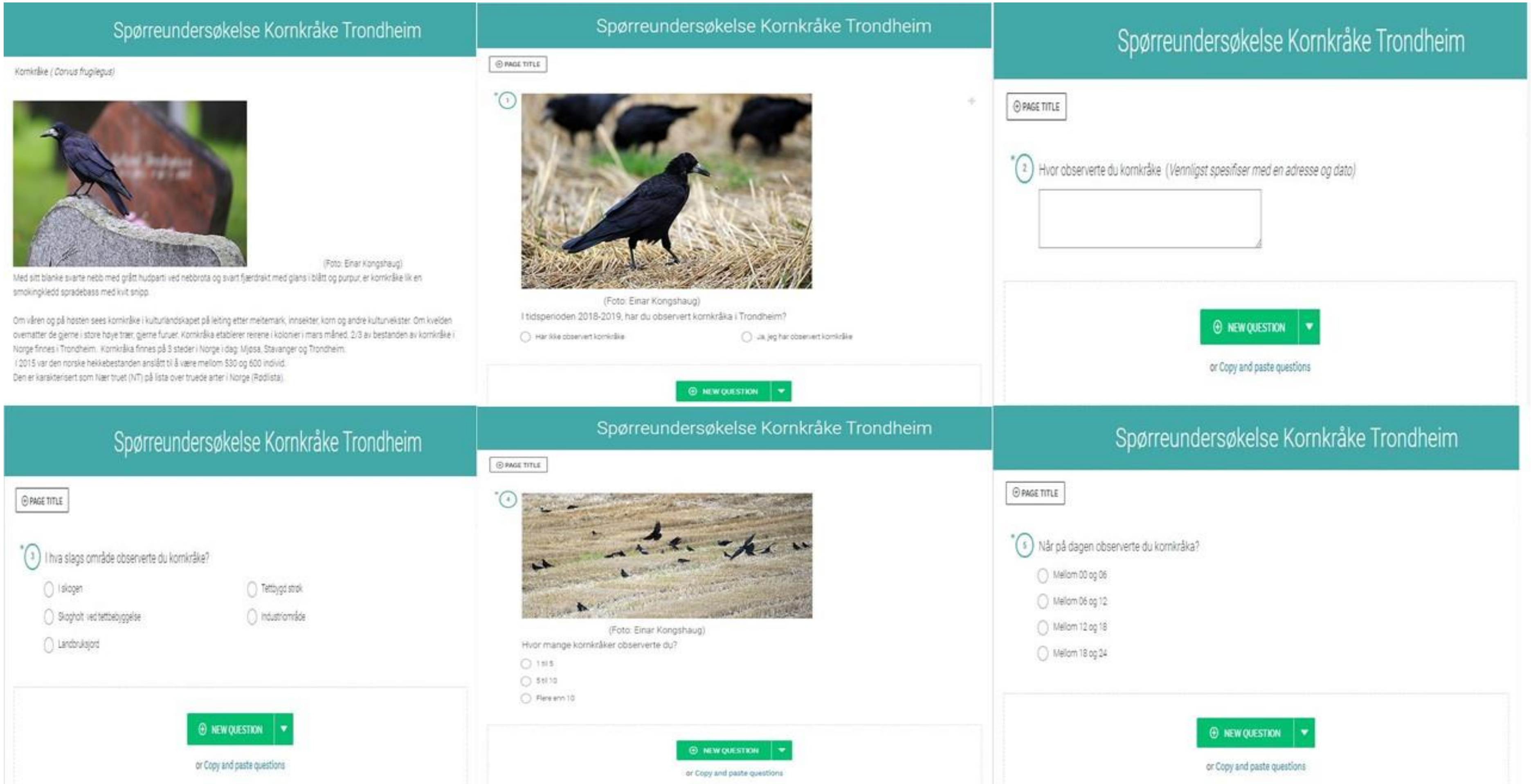


Figure S2: Shows the questionnaire used in the survey monkey. The first seven questions deal with the location of rookeries in Trondheim. Off n=271 responses in the period 02.03.2019 – 01.05.2020, n= 190 was complete responses.

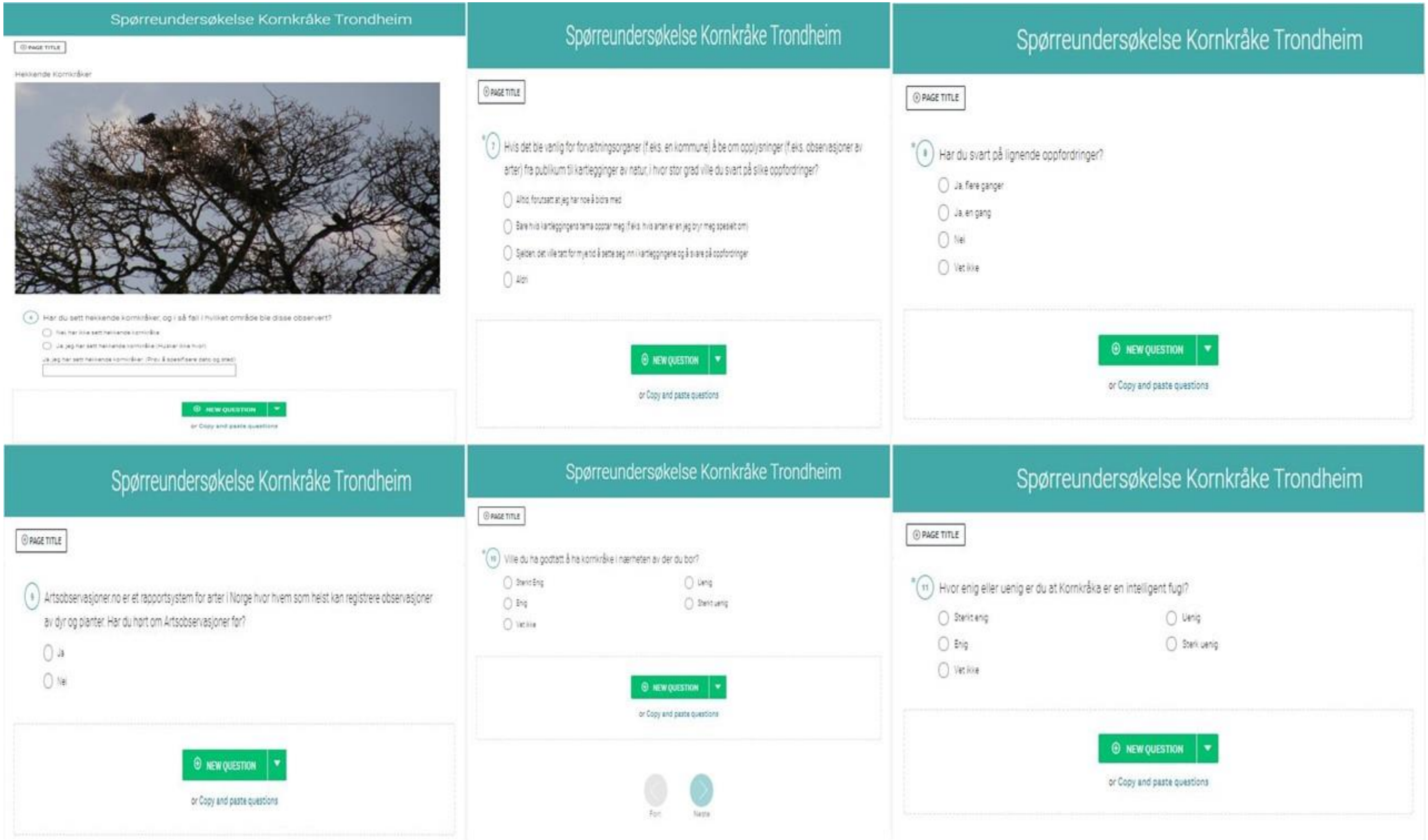


Figure S3: This section was to map attitudes towards the rook in Trondheim. The survey is still operational link (https://no.surveymonkey.com/r/BKNSPX3)

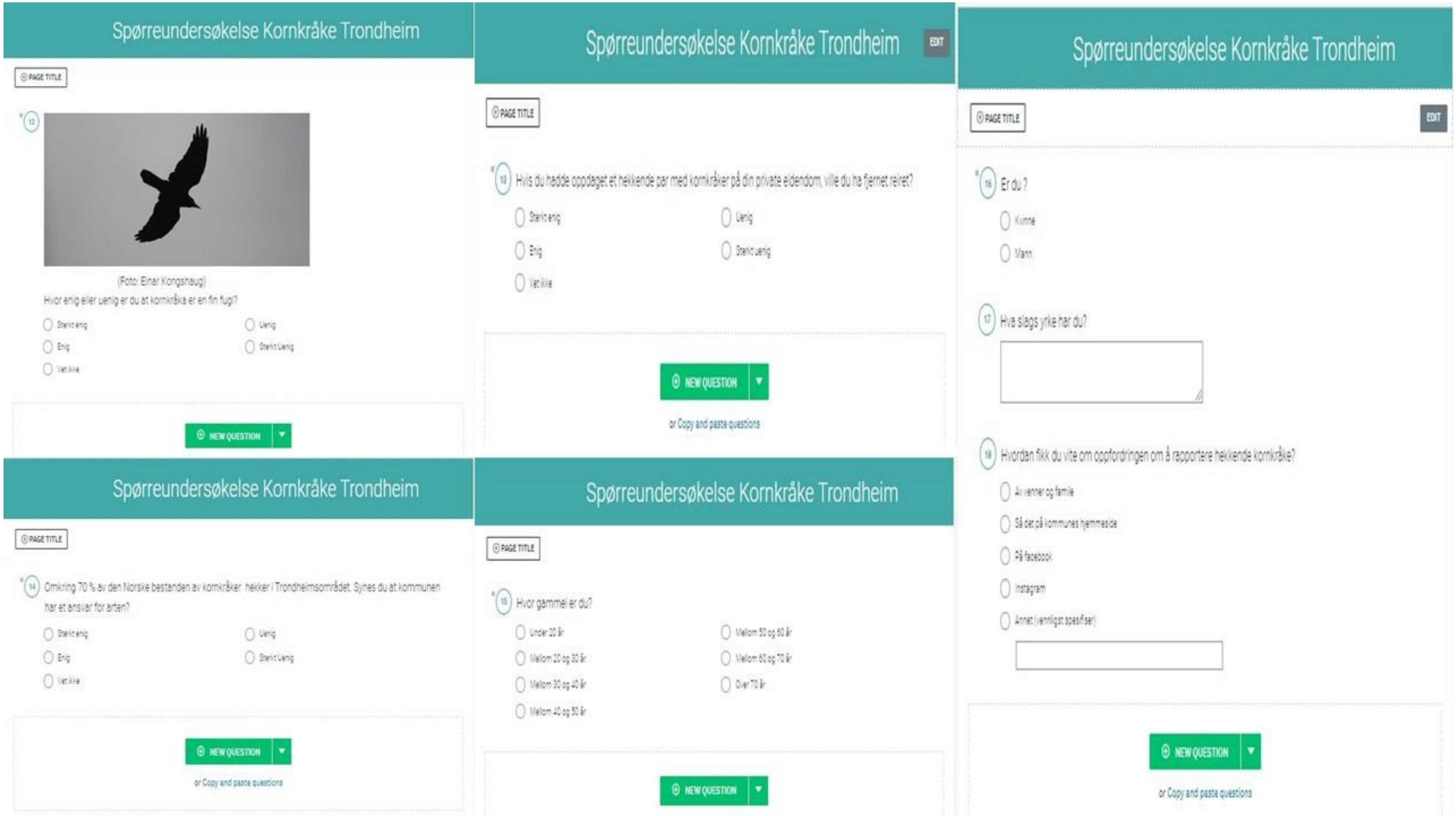


Figure S4: The last part of the survey was to map age and sex.

C. Fieldwork 2019

Table S1: The table shows the GPS coordinates for every rookery and vantage point used during my fieldwork in 2019 in Trondheim. This point was revisited 20 times, two times a day, for a 20-minute duration.

Name	Number of rookeries	Rookery North	Rookery East	Vantagepoint North	Vantagepoint East
Tungakretsfengsel	34	7040395.94	274207.16	7040362.41	274189.30
Charlottenlund Gravlund	11	7040033.57	275649.97	7040221.76	275780.64
Grillstadmarina	19	7042705.69	275002.79	7042352.59	275404.79
Ovenfor Hundeparken Lade	3	7043989.36	273117.20	7043962.45	273058.43
Låven Østmarka	49	7043954.49	273250.99	7043937.32	273206.52
Østmarka Parkeringplass	11	7044088.93	273275.34	7044047.65	273253.79
Lade Gård	1	7043497.54	272717.45	7043546.68	272694.81
Lade Kirke	1	7043378.02	272607.59	7043348.25	272607.70

D. Definition N50

Table S2: The table shows the classification of polygons on a scale of 1: 10 000 (Steinnes, 2014). Older data from Statistics Norway is based on this way of classification. This map is continuously updated using data from cadastre that contains information on land properties, addresses and buildings and digital real estate mapping.

N 50 CLASSIFICATION SYSTEM	
Industry:	Factory buildings, workshop buildings, production halls, power plants, transformer stations or other production buildings.
River with dry fall:	Area of running water bounded by mainly riverside. Larger sandbanks and river deposits that are flooded by normal high tide flow. Minimum area 1000 m^2.
Bog:	Open - not wooded area - with a lot of vegetation (topographic marsh). The marsh may be overgrown, but few or small trees (about 1-4 m high)
Forest:	All types of woodland (coniferous forest, deciduous forest, mixed forest) - also harvested areas – although new planting is not visible
Farming:	Fully cultivated land (Farming), pasture, which is surface treated and berries. Agricultural land that is fallow for shorter periods or used for grazing is also considered as cultivated land

Development:	Contiguous area of buildings with less average spacing than 50 meters. Predominant housing - may have features of other types of buildings
Open Area	Area that is not forested.

E. Explanation of AR5 classes

Table S3: AR5 maps are based on interpretation from aerial images and field validation. The classification of AR5 divides land surfaces into polygons of specific land cover types, forest habitats, tree species, and soil conditions (Bjørdal & Bjørkelo, 2006).

AR5 CLASSIFICATION SYSTEM	Explanation
Water	Water includes the sea, lakes, rivers and streams, minimum area 0.5acres
Development	Area that has been developed or significantly worked up, as well as adjoining areas that are close to function. It is linked to the settlement.
Roads	Transport mainly comprises roads and railways. The demarcation of the transport area in AR5 should follow the boundaries of the most accurate datasets for the current topic (* Merged with Development).
Fully cultivated soil	Agricultural land cultivated to ordinary ploughing depth and can be used for arable crops or to the meadow, which can be renewed by ploughing.
Surface cultivated soil	Agricultural land that is mostly cleared and level in the surface so that mechanical harvesting is possible (** Merged with fully cultivated soil).
Cultivated pastures	Agricultural land that cannot be harvested mechanically. At least 50% of the area shall be covered with cultivated grass or grazing herbs.
Forest	Area with at least six trees per acre that is or can be five meters high and these should be evenly distributed over the area. Harvest areas are considered as forests. Area planted with forest trees shall be classified as forest, without consideration of the age of the tree plants.

Bog	Area with marsh vegetation and at least 30 cm thick peat layer (*** Merge with open area).
Open Area	Land that is not agricultural land, forest, built-up or transport. The area type covers a wide range of natural and culturally affected areas. Both the snow mountain and golf courses are often open land, and the class includes partly wooded areas (scrub forest, glistening forest) that do not meet forest requirements.

F. ArcGIS Model builder

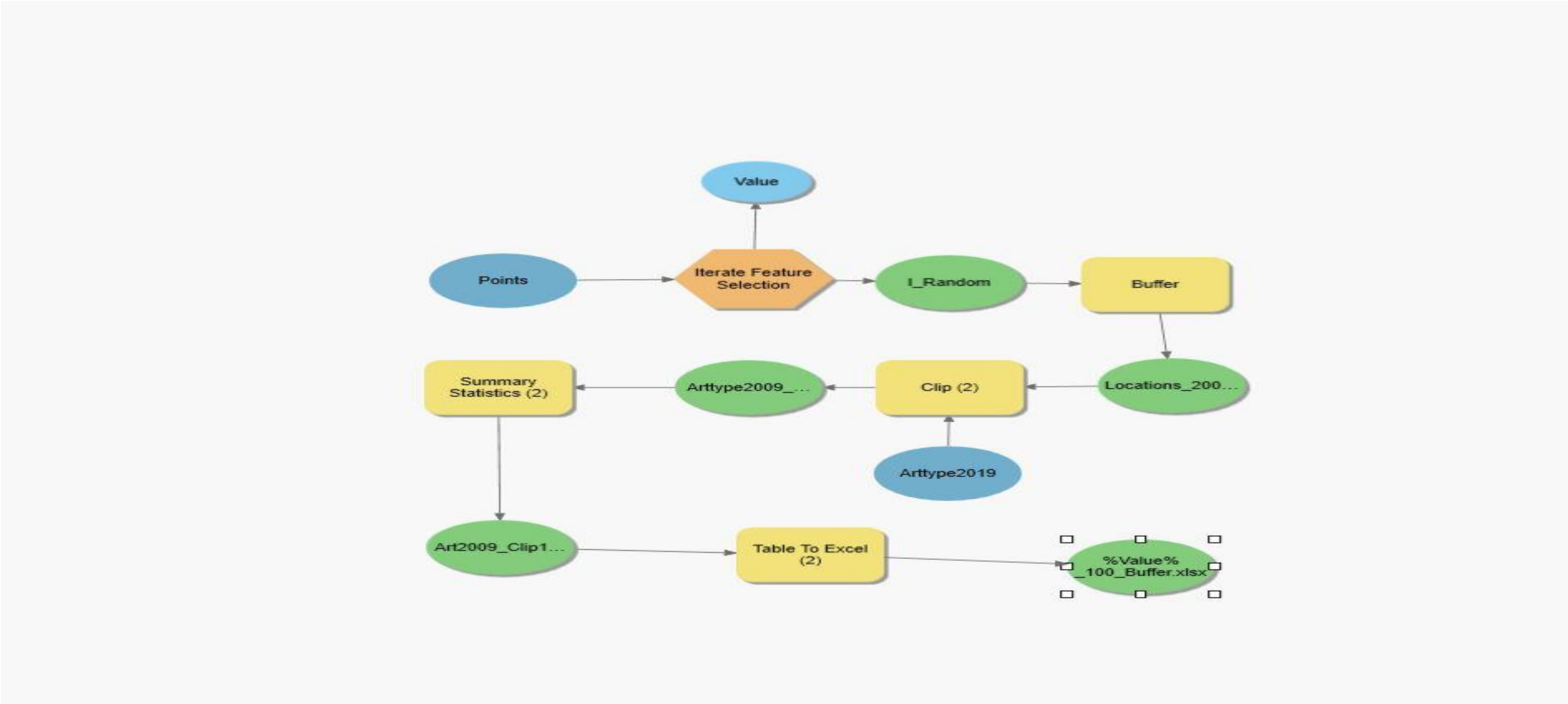


Figure S5: Model builder in ArcGIS Pro. The figure shows how I modelled the geospatial data. This model was used for the statistical test 2-3. Historical maps were provided from Trondheim municipality. Spatial data was then extracted out of each map, using 19 locations of rookeries in Trondheim.

G. Worksheet Reclassification

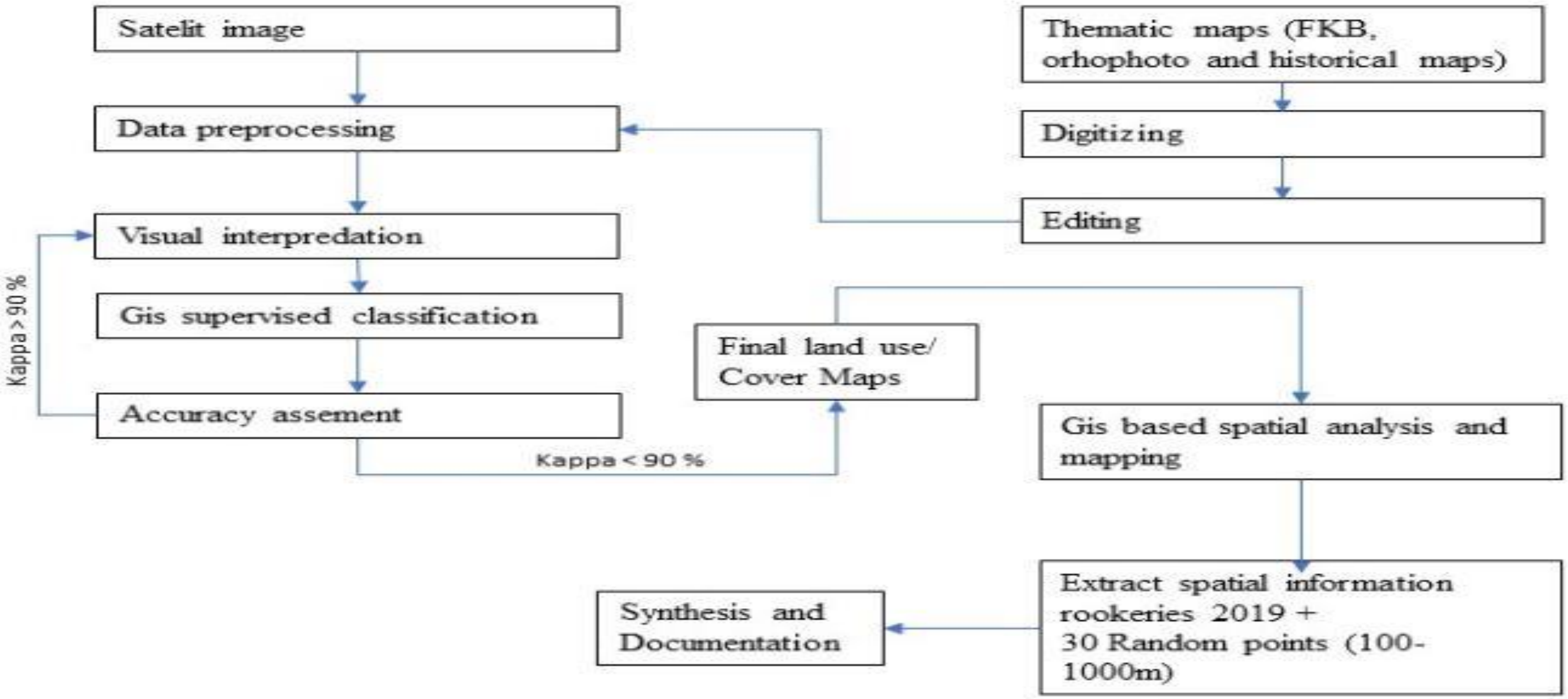
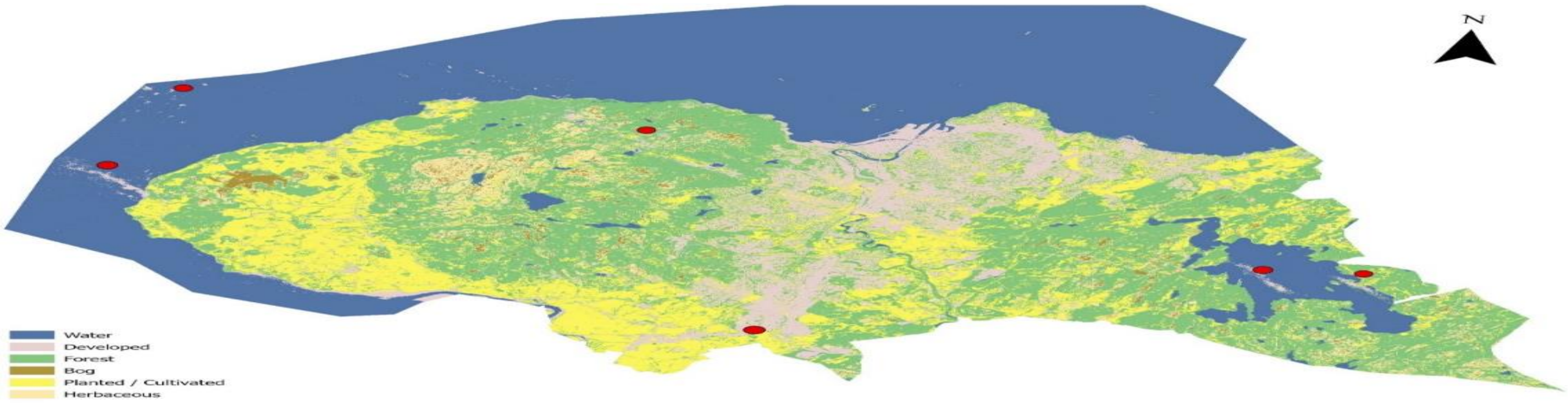


Figure S6: To classify in heavily built areas, it was necessary to have satellite images of the highest possible resolution. The land change mapping and analysis I did, was based on the procedural route develop by J.R. Jensen (Liu & Yang, 2015)**.** Unfortunately, my reclassification did not meet the standard < 90%.

H. Reclassification image and spectral profile

A)



B)

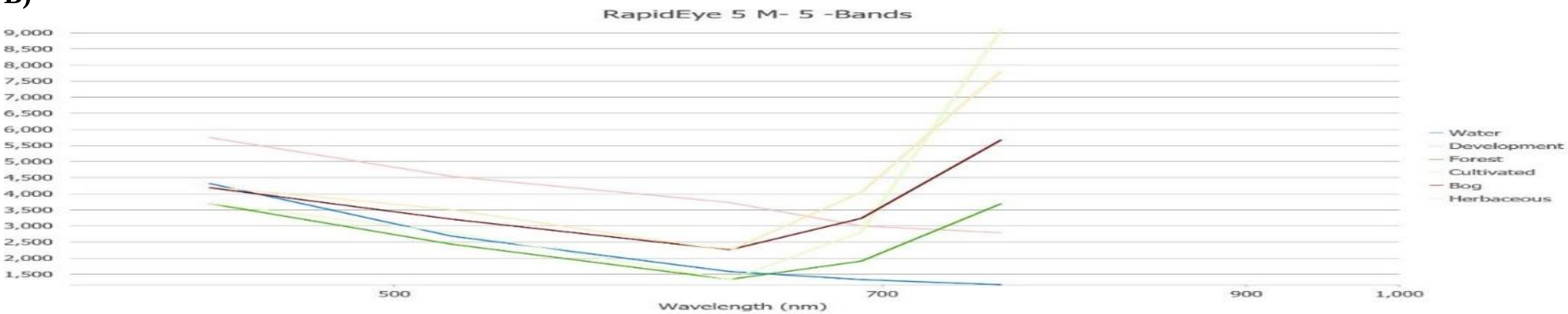


Figure S7: A) show the results of the supervised reclassification job. Unfortunately, the reclassification (77 %) did not meet good enough standards to include in this thesis. The red dots in the maps show the solar interference that made my classification difficult**. B)** Show the spectral profile of each of the landscape classes included in my reclassification.

I. Kappa table

Table S4: The table shows the overall score of my kappa. These accuracy rates range from 1 to 0 and 1 represents 100 percent accuracy. My accuracy column shows the false positives or errors of omission. I used 208 points to validate my reclassification, and blue marks how many points in each class. The total Kappa was 77 %.

Class Value	*Water*	*Development*	*Farming*	*Forest*	*Pasture*	*Open Area*	*Bog*	*Total*	*Accuracy*	*Kappa*
Water	61	13	0	0	0	0	0	74	0.82	0
Development	4	11	2	0	0	0	0	17	0.64	0
Farming	1	0	9	0	0	0	0	10	0.90	0
Forest	2	4	1	39	3	0	1	50	0.78	0
Pasture	0	0	0	0	9	1	0	10	0.9	0
Open Area	1	2	1	0	1	30	0	35	0.85	0
Bog	0	0	0	0	0	0	12	12	1	0
Total	69	30	13	39	13	31	13	208	0	0
Accuracy	0.88	0.37	0.69	1	0.69	0.96	0.92	0	0.82	0
Kappa	0	0	0	0	0	0	0	0	0	0.77

J. Random effects

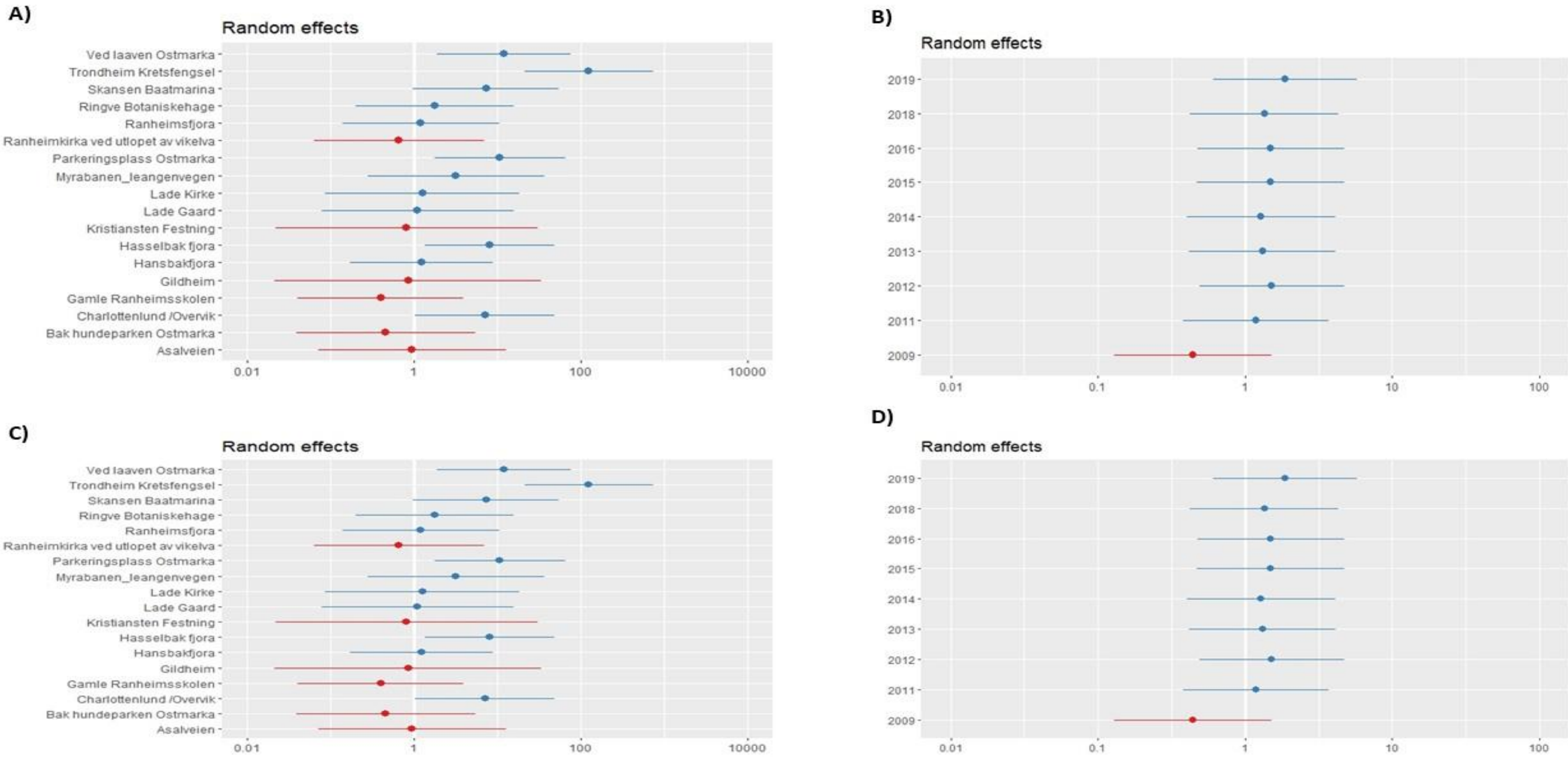


Figure S8: Show the Random effects of the generalized linear mixed-effect model within the home range of rookeries. **A)** The random effect for the location using a binomial distribution. **B)** The random effect for Year using a binomial distribution. The variance of the random effects for the presence was Location: 1.25 and Year:0.68 **C)** The random effect for the location using a Poisson distribution. **D)** The random effect for Year using a Poisson distribution. The variance of the random effects for the abundances was ID:5.52, Location: 5.7 and Year:0. Notice locations Østmarka, Tunga Krestsfengse and låven ved Østmarka. These are locations with almost continuous observations of rookeries in the period 2009-2019.

K. Results multiscale model

Table S5: Model selection for rookeries in the landscape, a summary from GLM. The table show effects of all 100-meter buffers. Order of result (Estimate, Standard error, and p-value).

Buffer Model	Intercept	Development	Farming	Pasture	Forest	DF	AIC_C	ΔAIC_C	w_i
Model_100	1.32,0.48,0.001	-0.02,0.01,0.001	-0.08,0.03,0.020			3	135,8	1,46	0.179
Model_200	-0.13,0.21,0.5			0.07,0.05,0.01		2	147,8	0,54	0.094
Model_300	-1.97,0.64,0.001	0.03,0.01,0.001		0.22,0.07,0.01		3	139,5	0,96	0.174
Model_400	0.740,0.34,0.02			0.19,0.10,0.01	-0.08,0.02,0.001	3	139,5	0,68	0.206
Model_500	0.76,0.36,0.03			0.06,0.11,0.55		2	143,7	0	0.305
Model_600	0.22,0.24,0.35				-0.17,0.11,0.13	2	143,3	0	0.258
Model_700	0.98,0.40,0.01				-0.07,0.02,0.001	2	142,3	0	0.365
Model_800	1.28,0.41,0.001				-0.08,0.02,0.001	2	136,1	0	0.378
Model_900	1.42,0.44,0.001				-0.09,0.02,0.001	2	135,4	0	0.305
Model_1000	1.29,0.42,0.001				-0.08,0.02,0.001	2	137,1	0	0.285

L. Attitudinal question: Male vs Female

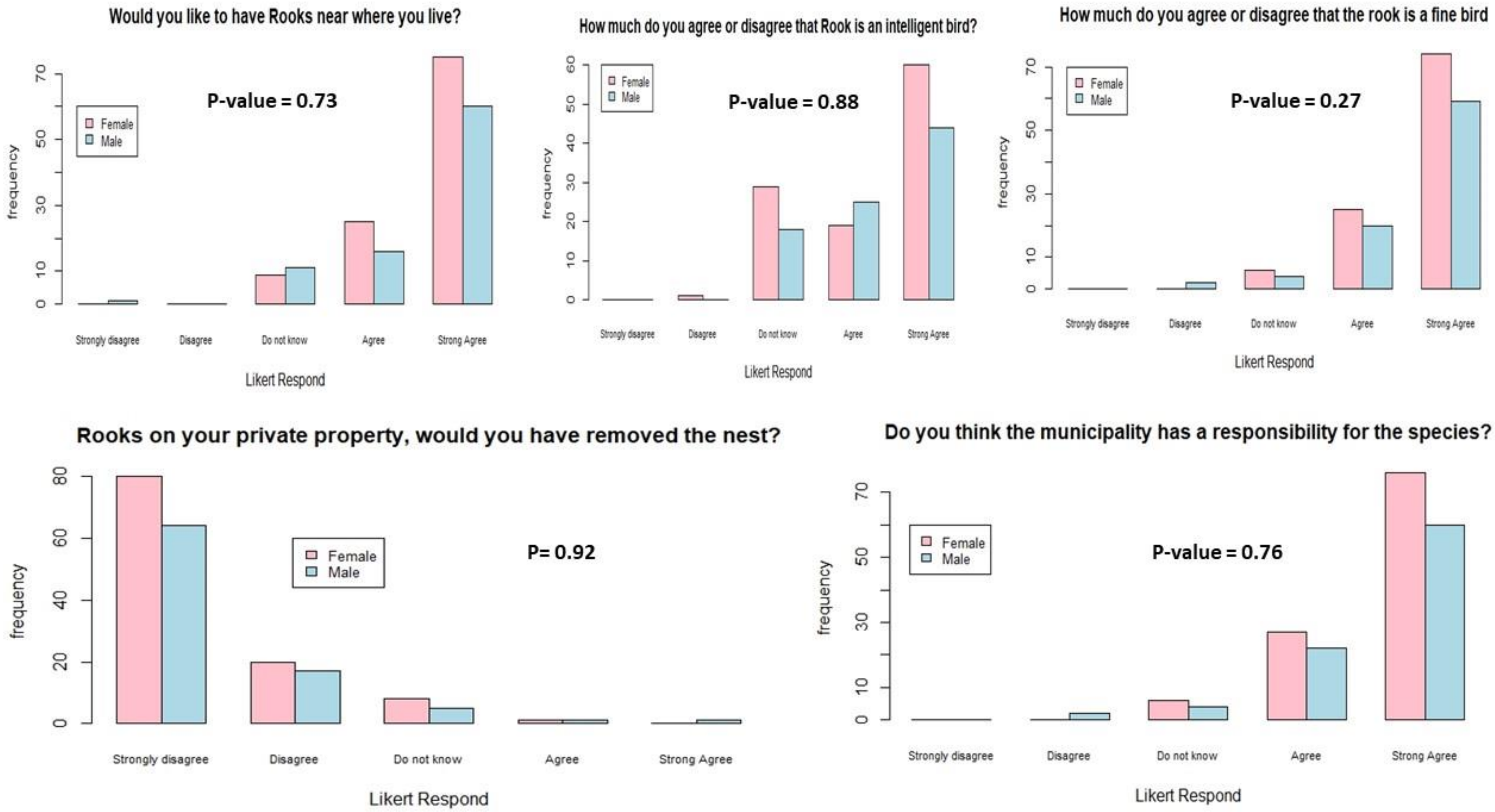


Figure S9: The results of the attitudinal questions between male and female are showed as a bar plot. In each bar plot, the p-value of the Mann U Whitney test is included. The statistical test showed that there was no correlation between male and female. However, females tended to answer more positively on each of the attitude questions than males.

M. Attitudinal question: Age

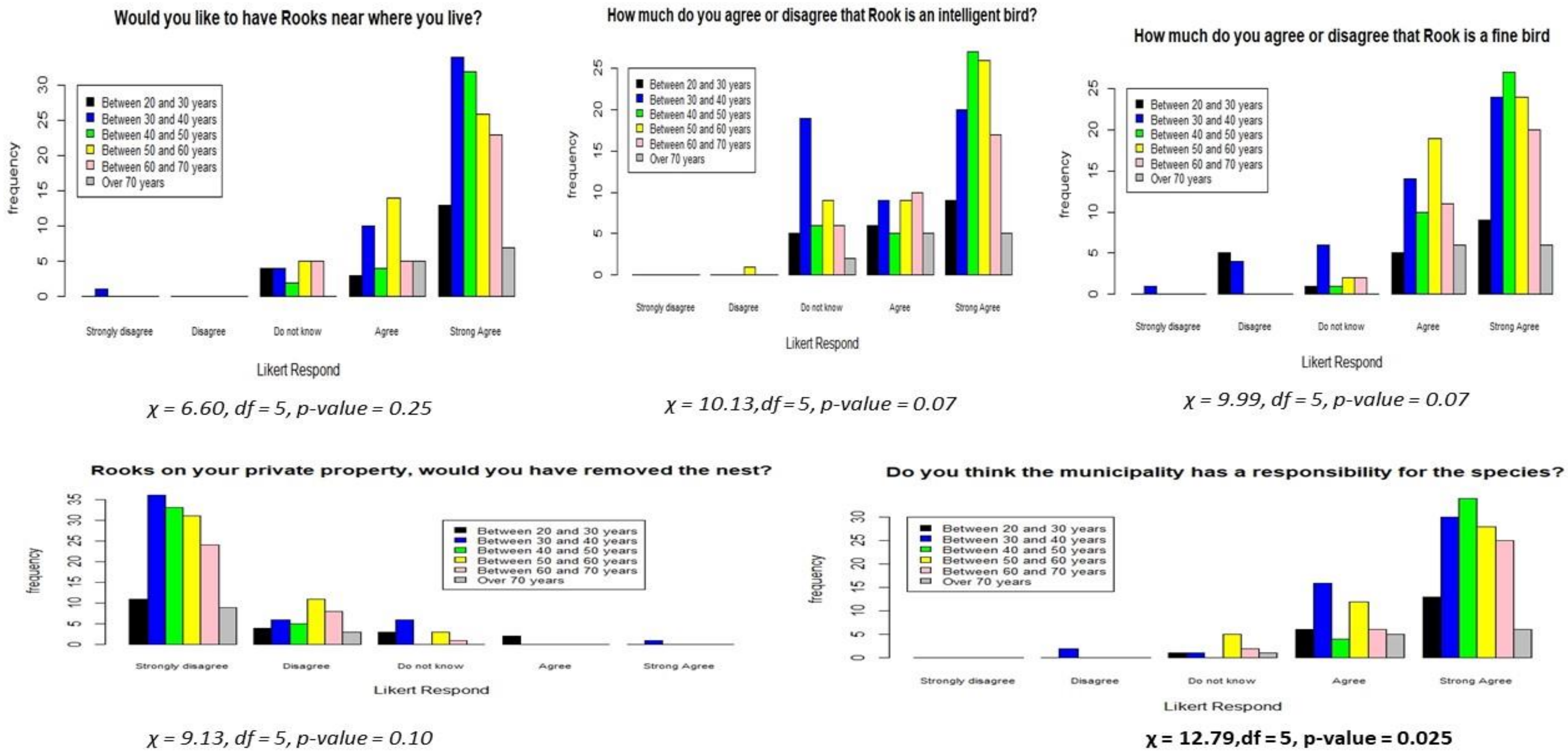


Figure S10: The results of the attitudinal questions between age classes. Ages consisted of six classes (between 20 and 30, between 30-40, between 40-50, between 50-60, between 60-70 and over 70). The result of the Kruskal-Wallis test is included and shows the Chi-square value, df (degrees of freedom) and P-value. It was only “Do you think the municipality has a responsibility of the species?” that showed a correlation between age classes (**p=0.025).**

N. RSF model with forest

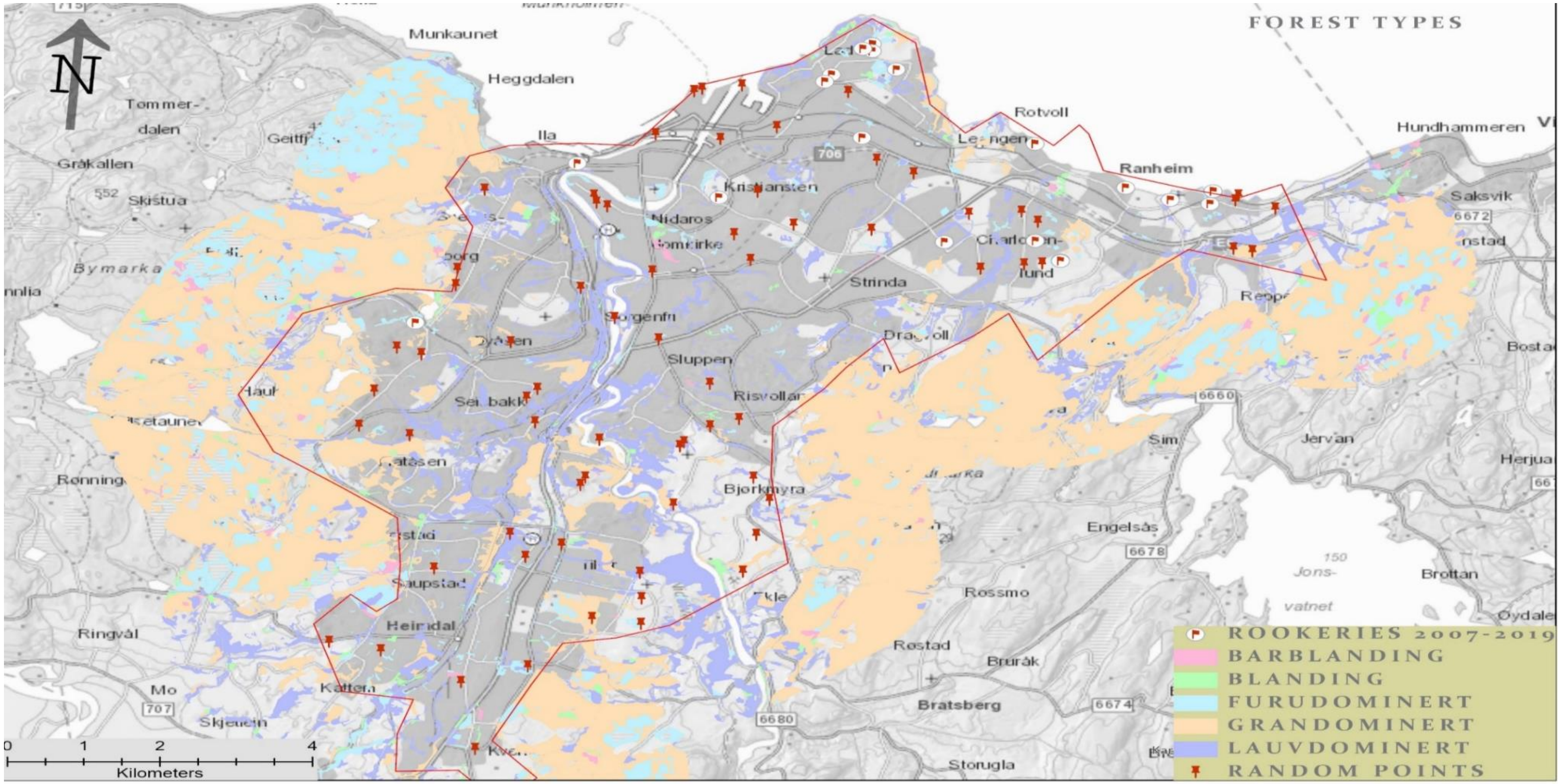


Figure S11: Shows the RSF Model with 100 random points and known rookery colonies in Trondheim. A substrate map with the forest is included. Noticed how spruce dominates the map. The red squirrel is often found in a highly dense spruce forest (Andrén & Lemnell, 1992).