

BIRDS LIVING ON THE EDGE:
POWER-LINE CORRIDORS INFLUENCE ON AVIAN
COMMUNITIES IN NORWEGIAN SECONDARY BOREAL
CONIFEROUS FOREST

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Birds living on the edge

Power-line corridors influence on avian communities in Norwegian secondary boreal coniferous forest.



Early morning with singing *Nucifraga caryocatactes*

(Photo Trygve D Øygard)

By Trygve Danbolt Øygard

Preface

My reason number one for writing this thesis was that I was able to use my great interest and knowledge in birds and bird counting to do a master thesis.

This thesis is a result of more than 130 kilometers of bird counting, 3200 minutes of bird sounds, 5.6 Gigabytes of spreadsheets figures and tables, complete computer brake down, economical support from NVE and The Norwegian Directorate for Nature Management and least but not last much more than the demanded 40 hours of supervising from my supervisor Katrine Eldegard.

I therefore want to thank my supervisor Katrine Eldegard for supervising me especially during the writing process. My co-supervisors Stein Ragnar Mo and Vidar Selås.

Norwegian Water Resources and Energy Directorate (NVE) and The Norwegian Directorate for Nature Management for founding making it possible to accomplish the bird counts.

My field assistant and companion John Trygve Johnson for bird counting and early morning coffee

And of course my wife Ragnhild D Øygard who have been there supporting me listening to frustrations and shared the enthusiasm.



Norwegian University of Life Science

Ås 14.08.2012

Trygve Danbolt Øygard

Abstract

Power-line corridor edges differ from other edge habitats by its long shape with a high amount of edge habitat compared to open fields, and the regular maintenance clearing the corridor for forest trees not allowing forest re-growth. Power-line corridors in northern boreal secondary coniferous forests have a low avian abundance compared to the adjacent edge habitat. Bird species associated with open fields and clearings do to a very little extend appear in the power-line corridor. The edge habitat does have the highest avian abundance and richness compared to both the corridor habitat and the adjacent forest interior. Species abundance is highly influenced by the forest development classes, where most birds are found in the middle classes where forest net primary production is highest.

Resymé

Kraftgate kanter er unike fra andre typer kanter ved den lange formen med mye kant i forhold til åpent område, og det jevnlike vedlikeholdet av gaten som gjør at skogen ikke kommer opp igjen. Kraftgater i nordlig sekundær boreal barskog har relativt få fugler i forhold til det tilgrensende kant habitatet. Fuglearter som er assosiert med åpen mark og ryddinger i skogen, oppholder seg i liten grad i kraftgatene. Det tilgrensende kanthabitatet har den høyeste antall arter og fugler i forhold til kraftgata og indre deler av skogen. Mengden fugl ble først og fremst påvirket av hvilke hogstklasse skogen hadde, det var størst tetthet av fugl i de mellomste hogstklassene hvor skogen har høyest vekst.

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Introduction

Since Aldo Leopold Wrote his book Game management (Leopold and Brooks 1933) Much attention have been drawn towards edge habitats. Leopolds discovery was that the edge habitat contained more games than the adjacent forest or field, and he called it for the edge-effect, or the law of interspersation.(Leopold and Brooks 1933) Later edge effect is redefined in the scientific community including all change in biological and physical conditions at an ecosystem boundary and within the adjacent ecosystem(Lindenmayer and Fischer 2006). Edges have been stated as richer habitats, than the adjacent, in the ecological literature i.e. (Lindenmayer and Fischer 2006) The reason is the creation of more ecological niches, giving room to a larger variety of organisms (Smith and Smith 2001)p454.

Edge habitats vary from soft edges like two adjacent forests, to hard edges like a new made clear cut in an old growth pine forest. Some edges are small relative to the area, like the edge of a forestry clear cut, and some edges are long relative to the area, like the edge of a forest road.

Anthropogenic edge between forests and open areas such as clear cuts and agricultural fields, are known to alter the general species richness in a area((Leopold and Brooks 1933; Kroodsma 1982; Hansson 1983; Johns 1991; Hansson 1994; Murcia 1995; Edenius and Elmberg 1996; Owionji and Plumptre 1998; Dale, Mork et al. 2000). I did not find any evidence of power line corridor increasing species richness in continuous boreal forest.

The power-line corridor edge do have an altered avian abundance and richness compared to the forest interior because of possible altered habitat quality, or as a result of birds using the edge forest to position during singing.

In this study I have investigated the differences of species abundance, richness and diversity between the power-line corridor, the edge habitat and a bordering forest interior. I have tried to find out the environmental variables explaining the variation in the bird community between the three habitats. And I have also looked at what mechanisms that influence the avian community in the power line corridor habitat.

Methods

The 17 study sites were distributed across southeast Norway between latitudes 58°-61°N, longitudes 8-11°E, and at altitudes of 78 to 648 meter above sea level (Figure 1) These 17 sites were a sub-sample of 51 study sites¹ that were previously established for monitoring biodiversity effects of power-line corridors. I used satellite photos available on <http://www.norgebilder.no/> and zoomed in on each site in order to identify sites where it was possible to establish a 3.8 km long point transect route parallel to the power-line corridor, 300 m into the adjacent forest. I found 26 sites among these 51 sites in which such a parallel transect route could be placed (almost) entirely within boreal forest. The 25 other sites were unsuitable because the surrounding forest landscape was too fragmented, with large proportion of agricultural fields, bogs, etc.

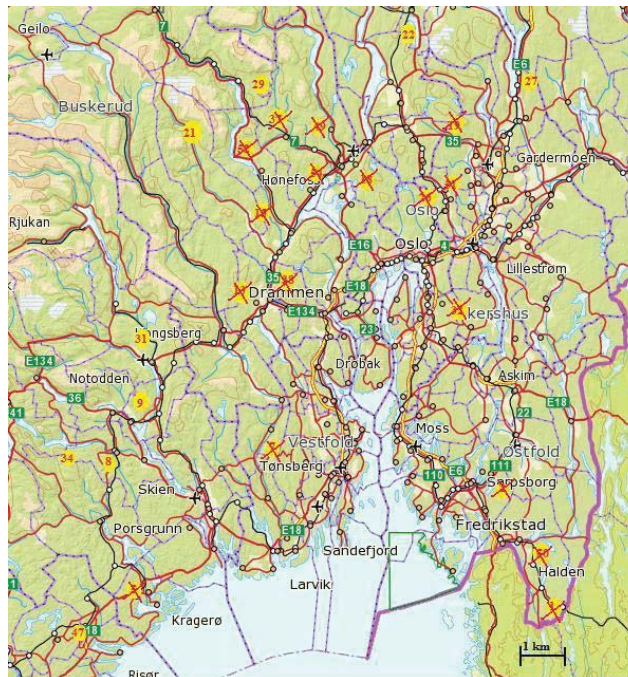


Figure 1 All sites selected for bird counts, only sites with red crosses where visited.

¹ These 51 study sites were selected by haphazardly placing 84 crosses along the main power-line grid in southeast Norway, as shown on a low-resolution map provided by the national main grid owner (Statnett). We randomly selected 51 sites out of these 84 by drawing lots. Each of these 51 sites was assigned a preliminary geographic position in the UTM32 system. Thereafter we used satellite photos available on <http://www.norgebilder.no/> and zoomed in on each site in order to determine a more precise geographic position at the closest location along the power-line corridor's longitudinal direction where there was a minimum of 200 metres wide forested area perpendicular to the edge of the power-line corridor.

Site selection

In addition I primarily looked at sites located at a lower altitude than 600 meters above sea level (MLS). The goal of the field season was to visit all 26 remaining sites, but because of a very wet summer we only managed 17 sites and 624 points. 96% of the count points were located in coniferous forest, the rest 4% (i.e. clear cuts, lakes or marches) was not used in the later analysis.

Field Work

Bird point counts

We used fixed 50 meters radius point count method as described by (Hutto, Pletschet et al. 1986; Huseby 2011) .

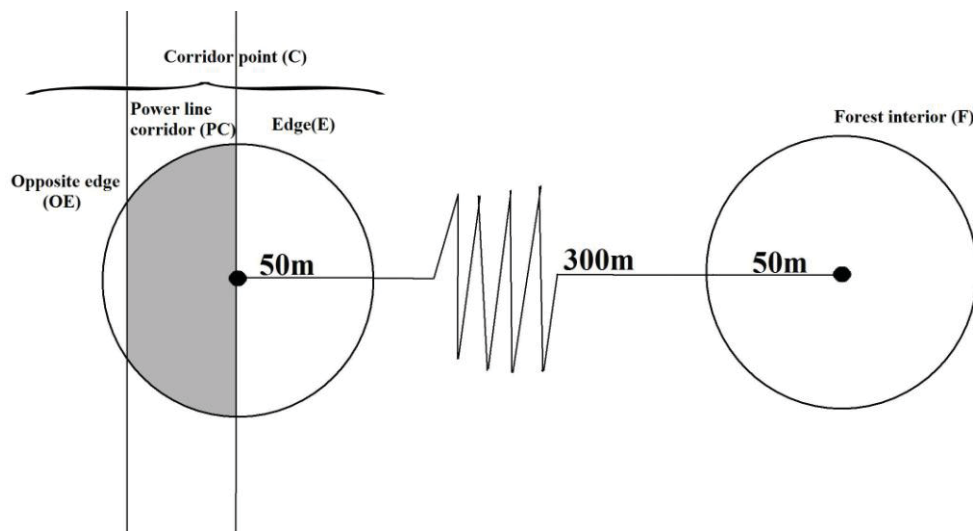


Figure 2: At each site I systematically placed a point transect line of 20 counting points in the corridor habitat (C) with 200 meter distance between each point and a parallel transect line of points 300 meters into the forest termed forest interior habitat (F). The C habitat was divided into 3 sub-habitats; the forest edge (E), the power-line corridor (PC), and the opposite edge (OE). If the PC was wider than 50 meters I did not have any opposite edge sub-habitat.

At each site we had a total of 40 counting points with 200 meters distance in-between, 20 points were located alongside the corridor (C), and 20 points along a parallel transect line, 300 meters into the forest interior (F) (Figure 2). The forest interior (F) points were sampled on the same side of the power-line corridor as the corridor (C) points. The corridor (C) points were divided in three sub-habitats: forest edge (E) power-line corridor (PC) and the opposite edge (OE) (see Figure 2).

The field registrations (point count registrations) were carried out by two observers working in duo. To avoid systematic sampling error, the observers switched counting at forest and corridor points by tossing coin before starting. Both observers continued counting until all points in the site was counted. Because it is easier to move and navigate in the power-line corridor, the observer counting in the corridor habitat also often counted a few forest points.

At each point, bird registration started on arrival. Both visual and audio observations of birds were registered. Singing males were registered as couples, and if one male and one female bird were observed, they were counted as one couple. Non-territorial birds and flocks were not counted (e.g. overflying crossbills (*Loxia* spp.) and ravens (*Corvus corax*)). At the forest interior counting points (F) we also counted birds singing outside of the counting point, these were not used in any analysis.

Registration of environmental variables

At each counting point we registered development class (DC) forest tree composition, and forest density.



Image 1 Left: a forest interior point with development class DC4 and forest density class 'not dense'. Right: a corridor point with a dense edge, development class DC3, and a not dense corridor DC1

Development class (DC) was divided in 5 categories; DC1: no or just very small trees occurred. DC2: trees from one-half meter height up to 15 centimeters in stem diameter at breast height, DC3: from 15cm to about 25 cm in tree stem diameter at breast height, DC4: larger than 25 centimeters in tree stem diameter at breast height, but still growing. DC5: trees are of old forest dimension and growth has stagnated. Development class was registered in situ, post bird-counting.

Forest types were registered in 9 categories: spruce, pine, mixed coniferous (consisting of both spruce and pine trees), mixed (both coniferous and deciduous trees), birch, deciduous, marsh, clear cut (no trees at all) and cultural landscape.

Forest density was divided into two categories; “dense” and “not dense”. Points in which trees or shrubs were so dense that it hindered movement were categorized as “dense”, and points where movement was easy, were categorized as “not dense”.

At each site, we registered temperature, precipitation, wind, and date when starting bird-counts. If it was raining, or wind-speed exceeded 8 meters/second we ended the registration.

We extracted elevation data in meters above sea level(MSL) and width of the power-line corridors, from digital maps (Geovekst 2012).

We extracted data on average temperature and precipitation for the period of data collection from meteorological stations. (Met.no 2012)

Edge abilities

To have a quantitative measure on the edge difference between the power-line corridor (PC) and the edge (E) we made an index of ‘development class difference’. The index was calculated by first giving value to the forest density categories (Dense=1, not dense=0) then add the densities to the development class (e.g. development class 1 in the power-line corridor habitat with dense shrub cover would be calculated: $DC + \text{Density} = 1 + 1 = 2$). Then subtracting the edge with the power-line corridor making a value that describes the differences between the two habitats. A high negative or positive high index number would represent a great difference between the habitats, while a low number would be an indication of equal habitats.

Data analysis

The data were analyzed using SAS/STAT[®] 9.2(SAS Institute, Inc., Cary, NC, USA) and the BiodiversityR package in R2.13.2 Statistical software (Kindt 2005)

Sample size and sample area

We counted birds at 17 sites, and altogether 624 points, (318 corridor points and 306 forest points). We excluded all points that were located in agricultural landscapes, broadleaf forests and all points that had development class less than DC2; i.e. clear cuts, marches and lakes (4%). Thus, only points from the forest type categories: pine, spruce, mixed coniferous, and mixed deciduous/coniferous were included in the data analyses (i.e. 96% of all the counting points).

Datasets

To do the analysis we created 3 separate datasets, all of them where the above mentioned noise where eliminated. All of the dataset included the environmental variables as mentioned and count of species as a matrix with every counting point as the first axis level, and bird species as the row level as described by (Kindt and Coe 2005).

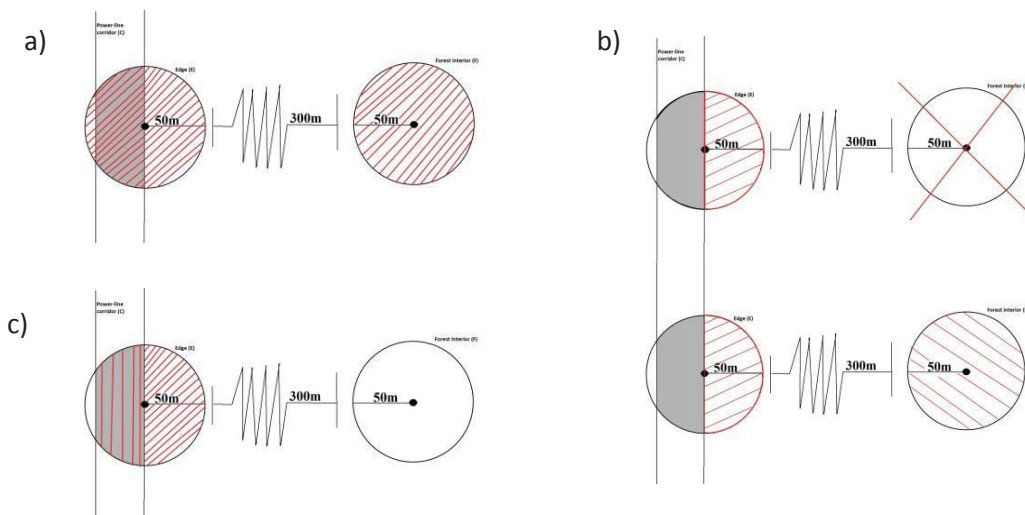


Figure 3 a-c To analyze the edge effect of the power-line corridor we used three datasets, a) where we compared the whole corridor counting point (C) with the forest interior (F), b) adding the edges alongside the corridors (E) from two and two neighboring points, compared with one of the parallel forest points (F), c) comparing the corridor itself (PC) with the edge (E).

Forest interior vs. Forest edge (Figure 3a-b)

We made two different datasets and comparisons; 1) the whole C counting point with the F counts (Figure 3a), 2) two sets where the sum of two half-circles of the E habitat were compared to one F point (Figure 3b). By using the sum of two neighboring half circles, we made sure that the bird count data compared were sampled from areas of equal size. When using this latter approach, we analyzed our data both after systematically excluding one half of the forest interior points (i.e. the number of point counts were the same for both forest interior and forest edge habitat), and without excluding any of the forest interior points.

Forest edge vs. power-line corridor

For analyses of power-line corridor (PC) versus edge (E), we created a dataset without forest interior (F) point counts, and also excluding birds counted at the opposite edge (OE), for corridors narrower than 50 meters (Figure 3c). To account for varying corridor width, and thus varying area of PC habitat, we included the width of the corridor as a random effect in the statistical analyses.

Statistical analysis

Species richness analysis

The data on species richness were counts, with response variable ‘number of species’. I used generalized linear mixed models (GLMMs) for analyses of species richness. For the Forest interior versus edge comparison I created a full (most complex) model including the fixed effects ‘habitat’ (forest edge (E), forest interior (F)), ‘forest type’ (pine, spruce, mixed coniferous, mixed deciduous/coniferous), ‘development class’ (DC3, DC4 DC5), and the ‘habitat×forest type’ and ‘habitat×development class’ interactions. The two interaction terms were included because our purpose was to find out whether there was a difference in species richness between forest edge and forest interior habitat, and whether this difference changed when environmental conditions (forest type, development class) changed. ‘Site’ and ‘observer identity’ were modeled as random effect because we carried out many point counts at the same location, and because there was a significant between-observer difference (see results section).

For the Power-line corridor versus edge comparison I created a full (most complex) model including the fixed effects ‘habitat’ (Power-line corridor (PC) and edge (E)) ‘development class’ (DC1, DC2, DC3, DC4 and DC5) ‘DC difference’ (Diff0, Diff1, Diff2, Diff3) and the ‘habitat×development class’ and ‘habitat×DC difference’ interactions. The two interaction

terms were included because our purpose was to find out the difference in species richness between the edge (E) and power-line corridor (PC) habitat, and whether this difference changed when environmental variables changed. ‘Site’, ‘observer identity’ and ‘width of corridor’ were modeled as random effects.

We fitted a model with log link function, Poisson distribution, and Laplace technique for GLMM parameter estimation (Bolker, Brooks et al. 2008). I carried out graphical diagnostics and inspected the scaled Pearson statistic for the conditional distribution to check if the models fitted our data in each case. None of the models were over-dispersed, and there was only moderate under-dispersion in some cases (all χ^2/df values were in the range from 0.65 to 0.75).

After fitting the full model, selection among a set of candidate models was performed using a backward elimination procedure (Larose 2006). I provide Wald F tests of fixed effects, and likelihood ratio (LR) tests of random effects for the final model(s). I used $\alpha = 0.05$ as level of statistical significance.

I analyzed the species richness for both the C versus F habitat (Figure 3c) and the E versus F habitat (Figure 3b). We also did the analysis both with all the forest points and with the dataset where half of the points were eliminated. However, because the results remained qualitatively unchanged irrespective of whether we included all forest interior points or not, only the results from the dataset including all the forest interior points are presented.

Analysis of number of birds per point.

Here I used the same method as for the species richness, and the response variable “number of birds”. Also here we run the test using both all the forest interior (F) points (Figure 3a), and the reduced dataset (i.e. excluding one-half of the forest interior points; Figure 3b), but there were no qualitative difference, and therefore the data presented is then from the analysis using all F counts.

Analysis of biodiversity

The data on biological diversity were index values (Shannon biodiversity index and Simpson biodiversity index). The strengths and weaknesses of the various biodiversity indexes are much debated in the literature, and no consensus has yet been reached (Magurran and McGill 2011). Exploratory analysis, graphical diagnostics and analysis of fit between data and statistical models, indicated that the Shannon index performed better than the Simpson index. Therefore, I report analysis with the Shannon index as response variable, however, using the Simpson index as response did not qualitatively change the results. I used GLMMs for analyses of biodiversity. As in the analysis of the species richness data, I created a full (most complex) model including the fixed effects ‘habitat’ (forest edge, forest interior), ‘forest type’ (pine, spruce, mixed coniferous, mixed deciduous/coniferous), ‘development class’ (DC2, DC3, DC4, DC5), and the ‘habitat×forest type’ and ‘habitat×development class’ interactions. ‘Site’ and ‘observer identity’ were modeled as random effects. We fitted a model with identity link function, normal distribution, and restricted maximum likelihood (REML) technique for GLMM parameter estimation (Bolker, Brooks et al. 2008). Graphical diagnostics indicated that the model provided a good fit to the data.

After fitting the full model, selection among a set of candidate models was performed using a backward elimination procedure. I provided Wald F tests of fixed effects, and LR tests of random effects for the final model(s). I used $\alpha = 0.05$ as level of statistical significance.

The analyses described above were done on the same three datasets as described above for the analyses of species richness (see Figure 3).

Analysis of species composition

I used a Canonical Correspondence Analysis (CCA) and Monte-Carlo permutation tests to determine if the variation in species composition attributable to the categorical variables ‘Site’ (17 levels = sites), ‘habitat (two levels; forest edge, forest interior), ‘forest type’ (four levels; pine, spruce, mixed coniferous, mixed) and development class (four levels: DC2, DC3, DC4, DC5) were larger than attributable to a random variable. In order to find significant additional variation explained by each of these variables after the variation attributable to ‘the others’ had been explained, I performed a partial constrained ordination.

Results

We recorded a total of 3312 couples and 67 bird species. Of these, 2079 birds and 59 species were registered within the 50 m radius of the counting points, and were used in the analyses.

The most common species was the Chaffinch (*Fringilla coelebs*) and the willow warbler (*Phylloscopus throchilus*). The general bird species abundance distribution was dominated by a few very common and many rare species (Figure 4).

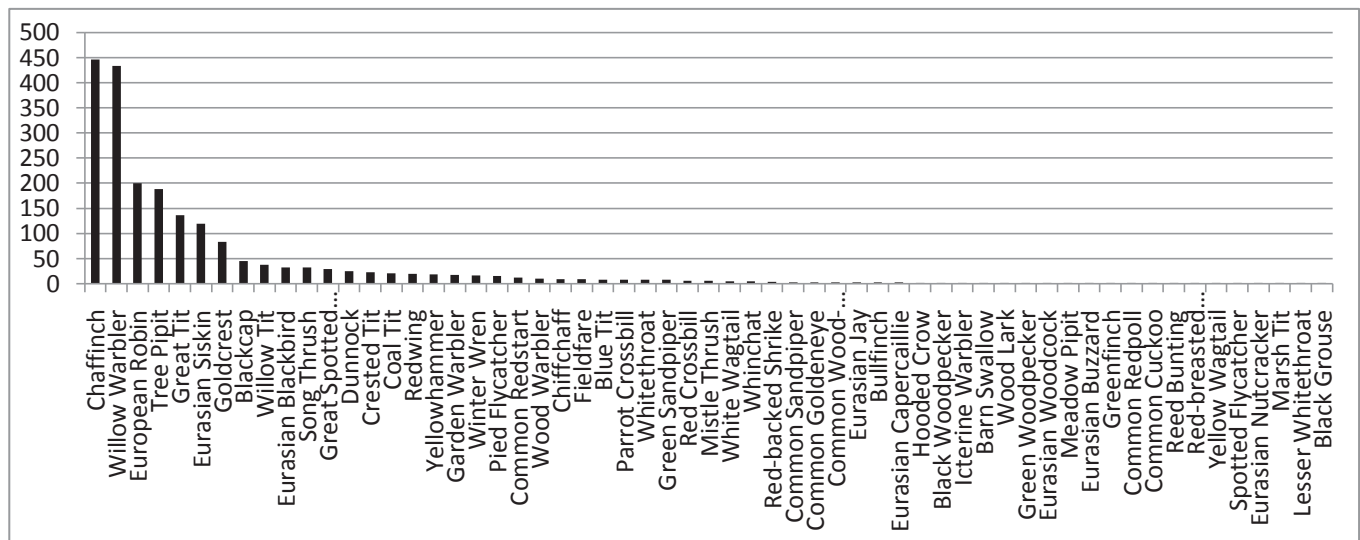


Figure 4 The Species Abundance Distribution is a “Hallow curve”. The most common species the chaffinch and the willow warbler accounted for 42.7% of all birds recorded. The majority of bird species >90% was detected less than 8 times.

We were two observers counting with an estimated difference of 0.79 birds per point count (Table 1). The observer difference was incorporated as a random effect in all analysis.

Table 1 Difference between the two observers JTJ and TDOE. I used a wald F-test of fixed effects.

Observer	Mean	±SE	DF	F _{DF}	P
JTJ	2.64	0.054	409	16.38	0.0001
TDOE	3.43	0.034	409	16.38	0.0001

Species richness

Edge versus Forest interior

Estimated mean species richness within each counting point was higher in ‘Edge’ habitats than in ‘Forest interior’ habitats (Table 2a and b). The significant ‘Habitat’*‘Development class’ interaction and associated parameter estimates indicate that this difference between habitats depended on development class, with highest species richness in intermediate development classes in edge habitat (Table 2b).

Table 2a Analysis of environmental variables influencing species richness. Response variable was number of species counted within each point (see Figure 3b). Explanatory variables were ‘Habitat’ (Edge or Forest interior; see Figure 3b) and ‘Development class’ (DC2, DC3, DC4 DC5). ‘Observer identity’ and ‘site’ were modeled as random effects.

Environmental variable	<i>df</i>	F	P	Log (Likel)	X^2
Fixed effects					
Habitat	1,402	3.12	0.078		
Development class	3,402	4.13	0.0067		
Habitat*Development class	2,402	3.39	0.035		
Random effects					
Observer + Site	2		0.0024	1557	10.0

Table 2b Estimated (SE) mean species richness values from the model presented in Table 2a.

Habitat	Development class	Mean species richness	SE
Edge	DC2	3.0	0.52
	DC3	3.6	0.30
	DC4	3.5	0.32
	DC5	2.5	0.22
Forest interior	DC2	2.7	0.30
	DC3	2.8	0.16
	DC4	2.9	0.20
	DC5	2.8	0

Edge versus power-line corridor

Estimated mean species richness within each counting point was higher in ‘Edge’ habitats than in ‘power-line corridor’ habitats (Table 3a and b). This difference between habitats was most pronounced when the difference in development class between ‘Edge’ and ‘Power-line corridor’ was large (Table 3b).

Table 3a Analysis of environmental variables influencing species richness. Response variable was number of species counted within each point (see Figure 3c). Explanatory variables were ‘Habitat’ (Edge or Power-line corridor; see Figure 3c and ‘difference in Development class between Edge and Power-line corridor’ (0,1,2,3). ‘Observer identity’, ‘site’ and ‘corridor width’ were modeled as random effects.

Environmental variable	<i>df</i>	F	P	Log (Likel)	X^2
Fixed effects					
Habitat	1,545	183.1	<0.0001		
DC difference	3,545	25.7	<0.0001		
Habitat* DC diff	3,545	10.6	<0.0001		
Random effects					
Observer + Site + Corridor width	3			1435	7.75

Table 3b Estimated (SE) mean species richness values from the model presented in Table 3a.

Habitat	Development class difference	Mean species richness	SE
Edge	0	2.1	0.26
	1	2.1	0.18
	2	2.1	0.32
	3	1.8	0.15
Power-line corridor	0	1.03	0.26
	1	0.50	0.099
	2	0.22	0.038
	3	0.22	0.019

Note that the estimated value for mean species richness for the edge habitat was 2.03 species per point (\pm SE=0.16) for the power-line corridor-edge comparison, and 3.13 species per point (\pm SE=0.18) for the forest interior (F) versus edge (E) comparison. The estimated richness varies between the models because different environmental variables were used in the GLMMs.

Total species richness for all three habitats in counts of species, did not differ much (Figure 5). Edge habitat had fewest species 33, the power-line corridor 36 and the forest interior 37 species represented in the whole sample (The total richness for forest interior habitat is from the reduced dataset Figure 3b).

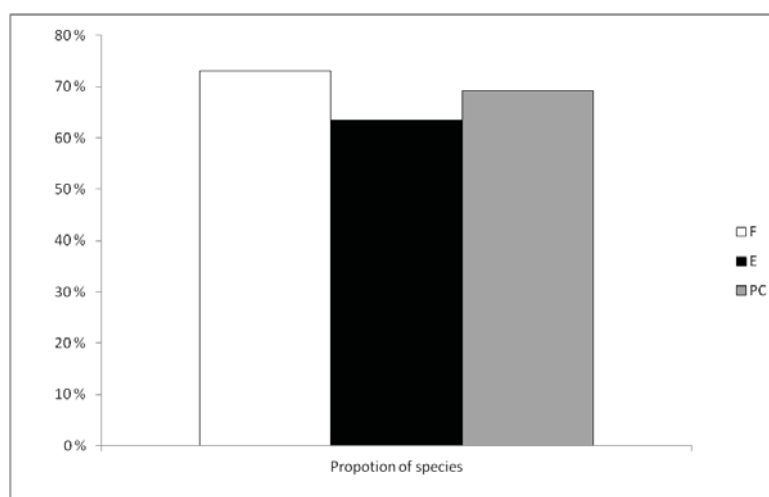


Figure 5 Percentage of total number of species detected within each habitat type. The figure is done on the reduced forest interior set to equal sample size (Figure 3b). Total of 52 unique species F=38, E=33, PC= 36.

Abundance and densities

Table 4 Bird abundance and richness on habitat as counts.

	C counting points n=311			Total	F counting points n=299
Habitat	E	PC	OE		F
No.birds	732	145	175	1052	1027
No.species	37	36	25	48	50

The abundance in the edge habitat was calculated to be 4.4 (\pm SE 0.56) per point count, and 5.47 birds per hectare. Forest interior habitat had 3.2 (\pm SE 0.40) per point count, and 4.07 per hectare. The difference in abundance between the forest interior habitat and the edge habitat differed significantly ($F_{1,408}=38.17$, $P<0.0001$).

In the power-line corridor (PC) versus edge (E) comparison the power-line corridor habitat had an abundance of 0.41(\pm SE=0.06) per point and per hectare, and the edge habitat had in the same comparison 3.3(\pm SE=0.32) birds per point or 4.2 birds per hectare. The difference abundance between the power-line corridor habitat and the edge habitat differed significantly ($F_{1,1571}=199.2$, $P<0.0001$)

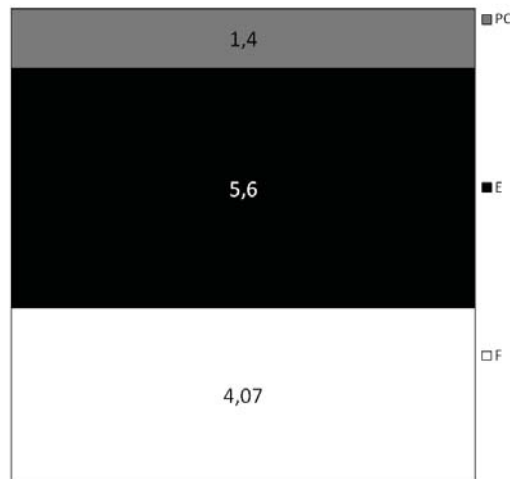


Figure 6 estimated abundance (number of birds) per hectare in each of the investigated habitats.

Species Abundance distribution

The calculated empirical cumulative distribution function (ECDF) for the three habitats were different (Figure 7). For the edge versus the forest interior habitat, the Kolmorov-Smirnov test indicates that the two habitats are qualitatively different ($D=0.296$, $P=0.061$). For the power-line corridor –edge comparison the Kolmorov-Smirnov test also showed a significant difference between the two habitats ($D=0.46$, $P=0.001$). The ECDF curve is more sharply vertical for the power-line corridor (PC) habitat than for the others, indicating that evenness is higher ($J'=0.804$). In both the edge and the forest interior the evenness is relatively low ($J' (E) =0.693$, $J' (F) =0.684$).

The general pattern for species distribution in all habitats is the relative large amount of rare species and a few very common species (Figure 4).

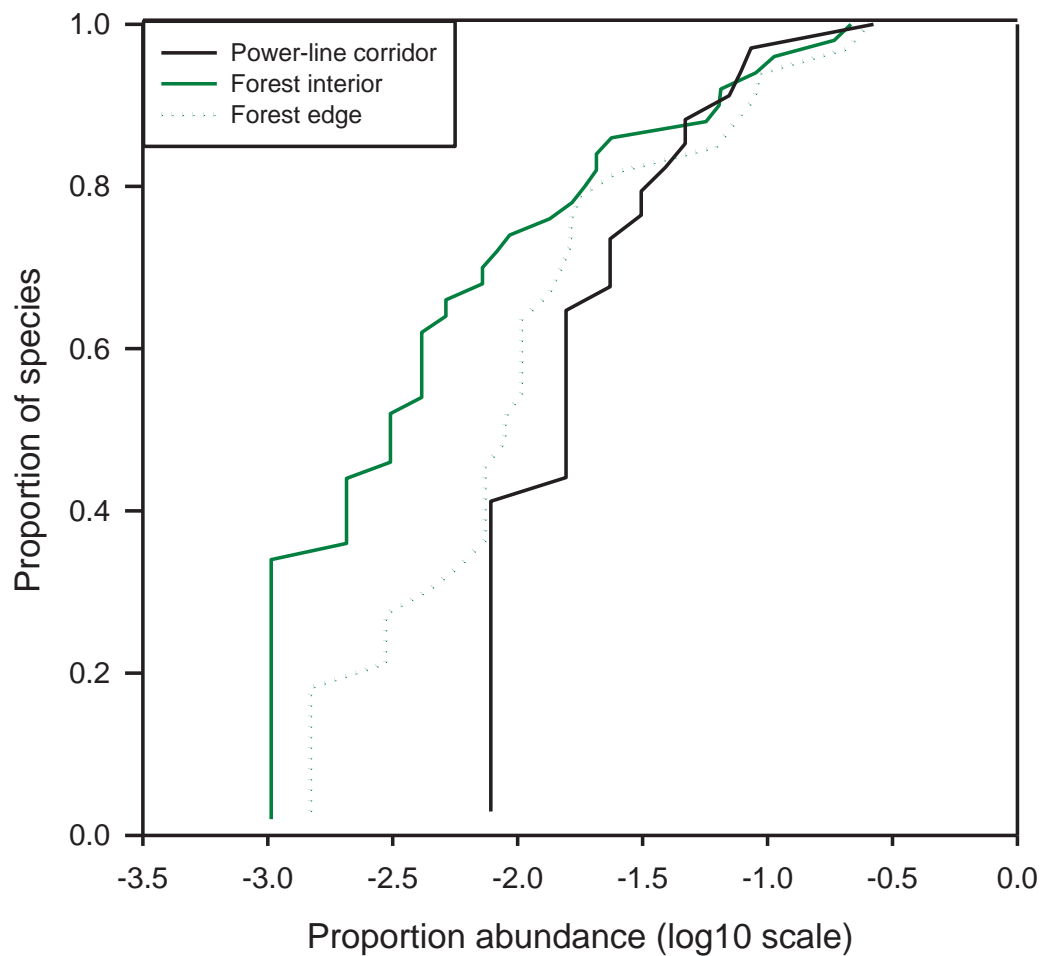


Figure 7

Comparison of species abundance distributions for PC, E and F habitats using ECDF (empirical cumulative distribution) plots. X-axis is proportion of abundance on a log10 scale. Y-axis is a proportion of species richness and plots the values S-1 to 1. Evenness is higher in the PC since the line is more sharply vertical; >40% species have an abundance of about 0.8%, >60% of the species have abundance less than about 1.5%. Most species have low abundance in all habitats; >90% of the species have abundance less than about 8%.

Biodiversity

The Renyi profile comparing the three habitats shows that diversity in the forest interior habitat was higher than in the edge habitat. Note that the Renyi profile was calculated from the pooled data from all sites, and within-site variation was not controlled for. The plot for the power-line corridor habitat intersected both the plot for forest interior and the plot for edge, and thus it not be stated that power-line corridors in general had lower (or higher) diversity than edge or forest interior (Figure 8). However, both the abundance of the most common species (antilogarithm to alpha value = Infinity in Figure 9) and species richness (antilogarithm to alpha value = 0 in figure 9) was lower in the power-line corridor habitat than the two others, whereas the evenness was highest in the power-line corridor (more horizontal plot in Figure 8).

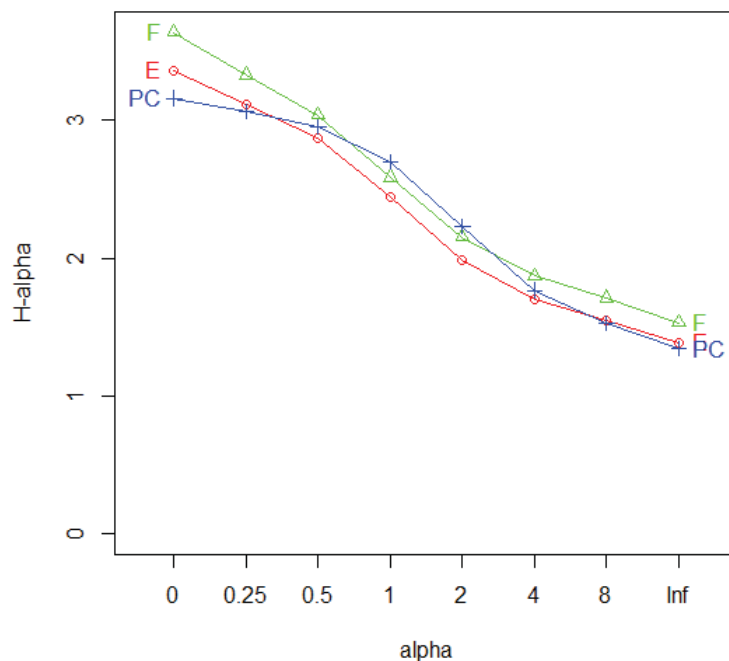


Figure 8 comparison of biodiversity of the three habitats, power-line corridor (PC), edge (E), and forest interior (F) (n=426)). The three curves shows a clear result for the forest interior (F) being the most diverse, than the edge habitat (E) (higher H-alpha values for all values of alpha). The slope for the power-line corridor habitat (PC) intersect, and do not give any clear conclusion. Each point in the profile indicates a diversity index, the number of the x-axis indicates the index (i.e. 0=species richness, 1= Shannon-wiener entropy, 2= Simpson diversity index,

In addition to comparing biodiversity of the main habitats by calculating Renyi profiles, I also estimated biodiversity per point count in different, controlling for between-observer and between-sites variation.

Edge versus forest interior

In analyses of F (forest interior) versus E (Edge), we started out with a global model with both Development class and Forest type as explanatory variables (and second-order interactions with Habitat), but after backward elimination, only Habitat (F or E) was included in the model as a significant explanatory variable (Table 5a). Both Shannon and Simpson diversity was slightly higher in Edge habitat than in Forest interior habitat (Table 5b). To compare Shannon and Simpson indices I transformed the index values into number of effective species in the population, then comparing the two by looking at the difference. ($E = 0.35$ and $F = 0.26$).²

Table 5a Analysis of environmental variables influencing diversity. Response variable was number of species counted within each point (see Figure 3b). Explanatory variable were 'Habitat' (Edge or Forest interior; see Figure 3b). 'Observer identity' and 'site' were modeled as random effects.

Environmental variable	<i>df</i>	F	P	Log (Likel)	X^2
Fixed effects					
Habitat	1,408	10.68	0.0012		
Random effects					
Observer + Site	2		<0.0001	656	24.15

Table 5b Estimated Shannon and Simpson index values for the edge (E) versus forest interior (F) comparison. Values are calculated into effective species in the population. Shannon index = $e^{H'}$ and Simpson index = $1/(1-D)$. I created a full most complex model including forest type and development class as fixed effects, and site and observer identity as random effects. The habitat as an effect were still significantly different ($F_{408} = 5.63$, $P = 0.018$)

Edge (E) versus forest interior (F)						
	E	$\pm SE$	P	F	$\pm SE$	P
Shannon (H')	1.07	0.15	<0.0001	0.91	0.15	<0.0001
$e^{(H')}$	2.92			2.48		
Simpson (D)	0.61	0.054	<0.0001	0.55	0.052	<0.0001
$\frac{1}{1-D}$	2.56			2.22		

² A large difference in Shannon-Simpson indicates a greater evenness since the Simpson index gives species with high abundance a greater value compared to rare species, while the Shannon index treat every observation even.

Edge versus power-line corridor

Estimated mean biodiversity within each counting point was much higher in ‘Edge’ habitats than in ‘power-line corridor’ habitats (Table 6a and b). This difference between habitats was most pronounced when the difference in development class between ‘Edge’ and ‘Power-line corridor’ was large (Table 6b).

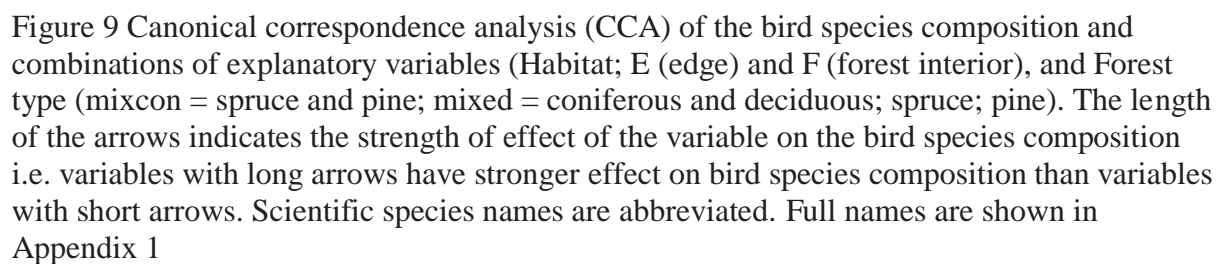
Table 6a Analysis of environmental variables influencing biodiversity. Response variable was Shannon index estimated for each counting point (see Figure 3c). Explanatory variables were ‘Habitat’ (Edge or Power-line corridor; see Figure 3c and ‘difference in Development class between Edge and Power-line corridor’ (0,1,2,3). ‘Observer identity’, ‘site’ and ‘corridor width’ were modeled as random effects.

Environmental variable	<i>df</i>	F	P	Log (Likel)	X^2
Fixed effects					
Habitat	1,545	176.1	<0.0001		
DC difference	3,545	3.3	0.021		
Habitat* DC diff	3,545	3,7	0.011		
Random effects					
Observer + Site + Corridor width	3			618.5	19.8

Table 6b Estimated (SE) mean Shannon index values from the model presented in Table 3a.

Habitat	Development class difference	Mean Shannon index	SE
Edge	0	0.30	0.12
	1	0.10	0.11
	2	-0.013	0.10
	3	0.024	0.11
Power-line corridor	0	0.63	0.12
	1	0.69	0.11
	2	0.67	0.10
	3	0.56	0.11

To investigate how the power-line transect affect the species composition, I have constructed a CCA diagram where both forest type (or biotope) and what I in this thesis name habitat (Edge and Forest interior) are factors, and the bird species are the explanatory variables. This allows us to see if it is the power-line corridor or the forest type that explain most of the variation in the bird community. In Pine, spruce and mixed forest the biotope explained most of the variation, and not the corridor. In mixed forest types (both deciduous and coniferous trees) the habitat disturbance explain most of the variation (Figure 9)



A CCA analysis showed that the site effect explained ca. 6 % of variation in species composition (Monte-Carlo permutation test: $F_{16,402} = 1.45$, $p = 0.001$, 999 permutations). A partial constrained ordination was then performed to find variation explained only by ‘Habitat’ and ‘Forest type’. Habitat explained <1 % of bird species composition not also explained by ‘Site’ (Monte-Carlo permutation test: $F_{1,401} = 1.67$, $p = 0.001$, 999 permutations), and Forest type also explained <1 % of bird species composition not also explained by ‘Site’ and ‘Habitat’ (Monte-Carlo permutation test: $F_{3,398} = 1.66$, $p = 0.001$, 999 permutations). Thus all the explanatory variables ‘Site’, ‘Habitat’ and ‘Forest type’ influenced bird species composition, but the effects were small.

Species composition in the habitats (Edge versus power-line corridor)

I was not able to run a CCA analysis on the edge versus power-line corridor comparison because the dataset have too many 0 values due to the few observations in the corridor. Most birds that were included in the analysis were more abundant in the edge (E) habitat than in the power-line corridor (PC) habitat. In raw dataset before elimination of unsuited points 11 bird species were recorded in the PC habitat that were not present in the E habitat. And 3 species were recorded more often in the PC habitat. All only observed 1 or 2 times. When points where edge had a development class 1 (Lakes, mashes, clear cuts and agricultural fields) were eliminated only 2 birds of the 11 were left in the power-line corridor data; the green sandpiper (*Tringa ochropus*), and Eurasian capercaillie (*Tetrao urogallus*). The Green sandpiper was observed in development class 3 and the Eurasian capercaillie is a polygamous species that only claim territories in spring during copulation, and not throughout the breeding season.

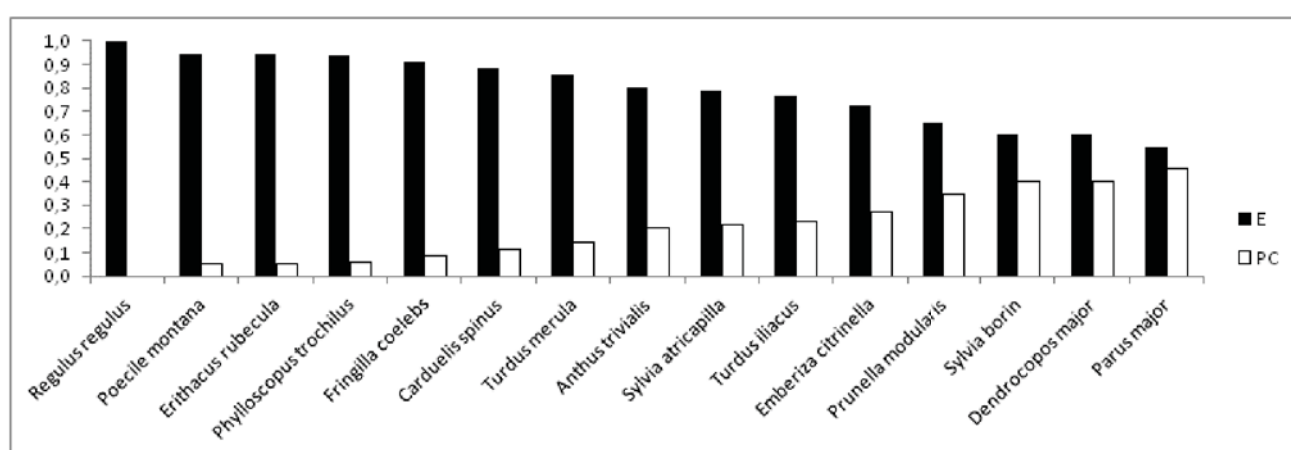


Figure 10 The figure shows proportion of each species observed more than 10 times in the corridor counting point (C) in the two habitats E and PC. The figure is constructed on the original counts.

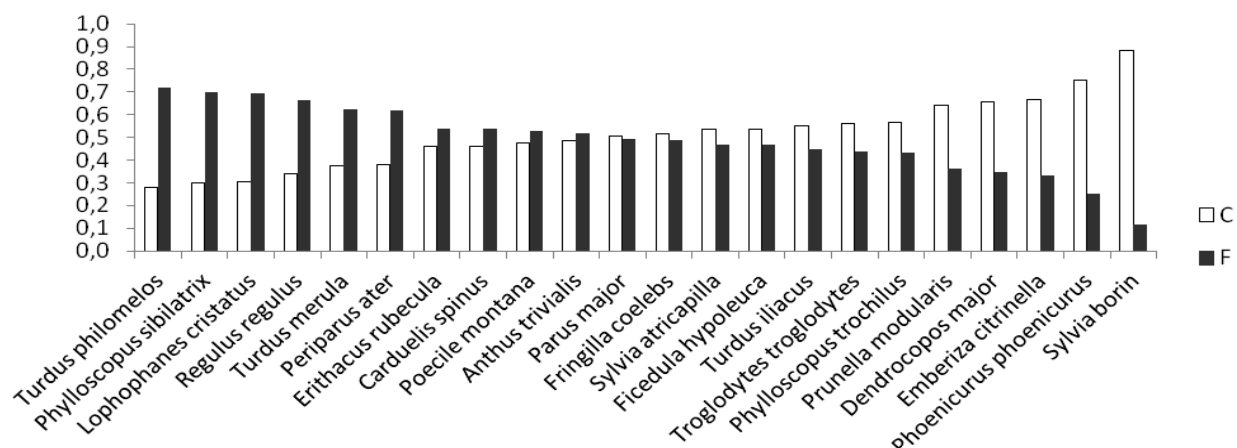


Figure 11 Total dataset (Figure 3a) adjusted for sample size, with all species represented by more than 10 individuals. The proportion of each species in the two point counts C and F. The corridor counting point(C) includes both the edge (E) habitat and the power-line corridor (PC) habitat. The data is based on the originally counts. On the left is the species with highest preference of forest interior and to the right the corridor preferring species. In the middle are habitat generalists.

Species observations and numbers

Chaffinch was the most common bird in the survey, every fifth bird counted was a chaffinch.

The chaffinch did not seem to have any preference on forest type.

Willow warbler was the most abundant species both at the edge, and in the corridor habitat. In the forest interior the chaffinch had a higher density.

The Yellowhammer (*Emberetcia citrinella*) was counted 18 times where 12 of them were in the Corridor counting point, and the 6 rest in the forest. Within the corridor counting point 3 were observed in the Power-line corridor habitat and the rest 9 at the edge. The yellowhammer had a preference for mixed forest (Figure 9).

The goldcrest (*Regulus regulus*) were not counted in the power-line corridor habitat at all. Of a total of 83 individuals counted 18 were observed in the edge, and the rest in the forest interior. Most of the observations were done in spruce forest (Figure 9)

The species less affected by habitat was the great tit (*Parus major*), having an close to equal distribution both between the edge habitat and the power-line corridor habitat (Figure 10), between the two counting points(Figure 11) and between the edge habitat and the forest interior by being in the center of the CCA diagram (Figure 9)

Discussion

In this study we have looked at edge effects on bird populations along power-line corridors. Many studies of edge effects in boreal forest systems are done on clear cuts or agricultural fields; (Hansson 1983; Helle 1986; Edenius and Elmberg 1996; Hanski, Fenske et al. 1996; Banks-Leite, Ewers et al. 2010). Power-line corridors separates from forest clear cuts by its shape, (i.e. long and thin with high amount of edges compared to open field with low amount of edge area compared to open area) and maintenance practice (i.e. power-line corridors are regularly maintained not allowing forest re growth and leaving behind dead wood versus forest clear cuts were forest re-vegetate and wood are transported out of the field).

I have looked at how power-line corridors affect avian species richness, abundance distribution and diversity in secondary temperate continuous coniferous boreal forest. I have found statistically significant differences between the open field in the power-line corridor, the edge habitat and the adjacent forest interior.

When comparing the edge habitat with the forest interior habitat I found that the species richness (Table2b), abundance (figure 6) and diversity (table5b) was higher at the edge habitat than the forest interior habitat. This correspond with similar studies done on edges and avian diversity (Leopold and Brooks 1933; Hansson 1983; Dale, Mork et al. 2000; Lindell, Riffell et al. 2007). The reason for an altered bird community at the corridor edges is suggested to be because of increased primary production as a result of more sunlight reaching the forest floor (Smith and Smith 2001)p445. (Hansson 1983) suggests that the increase in avian densities along clear cut edges is because of severe insect attacks, altered climatic conditions and higher primary productivity. Insect attacks on remaining forest post harvest is higher in the first year after cutting than in the coming years (Schroeder, Weslien et al. 1999). The power-line corridor is maintained as an open field continuously, and it is therefore likely to believe that large insect attack, compared to those in forest clear cuts, do not occur or at least not to such extend.

The edge habitat was richer (193%) and more than 3 times the abundance of the power-line corridor habitat. This is in accordance with similar studies done in the USA (Anderson, Mann et al. 1977; Askins, Folsom-O'Keefe et al. 2012). and a study done on bird numbers in clear cuts in Sweden (Hansson 1983). The reason for low species richness could be predation risk. I observed one buzzard (*Buteo buteo*) hunting in the power-line corridor (not during point counting) and both buzzards and kites (*Falco tinnunculus*) have been observed while they use

the power-line masts as viewpoints (Katrine Eldegard personal communication 13. August 2012). Also Hansson suggests that predation could be the reason for birds avoiding the close to forest open field (Hansson 1983).

The high abundance and richness in the edge habitat in comparison with the power-line corridor could alternatively to the altered primary production theory (as mentioned above) be a result of birds preferring to sit at high positions, such as tree tops, when singing. In the power-line corridor the amount of high positions are very scarce compared to the adjacent edge, and birds that include the power-line corridor as part of their territory then is likely to position in the edge.

The main variable describing the species richness and abundance was the development class parameter. In the comparison between edge and power-line corridor habitat I have used the differences in development class and density as a parameter instead of development classes (Table 3b) I also tested for development classes, getting the same result. The middle classes (DC 3 and DC4) had the highest species richness and abundance in all habitats (table 2b). The young (DC2) and old (DC5) growth forest had a lower abundance and richness. This pattern might be explained with the altered net primary production (NPP) in middle aged forests compared to young and old growth forest stands (Ryan, Binkley et al. 1997).

For all three habitats the species abundance distribution is characterized with a few very common species, and many rare (Figure 4 and Figure 7). The ECDF curve showed a significantly more even species distribution in the power-line corridor habitat than in the others (Figure 7). The diversity of the power-line corridor habitat was also higher (Table 6b). When a habitat has a higher evenness it means that the community has many species with equal abundance. Shannon species diversity index is a measure of the chance of the next bird observed to be of the same species. The power-line corridor habitat had a low amount of birds counted but many species observed compared to the other habitats (Table 4). A possible reason for a higher evenness in the power-line corridor habitat is the assumed less competition. (Cotgreave and Harvey 1994) suggest that habitats with low competition often have a more evenly distributed community, in this case avian community.

The CCA analysis of species composition between the forest interior and the edge habitat (Figure 9) showed that habitat and biotope explained less than 1% of the variation after the difference between sites was explained. There were also very little difference in the biodiversity measures. This pattern is also found in (Hansson 1994). The reason for such little

variation might be the two habitats are relatively equal in tree species composition, and development classes.

Species known to prefer open fields in boreal forests i.e. yellowhammer and red backed shrike, was poorly represented, or absent from the corridor habitat. The phenomena is also mentioned by (Hansson 1983), who claims it to be a result of increased predation risk close to edges. I believe that it also have to do with the habitat demands where the yellowhammer is known to prefer cultivated land in or close home range, and the red backed shrike who prefer larger open areas with shrub vegetation (Haftorn and Gidstam 1997). The power-line corridors that I have studied are in continuous forest far from cultivated land, and all points located at clear cuts were not investigated.

Conclusion

In the forest edge close to power-line corridors there were altered species richness, abundance and diversity in the avian community compared to the forest interior habitat. The high abundance of birds in the edge habitat might be a result of altered food availability, or preferred high positioned viewpoint during singing.

The power-line corridor habitat had a low abundance and species richness. The species were more evenly distributed than the other habitats. Open field species were absent from the corridor except when the corridor habitat bordered to a larger clear cut or agricultural field. The reason for the low amount of birds in the corridor might be altered predation risk, and/or lack small trees and shrubs.

Forest succession stages were the main variable influencing species abundance in all habitats.

To alter avian densities in power-line corridors I suggest a shift in the management regime in

1. Allowing deciduous shrubs to grow
2. when cutting trees below transition line, leave stumps of a few meters

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Appendix I

Name list and abbreviations of all species observed in field.

Acronyms	Scientific names	English	Norwegian
ActHyp	<i>Actitis hypoleucos</i>	Common Sandpiper	Strandsnipe
AntPra	<i>Anthus pratensis</i>	Meadow Pipit	Heipiplerke
AntTri	<i>Anthus trivialis</i>	Tree Pipit	Trepiplerke
ApuApu	<i>Apus apus</i>	Common Swift	Tårnseiler
BucCla	<i>Bucephala clangula</i>	Common Goldeneye	Kvinand
ButBut	<i>Buteo buteo</i>	Eurasian Buzzard	Musvåk
CarChl	<i>Carduelis chloris</i>	Greenfinch	Grønnfink
CarFla	<i>Carduelis flammea</i>	Common Redpoll	Gråsisik
CarSpi	<i>Carduelis spinus</i>	Eurasian Siskin	Grønnsisik
ColOen	<i>Columba oenas</i>	Stock Pigeon	Skogdue
ColPal	<i>Columba palumbus</i>	Common Wood-Pigeon	Ringdue
CorCor	<i>Corvus cornix</i>	Hooded Crow	Kråke
CorCora	<i>Corvus corax</i>	Raven	Ravn
CucCan	<i>Cuculus canorus</i>	Common Cuckoo	Gjøk
CyaCae	<i>Cyanistes caeruleus</i>	Blue Tit	Blåmeis
CygOlo	<i>Cygnus olor</i>	Mute Swan	Knoppsvane
DenMaj	<i>Dendrocopos major</i>	Great Spotted Woodpecker	Flaggspett
DryMar	<i>Dryocopus martius</i>	Black Woodpecker	Svartspett
EmbCit	<i>Emberiza citrinella</i>	Yellowhammer	Gulspurv
EmbSch	<i>Emberiza schoeniclus</i>	Reed Bunting	Sivspurv
EriRub	<i>Erithacus rubecula</i>	European Robin	Rødstrupe
FicHyp	<i>Ficedula hypoleuca</i>	Pied Flycatcher	Svarthvit fluesnapper
FicPar	<i>Ficedula parva</i>	Red-breasted Flycatcher	Dvergfluesnapper
FriCoe	<i>Fringilla coelebs</i>	Chaffinch	Bokfink
GalGal	<i>Gallinago gallinago</i>	Common Snipe	Enkeltbekkasin
GarGla	<i>Garrulus glandarius</i>	Eurasian Jay	Nøtteskrike
GruGru	<i>Grus grus</i>	Common Crane	Trane
HipIct	<i>Hippolais icterina</i>	Icterine Warbler	Gulsanger
HirRus	<i>Hirundo rustica</i>	Barn Swallow	Låvesvale
LanCol	<i>Lanius collurio</i>	Red-backed Shrike	Tornskate
LopCri	<i>Lophophanes cristatus</i>	Crested Tit	Toppmeis
LoxCur	<i>Loxia curvirostra</i>	Red Crossbill	Grankorsnebb
LoxPyt	<i>Loxia pytyopsittacus</i>	Parrot Crossbill	Furukorsnebb
LulArb	<i>Lullula arborea</i>	Wood Lark	Trelerke
MotAlb	<i>Motacilla alba</i>	White Wagtail	Linerle
MotFla	<i>Motacilla flava</i>	Yellow Wagtail	Gulerle
MusStr	<i>Muscicapa striata</i>	Spotted Flycatcher	Gråfluesnapper
NutCar	<i>Nucifraga caryocatactes</i>	Eurasian Nutcracker	Nøttekråke
ParMaj	<i>Parus major</i>	Great Tit	Kjøttmeis
PerAte	<i>Periparus ater</i>	Coal Tit	Svartmeis
PhoPho	<i>Phoenicurus phoenicurus</i>	Common Redstart	Rødstjert

PhyCol	<i>Phylloscopus collybita</i>	Chiffchaff	Gransanger
PhySib	<i>Phylloscopus sibilatrix</i>	Wood Warbler	Bøksanger
PhyTro	<i>Phylloscopus trochilus</i>	Willow Warbler	Løvsanger
PicVir	<i>Picus viridis</i>	Green Woodpecker	Grønnspekk
PoeMon	<i>Poecile montana</i>	Willow Tit	Granmeis
PoePal	<i>Poecile palustris</i>	Marsh Tit	Løvmeis
PruMod	<i>Prunella modularis</i>	Dunnock	Jernspurv
PyrPyr	<i>Pyrrhula pyrrhula</i>	Bullfinch	Dompap
RegReg	<i>Regulus regulus</i>	Goldcrest	Fuglekonge
SaxRub	<i>Saxicola rubetra</i>	Whinchat	Buskskvett
ScoRus	<i>Scolopax rusticola</i>	Eurasian Woodcock	Rugde
SitEur	<i>Sitta europaea</i>	Eurasian Nuthatch	Spettmeis
SylAtr	<i>Sylvia atricapilla</i>	Blackcap	Munk
SylBor	<i>Sylvia borin</i>	Garden Warbler	Hagesanger
SylCom	<i>Sylvia communis</i>	Whitethroat	Tornsanger
SylCur	<i>Sylvia curruca</i>	Lesser Whitethroat	Møller
TetTet	<i>Tetrao tetrix</i>	Black Grouse	Orrfugl
TetUro	<i>Tetrao urogallus</i>	Eurasian Capercaillie	Storfugl
TriGla	<i>Tringa glareola</i>	Wood Sandpiper	Grønnstilk
TriOch	<i>Tringa ochropus</i>	Green Sandpiper	Skogsnipe
TroTro	<i>Troglodytes troglodytes</i>	Winter Wren	Gjerdsmett
TurIli	<i>Turdus iliacus</i>	Redwing	Rødvingetrost
TurMer	<i>Turdus merula</i>	Eurasian Blackbird	Svarttrost
TurPhi	<i>Turdus philomelos</i>	Song Thrush	Måltrost
TurPil	<i>Turdus pilaris</i>	Fieldfare	Gråtrost
TurVis	<i>Turdus viscivorus</i>	Mistle Thrush	Duetrost

Appendix II

Acronyms:

• C	Corridor counting point
• F	Forest interior habitat
• OE	Opposite edge
• E	Edge habitat
• PC	Power-line corridor habitat
• DC	Development class (For tree development measure)
• MSL	Meters above sea level
• GLMM	Generalized linear mixed model
• LR	Likelihood ratio
• CCA	Canonical Correspondence Analysis
• REML	Restricted maximum likelihood
• SAD	Species abundance distribution
• RAD	Rank abundance diagram
• CDF	Cumulative distribution function
• ECDF	Empirical cumulative distribution function
• Evar	Smith and Wilsons index of evenness
• J'	Peoul's evenness index
• H'	Shannon – wiener index of diversity
• D	Kolmorov-Smirnov test result
• NPP	Net primary production