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MASTER THESIS

Abundance and distribution of yellowhammer *Emberiza citrinella* in the Norwegian agricultural landscape

Author:
Amauta Choque Halvorsen

ECOLOGY AND EVOLUTION

DEPARTMENT OF BIOSCIENCES CEES
60 CREDITS

July, 2022

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Abstract

Farmland bird populations in Europe have experienced a decline the last forty years due to agricultural intensification and land abandonment. This included Yellowhammer (*Emberiza citrinella*) populations. Yellowhammer population decline have been monitored in the period between 2000-2017 by the Norwegian monitoring programme for agricultural landscapes. This study investigates if specific land type combinations, climate variables, together with geographic location can explain yellowhammers distribution and abundance in Norway. A generalized additive binomial model was used to explain yellowhammer distributions. This showed that this species distribution had become more restricted throughout the monitoring period, and that geographic location and land type combinations were significant. For yellowhammer abundance a generalized additive quassi-Poisson model was the most adequate, showing that yellowhammer abundance declined in the monitoring period. In addition, geographic location and land type combinations were also significant in the abundance model. Both models showed that land types had a stronger explanatory effect than climatic variables. The distribution model was considerably more accurate than the abundance model. This was probably due to a low amount of observations of yellowhammer in each monitoring plot every year. This study confirms the importance of having long time series data of farmland birds, and that the conservation of cereal crops and vegetation around fields in the Norwegian agricultural landscape is important for good nature management.

1 Acknowledgements

Studying in COVID times was a unique experience, which brought its own set of challenges. Therefore, without the support I had for the last two years, I would have not finished this thesis . First of all, I have to give a big thanks to my supervisors Jöel Durant and Christian Pedersen. Jöel for being such a dedicated supervisor, being so available for me and asking me for updates practically every week the last year and a half. And Christian for being so welcoming at NIBIO (Norwegian Institute of Bioeconomoy and Research) in Ås, making it possible for me to get access to data from NIBIO and discussing all the stages of the monitoring programme with me. Also, a big thanks to NIBIO for allowing me to use their large data set from their monitoring programme for agricultural landscapes, without this type of time series data this kind of studies would have not been possible. A special thanks to Herdis Motrøen Gjelten from the Norwegian Meteorological Institute for helping me get access to data that was not yet published.

Last but not least a big thanks to my family and friends that encouraged me the last two years. Thanks to my dad Kjetil Halvorsen for discussing with me statistics and giving me some tips about R. Also, a huge thanks to my boyfriend Jacob for his unconditional support in all the up and downs a thesis process has, and going through my English in this thesis. Thanks to my friend Clarissa for reading my thesis and offering me some comments from Brazil, I really appreciate it. A special thanks to my sister Phajsi who introduced me to LaTex in Overleaf, and took her time to help and explain me things when I was loosing my patience with technology. And a last thanks to my mom Miriam who has always supported my education, my granny Marit who always believed in me, and my friends Ellinor and Karoline for always giving me emotional support when I needed it.

2   Introduction

Farmland bird populations in Europe have experienced a decline since 1975, due to agricultural intensification and land abandonment (Donald et al., 2001; Eurostat, 2022). Yellowhammer (*Emberiza citrinella*) is one of them. In Norway, their declining population and weak declining distribution have been registered since the early 2000s (Pedersen, 2020). As a consequence yellowhammer is in the IUCN red list in Norway (Artsdatabanken, 2022). It is hard to know when the decline of yellowhammer actually started in Norway, since there is little documented data. In the UK, yellowhammer population decline was documented in the late 1980 (Kyrkos & Wilson, 1998). Neighboring countries follow a similar pattern. Yellowhammer populations have shown a decline of approx. 40% in Sweden in the period 1976-2001 (Wretenberg et al., 2006) and a population decline in Denmark in the period 1983-2001 (Fox, 2004). The population decline have been more severe in Sweden and Norway, compared to Denmark (Fox, 2004; Pedersen, 2020; Wretenberg et al., 2006).

The distribution of yellowhammer in Europe extends from the northern regions of the Mediterranean to Eastern Europe, the British Isles, to Scandinavia and northern regions of Russia (Svensson et al., 2010). The breeding population in Europe is estimated to be 18 000 000-31 000 000 pairs (Dean, 2014). In Norway, they are common at the south and middle of Norway, while they are quite rare in the north (Bakken et al., 2003). Since yellowhammer is a farmland specialist, their distribution in Norway reflects the distribution of the agricultural landscape in the country (See fig. 3) (Pedersen, 2020). The Norwegian population is estimated to be around 100 000-200 000 pairs (Kålås & Husby, 2002). Yellowhammer is mainly a resident bird and their breeding season starts in April and lasts roughly until July. Nevertheless, there are some exceptions. Some yellowhammers migrate to Norway in April for the breeding season (Svensson et al., 2010) or later since the breeding season starts later at higher latitudes (Dean, 2014). In September/October yellowhammers living in the north of Norway migrate to southern regions of Norway or migrate to countries around the North Sea for the winter (Bakken et al., 2003).

Yellowhammer is 15,5-17 cm big and adult males have a stronger yellow color than females (see fig. 1 (Svensson et al., 2010) . There are three known subspecies of yellowhammer, the subspecies in Norway is called *Emberiza citrinella Linnaeus* (Dean, 2014).

Figure 1: Yellowhammer *Emberiza citrinella* (15,5-17 cm). Adult males have a stronger yellow color than females. Photo: Steinar Sannes.

In Norway, this characteristic yellow bird thrive in diverse agricultural landscapes with field boundaries, pastures and open spaces with bushes and trees (Pedersen, 2020). They like to sing from trees and bushes at wood or field margins (Goławski & Dombrowski, 2002) and the presence of song post seemed to be significant for their habitat distribution (MC Hugh et al., 2013). They try to avoid very forested areas and open areas of arable land (Pedersen, 2020). Yellowhammers nests are often placed on the ground or low in dense bushes by road edges, ditches, and areas adjacent to forests in Norway (Pedersen, 2020). In Poland nests in shrubs are more common than nests on the ground (Goławski & Dombrowski, 2002). Normally yellowhammers will have 2-3 broods (Dean, 2014), but maximum two of them will be successful (Bradbury et al., 2000). Each of their broods have approximately 4-5 eggs that need to be incubated for approximately two weeks (Pedersen, 2020). Fledglings are fed with insects, other invertebrates, and seeds by the male and female (Dean, 2014). Unripe cereal grain is an important component of nestling diet (approximately 50%) (Stoate & Moreby, 1998). Invertebrates as Lepidoptera larvae, Aranea, Diptera (especially Tipulidae) and gastropoda were also important food sources (Moreby & Stoate, 2001). Nutrition wise cereal grain is inferior to invertebrates for nestlings (Douglas et al., 2012). Fledglings leave the nest around 15-16 days of age (Pedersen, 2020). Adult yellowhammers eat mostly seeds (Stoate & Moreby, 1998).

Yellowhammer density is known to increase with the presence of spatial heterogeneity of areas growing cereals and winter rape, crop diversity, hedgerow length and branch density, intermediate altitudes (around 300 masl) and herbaceous vegetation in field boundaries (Kyrkos & Wilson, 1998; MC Hugh et al., 2013; Pedersen, 2020). Some territories were disadvantageous for yellowhammer distribution, like grass in adjacent habitats in the breeding season (MC Hugh et al., 2013). When it came to foraging sites, they tend to favor different vegetated areas throughout the breeding season (Stoate & Moreby, 1998). In the breeding season they forage approximately within 400m of the nest (Morris et al., 2001). Broad-leaved crops were favoured early in the breeding season while cereal crops became more popular later in the season when they ripened (Stoate & Moreby, 1998). It was not just foraging sites that changed throughout the breeding season, but also nestling location (Bradbury et al., 2000). Nest height increased slightly later throughout the summer by hedges becoming more popular nesting places than earlier in the breeding season (Bradbury et al., 2000). Yellowhammer are territorial birds, but as long intruders are more than 10-15m away they usually ignore them (Andrew, 1956).

In autumn and winter, they assemble in flocks and forage together waste grains in stubble fields (Svensson et al., 2010), and seeds in pastures and field margins (Dean, 2014). Orchards, forest edges and waste grounds are also important winter foraging areas (Dean, 2014). Yellowhammer and other farmland passerines prefer low stubble height than tall stubbles, to get a better overview while seeking food and looking out for predators (Butler et al., 2005). Nowadays, modern machinery, denser agricultural holdings and autumn plowing followed by stubble burning, results in less grain availability (Pedersen, 2020). This latter changes will affect yellowhammer survival over the winter (Pedersen, 2020).

Most nest failures were caused by predation (64%) (Bradbury et al., 2000). There is some disagreement if a position in the ground or low vegetation gives a higher predation risk than a tall singing post for yellowhammer (Bradbury et al., 2000; Götmark & Post, 1996). However, nests in hedges were more susceptible to predation than nests in herbaceous vegetation (Stoate & Szczur, 2001). Nests are frequently prayed by rodents, crows (Corvus), Eurasian jay (*Garrulus glandarius*), Common magpie (*Pica pica*) and sparrowhawk (*Accipter nisus*) (Dean, 2014; Götmark & Post,

1996). Yellowhammers predation risk by sparrowhawks (predator of adult yellowhammers) and nest predators increases in forest edges (Götmark & Post, 1996). How big the predation risk is in Norway is unknown.

2.1 The Norwegian agricultural landscape

The agricultural landscape in Norway is formed by arable fields and meadows, patches of forest, bushes and trees along side roads, ditches, streams, and fields (Petersen, 2016). It has changed significantly since the 1950s (Ladstein & Skoglund, 2008). The most prominent difference is a more homogeneous agricultural landscape due to farmland intensification (Pedersen, 2020). Today 3.5% of the total Norwegian area is agricultural area, excluding Svalbard and Jan Mayen (SSB) and it has decreased with 6% since 2001 (Berger et al., 2021).

Most of the agricultural area in Norway is arable land, and the arable land is predominantly used to produce grass (approx. 67%) and cereals along with oil seed (approx. 33%) (Store norske leksikon Syverud et al., 2021). Norway produce cereals like barley, wheat, oats and rye, and most of them are spring-sown because of the long and cold winters (Statistics Norway, 2021c). Cereal crops are mainly located east and middle Norway, since it is here most flat regions with adequate climate are found (Berger et al., 2021). Cereal in Norway is predominantly used as animal fodder (Store norske leksikon.Sivhus, 2019). Barley is the cereal that is most produced in Norway, followed by similar amounts of wheat and oats since 1995 (Statistics Norway, 2021d). In the period 1950-1980 in the East and middle of Norway meadows and pastures were transformed to cereal corps, this increase in cereal crops continued until the 90s (Stabbetorp, 2014). This was followed by small arable land areas turning into meadows, pastures or being abandoned, and agricultural areas around cities and villages became building lands (Stabbetorp, 2014). Therefore, it was not surprising that the agricultural area used for cereal crops has decreased 15% in the period 2001-2020 (Berger et al., 2021). Nevertheless, the cereal production is three times bigger than in 1950 because of more robust crops and modern machinery (Ladstein & Skoglund, 2008). Robust crops were possible due to the more efficient sawing, better fertilization and efficient pesticides (Bye et al., 2020). Agricultural grassland takes place in the valleys and mountain villages of the west and north of Norway (Stabbetorp, 2014). In the southwest region of Norway most of the agricultural area are pastures and meadows (Stabbetorp, 2014). In addition, the geographic distribution of grazing animals have also become more restricted and is followed by the regrowth of pastures (Pedersen, 2020). Bushes and vegetation at field boundaries adjacent to streams and ditches are disappearing (Pedersen, 2020). Streams and ditches in the agricultural landscape decreased in the process of levelling arable land in the period 1970-80 when modern machinery was being introduced (Pedersen & Krøgli, 2017). The last 20 years the presence of streams and ditches have stabilized again (Pedersen & Krøgli, 2017).

2.2 Climate

Norway is a long country with a long coastline in the west side (it extends roughly between 57°N-71°N). Consequently, the mean temperatures in southern regions are much warmer than the mean temperatures in northern regions (Klimaservicesenter, 2022). Important factors as topography and the distance from the sea will also affect the climate. Naturally, agricultural areas are present in valleys and flat regions, and not at very high altitudes, but (Pedersen, 2020). In the middle of

Norway, the highest agricultural areas are found in altitudes between 365-450 meters above sea level (Store norske leksikon Svendsen, 2022). Climate will influence crop growth, what is planted in arable land and it will restrict plant diseases and pests (Berger et al., 2021).

Temperature, wind and rain affect the ability to observe small passerines. Birds can have temperature preferences, and wind and rain can make it harder to identify and hear them. In the other hand, wind can be advantageous for passerine predators like hawks. Cloud cover has showed to have little influence on detection of passerines early in the mornings in the breeding season (Robbins, 1981).

Temperature had a positive influence on yellowhammer nest survival, since nestlings will less likely quick-freeze then and invertebrate activity will be improved (Stoate & Szczur, 2001). Partial migrants in Finland are quite affected by the strength of NAO (North Atlantic Oscillation) when they start migrating (Rainio et al., 2006). In other words they are quite affected by the temperatures in early spring. A study by Englington and Pearce-Higgins in 2012 showed that climate change does not overpower land-use intensity as an explanatory variable for yellowhammer population growth, but that used together in a model they can present better and more realistic bird population trends.

Climate change has been an important driver for the distribution and abundance of many species (Johnston et al., 2013; Weiskopf et al., 2020). When it comes to farmland birds, agricultural intensification and land-use in Europe have showed to have the same explanatory power as climate change in understanding future farmland birds distribution (Reino et al., 2018), and present annual fluctuations in population growth (Eglington & Pearce-Higgins, 2012). Heterogeneous landscapes have also shown to be important for farmland bird species abundance (Pickett & Siriwardena, 2011). Therefore, this study anticipates that the decline of yellowhammer distribution and abundance in Norway will depend on land-use and climate. The aim of this study is to explain the abundance and distribution of the declining yellowhammer populations in the Norwegian agricultural landscape in the period 2000-2017, by combining climate variables (temperature and wind) and land types.

3   Methods

3.1   Monitoring programme

The Norwegian monitoring programme for agricultural landscapes driven by the Norwegian Institute of Bioeconomy Research (NIBIO) aims to monitor and document changes of farmland use, biodiversity, spatial structure of the landscape, cultural heritage, and accessibility (Dramstad et al., 2002). To do this, surveys of approximately 1000 1x1 km monitoring plots around the country are taken. The plots are randomly located and their location depend on where agricultural landscapes are present. The monitoring programme started in 1998. The precise location of the monitoring plots is protected by the duty of confidentiality.

3.2   Bird survey

This study is using data from the bird monitoring scheme from 2000-2017 that is a part of the monitoring program for agricultural landscapes and consists of 1093 observations. NIBIO and Birdlife Norway collaborated in the bird monitoring process. The methodology used for the bird monitoring is the same as the Norwegian Breeding Bird Survey (Kålås & Husby, 2002). This

includes using a grid with observation points and collecting vegetation data at each of these points. Due to budget reasons, 130 plots of the 1000 were selected for bird monitoring (see appendix for monitoring plots). In this study the bird surveys were done by 77 observers that collected data just once or collected data in the same Norwegian region the year(s) after (see appendix).

Each monitored plot had nine observation points in a grid with 333m between each observation point, and 166m between the observation points and the edge of the plot (Figure 2). The observation points had to be moved if they were not accessible for the observer, for example if they were in water or in the middle of cultivated land. If it was not possible to visit more than six observation points per plot, the monitored plot was discarded. The plots and observation points were registered with coordinates in UTM33 (WGS84) and were visited every 2-4 years between mid-May to mid-June (in the yellowhammer breeding season). This makes it possible to compare the data over time.

Figure 2: A monitoring plot (red square) with nine observation points. The observation points were 333m from each other and 166m from the edge of the plot. The observation points were not always aligned due to the inaccessibility of the specific location. Eg. if an observation point was placed in the middle of crop fields it was moved to the edge of them instead.

Most of the bird counts were taken between 4:00 am and 09:00 am, since this is a time most birds have their peak activity (or are at least highly active). Bird counts were taken over a 5min period at each observation point within a ratio of 50m. Birds outside the 50m ratio were also registered. However, in this study we only use yellowhammer observations from within 50m ratio, for data credibility. The birds are counted by breeding pairs. A breeding pair is defined as a male heard or seen or one pair observed or one female observed or observations of fledglings or a recent nest.

3.3   Land types

Vegetation type and structure (%coverage and height) around the observation points within 50m were collected together with the bird surveys in the monitoring process. The vegetation or lack of vegetation gave us an indication of which land types are present in the monitored plots. Therefore, we included in the data set two different land type variables. The first variable is the land type in where yellowhammers were observed (land_type1 see in appendix). The second variable is the combination of the two most common land types that are present in the plot (land_type2). The

different land type combinations are in table 1. Three agricultural land use types were registered, field, meadow, and pasture.

Table 1: Land type combinations (land_type2) used in this study.

Land type combination names	Land type combination
field_bog	Field and bog
field_built	Field and built areas
field_gard	Field and garden
field_past	Field and pasture
field_water	Field and water
forest_bog	Forest and bog
forest_built	Forest and built areas
forest_fell	Forest and felling site
forest_field	Forest and field
forest_gard	Forest and garden
forest_mead	Forest and meadow
forest_past	Forest and pasture
forest_sea	Forest and sea
forest_thick	Forest and thicket
forest_water	Forest and water
mead_bog	Meadow and bog
mead_built	Meadow and built areas
mead_field	Meadow and field
mead_moor	Meadow and moorland
mead_past	Meadow and pasture
mount_past	Mountain and pasture
past_moor	Pasture and moorland
past_bog	Pasture and bog

3.4 Climatic effect

Temperature, wind, rain, cloud cover, and visibility were registered for each bird observation in the bird survey. In this study temperature and wind are included in the data set since they can affect the bird counting (Robbins, 1981), while heavy rain and bad visibility are included as comments since none or very few observations were taken when there was poor visibility conditions and heavy rain. Temperature was recorded in degrees Celsius, and wind was measured in the Beaufort wind force scale. The maximum wind level in the monitored plot was used in the data set. No observations were taken above fresh breeze. The visibility was either good, medium, or bad.

Rain was categorized in four classes:

- No rain

- Light rain (when droplet size is < 0.5 mm)

- Moderate rain (when the average droplet size is 0.5 mm)

- Rain (when the droplet size is > 0.5 mm)

Additionally, local temperature data were obtained from the Norwegian Centre for climate services (Klimaservicesenter, 2022). Spring middle temperature (average April temperature) and the summer middle temperature (average June temperature) taken from the weather station closest to the monitored plot were included in the data set. Spring temperature (temp2) reflects the temperature conditions before and at the start of the yellowhammer breeding season, the Summer temperature reflects the temperature conditions in the breeding season. Both temperature conditions are important for the presence of insects and yellowhammer nestling survival (Stoate & Szczur, 2001). When mean temperatures for April or June were not available, an average of Mars and May or May and July were taken respectively. If the temperature of just one month was available, no temperatures were registered for the season. The weather station and its respective observation plot had mostly similar altitudes. When this was not the case, the altitude difference was commented.

3.5 Statistical analysis

For the statistical analysis we chose to use Generalized additive models (GAM), because we are not expecting all the parameters to follow a specific distribution and we do not assume a linear relationship. This study used GAM trough the mgcv library in R 4.2.0 (R Core Team, 2022).

3.5.1 Distribution analysis

Since this study uses bird count data a poisson distribution model response is what is expected. Nevertheless, a poisson distribution model will not be able to explain the absences of yellowhammer observations. Therefore, a two stepped analysis was conducted starting with a binomial distributed response model to explain the distribution of yellowhammer (presences and absences). A zero-inflated poisson model was not used, because we could not discard the possibility that the covariates we were going to use in the models would not explain the zeros in the data (Wood, 2016). Five models were part of the binomial distribution response model selection see table 2 In all models yellowhammer presences or absences were the response variable, and land type combinations (Land_type2), spring temperature (temp2), year (year), latitude (lat), longitude (long) and observers (observer) were tested as explanatory variables. Spring temperature (temp2) was chosen as a climate variable, because low temperatures affect the survival of yellowhammer nestlings by reducing invertebrate activity (Stoate & Moreby, 1998). The variable "land_type2" is the only one used in the data analysis, because this variable is also available for monitored plots were yellowhammers were absent. Observers were also a part of the analysis since they were so many and their variation could affect the quality of the observations. The wiggeliness of the splines were restricted to k= 10 for the geographic location "long" and "lat" and k = 5 for spring temperature (temp2). In addition the splines for "observer" and "Land_type2" were penalized with the assumption that their coefficients are independent and identically distributed normal random effects (bs = "re") (Wood, 2012). While the spline of temp2 was penalized to thin plate regressions splines (bs = "ts"), because we were expecting that temperature will change naturally due to Norway's long geographical structure. In other words the rotation of the covariate coordinate system will be able to change the result of the temp2 smoothing (Wood, 2012). In addition, the thin plate regression splines "ts" is also shrinking the effective degrees of freedom (edf) (Wood, 2012).

In the model selection all models were compared by using delta AIC (Akaike Information Criterion) and AIC weights. The AIC statistics evaluates how well the model fits the used data and finds the best-fit model(s) that explains most of the variation, using the fewest possible independent variables. AIC (delta AIC) values shows the difference between the best model and the model being compared. While AIC weight shows the proportion of predicting power of a specific model in comparison to all the evaluated models (*Scribbr*, 2020).

This study did not correct for for spatial and temporal autocorrelation since it was hard to find an appropriate method to correct for this in a data set with no continuous observations (taken approximately every third year). Nevertheless, we expected some spatial and temporal autocorrelation because the monitored plots had similar vegetation types, latitudes, and temperature.

3.5.2 Abundance analysis

A poisson distributed response model was used to explain the abundance of yellowhammer. Seven models were part of this selection (see table 3). In this model selection the amount of yellowhammer pairs were the response variable, and land type combinations (Land_type2), temperature (temp2), year (year), wind (wind), observers (observer) and the interaction therm "long, lat" were tested as explanatory variables. The same penalization used in the splines from the binomial distributed models were used in the explanatory variables Land_type2, temp2 and observers of the poisson distributed response models. In addition, the wiggeliness of wind was restricted to k = 3 in all models, since just five levels of the Beaufort scale were used to measure wind. The model selection was made in the same manner as in the distribution model selection. We took into account for overdispersion and underdispersion by using the quasi-poisson family.

4 Results

Latitude (lat) and longitude (long) correlated with each other and with spring temperature (temp2), that is why we chose to use the interaction therm (long,lat) instead in all models.
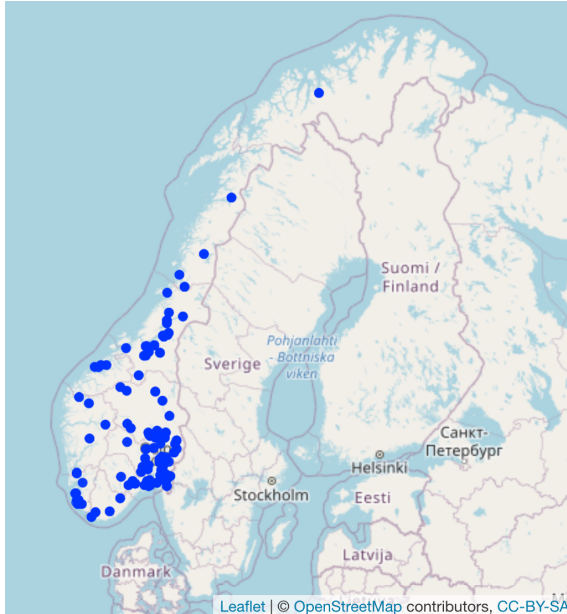
Figure 3: Yellowhammer observations (blue points) in the monitoring plots, they were particularly present in the east and middle of Norway. Very few yellowhammer pairs were observed in the North of Norway.
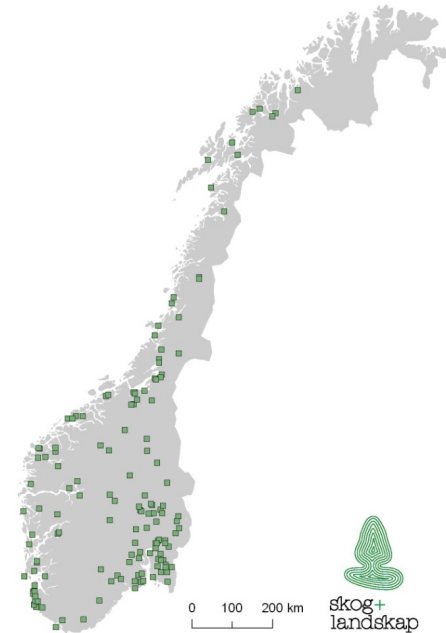
Figure 4: Bird monitoring plots (130 plots) in the period between 2000-2017. The monitoring was driven by the Norwegian Institute of Bioeconomy Research (NIBIO)

4.1 Land type diversity

Yellowhammers were observed in 86,9% of the 130 monitored plots. Most of the monitoring plots were located in the east and middle of Norway (see figure 4). Yellowhammers were primarily seen in the east and middle of Norway too and very few pairs were observed in the north and west of Norway (see figure 3). This farmland bird was observed in the land type combinations "forest_field" (minimum 408 times), "meadow_field" (149), "forest_meadow" (86), "forest_pasture" (61), "forest_fellingsite" (50), "field_builtareas" (34), "field_pasture" (29), "forest_bog" (18), "forest_builtareas" (16),"mead_pasture" (14), "field_garden" (11), "field_water" (11), "meadow_bog" (8), "pasture_bog" (7), "meadow_builtareas" (6), "pasture_moorland" (5) and "field_bog" (5)(Figure 5. They were absent in the land type combinations "mountain_pasture", "forest_sea", "meadow_moorland" and "forest_garden". The land type combinations that were popular for yellowhammers in Norway were also the most common land type combinations observed in the monitoring programme (Figure 9). One pair of yellowhammers was observed 630 times, two pairs were observed 46 times, three pairs were observed 2 times and four pairs were observed 1 time in all the monitored plots every year they had been monitored.
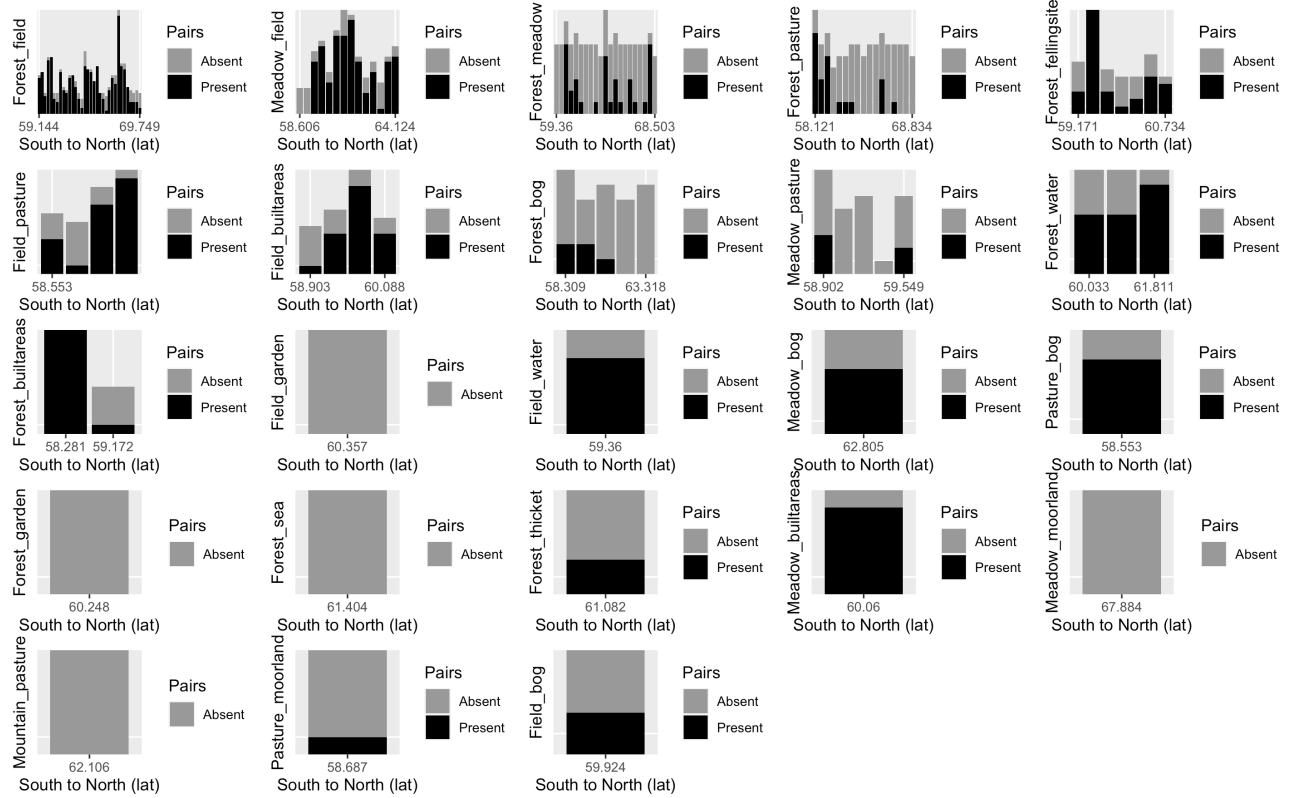
Figure 5: Land type combinations (*land_type2*) in our study. The land type combinations "forest_field" (visited 408 times), "meadow_field" (149), "forest_meadow" (86), "forest_pasture" (61), "forest_fellingsite" (50), "field_builtareas" (34), "field_pasture" (29), "forest_bog" (18), "forest_builtareas" (16) and were present in different geographic locations in the Norwegian agricultural landscape. The rest of the land type combinations "mead_pasture" (14), "field_garden" (11), "field_water" (11), "meadow_bog" (8), "pasture_bog" (7), "meadow_builtareas" (6), "pasture_moorland" (5) and "field_bog" (5) were observed between 14-5 times, and were located just in one specific location.
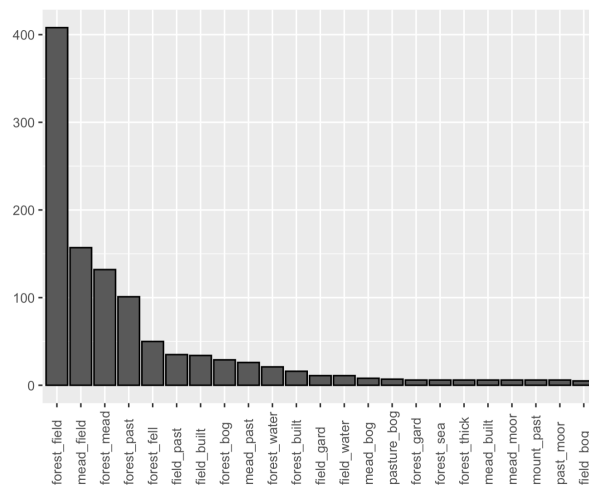
Figure 6: Land type combinations in the monitoring programme. "Forest_field", "meadow_field", "forest_meadow" and "forest_pasture" are the most common land type combinations and are the habitat were most yellowhammers were observed.

4.2 Yellowhammer distribution

The best fitted GAM model for yellowhammer distribution included the variables "land_type2", "temp2", "observer", "year" and the interaction "long,lat" (see model 5 in table 2). All explanatory variables except "temp2" were significant in the model. Wind was not used as an explanatory variable in this model selection since it did not have any effect in models.

Table 2: Model selection of GAM binomial distributed response models with their respective significance codes, Delta AIC, AIC weight, R.sq.(adj) and the proportion of the deviance explained by each model. If the p-values for the splines were significant they are marked with either '***'0.001 or **' 0.01.

	Models	Delta AIC	AIC weight	R-sq. (adj)	Deviance explained
1	te(long,lat)*** + s(land_type2)***	123.001	0.000	0.36	31.5 %
2	te(long,lat)*** + s(land_type2)*** + s(temp2)	60.709	0.000	0.35	18%
3	te(long,lat)*** + s(land_type2)*** + s(temp2) + s(observer)***	12.674	0.002	0.43	39,8%
4	te(long,lat)*** + s(land_type2)*** + s(observer)***	61.315	0.000	0.45	41.3%
5	te(long,lat)** + s(land_type2)*** + s(temp2) + s(observer)*** + s(year)**	0.000	0.998	0.44	41.5%

The splines of the best fitted model (model 5) for the distribution of yellowhammer showed that that spring temperature (temp2) did not have a strong effect on distribution, while years effect changes from around 2012 (see fig. 7). The confidence interval for temp2 was quite wide at the lowest and highest temperatures, although the spline of year had narrower confidence intervals than temp2. The models spline for the interaction therm "long,lat" resembled the geographical form of Norway quite well (except an area southeast were a spline went over to Sweden) and showed that yellowhammer distribution depended on geographic location by being distinctly present in the southeast and middle of Norway (fig. 8). This figure suggested that yellowhammer could be present in the northeast border of Norway too. The splines for geographic position showed little effect in the west and north of Norway when trying to explain yellowhammer distribution. In the Northern Norway there is a data gap due to a lack of observations, but we can assume that the yellowhammer distribution is similar to the surrounding areas. Yellowhammer is also present in Sweden, but this model only uses data of breeding populations in Norway. Since no observations were made above a latitude of 70°N, the furthest north part of Norway is not showed in the figure.
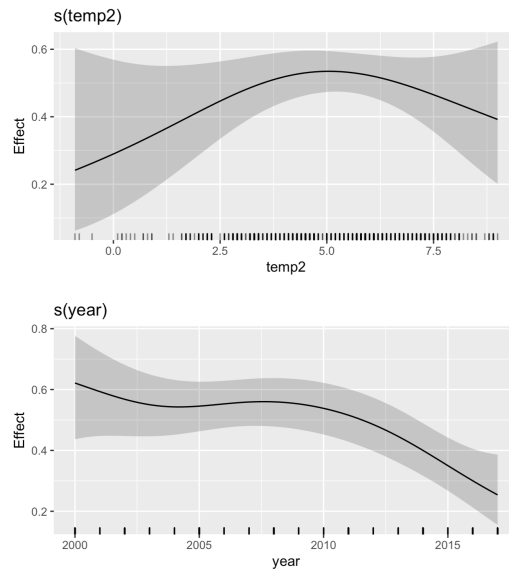
Figure 7: Splines for the explanatory variables "temp2" and "year" in the binomial response model number 5 in table 2. The spring temperature starts at -0.9°C and ends at 9°C. The effect of the spline for year changes around 2012. The confidence intervals for the spline of temp2 are quite wide at the ends, while the spline of year had narrower confidence than temp2.
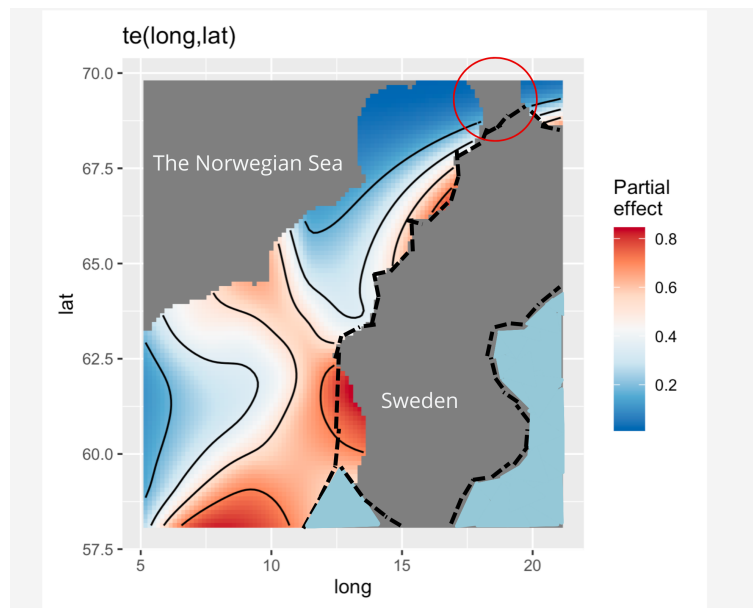
Figure 8: Splines for the interaction therm "lat,long" in the best fitted model (model 5 in table 2) for yellowhammer distribution. There is a gap in the splines (the red circle). Nevertheless, this study assumes that this part of the model is similar to its surroundings. The splines structure resembles the geographical form of Norway, with just a small overlap to Sweden southeast of Norway. The Norwegian Sea is located to the left of the splines, while Sweden and the Baltic Sea (in light blue) are located right of the splines.

The best fitted model to explain yellowhammer distribution (model 5) was used to model yellow-hammer distribution in the thirteen most common land type combinations (with a minimum of 11 observations sights per land type). For more details about this prediction model, see appendix. Yellowhammer distribution in all the thirteen land type combinations declined between 2000 and

2017 see fig. 9, but the decline was more severe in land type combinations were yellowhammers persistently chose as a breeding habitat. In 2000 yellowhammers breeding in land type combinations like "forest_field", "meadow_field" and "field_pasture" were observed, while in 2017 far fewer were observed, especially in the southwest and the middle of Norway. At the start of the monitoring period land type combinations like "forest_meadow", "forest_fellingsite", "forest_builtareas", "meadow_pasture" and "field_water" were visited by breeding yellowhammers in the southeast and the middle of Norway, but these same areas were hardly visited seventeen years later. Land type combinations that were seldom picked by yellowhammers for breeding in 2000 were not visited anymore at the end the monitoring period, this was the case for "forest_pasture", and "forest_bog". In general, the distribution of yellowhammers in all land type combinations had a weak decline until 2013, followed by an abrupt decline until 2017 (see fig. 7).

(a)

(b)
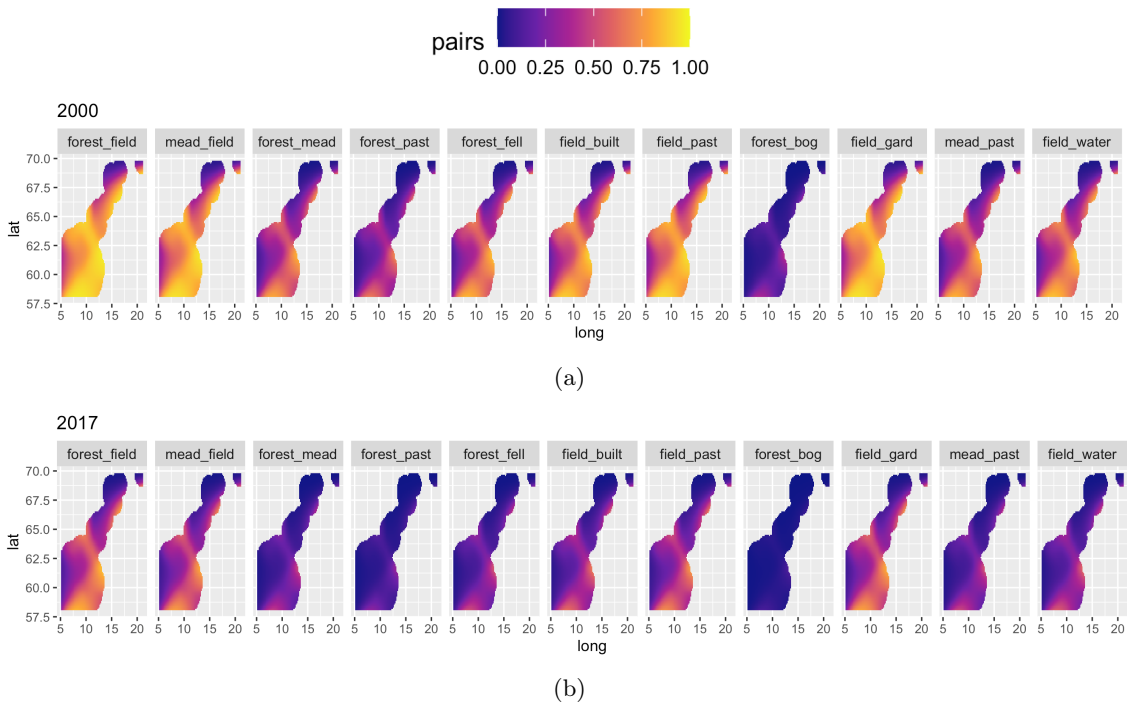
Figure 9: Modelling yellowhammer distribution using model 5 from table 2 in the land types "forest_field","mead_field","forest_mead","forest_past","forest_fell","field_built","field_past", "forest_bog","field_gard","mead_past" and "field_water" in 2000 and 2017.

4.3 Yellowhammer abundance

There were three competitive GAM poisson distributed models to explain yellowhammer abundance (see model 3, 4 and 7 in table nr. 3). These three models did not have more than 2 delta AIC units differentiating them. This means that none of them were significantly better than the other one (*Scribbr*, 2020). The proportion of predictive power for model 3, 4 and 7 was 32.7%, 46,4% and 20.2% respectively. These predictive powers are similar and high. These three models have in common the variables "land_type2", "temp2", "wind" and the interaction therm "long,lat". Model 3 and 4 include "observer", while model 7 does not. Model 4 and 7 include the variable "year", while model 3 does not.

Table 3: Model selection of the GAM poisson distributed models with their respective significance codes, Delta AIC , AIC weight, R.sq.(adj.) and the proportion of the deviance explained by each model. If the p-values for the splines were significant they are marked with either '***'0.001, **' 0.01 or '*' 0.05. Model 3, 4 and 7 are competitive models (coloured gray) since they do not have more than 2 delta AIC differentiating them, and their proportion power showed in AIC weitghts were similar and big.

	Models	Delta AIC	AIC weight	R-sq. (adj)	Deviance explained
1	te(long,lat)** + s(land _type2)***+ s(wind)	170.304	0.000	0.16	13,8%
2	te(long,lat)** + s(land _type2)** + s(wind) + s(temp2)	8.256	0.008	0.15	13.3%
3	te(long,lat)** + s(land _type2)** + s(wind) + s(temp2) + s(observer)**	0.701	0.327	0.22	18%
4	te(long,lat)* + s(land _type2)** + s(wind) + s(temp2) + s(observer)* + s(year)*	0.000	0.464	0.23	18.8%
5	te(long,lat)** + s(land _type2)** + s(wind) + s(observer)**	167.716	0.000	0.23	18.2%
6	te(long,lat) + s(land _type2)** + s(wind) + s(observer)* + s(year)*	169.115	0.000	0.24	19.5%
7	te(long,lat)* + s(land _type2)** + s(wind) + s(temp2) + s(year)*	1.665	0.202	0.18	15.3%

To assume that the different observers in this study did no have any effect on the bird observations is not realistic. This variation is corrected by the explanatory variable "observer". After correcting model 3 and 4 for overdispersion or underdispersion assuming a quassi-Poisson distribution the R.sq.(adj) and the deviance explained by each model improved with around 0.8 and 9% respectively in comparison to their corresponding poisson distributed models (see table 4). The variation in the models that were explained by the chosen variables was R.sq.(adj) = 0.299 for model 3b and R.sq.(adj) = 0.311 for model 4b. The deviance that is explained by these models were 26.3% and 27.2% respectively. The scale estimator correction for both quassipoisson distributed models was 0.35.

Table 4: The two competitve GAM quasi-Poisson distributed models to explain yellowhammer abundance with their respective significance codes, R.sq.(adj.) and the proportion of the deviance explained by each model. If the p-values for the splines were significant they are marked with '***'0.001. The R.sq.(adj.) and the deviance explained by the two models are very similar.

	Models	R-sq. (adj)	Deviance explained
3b	te(long,lat)*** + s(land _type2)*** + s(wind) + s(temp2) + s(observer)***	0.299	26.3%
4b	te(long,lat)*** + s(land _type2)*** + s(wind) + s(temp2) + s(observer)*** + s(year)***	0.311	27.2%

The splines of the explanatory variables temperature, wind and the interaction therm "long,lat" in the models 3b and 4b were very similar see fig. 10 and 12. The confidence intervals of the "temp2" and "wind" splines were wide. Therefore, taking conclusions from just looking at the splines was not possible. The splines for geographic location in model 3b and 4b showed that there would be a higher abundance of yellowhammer by the coast in middle and southern parts of northern Norway (see fig 12). In the southeast of Norway yellowhammer abundance is lower than by the coast. In the western and northern (excluding the coast) Norway the splines for geographic position had little effect on yellowhammer abundance. No observations were made above latitude of 70°N. There is a gap in northern Norway, but this area is expected to be similar to the surrounding areas. Nevertheless, model 4b is the best fitted since the spline for year showed that there was an effect on yellowhammer abundance around 2011/2012 (see fig.11). The spline of the explanatory variable year had quite narrow confidence intervals in comparison the the splines of "temp2" and "wind".
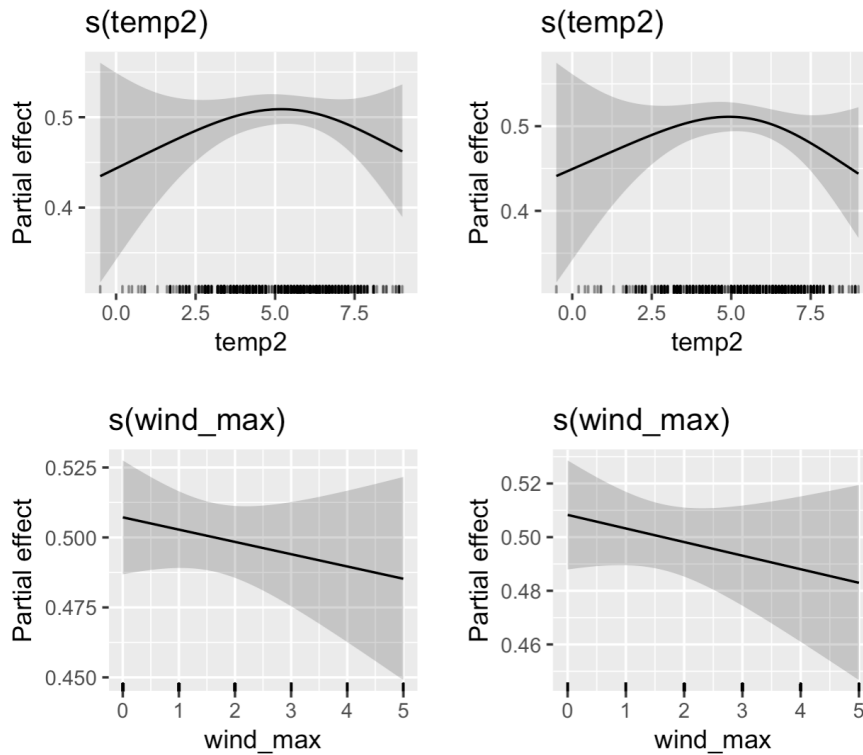
Figure 10: Splines of the explanatory variables "temp2" (at the top) and "wind" (at the bottom) from the two quasi-Poisson models in table 4. The spring temperature starts at -0.5°C and ends at 9°C, while the x axis for wind starts in the level 1 in the Beaufort scale and ends in level 5 (fresh breeze). The splines that are compared are very similar and have wide confidence intervals.
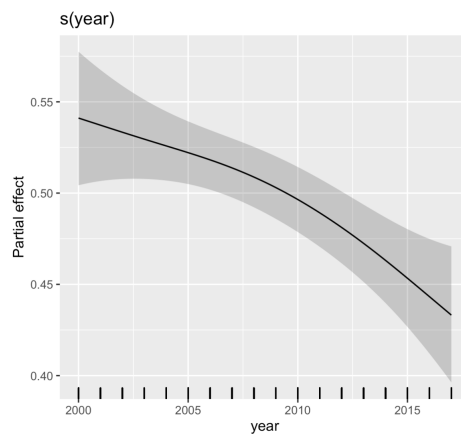
Figure 11: Spline for the explanatory variable year from the quassipoisson model 4b (see table 4). The spline shows that around 2011/2012 the effect of year in the model decreases.

(a) Model 3b   (b) Model 4b
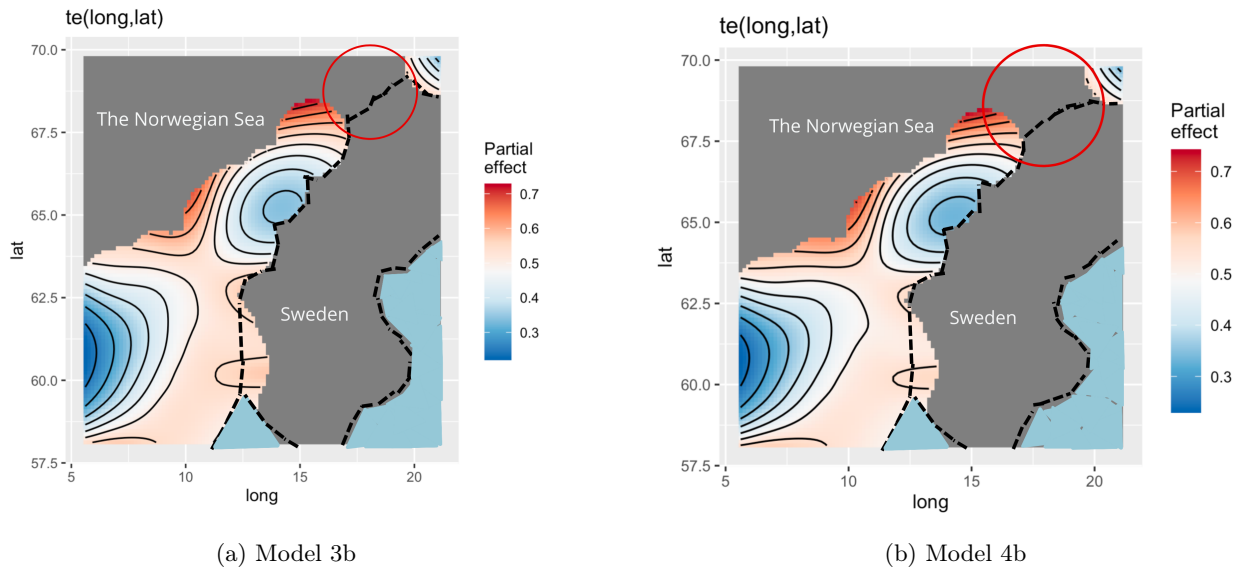
Figure 12: Splines for the interaction therm "lat,long" in the two competitive quassipoisson models (model 3b and 4b in table 4) explaining yellowhammer abundance. There is a gap in the splines (the red circle), this area would most probable be similar to its surroundings. The splines structure resembles the geographical form of Norway, with just a small overlap to Sweden southeast of Norway. The Norwegian Sea is located to the left of the splines, while Sweden and the Baltic Sea (in light blue) are located on the right side of the splines.

5 Discussion

Yellowhammer data in this study was used to explain the distribution and abundance of this bird in a national scale, since most of the monitored plots gave a good representation of where agricultural landscapes were located in Norway (Statistics Norway, 2021b). This study used data collected throughout seventeen years (2000-2017), from 130 monitored plots and had 1093 observations. The difficulty in differentiating land types (like for eg. forest and thickets, pasture and meadows) because they were taken by different observers have to be acknowledged.

5.1 Important land types for yellowhammer

Yellowhammer was present in the agricultural landscape east and middle of Norway, especially in the land type combinations "forest_field", "meadow_field", "forest_meadow", "forest_pasture", "forest_fellingsite", "field_builtareas and "field_pasture". Most of the land types that were often visited by yellowhammers were close to fields. This was not surprising since many fields in Norway contained grains, and this is yellowhammers food source all year (Bradbury et al., 2000; Douglas et al., 2012; Stoate & Moreby, 1998). Yellowhammer being most often present in the land type combination "forest_field" can be explained by the vertical component forests give them to sing, get a good overview of potential predators and food availability (Kyrkos & Wilson, 1998; MC Hugh et al., 2013). This vertical element is often found in hedgerows in the agricultural landscape in the UK (Bradbury et al., 2000; Kent, 1964), but in Norway hedgerows are replaced by bushes, thickets, and small trees. Yellowhammer showed a preference for "Forest_field" in comparison to "forest_meadow", this contradicts the study done in 2002 by Golawski Dombrowski in the agricultural landscapes in Poland. In this polish study wood-grassland ecotones were preferred over wood-field ecotones. However, this study is not just looking at the ecotone between these two land types, but at two land types. A previous study in Sweden showed that low intensity land use (like non-rotational set aside, short-rotation coppice, leys and cultivated pasture), and spring-sown crops had a negative effect on farmland bird species richness in areas surrounded by forests (Wretenberg et al., 2010). Nevertheless, it was in this land type combination that yellowhammers were most observed. This could indicate that the fields by the forests in this study were intensively managed and since Norway does not have a big agricultural area they were not affected negatively by this. Set-aside for birds are not common in the Norwegian agricultural landscape (Bye et al., 2020), and cultivated pasture in this study was included in land type combinations with meadows. On the other hand, the frequent presence of yellowhammers in the land type combinations "forest_meadow" could indicate that meadows were also intensively managed in Norway (Morris et al., 2001; Wretenberg et al., 2010). Pasture will have animals who attract insects, and insects are an important food source for yellowhammer nestlings in the breeding season. Yellowhammers presence in the land type combination "forest_fellingsite" was not a surprise, since they thrive an open spaces with trees. Built areas with roads and gardens are not known to be popular for yellowhammers (Bradbury et al., 2000), but when the built areas are close to fields, food availability could balance out the dangers of these areas.

5.2 Yellowhammer distribution

Yellowhammer distribution will depend on geographic position, land type, spring temperature (Mars-May), observers and year (see model 5 in table 2). Nevertheless, the climatic variable spring temperature (temp2) was the only explanatory variable that was not significant in the model. These results do not show that land-use and climate change had the same explanatory power to understand yellowhammer distribution. However, this supports that land use and climatic effects, like temperature, have a role in explaining yellowhammer distribution. Geographic location could be masking a bit of the effect of spring temperature in the model since climate changes with geography and topography. Geographic location will in most cases be an important explanatory factor to understand any species distribution, so its significance was not surprising. The coordinate splines in the model showed a good reflection of where yellowhammer were present (see figure 8). The explanatory effect year confirms that there was a change in yellowhammer distribution throughout the monitoring period of seventeen years. Interestingly enough the spline for year showed that around 2012 a decline in yellowhammer distribution took place. This restricted distribution and can be a consequence of the decrease of agricultural areas used for cereal crops since 2001, and yellowhammers struggle to find appropriate habitats in the breeding season due to the decrease of the important land type combination "forest_field" since 2004 (visited 408 times) see appendix A. Forest areas have increased slightly since they have been protected the last twenty years in Norway (Store norske leksikon Sunding et al., 2022). For that reason, fields would be the land type experiencing most changes throughout the monitoring years. The R.sq.adjusted of 0.44 is quite good comparing to other studies in ecology (Møller & Jennions, 2002). Therefore, we can conclude that this model is quite robust. The variation in the model the data cannot explain, can be due to the lack of information of agricultural intensity, predation and inter- or intraspecific competition. Yellowhammers are known to avoid foraging in intensively-managed grass fields and intensive cropped areas in the breeding season (Bradbury et al., 2000; Morris et al., 2001). How big the predation risk for yellowhammers and other farmland bird is in the Norwegian agricultural landscape is uncertain. Yellowhammer males are territorial, but neither the male or the female are very aggressive towards other yellowhammers or other bird species (Andrew, 1956). In the Norwegian agricultural landscape yellowhammer could be competing for territory with Reed runting (*Emberiza shoeniclus*), Common linnet (*Linaria cannabina*, Chaffinch (*Fringilla coelebs*), House Sparrow (*Passer domesticus*) and Skylark (*Alauda arvensis*) (Andrew, 1956; Kent, 1964). How agricultural practices affect Lepidoptera larvae, Aranea, Tipulidae and gastropoda (important food for yellowhammer nestlings), and in which parts of the agricultural landscape these invertebrates thrive most could also help to explain yellowhammers foraging area. This study cannot disregard the possibility that yellowhammer distribution was declining in the monitoring period because of declining invertebrate populations.

5.3 Yellowhammer abundance

Explaining yellowhammer abundance was not as straightforward as explaining yellowhammer distribution in this study. There were two competitive models (see table.3), but yellowhammer abundance was best explained by model 4b (table 4) were geographic position, land type, observers and year were significant explanatory variables. In this model climatic effects (temperature and wind) were not significant. In other words they did not have the same explanatory power as land types. Decoupling geographic location and spring temperature (temp2) can be complicated, but

there is no doubt that temperature plays a role in explaining yellowhammer abundance (Eglington & Pearce-Higgins, 2012). Spring temperature can have an effect on invertebrate activity and this could effect yellowhammers ability to find food (Stoate & Moreby, 1998). Less yellowhammers were observed when it was windy (see fig. 10, but this does not necessary mean that yellowhammer abundance was lower in windy areas. Yellowhammers could have just been still and waiting for the wind to go over when the observations were taken. The splines for the interaction therm "long,lat" did not show an accurate pattern of where yellowhammers where most observed (see fig. 3), and consequently could not explain accurately yellowhammer abundance. The reason for this could be due to a low number of yellowhammers observed in each monitoring plot every year. One yellowhammer pair was observed each year in a monitoring plot 92.8% of the time. Therefore, to get a good representation of yellowhammer abundance more observations of yellowhammers at each plot every year would be needed. The gap in fig. 12 in Northern Norway could also be explained by the low number of observations in the north and in each monitored plot. Land types being significant in the quassi-Poisson model was not surprising since yellowhammers are more abundant close to cereal crops and heterogeneous landscapes (Kyrkos & Wilson, 1998; Pickett & Siriwardena, 2011). The explanatory variable "Land_type2" represented land type diversity, but not to spatial heterogeneity. Nonetheless, a previous study concluded that yellowhammers preference for heterogeneity showed great variability (Pickett & Siriwardena, 2011). The land type combinations yellowhammers used for foraging and building nests in the breeding season would be the areas affecting their abundance. The spline for the variable "year" showed that yellowhammer abundance declined around 2011/2012 like in the distribution model. The decrease of cereal crops areas since 2001, the decrease of the important land type combination "forest_field" since 2004 (see appendix B) and declining invertebrates populations could have affected this decline. The land type "field" would have affected yellowhammer abundance more than "forest" since forested areas have been quite unchanged the last years (Statistics Norway, 2021a). So addressing agricultural intensification and spatial heterogeneity could improve the model. The R.square (adj.) of 0.311 is low, but not necessary bad for a study in ecology (Møller & Jennions, 2002). Nonetheless, the splines for geographic position showed that this abundance model did not explain yellowhammer abundance correctly. The few number of yellowhammer observations per year in each monitored plot makes it difficult for a quassi-Poisson distributed model to predict yellowhammer abundance.

Yellowhammer survival in hard winter conditions was not taken into consideration in the study, but having access to a long time series can still indicate how yellowhammer survival changes from year to year.

5.4   Conservation implications

Temperature as a climatic variable did not have a strong effect in either the distribution or abundance model used in this study. This means, that changes in land type had more to say than climate change, and that seventeen years was possibly not a long enough time series to address climate change (30 years being the most common). Temperature is an important explanatory variable in an ecological perspective, but it had not been often combined with land types when discussing farmland birds. Focusing on taking long time series of yellowhammer observations could enhance studies on farmland birds.

The Norwegian agricultural area is not big in the first place, so conserving these areas would be essential for yellowhammer survival. Having access to cereal fields, meadows, open spaces as felling

sites, and forests or other vegetation structures that give a vertical component to the landscape (for example bushes and thickets), would enhance the continuity of yellowhammer populations.

Throughout the winter having access to food (especially in February) and short stubbles were important factors for yellowhammer survival (Butler et al., 2005; Siriwardena et al., 2008). Ploughing in Autumn is the most common in Norway (Mangerud, 2009), continuing doing this would also protect the bird nests yellowhammer lay in the ground early in the Spring. Yellowhammer showed in this study being very dependent on cereal fields and forests. Therefore, nature management in Norway should look closer into cereal farming practices and forest conservation to preserve this red listed species in Norway.

References

Andrew, R. (1956). Territorial behaviour of the yellowhammer emberiza citrinella and corn buntin e. calandra. *Ibis*, *98*(3), 502–505.

Artsdatabanken. (2022). *Gulspurv emberiza citrinella linnaeus, 1758*. Retrieved June 10, 2022, from https://artsdatabanken.no/taxon/Emberiza%5C%20citrinella/4198

Bakken, V., Runde, O. J., Tjørve, E. & Koblik, E. A. (2003). *Norsk ringmerkingsatlas* (Vol. 2). Stavanger museum Stavanger.

Berger, M., Bøe, E., Halland, A., Hjukse, O., Knutsen, H. (, Kårstad, S., Rustad, L., Svennerud, M. & Øvren, E. (2021). Utsyn over norsk landbruk tilstand og utviklingstrekk 2021. *NIBIO Report*, *7(4) 2021*, 30–34.

Bradbury, R. B., Kyrkos, A., Morris, A. J., Clark, S. C., Perkins, A. J. & Wilson, J. D. (2000). Habitat associations and breeding success of yellowhammers on lowland farmland. *Journal of Applied Ecology*, *37*(5), 789–805.

Butler, S. J., Bradbury, R. B. & Whittingham, M. J. (2005). Stubble height affects the use of stubble fields by farmland birds. *Journal of Applied Ecology*, *42*(3), 469–476.

Bye, A., Aarstad, P., Løvberget, A. I., Rognstad, O. & B., S. (2020). Jordbruk og miljø 2019 tilstand og utvikling. *Statistics Norway Report*, 4–5.

Dean, W. (2014). Handbook of the birds of the world, volume 16: Tanagers to new world blackbirds.

Donald, P. F., Green, R. & Heath, M. (2001). Agricultural intensification and the collapse of europe's farmland bird populations. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *268*(1462), 25–29.

Douglas, D. J., Moreby, S. J. & Benton, T. G. (2012). Provisioning with cereal grain depresses the body condition of insectivorous yellowhammer emberiza citrinella nestlings. *Bird Study*, *59*(1), 105–109.

Dramstad, W. E., Fjellstad, W., Strand, G.-H., Mathiesen, H. F., Engan, G. & Stokland, J. N. (2002). Development and implementation of the norwegian monitoring programme for agricultural landscapes. *Journal of Environmental management*, *64*(1), 49–63.

Eglington, S. M. & Pearce-Higgins, J. W. (2012). Disentangling the relative importance of changes in climate and land-use intensity in driving recent bird population trends. *PloS one*, *7*(3), e30407.

Eurostat. (2022). *Common bird indices by type of estimate (sources: Ebcc, birdlife, rspb, cso)*. Retrieved June 10, 2022, from https://ec.europa.eu/eurostat/databrowser/view/ENV_BIO3/bookmark/table?lang=en&bookmarkId=c1c06e47-a120-4c4a-b337-97f60db7a954

Fox, A. (2004). Has danish agriculture maintained farmland bird populations? *Journal of Applied Ecology*, *41*(3), 427–439.

Goławski, A. & Dombrowski, A. (2002). Habitat use ofyellowhammers emberiza citrinella, ortolan buntings e. hortulana, and corn buntings miliaria calandra in farmland of east-central poland. *Ornis Fennica*, *79*, 164–172.

Götmark, F. & Post, P. (1996). Prey selection by sparrowhawks, accipiter nisus: Relative predation risk for breeding passerine birds in relation to their size, ecology and behaviour. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *351*(1347), 1559–1577.

Johnston, A., Ausden, M., Dodd, A. M., Bradbury, R. B., Chamberlain, D. E., Jiguet, F., Thomas, C. D., Cook, A. S., Newson, S. E., Ockendon, N. et al. (2013). Observed and predicted

effects of climate change on species abundance in protected areas. *Nature Climate Change*, *3*(12), 1055–1061.

Kent, A. (1964). The breeding habitats of the reed bunting and yellowhammer in nottinghamshire. *Bird Study, 11*(2), 123–127.

Klimaservicesenter, N. (2022). *Norwegian centre for climatic services*. Retrieved June 10, 2022, from https://seklima.met.no/

Kyrkos, A. & Wilson, R., JD Fuller. (1998). Farmland habitat change and abundance of yellowhammers emberiza citrinella: An analysis of common birds census data. *Bird Study, 45*(2), 232–246.

Kålås, J. & Husby, M. (2002). Terrestrisk naturovervåking ekstensiv overvåking av terrestrisk fugl i norge. *NINA Norsk Institutt for naturforskning, 114*.

Ladstein, T. & Skoglund, T. (2008). Utviklingen i norsk jordbruk 1950-2005. *Norsk økonomi*, 41.

Mangerud, K. (2009). Veien til bedre pløying. *4*(2), 1–8.

MC Hugh, N., Hughes, S., Leather, S., Stilman, R., Holland, J. et al. (2013). Yellowhammer breeding distribution in relation to field boundary habitat and summer foraging resources. *Aspects of Applied Biology*, (118), 297–302.

Moreby, S. & Stoate, C. (2001). Relative abundance of invertebrate taxa in the nestling diet of three farmland passerine species, dunnock prunella modularis, whitethroat sylvia communis and yellowhammer emberzia citrinella in leicestershire, england. *Agriculture, ecosystems & environment, 86*(2), 125–134.

Morris, A. J., Whittingham, M. J., Bradbury, R. B., Wilson, J. D., Kyrkos, A., Buckingham, D. L. & Evans, A. D. (2001). Foraging habitat selection by yellowhammers (emberiza citrinella) nesting in agriculturally contrasting regions in lowland england. *Biological Conservation, 101*(2), 197–210.

Møller, A. & Jennions, M. D. (2002). How much variance can be explained by ecologists and evolutionary biologists? *Oecologia, 132*(4), 492–500.

Pedersen, C. (2020). Fugler i jordbrukslandskapet: Bestandsutvikling og utbredelse. perioden 2000-2017. *NIBIO Rapport*.

Pedersen, C. & Krøgli, S. (2017). The effect of land type diversity and spatial heterogeneity on farmland birds in norway. *Ecological Indicators, 75*, 155–163. https://doi.org/10.1016/j.ecolind.2016.12.030

Pickett, S. R. & Siriwardena, G. M. (2011). The relationship between multi-scale habitat heterogeneity and farmland bird abundance. *Ecography, 34*(6), 955–969.

R Core Team. (2022). *R: A language end environment for statistical computing. r foundationd for statistical computing, vienna austria*. Retrieved June 28, 2022, from https://www.r-project.org/

Rainio, K., Laaksonen, T., Ahola, M., Vähätalo, A. V. & Lehikoinen, E. (2006). Climatic responses in spring migration of boreal and arctic birds in relation to wintering area and taxonomy. *Journal of avian biology, 37*(5), 507–515.

Reino, L., Triviño, M., Beja, P., Araújo, M. B., Figueira, R. & Segurado, P. (2018). Modelling landscape constraints on farmland bird species range shifts under climate change. *Science of The Total Environment, 625*, 1596–1605.

Robbins, C. S. (1981). Bird activity levels related to weather. *Studies in avian biology, 6*, 301–310.

Siriwardena, G. M., Calbrade, N. A. & Vickery, J. A. (2008). Farmland birds and late winter food: Does seed supply fail to meet demand? *Ibis, 150*(3), 585–595.

Stabbetorp, H. (2014). Landbrukets utvikling siden 1950. utviklingstrekk av betydning for vannk-valiteten. Retrieved June 10, 2022, from https://vannforeningen.no/wp-content/uploads/2015/06/2014_898327.pdf

Statistics Norway. (2021a). *Arealbruk og arealressurser. arealbruk og arealressurser (km²), etter arealklasse, statistikkvariabel og år.* Retrieved July 6, 2022, from https://www.ssb.no/statbank/table/09594/chartViewColumn/

Statistics Norway. (2021b). *Gardsbruk, jordbruksareal og husdyr. jordbruksareal per jordbruksbedrift (dekar) (f) 1969 - 2021.* Retrieved June 29, 2022, from https://www.ssb.no/statbank/table/04500/

Statistics Norway. (2021c). *Gardsbruk, jordbruksareal og husdyr. jordbruksareal, etter bruken (dekar) 1969 - 2021.* Retrieved June 29, 2022, from https://www.ssb.no/statbank/table/05982/chartViewLine/

Statistics Norway. (2021d). *Korn og oljevekster, areal og avlinger. kornavling (1 000 tonn), etter statistikkvariabel og år.* Retrieved July 3, 2022, from https://www.ssb.no/statbank/table/07479/chartViewColumn/

Stoate, C. & Moreby, J., STEVE J Szczur. (1998). Breeding ecology of farmland yellowhammers emberiza citrinella. *Bird Study, 45*(1), 109–121.

Stoate, C. & Szczur, J. (2001). Whitethroat sylvia communis and yellowhammer emberiza citrinella nesting success and breeding distribution in relation to field boundary vegetation. *Bird Study, 48*(2), 229–235.

Store norske leksikon Sunding, P., Larrson, J. Y., Tomter, S. M. & Sandvev Dalen, L. (2022). *Skog.* Retrieved July 6, 2022, from https://snl.no/skog

Store norske leksikon Svendsen, T. O. (2022). *Lom.* Retrieved June 3, 2022, from https://snl.no/Lom

Store norske leksikon Syverud, G., Btarberg, E. & Almaas, R. (2021). *Jordbruk i norge.* Retrieved July 3, 2022, from https://snl.no/jordbruk_i_Norge

Store norske leksikon.Sivhus, B. (2019). *Korn.* Retrieved July 3, 2022, from https://snl.no/korn

Svensson, L., Mullarney, K. & Zetterström, D. (2010). Gyldendals store fugleguide–europas og middelhavsområdets fugler i felt. 3. rev. utg. norsk utgave ved v. ree (red.), j. sandvik & po syvertsen. *Gyldendal Fakta, Oslo.*

Scribbr, R. B. (2020). *Akaike information criterion | when how to use it (example).* Retrieved June 14, 2022, from https://www.scribbr.com/statistics/akaike-information-criterion/

Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., Hyde, K. J., Morelli, T. L., Morisette, J. T., Muñoz, R. C. et al. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the united states. *Science of the Total Environment, 733,* 137782.

Wood, S. (2012). *Smooth terms in gam. r documentation, package mgcv.* Retrieved June 29, 2022, from https://stat.ethz.ch/R-manual/R-devel/library/mgcv/html/smooth.terms.html

Wood, S. (2016). *Gam zero-inflated (hurdle) poisson regression family. r documentation, package mgcv.* Retrieved June 28, 2022, from https://stat.ethz.ch/R-manual/R-devel/library/mgcv/html/ziP.html

Wretenberg, J., Lindstrøm, Å., Svensson, S., Thierfelder, T. & Pært, T. (2006). Population trends of farmland birds in sweden and england: Similar trends but different patterns of agricultural intensification. *Journal of Applied Ecology, 43*(6), 1110–1120.

Wretenberg, J., Pärt, T. & Berg, Å. (2010). Changes in local species richness of farmland birds in relation to land-use changes and landscape structure. *Biological conservation, 143*(2), 375–381.
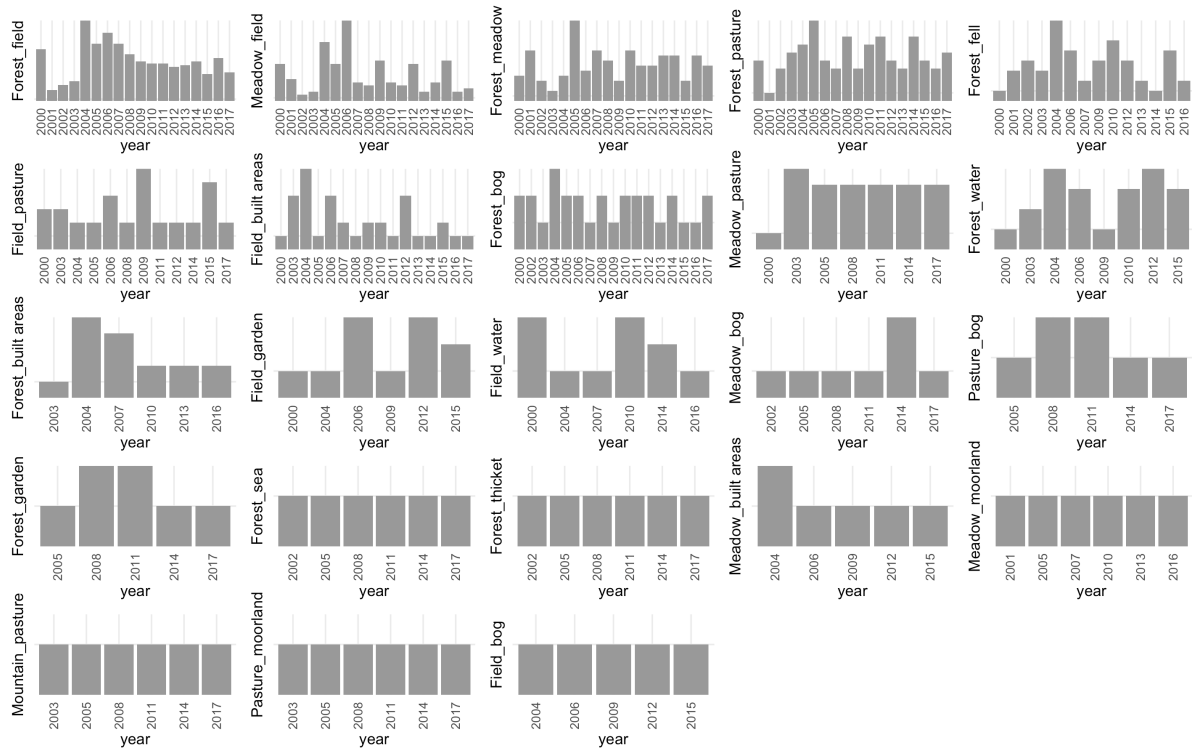
Appendix

A   Land type combinations

Figure 13: Land type combinations through out the monitoring years (2000-2017).

B Script of the land type combination modelling

```r
#Predict plot for vegetation type in 2000

pdata <- with(Yellowhammer1,
              expand.grid(veg_type2 = c("forest_field", "mead_field"
,"forest_mead", "forest_past", "forest_fell", "field_built","field_past"
,"forest_bog", "field_gard","mead_past","field_water"),
                          temp2= 5,
                          observer = c("Håkan Billing"),
                          year = 2000,
                          long = seq(min(long), max(long), length = 100),
                          lat = seq(min(lat), max(lat), length = 100)))

fit <- predict(mfinal4, pdata, type="response")
ind <- exclude.too.far(pdata$long, pdata$lat,
                       Yellowhammer1$long, Yellowhammer1$lat, dist = 0.1)
fit [ind] <- NA
pred <- cbind(pdata, Fitted = fit)

library(ggplot2)
plt <- ggplot(pred, aes(x=long, y=lat)) +
  geom_raster(aes(fill = Fitted)) + facet_wrap(~ veg_type2, nrow = 1) + theme
(strip.text.x = element_text(size = 10)) + ggtitle(2000) +
  scale_fill_viridis_c(name = expression(pairs),
                       option = "C",na.value = 'transparent', limits = c(0,1))
                     + coord_quickmap() + theme(legend.position = 'right')

plt
```