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Boreal Peatland Life-project

The effect of mire restoration on mire bird abundance and species richness

Abstract

Drainage is a serious threat to Finnish mire birds and populations of several mire birds have declined during recent decades. Here we report results on mire bird diversity and abundance from the Boreal Peatland Life-project, in which valuable mire areas in Natura 2000 network have been restored and monitored to evaluate the success of restoration. Our unique census data on mire birds revealed that in the drained sites, species diversity and abundance of mire birds was lower than in the pristine sites. The number of mire bird species tended to increase in restored sites right after restoration but the pattern was not very clear a few years after the restoration. In other than mire birds, there were more species in drained sites before restoration but restoration had no effect. The theme species Golden Plover (*Pluvialis apricaria*) was missing in all treatment sites before restoration, but was observed during first census after restoration in 4 sites out of 10 (in pristine sites species was observed in 7 of 10 sites). To increase the knowledge about the long term effects of restoration monitoring should be continued. Changes after historical wide-ranging peatland drainage may not be overturned, but under many mire bird species, restored mires can act as breeding patches that slow down the loss of species at the local level.

Introduction

A substantial part of European mire birds breeds in Finland (Tiainen et al. 2010), which has the highest proportion of peatlands in the world (Lappalainen 1996). This is why Finland has high national responsibility in conservation of mire birds (Tiainen et al. 2010). Regardless of the fact, that significant proportion of mire birds breeds in protected areas, populations of mire birds have declined during recent decades (Rassi et al. 2010; Valkama et al. 2011), and according to mire bird index (Luonnontila.fi 2013), decline has been almost 40 %. The most important threat to mire birds has been peatland drainage for forestry and fragmentation of mire habitats (Rassi et al. 2010). Altogether 60 % of peatlands in Finland have been drained (Vasander 1998, Heikkilä et al. 2002, Rassi et al. 2010), but in Southern and Central parts of Finland, the percentage is even greater, 75 %(Virkkala et al. 2000). Although new ditches are no longer being dug, the draining effect of earlier drainage operations still continues in many areas and deteriorates the natural state of mires. This is why drainage continues to be a significant threat factor for mire species (Rassi et al. 2010).

In addition to habitat deterioration, bird populations are affected also by climate change (Jiguet et al. 2007, Green et al. 2008, Gregory et al. 2009). Species ranges are expected to move polewards following the changing climate (Parmesan 2006, Brommer et al. 2012), which poses challenges to the protected area network, particularly at northern latitudes: climate change-driven range shifts are projected to be most dramatic at northern latitudes because of the greater projected increases in temperature (Jetz et al. 2007). Northern density shifts in populations of bird species in Finnish protected areas have already been observed with northern species showing greatest decrease in their trailing edge in southern Finland and

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southern species increasing most in their leading range boundary in northern Finland (Virkkala & Rajasärkkä 2011).

Restoring ecosystems has become internationally important way to slow down the loss of biodiversity and maintain ecosystem services (European Union 2010). Between 1989-2012 a total of 19 000 hectares of drained peatland area in Finland have been restored (Aapala et al. 2013) and restoration has become an established element of the management of protected areas. EU Life funding has played a key role in the financing of peatland habitat restoration work in Finland (Aapala et al. 2013).

The largest LIFE Nature project in Finland, the Boreal Peatland Life-project (2010-2014) restored nearly 4300 hectares of peatlands. This project includes 54 Natura 2000 sites around Finland. The main aim of the project was to restore the natural hydrology of the mires by filling in and blocking the ditches and by clearing trees to recreate the landscape as it was prior to the ditching. Restoration is concentrated on ecologically highly valuable areas and also some areas outside the Natura 2000 areas are included into the project. This project has increased the connectivity and decreased the fragmentation of the Natura 2000 peatland habitats (Boreal Peatland Life Project 2013).

Boreal Peatland Life-project initiated a monitoring scheme that aims at the evaluation of the success of the restoration at many levels. To evaluate the general success of restoration, birds are monitored among some other taxa. There are very few previous studies of the effects of restoration on mire bird species (Rajasärkkä 2013) and most datasets lack appropriate control and data before and after restoration. Boreal Peatland LIFE project has enabled a unique setup in which we have three important measures 1) The initial (before restoration state) of the sites that will be restored, 2) The state of the restored sites after restoration, and 3) the state of the pristine sites. The main aim is to determine the effects of drainage and restoration on species richness and territory abundance of mire birds and other birds with a special focus on the golden plover (*Pluvialis apricaria*).

Material and methods

Bird data was collected using Finnish line transect census method (Koskimies & Väisänen 1988), in which each site is counted once during breeding season. Each observed mire area (11 in total) includes treatment site, that will be restored and identically shaped pristine site that is considered as a control site. Example of a study mire with transect lines is in appendix 1. Treatment sites vary between 4,7-23,3 hectares. In many cases (in 6 treatment sites of 11) the edge of restored site is a part of undrained habitat. This is because of compact linings but also because the quality of undrained part of treatment site may improve after restoration. If territory is on the undrained part of treatment site, this is reported.

The recommended census period is between April 30th and June 20th. Censuses are performed during early morning, typically between 4 and 10 a.m. in dry weather with weak or no wind. The observer walks alone slowly along the route, using a map and GPS, walking 1,5 km/h and marking all observed territories to the map. Transects are planned to be at maximum 50 meters from each point in the census area. Census unit is a pair of birds, not an individual. Pair is 1) seen or heard male 2) pair 3) lonely female 4) brood 5) nest. Because pair of birds is also considered as territory, hereafter we use “territory” to refer pair of birds.

Censuses were performed in all 11 mires in 2010. Since that all restored sites were counted yearly: 2 sites in 2011, 5 sites in 2012 (includes the previous 2 + 3), 9 sites (includes the previous 5 + 4) in 2013 and 10 sites (includes the previous 9 + 1) in 2014.

All breeding bird species were counted during transect counts. List of all species observed and number of territories for each species are tabulated in appendix 2. List of mire species follow Rajasärkkä's (2013) definition of mire bird species. For mire bird species, threatened species are specified (Rassi et al. 2010). We included NT (Near Threatened) and VU (Vulnerable) species as "threatened" in our statistical tests. Golden Plover (*Pluvialis apricaria*), which is noisy and easy to observe, was a theme species in this study. Census data on this species is very accurate and this is why this species was separately reported. During first census, Golden plover was not observed in any of the treatment sites.

Data analysis

We used SPSS (20.0) in all statistical tests. Data was hierarchically structured because of different sites and different treatments, thus we used mixed model analysis. With this model, we first analyzed the effects of treatment and area on bird abundance and species richness using the data collected during the first year before restoration operations. Dependent variable was a number of territories or number of species (mire species, other species or threatened species). Fixed effects were treatment (undrained treatment site, drained treatment site to be restored and pristine site) and area (hectares). Site was added as a random effect.

Next we aimed to analyze the effects of treatment, area, repeated measure and the interaction between treatment and repeated measure (the effect of restoration) on dependent variable. We entered treatment (treatment site and pristine site), area (hectares), repeated measure (first and second census) and interaction between treatment and repeated measure as fixed effects in to the mixed model. Site was a random effect and repeated measure repeated effect. In this model, undrained treatment sites were combined with drained treatment sites to be restored, because based on the results of the first model, there were no differences between these sites.

We repeated the second analysis by including also third and fourth censuses (repeated measure included first, second, third and fourth censuses). One mire area was restored before the first census and thus we removed it from the analyses.

Species richness of mire birds before restoration

Treatment had an effect on species richness of mire birds, but area did not (Table 1). There were more mire bird species in the pristine sites than in the undrained treatment sites (Pairwise LSD comparison, MD = 2,513, SE = 0,705, df = 14,047, p = 0,003) or in the drained treatment sites to be restored (Pairwise LSD comparison, MD =2,832, SE = 0,612, df = 12,862, p < 0,001). There was no difference in species richness of mire birds between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,318, SE = 0,732, df = 14,449, p = 0,670) (Figure 1).

Table 1. Mixed model analysis for species richness of mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	8,053	3,473	0,099
Treatment	2	13,680	12,547	0,001
Area (ha)	1	8,111	0,050	0,829

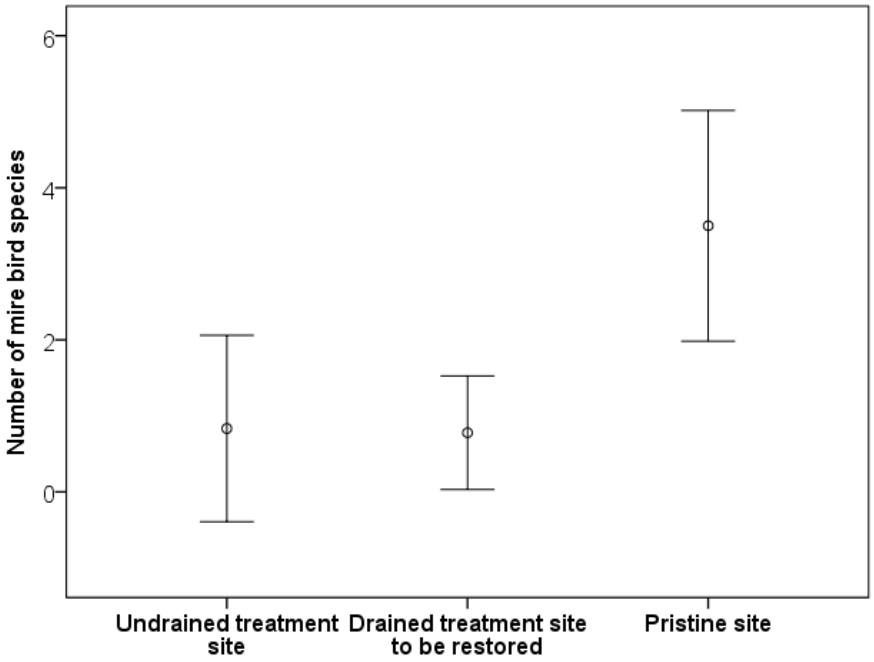

Figure 1. Number of mire bird species in different sites (error bars show 95% CI of mean)

Abundance of mire bird territories before restoration

Treatment had an effect on the abundance of mire bird territories, but area did not (Table 2). There were more mire bird territories in the pristine sites than in the undrained treatment sites (pairwise LSD comparison, MD = 6,015, SE = 2,135, df = 12,783, p = 0,015) or in the drained treatment sites to be restored (Pairwise LSD comparison, MD = 6,345, SE = 1,874, df = 10,856, p = 0,006). There was no difference in abundance of mire bird territories between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,330, SE = 2,206, df = 13,437, p = 0,883) (Figure 2).

Table 2. Mixed model analysis for abundance of mire bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	6,113	0,352	0,574
Treatment	2	12,157	7,007	0,009
Area (ha)	1	6,266	0,397	0,551

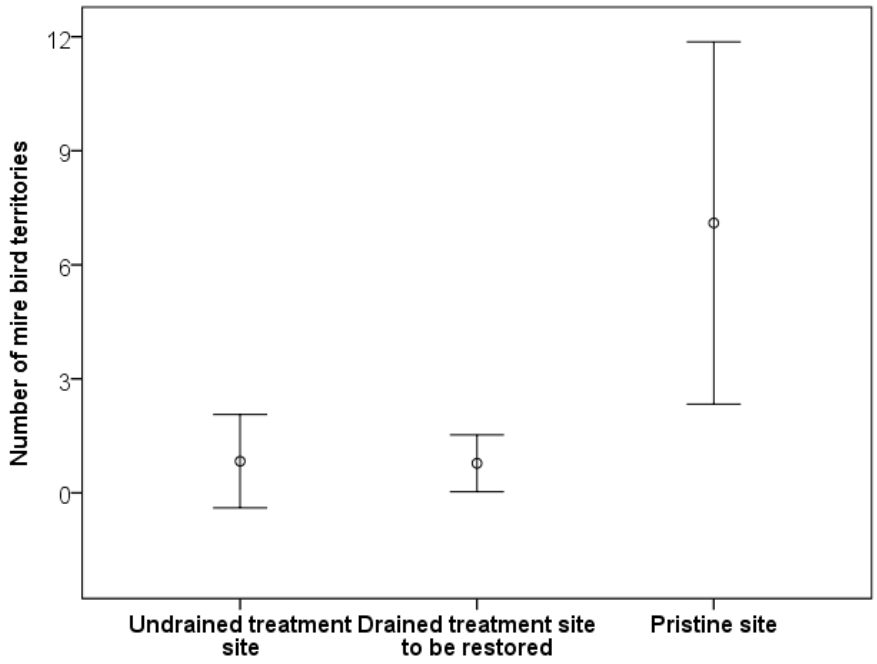

Figure 2. Number of mire bird territories in different sites (error bars show 95% CI of mean)

Species richness of other birds before restoration

Treatment and area had an effect on species richness of other birds (Table 3). There tended to be less other species in the pristine sites than in the undrained treatment sites (Pairwise LSD comparison, MD = -2,436, SE = 1,211, df = 21 , p = 0,057) and there were also less species in the pristine sites than in the drained treatment sites to be restored (Pairwise LSD comparison, MD = -3,187, SE = 1,078, df = 21, p = 0,008) but there was no difference in species richness between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = -0,750 , SE = 1,246, df = 21, p = 0,553) (Figure 3). Species richness increased with area (Estimate = 0,388, SE = 0,840) (Figure 4).

Table 3. Mixed model analysis for species richness of other birds

Source	Numerator df	Denominator df	F	p
Intercept	1	21	1,482	0,237
Treatment	2	21	4,750	0,020
Area (ha)	1	21	21,317	< 0,001

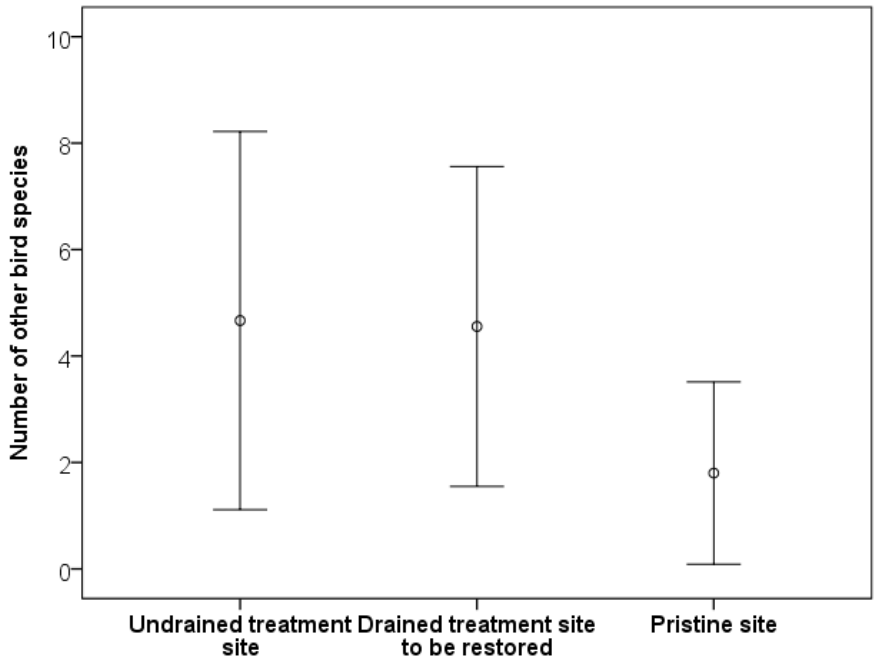

Figure 3. Number of other bird species in different sites (error bars show 95% CI of mean)

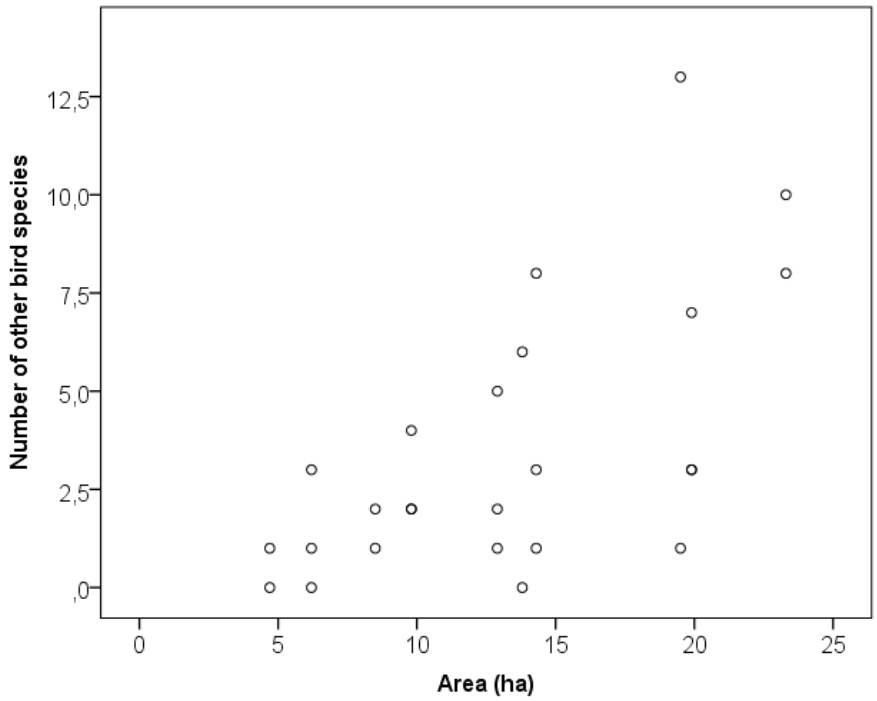

Figure 4. Number of other bird species in relation to area (ha)

Abundance of other bird territories

Treatment did not have an effect on abundance of other bird territories, but area had an effect (Table 4). The effect was such that abundance of other bird territories increased with area (Estimate = 1.176, SE = 0,274) (Figure 5).

Table 4. Mixed model analysis for abundance of other bird territories.

Source	Numerator df	Denominator df	F	p
Intercept	1	21	3,528	0,074
Treatment	2	21	2,419	0,113
Area (ha)	1	21	18,344	< 0,001

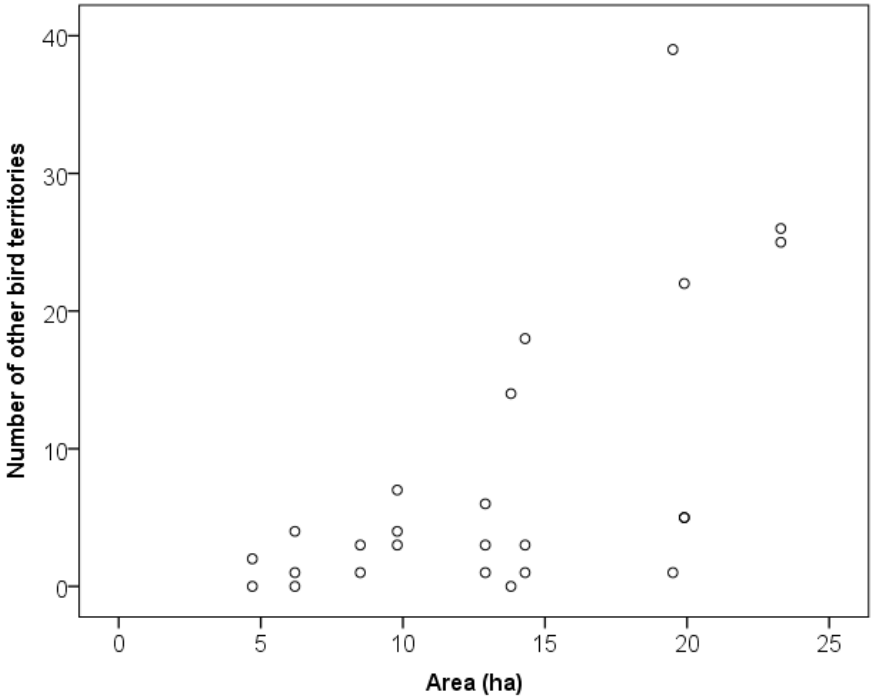

Figure 5. Number of other bird territories in relation to area (ha)

Abundance of Golden Plover territories

Treatment had an effect on number of Golden Plover territories, but area had no effect (Table 5). There were more Golden Plover territories in the pristine sites than in the undrained treatment sites (Pairwise LSD comparison, MD = 0,972, SE = 0,414, df = 15,202 p = 0,033) or in the drained treatment sites to be restored (Pairwise LSD comparison, MD = 1,016, SE = 0,366, df = 13,046, p = 0,016). There was no difference between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,044, SE = 0,426, df = 15,869, p = 0,919) (Figure 6).

Table 5. Mixed model analysis for abundance of Golden Plover territories

Source	Numerator df	Denominator df	F	p
Intercept	1	7,911	1,170	0,311
Treatment	2	14,513	4,736	0,026
Area (ha)	1	8,199	0,117	0,741

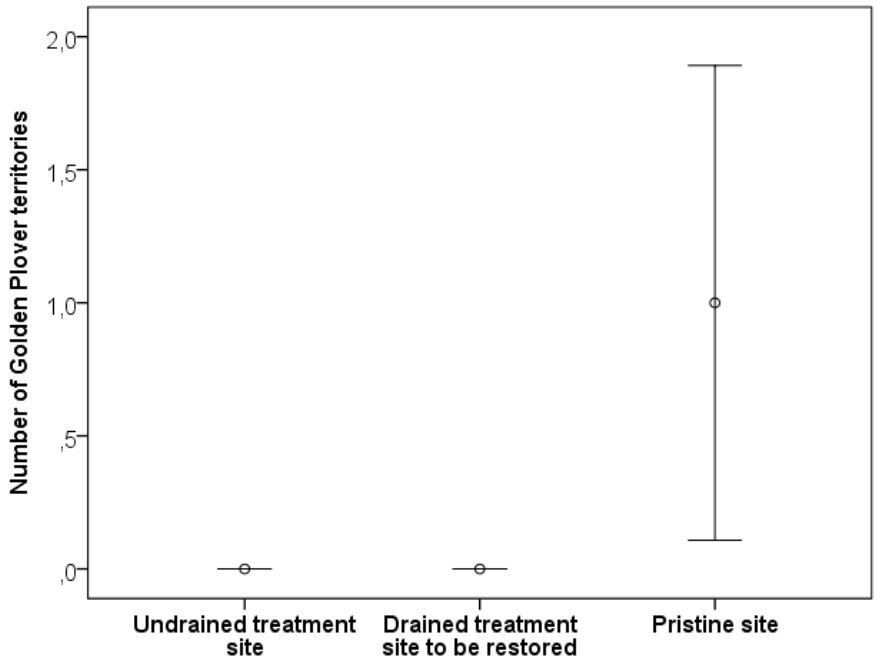

Figure 6. Number of Golden Plover (*Pluvialis apricaria*) territories in different sites (error bars show 95% CI of mean)

Species richness of threatened mire birds before restoration

Treatment had an effect on species richness of threatened mire birds, but area did not (Table 6). There were more threatened mire bird species in the pristine sites than in the drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,819 , SE = 0,283 , df = 13,523, p = 0,012) and there tended to be more threatened mire bird species in the pristine sites than in the undrained treatment sites (Pairwise LSD comparison, MD = 0,648 , SE = 0,325 , df = 14,859 , p = 0,065), but there was no difference in threatened mire bird species richness between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,171, SE = 0,336, df = 15,300, p = 0,618) (Figure 7).

Table 6. Mixed model analysis for species richness of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	8,705	2,504	0,149
Treatment	2	14,445	4,628	0,028
Area (ha)	1	8,801	0,208	0,659

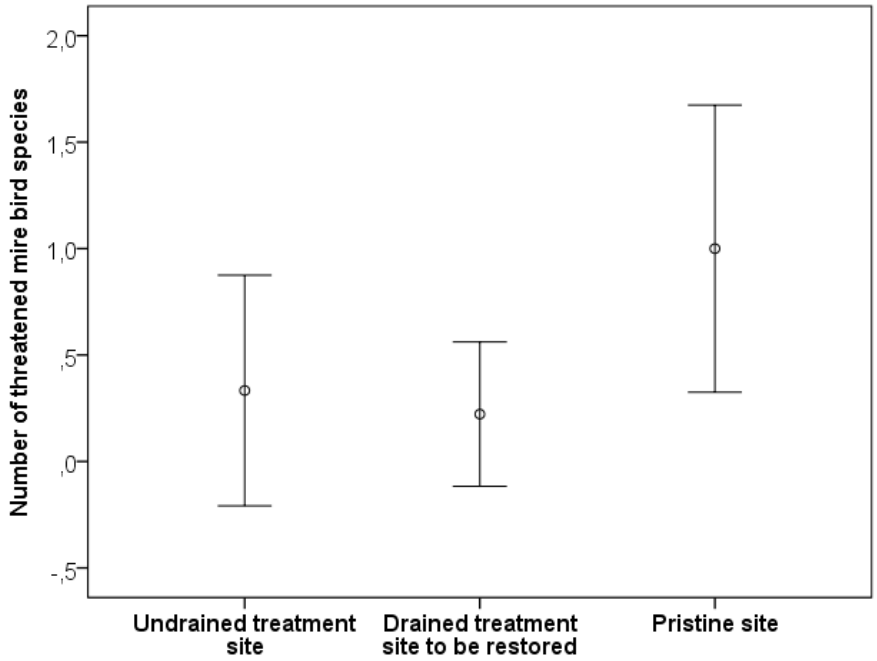

Figure 7. Number of threatened mire bird species in different sites (error bars show 95% CI of mean)

Abundance of territories of threatened mire birds before restoration

Treatment tended to have an effect on abundance of territories of threatened mire birds, but area did not (Table 7). There were more territories of threatened mire birds in the pristine sites, than in the drained treatment sites to be restored (Pairwise LSD comparison, MD = 3,230, SE = 1,419, df = 10,110, p = 0,046) and there tended to be more territories of threatened mire birds in the pristine sites than in the undrained treatment sites (Pairwise LSD comparison, MD = 3,086, SE = 1,609, df = 12,319, p = 0,079) but there was no difference in abundance of territories of threatened mire birds between undrained treatment sites and drained treatment sites to be restored (Pairwise LSD comparison, MD = 0,145, SE = 1,661, df = 13,071, p = 0,932) (Figure 8).

Table 7. Mixed model analysis for abundance of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	5,439	0,003	0,956
Treatment	2	11,585	3,185	0,079
Area (ha)	1	5,630	0,611	0,466

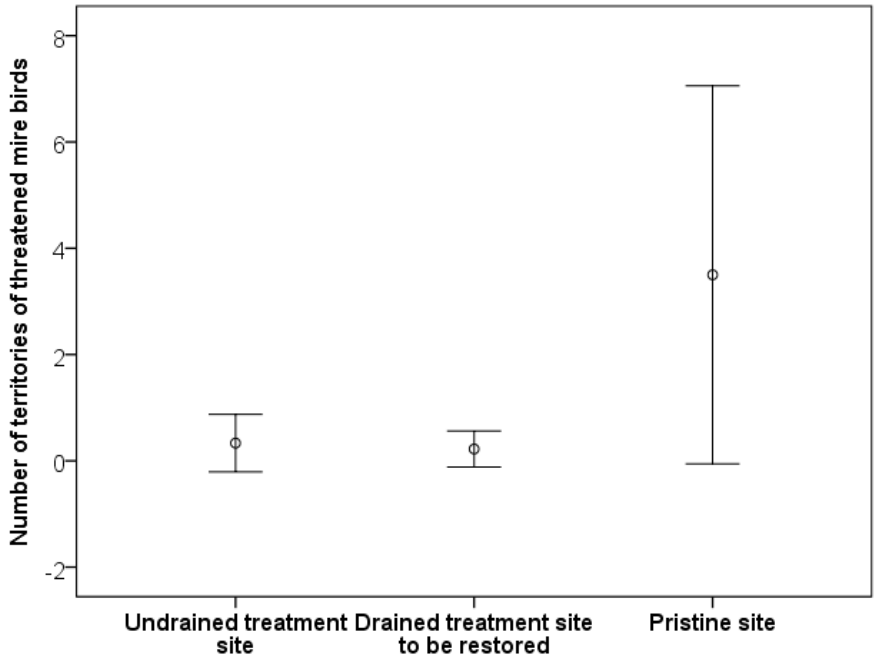

Figure 8. Number of territories of threatened mire birds in different sites (error bars show 95% CI of mean)

Effect of restoration (one census after restoration)

Effect of restoration on species richness of mire birds

There tended to be an interaction between repeated measure and treatment on the species richness of mire birds (Table 8). Interaction was such that there were more mire bird species in the treatment sites after restoration, but in the pristine sites richness of mire species declined after restoration. Treatment had also an effect on species richness of mire birds, but area and repeated measure had no effect (Table 8). Treatment had such an effect that there were more mire species in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 1,544, SE = 0,588, df = 6,881, p = 0,035) (Figure 9).

Table 8. Mixed model analysis for species richness of mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,724	7,534	0,026
Treatment	1	6,881	6,882	0,035
Area (ha)	1	7,952	0,056	0,818
Repeated measure	1	14,222	0,085	0,775
Repeated measure*Treatment	1	14,549	4,096	0,062

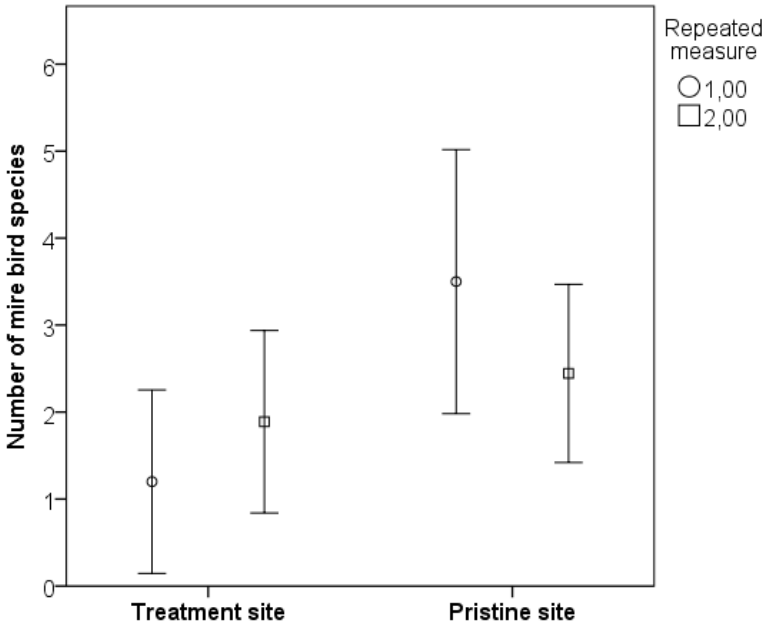

Figure 9. Number of mire bird species in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on the abundance of mire bird territories

Treatment had an effect on abundance of mire bird territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 9). There were more mire bird territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 4,964, SE = 1,964, df = 7,861, p = 0,036) (Figure 10).

Table 9. Mixed model analysis for abundance of mire bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	7,409	0,702	0,428
Treatment	1	7,861	6,391	0,036
Area (ha)	1	7,510	0,755	0,412
Repeated measure	1	14,501	0,033	0,859
Repeated measure*Treatment	1	14,554	2,295	0,151

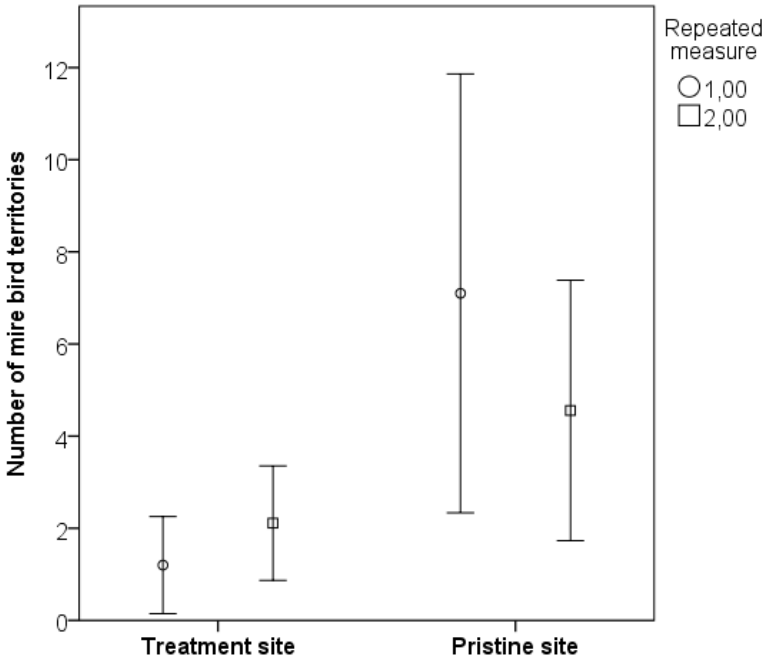

Figure 10. Number of mire bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of other birds

Treatment and area had an effect on species richness of other birds, but repeated measure or interaction between repeated measure and treatment had no effect (Table 10). Treatment had such an effect that there were more other bird species in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 4,144, SE = 0,775, df = 13,397, $p < 0,001$) (Figure 11). Species richness increased with area (Figure 12)(Estimate = 0,287, SE = 0,066).

Table 10. Mixed model analysis for species richness of other birds

Source	Numerator df	Denominator df	F	p
Intercept	1	12,928	0,001	0,980
Treatment	1	13,397	28,608	< 0,001
Area (ha)	1	13,550	18,731	0,001
Repeated measure	1	13,445	1,037	0,326
Repeated measure*Treatment	1	13,488	0,486	0,498

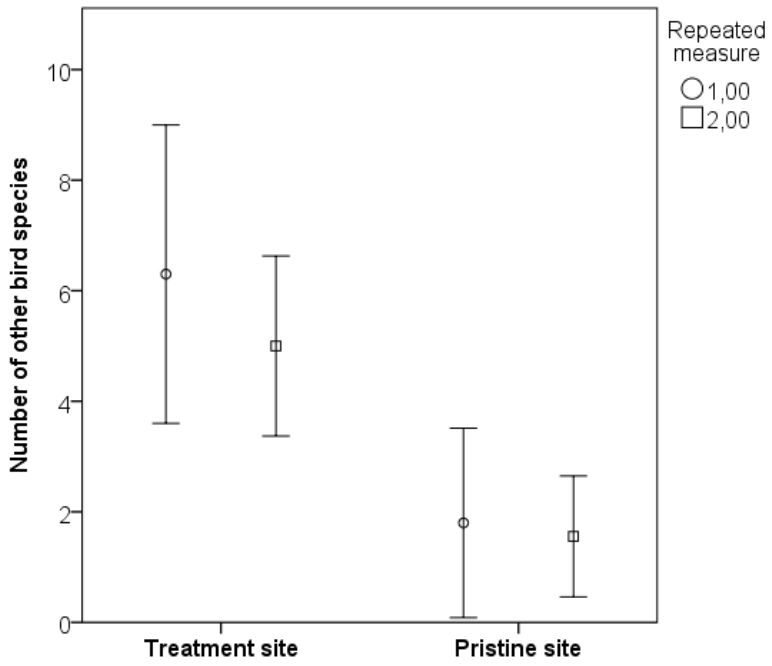

Figure 11. Number of other bird species in treatment sites and in pristine sites (error bars show 95% CI of mean).

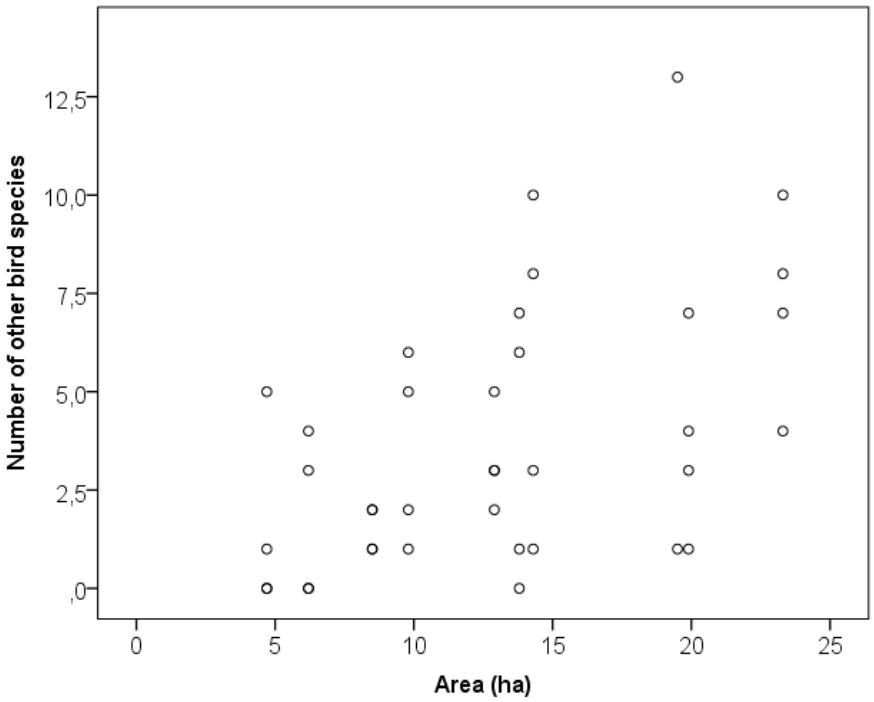

Figure 12. Number of other bird species in relation to area (ha).

Effect of restoration on abundance of other bird territories

Treatment and area had an effect on other bird species abundance, but repeated measure or interaction between repeated measure and treatment had no effect (Table 11). Treatment had such an effect that there were more other bird territories in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 8,908, SE = 2,086, df = 8,627, p = 0,002) (Figure 13). Area had such an effect that the number of territories increased with area (Estimate = 0,833, SE = 0,178) (Figure 14).

Table 11. Mixed model analysis for abundance of other bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	8,209	1,378	0,273
Treatment	1	8,627	18,237	0,002
Area (ha)	1	8,801	21,691	0,001
Repeated measure	1	9,209	2,914	0,121
Repeated measure*Treatment	1	9,225	1,737	0,219

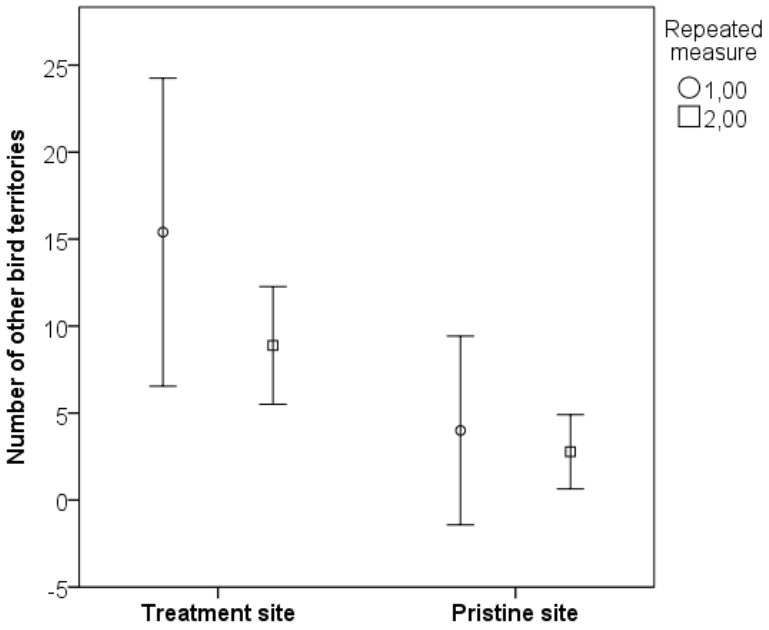

Figure 13. Number of other bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean).

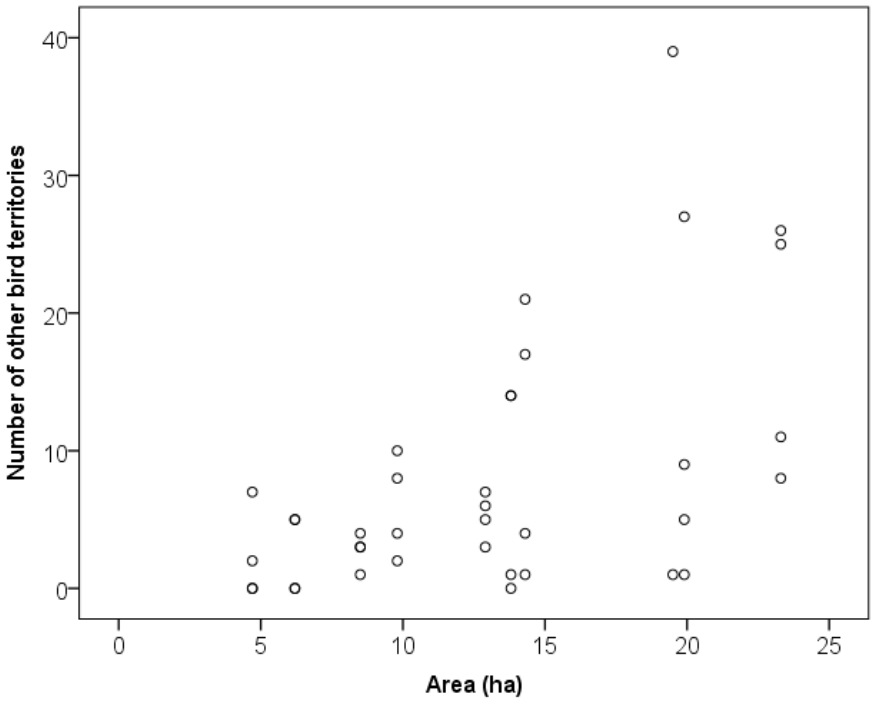

Figure 14. Number of other bird territories in relation to area (ha).

Effect of restoration on abundance of Golden Plover territories

Treatment had an effect on abundance of Golden Plover territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 12). Treatment had such an effect that there were more Golden Plover territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 1,000, SE = 0,327, df = 17,350, p = 0,007) (Figure 15).

Table 12. Mixed model analysis for abundance of Golden Plover territories

Source	Numerator df	Denominator df	F	p
Intercept	1	16,811	2,624	0,124
Treatment	1	17,350	9,359	0,007
Area (ha)	1	17,590	0,046	0,833
Repeated measure	1	18,389	1,775	0,199
Repeated measure*Treatment	1	18,393	0,000	1,000

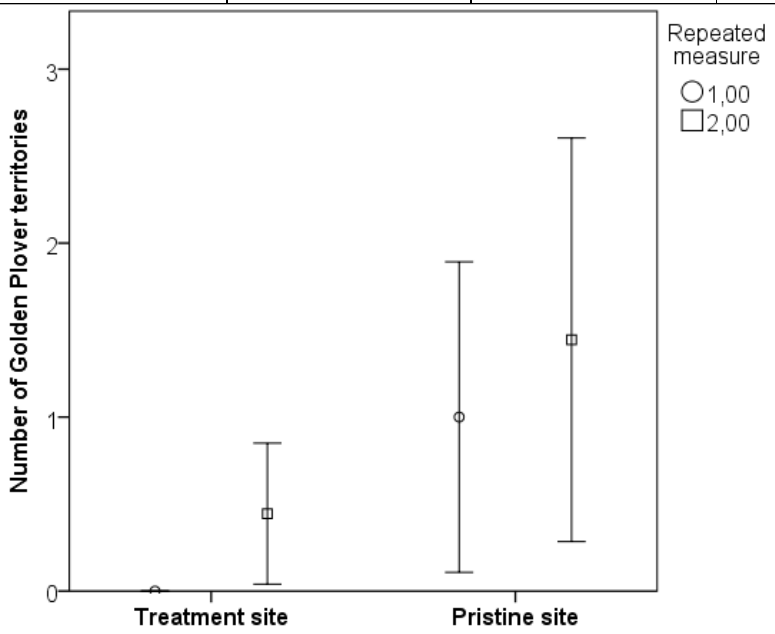

Figure 15. Number of Golden Plover (*Pluvialis apricaria*) territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of threatened mire birds

Treatment, area, repeated measure or interaction between treatment and repeated measure had no effect on species richness of threatened mire birds (Table 13).

Table 13. Mixed model analysis for species richness of threatened mire birds.

Source	Numerator df	Denominator df	F	p
Intercept	1	7,958	2,198	0,177
Treatment	1	8,125	2,419	0,158
Area (ha)	1	8,169	0,095	0,766
Repeated measure	1	15,944	2,664	0,122
Repeated measure*Treatment	1	16,339	1,526	0,234

Effect of restoration on abundance of territories of threatened mire birds

There tended to be an interaction between repeated measure and treatment, such that there were less threatened mire bird species in the pristine sites after restoration (Table 14, figure 16). Repeated measure had an effect on abundance of territories of threatened mire birds but treatment or area had no effect (Table 14). Repeated measure had such an effect that there were more threatened species during the first census.

Table 14. Mixed model analysis for abundance of territories of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,757	0,005	0,947
Treatment	1	8,602	3,011	0,118
Area (ha)	1	7,793	0,724	0,420
Repeated measure	1	15,453	4,663	0,047
Repeated measure*Treatment	1	15,471	3,196	0,093

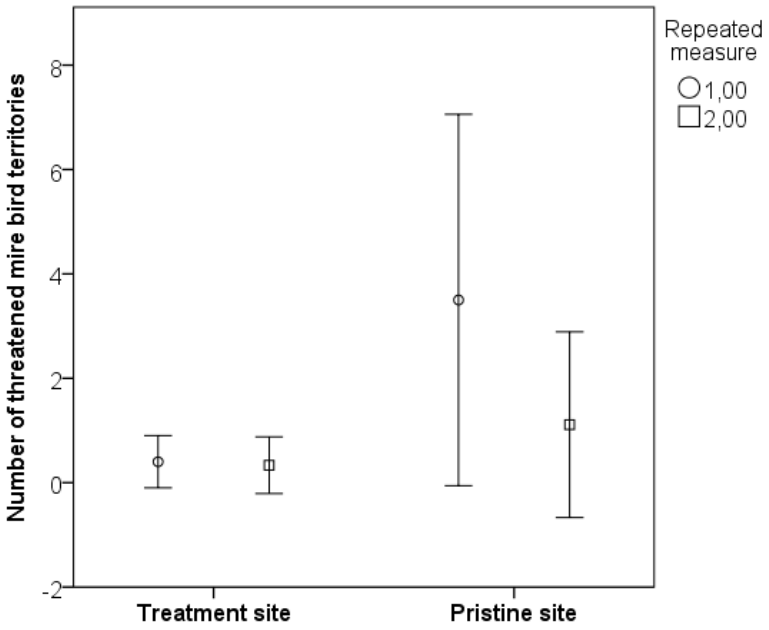

Figure 16. Number of threatened mire bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration (two censuses after restoration)

Effect of restoration on species richness of mire birds

Treatment had an effect on species richness of mire birds, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 15). Treatment had such an effect that there were more mire species in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 1,252, SE = 0,423, df = 8,811, p = 0,016) (Figure 17).

Table 15. Mixed model analysis for species richness of mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,100	6,961	0,033
Treatment	1	8,811	8,758	0,016
Area (ha)	1	7,401	0,033	0,862
Repeated measure	2	27,919	0,187	0,830
Repeated measure*Treatment	2	28,419	2,302	0,118

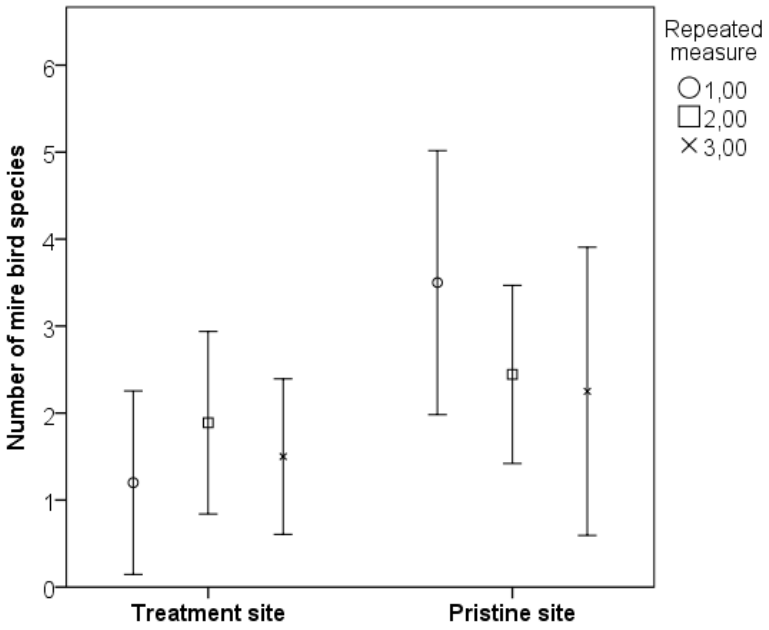

Figure 17. Number of mire bird species in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on abundance of mire bird territories

Treatment tended to have an effect on abundance of mire bird territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 16). There tended to be more mire bird territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 4,302, SE = 1,858, df = 7,683, p = 0,051) (Figure 18).

Table 16. Mixed model analysis for abundance of mire bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	7,310	0,639	0,449
Treatment	1	7,683	5,361	0,051
Area (ha)	1	7,419	0,588	0,467
Repeated measure	2	27,759	0,227	0,798
Repeated measure*Treatment	2	27,886	1,972	0,158

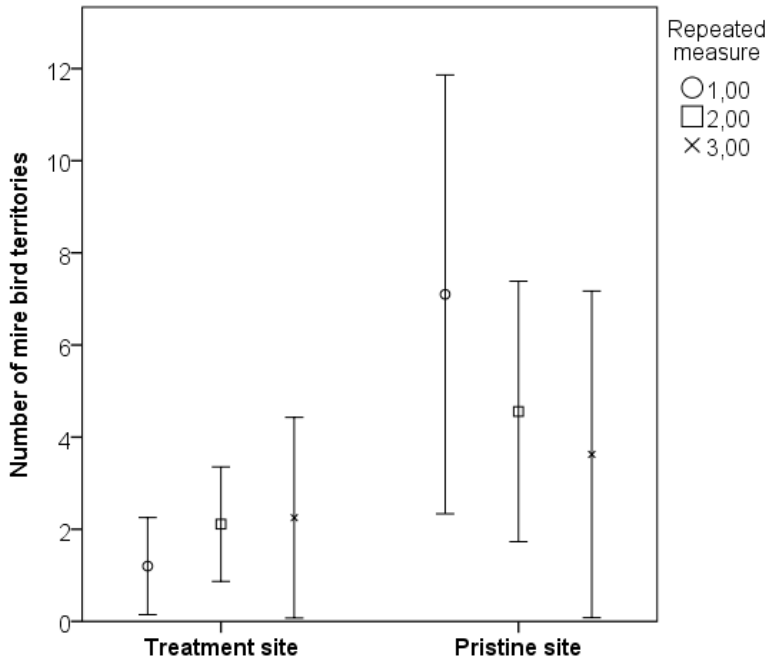

Figure 18. Number of mire bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of other birds

Treatment, area and repeated measure had an effect on species richness of other birds, but interaction between repeated measure and treatment had no effect (Table 17). Treatment had such an effect that there were more other bird species in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 4,150, SE = 0,579, df = 9,628, p < 0,001) (Figure 19). Species richness increased with area (Estimate = 0,349, SE = 0,066) (Figure 20). There were no difference in species richness between the first and second census (Pairwise LSD comparison, MD = 0,512, SE = 0,690, df = 22,651, p = 0,466), but there were more species during the third census period in comparison to first (Pairwise LSD comparison, MD = 2,850, SE = 0,718, df = 40,035, p = < 0,001) and second census (Pairwise LSD comparison, MD = 3,361, SE = 0,728, df =22,985, p < 0,001) (Figure 21).

Table 17. Mixed model analysis for species richness of other birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,247	0,044	0,840
Treatment	1	9,628	51,311	< 0,001
Area (ha)	1	7,625	27,804	0,001
Repeated measure	2	29,396	12,157	< 0,001
Repeated measure*Treatment	2	29,508	0,374	0,691

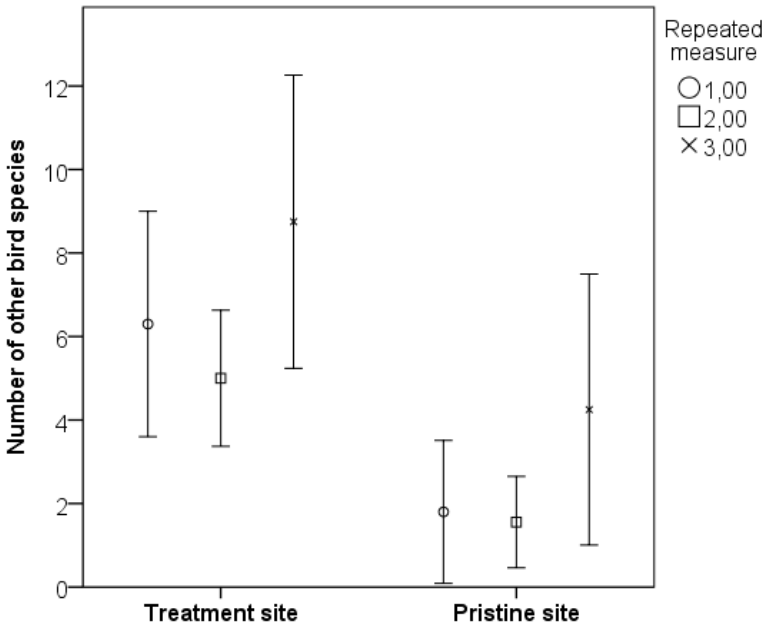

Figure 19. Number of other species in treatment sites and in pristine sites (error bars show 95% CI of mean)

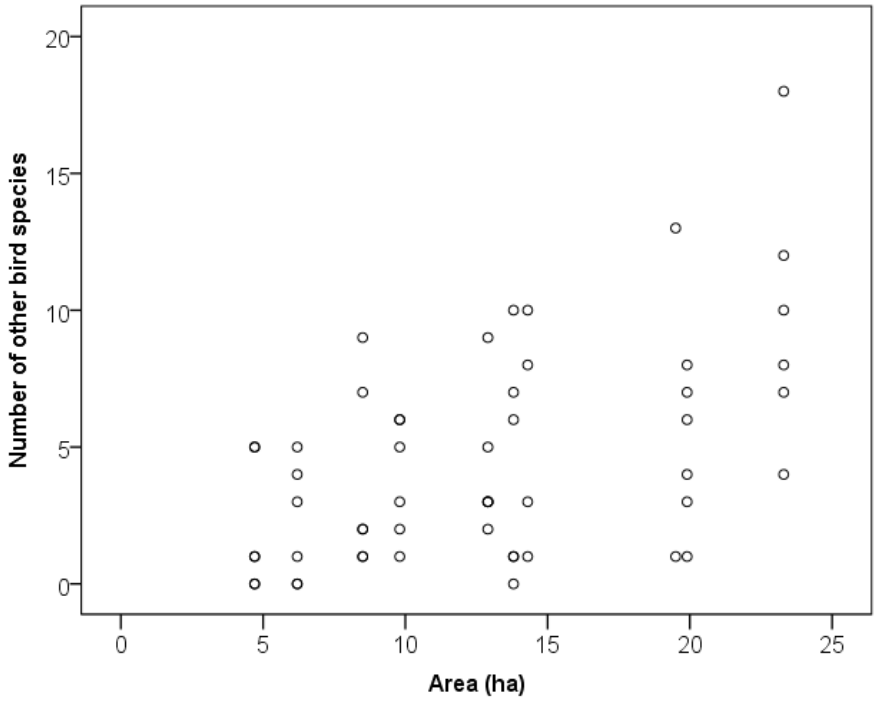

Figure 20. Number of other bird species in relation to area (ha).

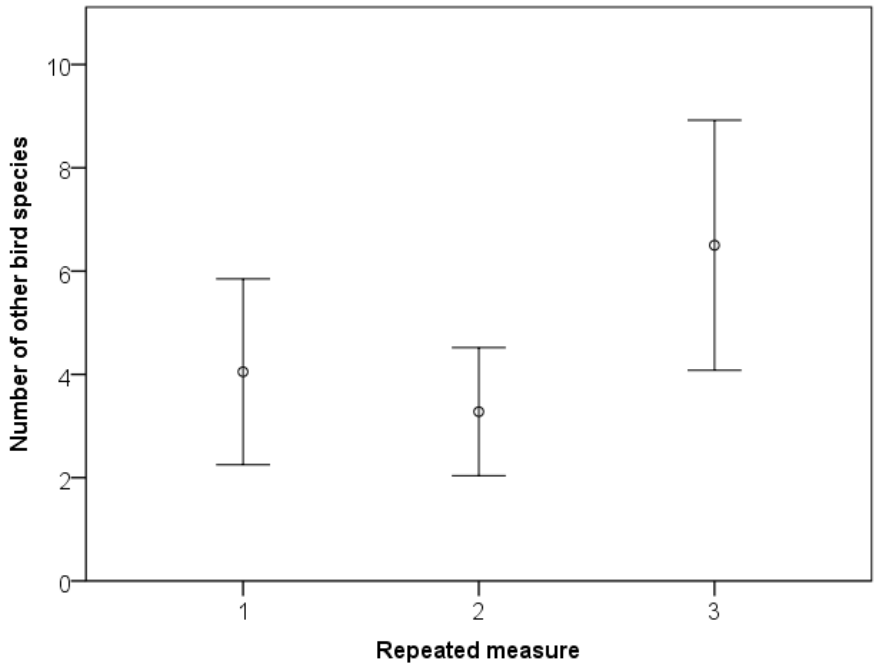

Figure 21. Number of other bird species (error bars show 95% CI of mean)

Effect of restoration on abundance of other bird territories

Treatment, area and repeated measure had an effect on other bird territory abundance, but interaction between repeated measure and treatment had no effect (Table 18). Treatment had such an effect that there were more other bird territories in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 9,371 SE = 1,562, df = 10,324, p < 0,001) (Figure 22). Area had such an effect that number of territories increased with area (Estimate = 0,914, SE = 0,132) (Figure 23). There tended to be more other bird territories during the third census than during the first (Pairwise LSD comparison, MD = 3,685, SE = 1,927, df = 46,882, p = 0,062) or the second (Pairwise LSD comparison, MD = 6,924, SE = 1,977, df = 16,703, p = 0,003) but there was no difference between first and second census (Pairwise LSD comparison, MD = 3,239, SE = 1,871, df = 16,526, p = 0,102) (Figure 24).

Table 18. Mixed model analysis for abundance of other bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	9,697	1,543	0,243
Treatment	1	10,324	36,013	< 0,001
Area (ha)	1	10,119	48,153	< 0,001
Repeated measure	2	23,884	6,136	0,007
Repeated measure*Treatment	2	23,913	1,134	0,338

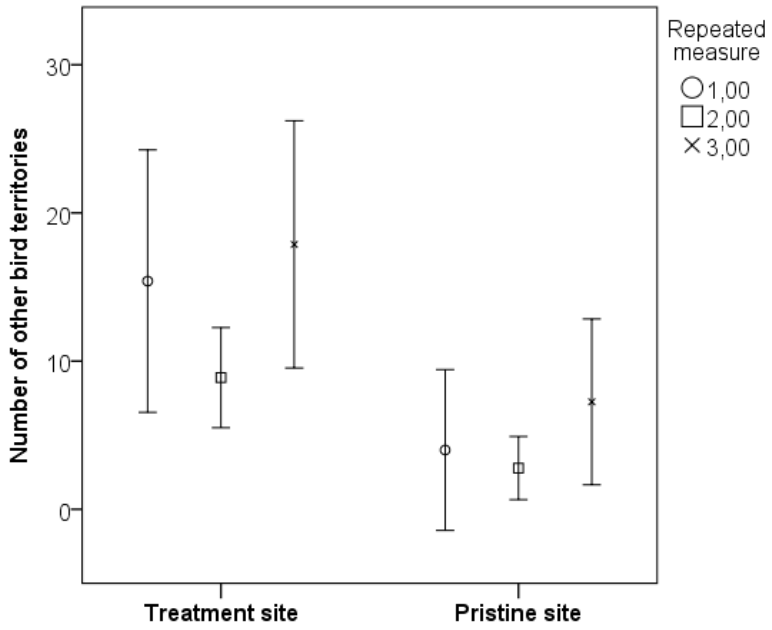

Figure 22. Number of other bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

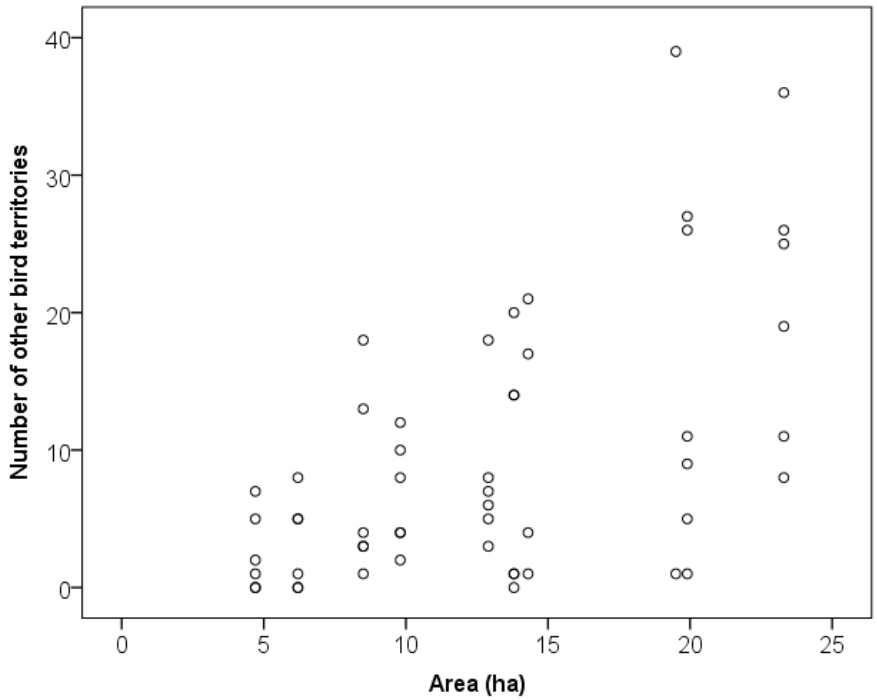

Figure 23. Number of other bird territories in relation to area (ha)

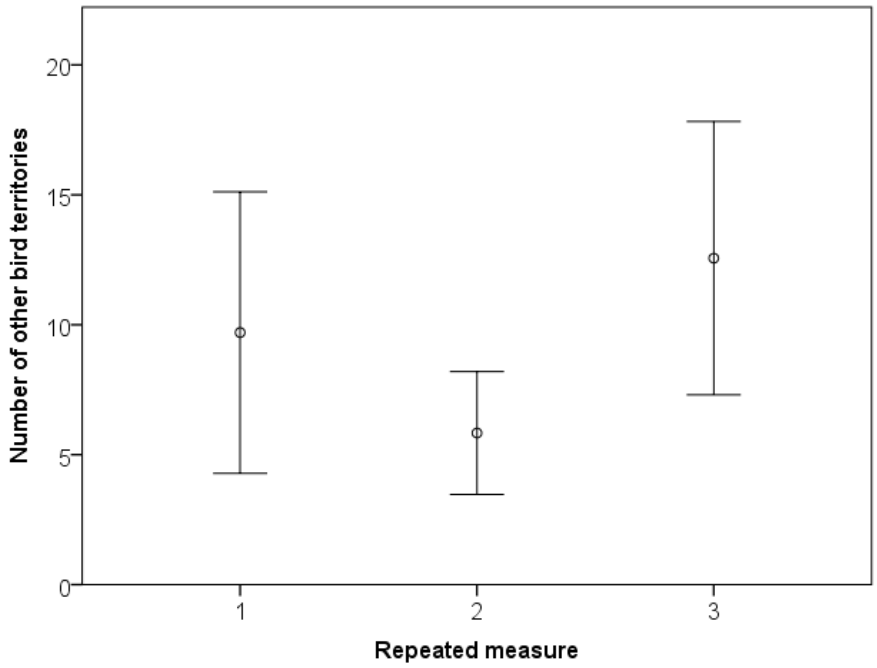

Figure 24. Number of other bird territories (error bars show 95% CI of mean)

Effect of restoration on abundance of Golden Plover territories

Treatment had an effect on abundance of Golden Plover territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 19). Treatment had such an effect that there were more Golden Plover territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 1,027, SE = 0,333, df = 10,348, p = 0,011) (Figure 25).

Table 19. Mixed model analysis for abundance of Golden Plover territories

Source	Numerator df	Denominator df	F	p
Intercept	1	7,084	2,386	0,166
Treatment	1	10,348	9,513	0,011
Area (ha)	1	7,424	0,041	0,846
Repeated measure	2	32,602	1,491	0,240
Repeated measure*Treatment	2	32,129	0,012	0,988

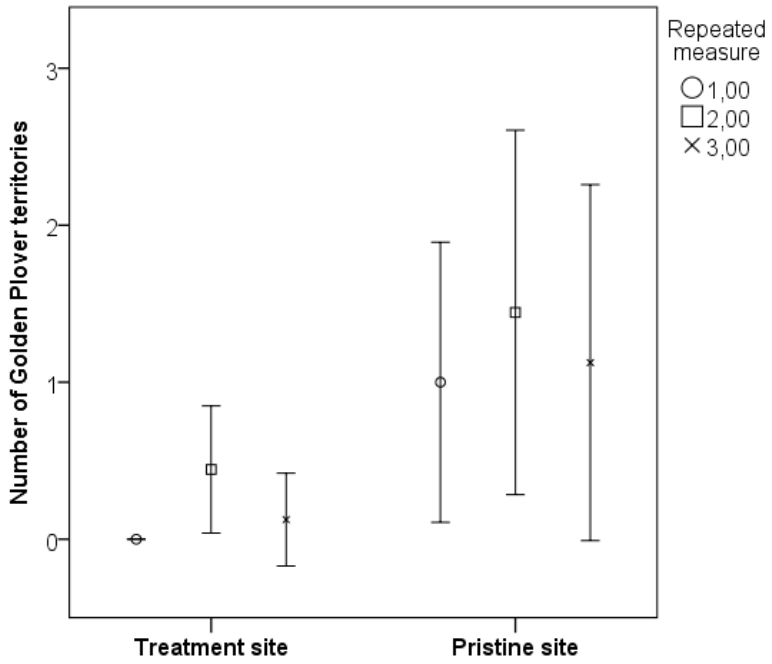

Figure 25. Number of Golden Plover (*Pluvialis apricaria*) territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of threatened mire birds

Treatment tended to have an effect on species richness of threatened mire birds, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 20). There tended to be more threatened species in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 0,378, SE = 0,197, df = 7,750, p = 0,092) (Figure 26).

Table 20. Mixed model analysis for species richness of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,538	1,520	0,255
Treatment	1	7,750	3,695	0,092
Area (ha)	1	7,759	0,030	0,868
Repeated measure	2	27,186	2,340	0,115
Repeated measure*Treatment	2	27,776	1,058	0,361

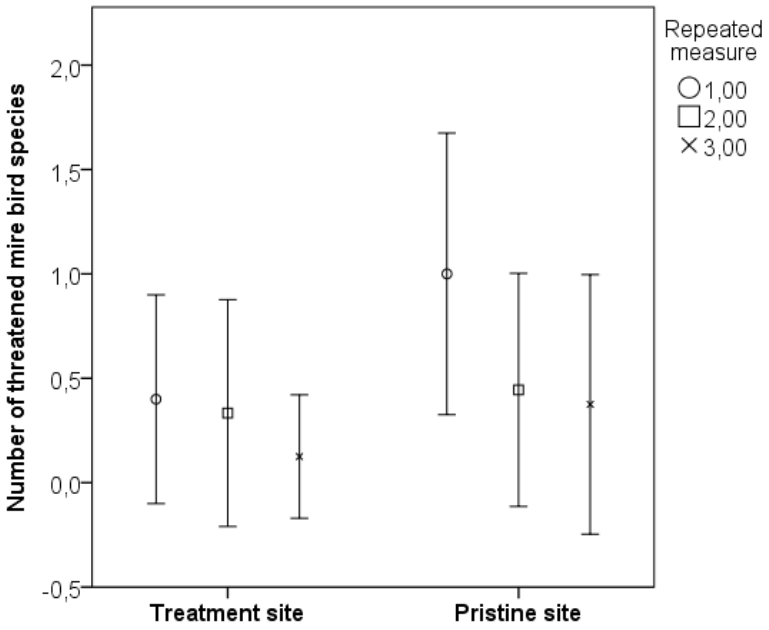

Figure 26. Number of threatened mire bird species in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on abundance of territories of threatened mire birds

Interaction between repeated measure and treatment tended to have an effect on abundance of territories of threatened mire birds. Interaction was such that there was a tendency that there were less territories in the pristine sites after restoration (Figure 27). Repeated measure had an effect on abundance of territories of threatened mire birds, but treatment or area had no effect (Table 21). There were more territories during the first census than during the second (Pairwise LSD comparison, MD = 0,574, SE = 0,205, df = 29,447, p = 0,009) or the third (Pairwise LSD comparison, MD = 0,716, SE = 0,296, df = 30,481, p = 0,022) but there was no difference between second and third census (Pairwise LSD comparison, MD = 0,143, SE = 0,217, df = 29,523, p = 0,516)(Figure 28).

Table 21. Mixed model analysis for abundance of territories of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,720	0,000	0,990
Treatment	1	8,651	2,811	0,129
Area (ha)	1	7,753	0,770	0,407
Repeated measure	2	29,477	4,180	0,025
Repeated measure*Treatment	2	29,494	2,701	0,084

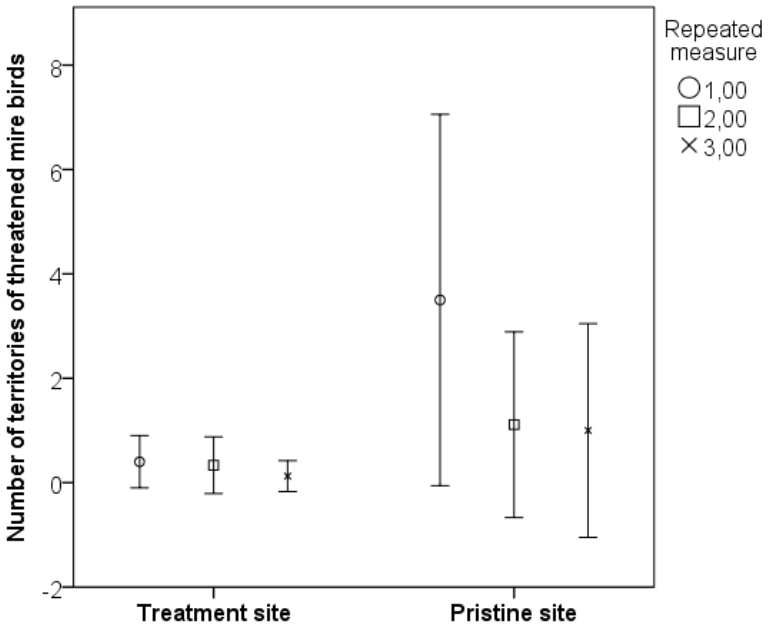

Figure 27. Number of territories of threatened mire birds in treatment sites and in pristine sites (error bars show 95% CI of mean)

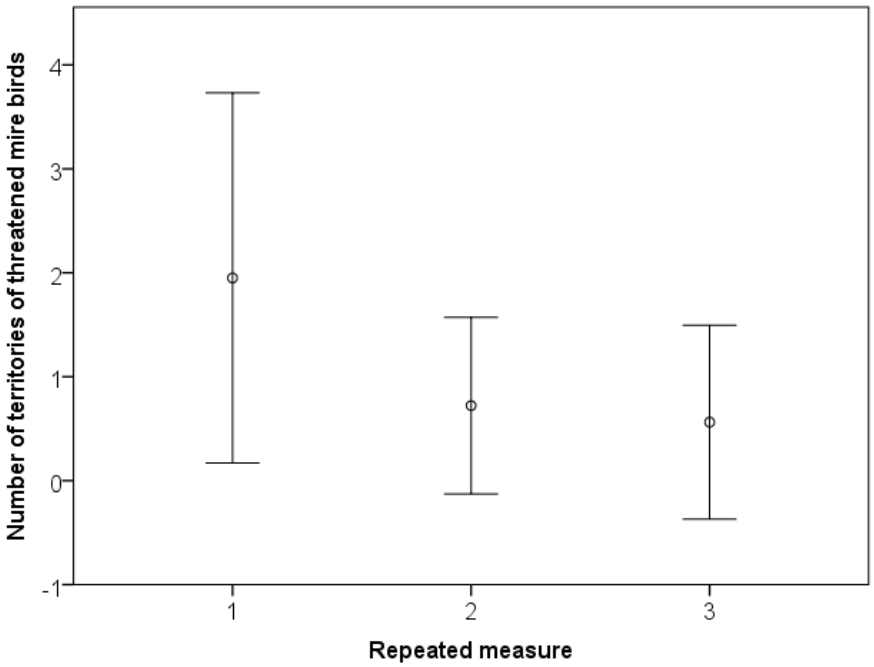

Figure 28. Number of territories of threatened mire birds (error bars show 95% CI of mean)

Effect of restoration on species richness of mire birds

Treatment had an effect on species richness of mire birds, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 22). Treatment had such an effect that there tended to be more mire species in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 1,163, SE = 0,428, df = 11,567, p = 0,019) (Figure 29).

Table 22. Mixed model analysis for species richness of mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,174	5,726	0,047
Treatment	1	11,567	7,382	0,019
Area (ha)	1	7,897	0,000	0,998
Repeated measure	2	33,275	0,123	0,946
Repeated measure*Treatment	2	33,120	1,640	0,199

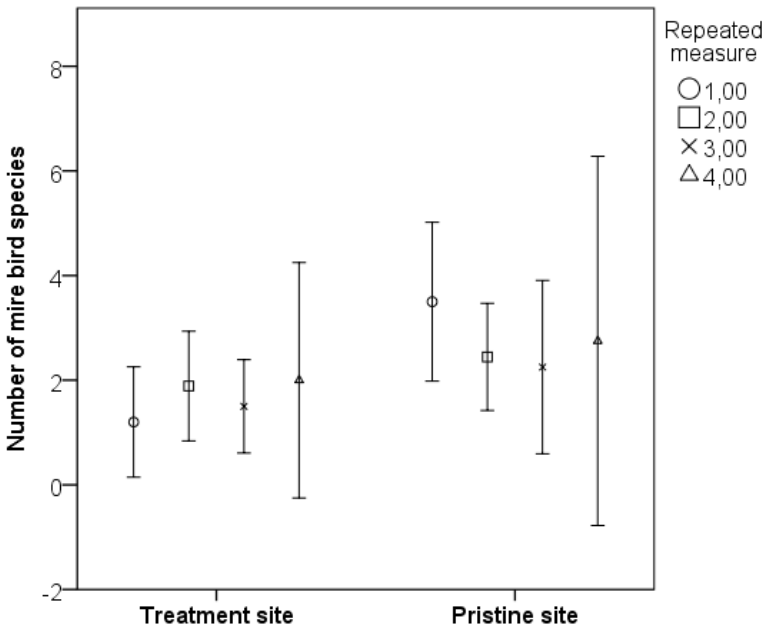

Figure 29. Number of mire bird species in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on abundance of mire bird territories

Treatment tended to have an effect on abundance of mire bird territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 23). There tended to be more mire bird territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 3,876, SE = 1,779, df = 7,611, p = 0,063) (Figure 30).

Table 23. Mixed model analysis for abundance of mire bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	7,191	0,489	0,507
Treatment	1	7,611	4,744	0,063
Area (ha)	1	7,544	0,683	0,434
Repeated measure	2	33,806	0,234	0,872
Repeated measure*Treatment	2	34,202	1,441	0,248

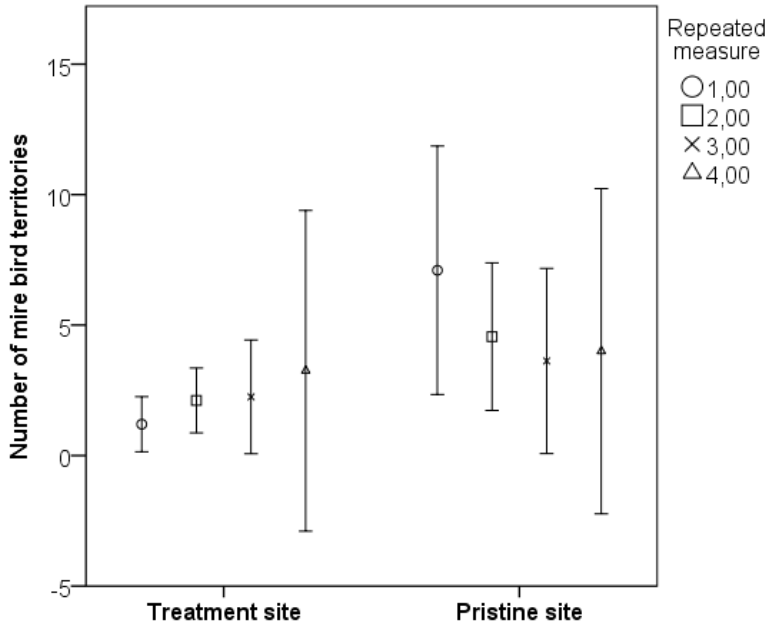

Figure 30. Number of mire bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of other birds

Treatment, area and repeated measure had an effect on species richness of other birds, but interaction between repeated measure and treatment had no effect (Table 24). Treatment had such an effect that there were more other bird species in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 4,335, SE = 0,649, df = 10,518, $p < 0,001$) (Figure 31). Species richness increased with area (Estimate = 0,367, SE = 0,062) (Figure 32). There were differences in species richness between censuses (Table 25, Figure 33).

Table 24. Mixed model analysis for species richness of other birds

Source	Numerator df	Denominator df	F	p
Intercept	1	5,645	0,027	0,875
Treatment	1	10,518	44,682	< 0,001
Area (ha)	1	7,020	34,955	0,001
Repeated measure	2	32,486	9,014	< 0,001
Repeated measure*Treatment	2	31,401	0,259	0,855

Table 25. Pairwise comparisons (LSD) between censuses

Comparison	MD	SE	df	p
1 vs. 2	0,497	0,634	28,387	0,439
1 vs. 3	-2,856	0,714	47,107	< 0,001
1 vs. 4	-1,549	0,926	47,874	0,101
2 vs. 3	-3,353	0,670	28,332	< 0,001
2 vs. 4	-2,046	0,924	49,307	0,031
3 vs. 4	1,307	0,887	36,326	0,149

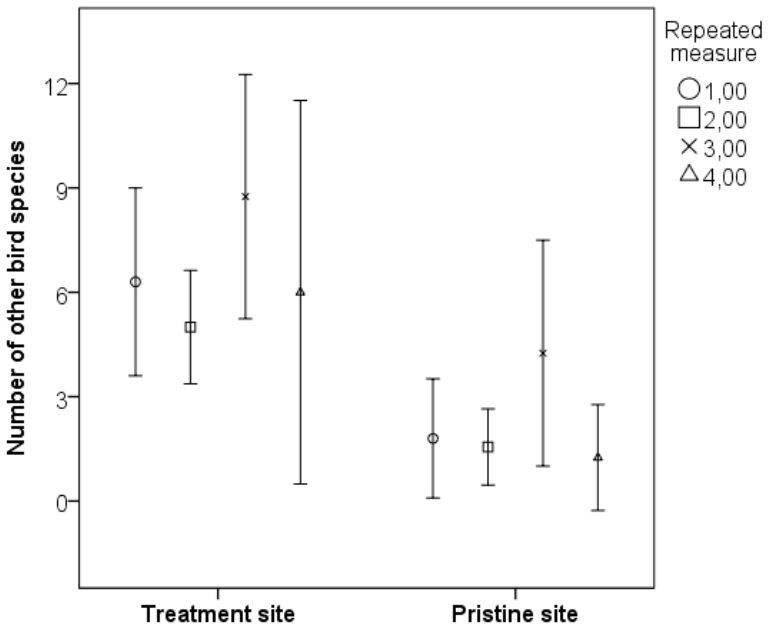

Figure 31. Number of other species in treatment sites and in pristine sites (error bars show 95% CI of mean)

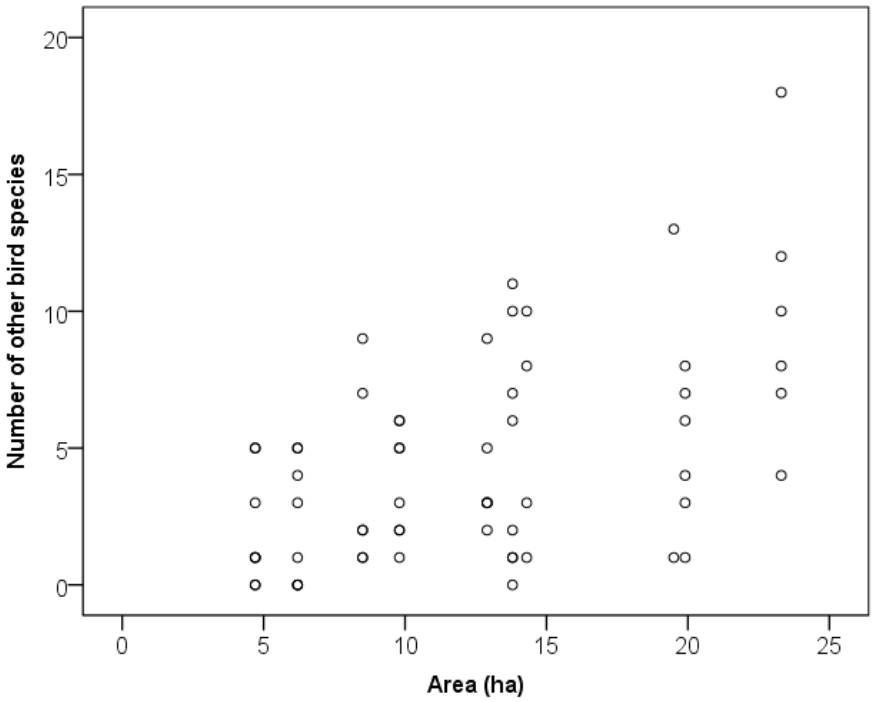

Figure 32. Number of other bird species in relation to area (ha).

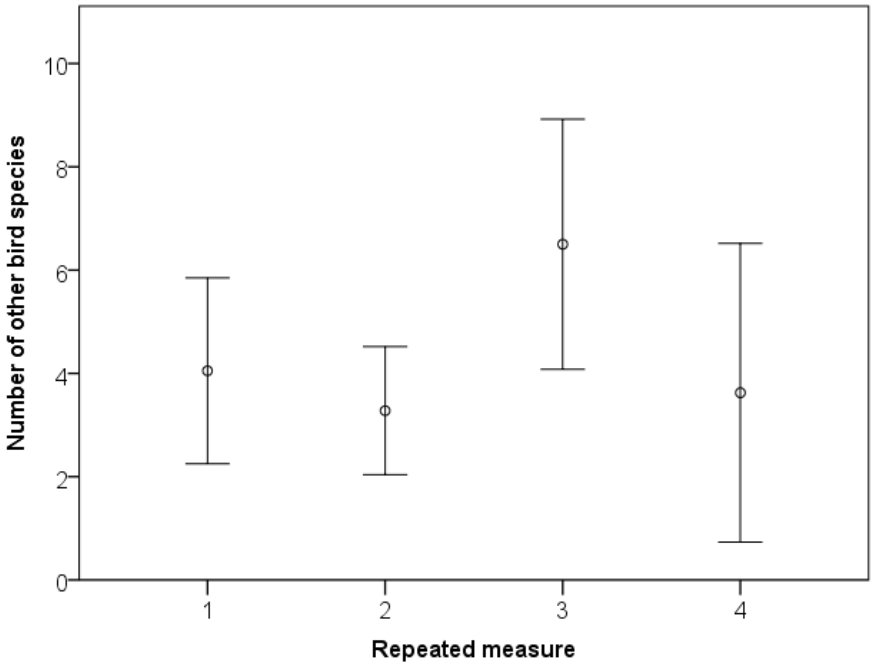

Figure 33. Number of other bird species (error bars show 95% CI of mean)

Effect of restoration on abundance of other bird territories

Treatment, area and repeated measure had an effect on other bird species abundance, but interaction between repeated measure and treatment had no effect (Table 26). Treatment had such an effect that there were more other bird territories in the treatment sites than in the pristine sites (Pairwise LSD comparison, MD = 10,186, SE = 1,796, df = 12,934, p = < 0,001) (Figure 34). Area had such an effect that number of territories increased with area (Estimate = 1,002, SE = 0,151) (Figure 35). Differences between censuses are in table 27 (Figure 36).

Table 26. Mixed model analysis for abundance of other bird territories

Source	Numerator df	Denominator df	F	p
Intercept	1	10,312	1,861	0,202
Treatment	1	12,934	32,162	< 0,001
Area (ha)	1	12,122	44,078	< 0,001
Repeated measure	2	28,568	5,288	0,005
Repeated measure*Treatment	2	28,664	0,829	0,489

Table 27. Pairwise comparisons (LSD) between censuses

Comparison	MD	SE	df	p
1 vs. 2	3,072	1,681	23,936	0,080
1 vs. 3	-3,875	1,916	52,065	0,048
1 vs. 4	-2,648	2,481	52,792	0,291
2 vs. 3	-6,947	1,776	23,783	0,001
2 vs. 4	-5,720	2,469	51,402	0,025
3 vs. 4	1,227	2,349	32,149	0,605

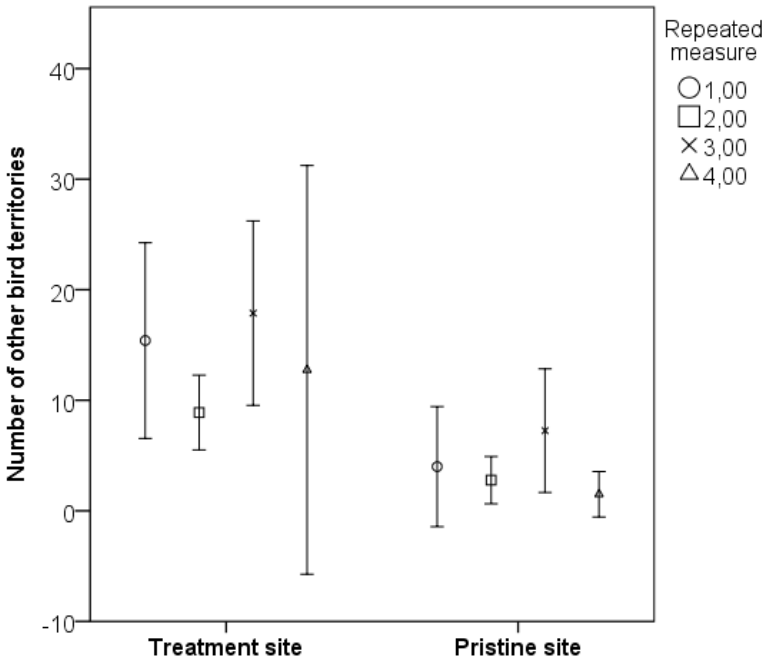

Figure 34. Number of other bird territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

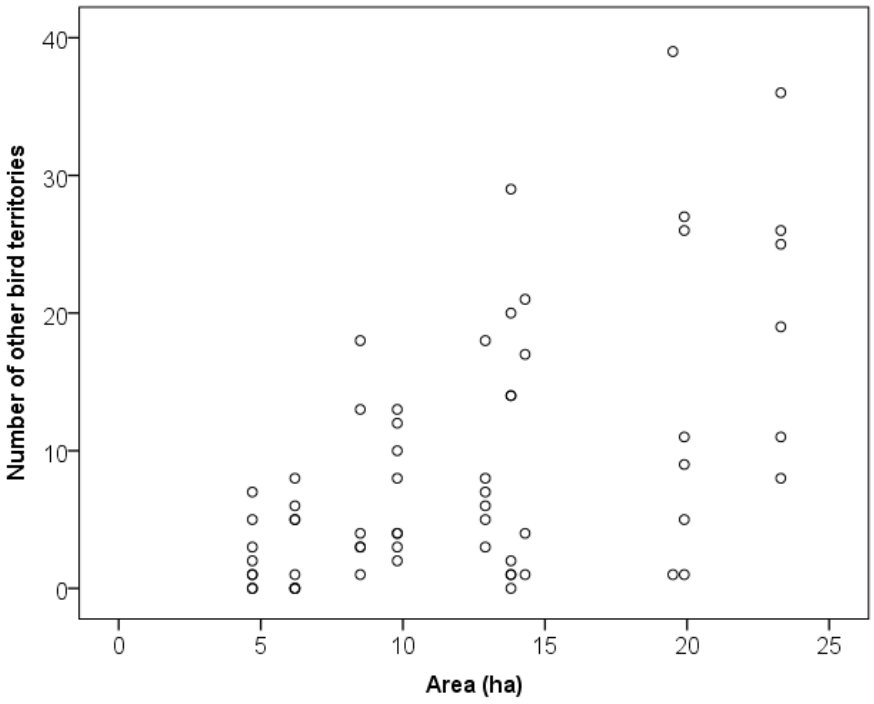

Figure 35. Number of other bird territories in relation to area (ha)

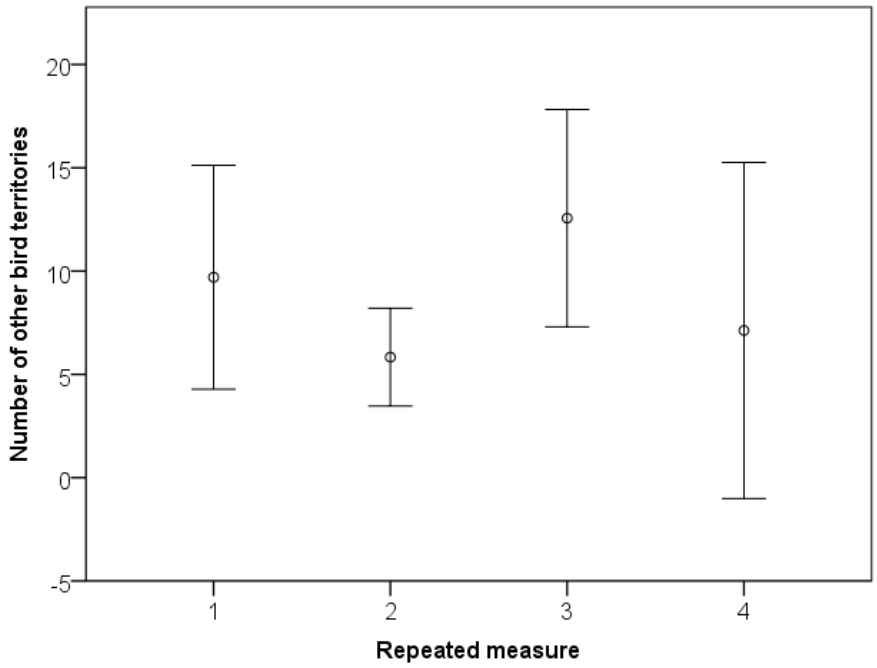

Figure 36. Number of other bird territories (error bars show 95% CI of mean)

Effect of restoration on abundance of Golden Plover territories

Treatment had an effect on abundance of Golden Plover territories, but area, repeated measure or interaction between repeated measure and treatment had no effect (Table 28). Treatment had such an effect that there were more Golden Plover territories in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 0,927, SE = 0,319, df = 10,135, p = 0,015) (Figure 37).

Table 28. Mixed model analysis for abundance of Golden Plover territories

Source	Numerator df	Denominator df	F	p
Intercept	1	6,193	2,081	0,198
Treatment	1	10,135	8,457	0,015
Area (ha)	1	7,723	0,011	0,920
Repeated measure	2	36,780	1,519	0,226
Repeated measure*Treatment	2	35,244	0,146	0,932

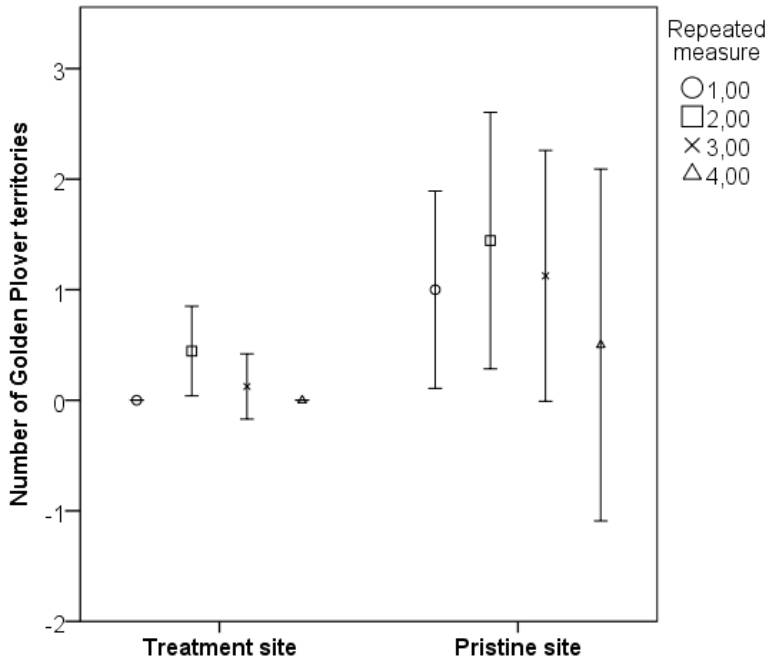

Figure 37. Number of Golden Plover (*Pluvialis apricaria*) territories in treatment sites and in pristine sites (error bars show 95% CI of mean)

Effect of restoration on species richness of threatened mire birds

Treatment and repeated measure tended to have an effect on species richness of threatened mire birds, but area or interaction between repeated measure and treatment had no effect (Table 29). There tended to be more threatened species in the pristine sites than in the treatment sites (Pairwise LSD comparison, MD = 0,473, SE = 0,219, df = 8,297, p = 0,062) (Figure 34). Differences between censuses are in table 30 (Figure 39).

Table 29. Mixed model analysis for species richness of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,713	1,166	0,313
Treatment	1	8,297	4,658	0,062
Area (ha)	1	8,212	0,000	0,994
Repeated measure	2	31,737	2,356	0,091
Repeated measure*Treatment	2	31,981	0,861	0,472

Table 30. Pairwise comparisons (LSD) between censuses

Comparison	MD	SE	df	p
1 vs. 2	0,284	0,148	30,554	0,064
1 vs. 3	0,346	0,187	46,005	0,071
1 vs. 4	-0,068	0,251	46,088	0,787
2 vs. 3	0,062	0,156	30,927	0,697
2 vs. 4	-0,352	0,241	45,361	0,150
3 vs. 4	-0,414	0,215	35,709	0,063

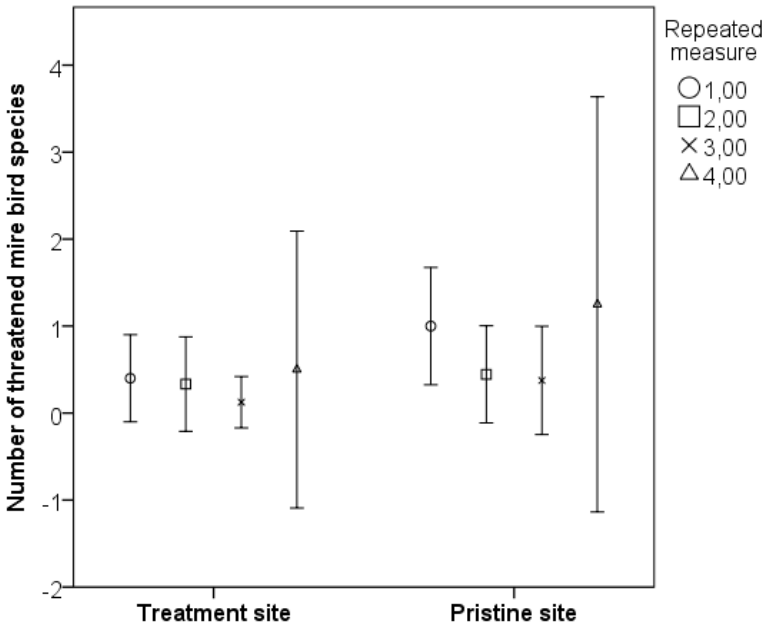

Figure 38. Number of threatened mire bird species treatment sites and in pristine sites (error bars show 95% CI of mean)

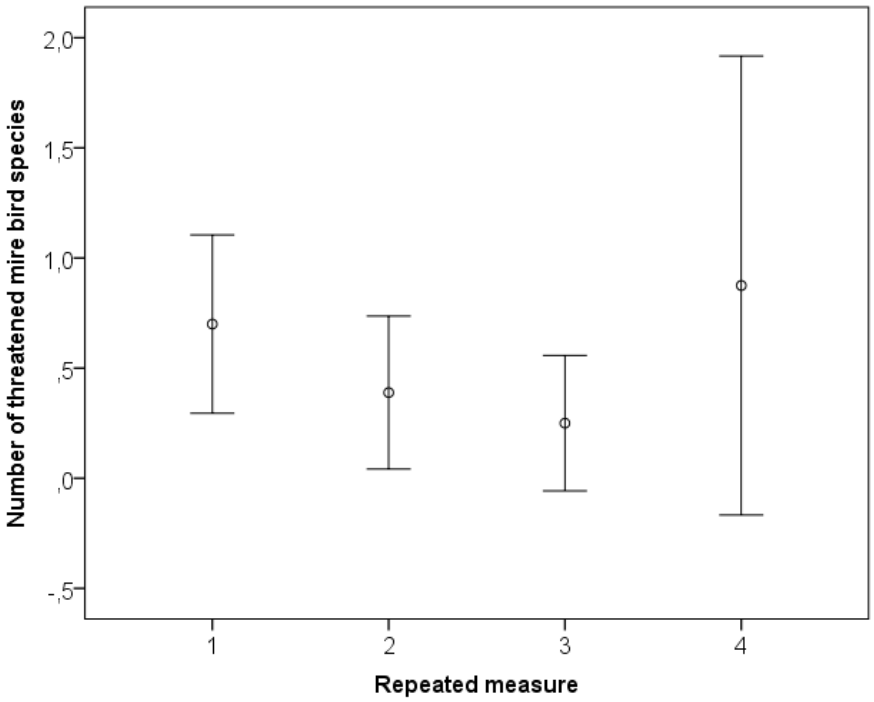

Figure 39. Number of threatened mire bird species (error bars show 95% CI of mean)

Effect of restoration on abundance of territories of threatened mire birds

Repeated measure had an effect on abundance of territories of threatened mire birds (Figure 40, table 32). Treatment, area or interaction between repeated measure and treatment had no effect (Table 31).

Table 31. Mixed model analysis for abundance of territories of threatened mire birds

Source	Numerator df	Denominator df	F	p
Intercept	1	7,687	0,002	0,968
Treatment	1	8,626	2,648	0,137
Area (ha)	1	7,794	0,821	0,392
Repeated measure	2	35,458	3,367	0,029
Repeated measure*Treatment	2	35,577	1,927	0,143

Table 32. Pairwise comparisons (LSD) between censuses

Comparison	MD	SE	df	p
1 vs. 2	0,572	0,202	35,347	0,008
1 vs. 3	0,713	0,292	36,592	0,019
1 vs. 4	0,325	0,416	37,288	0,441
2 vs. 3	0,141	0,214	35,432	0,514
2 vs. 4	-0,248	0,368	36,419	0,505
3 vs. 4	-0,389	0,302	35,617	0,206

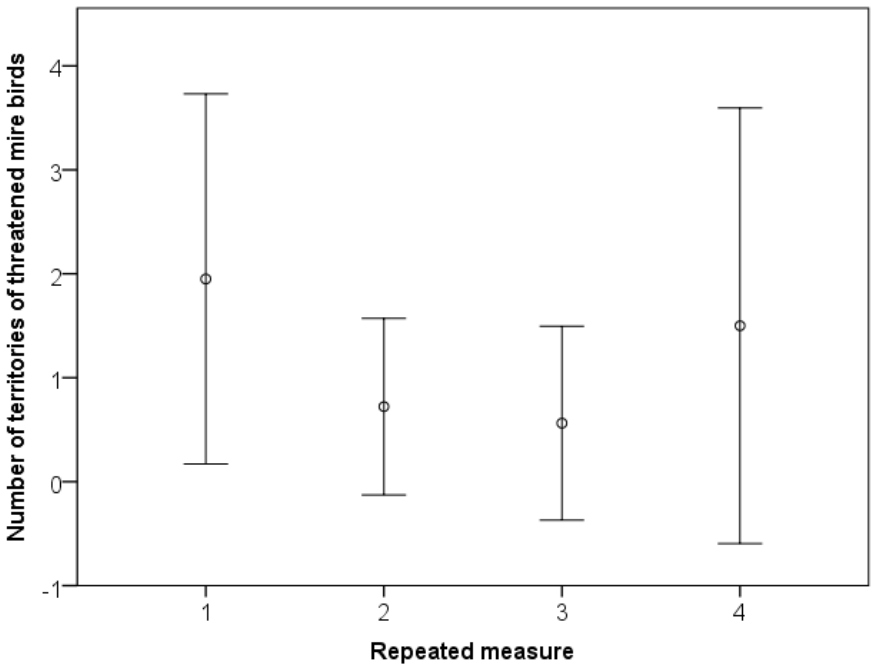

Figure 40. Number of territories of threatened mire birds (error bars show 95% CI of mean)

Discussion

Our results show, that pristine sites had more mire bird species and territories than treatment sites, both before and after restoration operations. In other birds, there were more species in treatment sites before restoration. In the situation after restoration, both other species richness and territory abundance were higher in treatment sites. However, before restoration in any of the groups studied, there were no differences between undrained treatment sites and drained treatment sites to be restored. This result shows how pristine state can be diminished by the drainage, which has been targeted to adjacent area.

When analyzing the effects of restoration after first year, there tended to be an interaction between repeated measure and treatment: species richness of mire birds increased in restored sites and declined in pristine sites. In threatened mire bird species, number of territories tended to decline in pristine sites.

These results may indicate that some mire birds moved from pristine sites to nearby restored sites, but this can also be due to natural fluctuation in species richness. The latter option is supported by the fact that when next census was included into the model, tendency for interaction in mire bird species disappeared. In threatened mire birds territories, this interaction changed into a tendency and after fourth census it disappeared. Our results show that difference in mire bird territory abundance between pristine sites and treatment sites was not significant but only a tendency after second census after restoration was taken into the model. This may indicate that restored habitats slowly change towards more pristine-like.

In other birds, variation in species richness and territory abundance between years could be seen when three or more censuses were included into the model. Variation between years can be seen also in threatened species: difference in territory abundances between censuses was evident already after second census. Before restoration there were no difference in territory abundance of other species between treatment sites and pristine sites, but afterwards there were more territories in the treatment sites. This may be due to temporary changes in restored habitat e.g. formation of logging waste and revelation of peat surface, which increases favorable nesting places.

Abundance and species richness of other birds increased with area, but this universal ecological pattern was not detected in mire birds. This is because most mire birds in our study are specialized into open wet areas and number of mire bird territories and species was low in drained sites. Other birds in our study are mainly common forest species that can use various habitat types.

The theme species Golden Plover (*Pluvialis apricaria*) was missing in all treatment sites before restoration, but was observed during first census after restoration in 4 sites out of 10 (in pristine sites species was observed in 7 of 10 sites). In southern parts of Finland this species is most commonly observed in open mire areas, but it is missing from wide continuous area in interior parts of southern Finland due to lack of suitable breeding habitat (Valkama et al. 2011). Golden Plover has northern distribution like most mire birds in our study (8 of 12) (Valkama et al. 2011, Virkkala & Rajasärkkä 2011) and southern populations are those that need most conservation attention.

Mire birds seemed to colonize restored mires right after restoration. Even though our results are promising we have no knowledge of the breeding success of mire birds or their invertebrate prey abundance after restoration. The production of offspring of mire birds relies largely on the short-duration peak of biomass production of non-biting midges (Chironomidae) on flarks and other open water pools (Luonnontila.fi 2013). Also crane flies (Diptera: Tipulidae) are vital component of the diet of many of the birds associated with peatland ecosystems (Park et al. 2001, Buchanan et al. 2006, Pearce-Higgins 2010). In a study of crane flies (Diptera, Nematocera: Limoniidae, Pediciidae, Tipulidae and Cylindrotomidae) in restored mires (Autio 2008), abundance of crane flies was lower in restored sites than in pristine sites about 3 years after restoration. It may take some time after restoration before invertebrate pray abundance returns near to the level of pristine state mire.

It has been stated (Rajasärkkä et al. 2013) that restoration has only local effects on birds, because restoration is small scaled in comparison to changes after wide-ranging peatland drainage. Overall there are very few studies of the effects of restoration on mire birds (Rajasärkkä 2013). Most of previous studies have been so small scaled, that reliable results could not be reached. There has been only one other large

census data on Finnish mire birds, that was collected in Seitseminen National Park, where 1 100 hectares of mires have been restored (Rajasärkkä et al. 2013). In Seitseminen, large scale restoration increased total abundance of mire birds (between 1980's and 2002), but could not prevent decline of *Motacilla flava* (nationally Near Threatened, Rassi et al. 2010), that has declined in the whole country. Rajasärkkä et al. (2013) suggest that restored mires can act as breeding patches that slow down the loss of species at the local level and if the amount of suitable habitat for these species increases in the future, species can spread from these patches. Conservation strategies under climate change emphasize the importance of protected area network (Kharouba & Kerr 2010, Ervin 2011) and if southern populations of many mire species will finally disappear, conservation and management of southern populations still may provide benefit by increasing the number of potential colonizers for sites further north. Most of the protected mires in Finland are in Northern parts of Finland (Virkkala et al. 2000) and to complete Natura 2000 network, this Boreal Peatland Life-project has given a special attention to Central Finland, where most peatlands have been affected by drainage schemes. Short term results are promising, but to verify the success of restoration on mire birds, monitoring should be continued.

Conclusions:

Drainage is a serious threat to Finnish mire birds. In Boreal Peatland Life-project, valuable mire areas in Natura 2000 network have been restored and monitored to evaluate the success of restoration. Our unique census data on mire birds revealed that in the drained sites, abundance and species diversity of mire birds was lower than in the pristine sites. The number of mire bird species tended to increase in restored sites right after restoration. To increase the knowledge about the long term effects of restoration monitoring should be continued. Changes after historical wide-ranging peatland drainage may not be overturned, but under many mire bird species, restored mires can act as breeding patches that slow down the loss of species at the local level.

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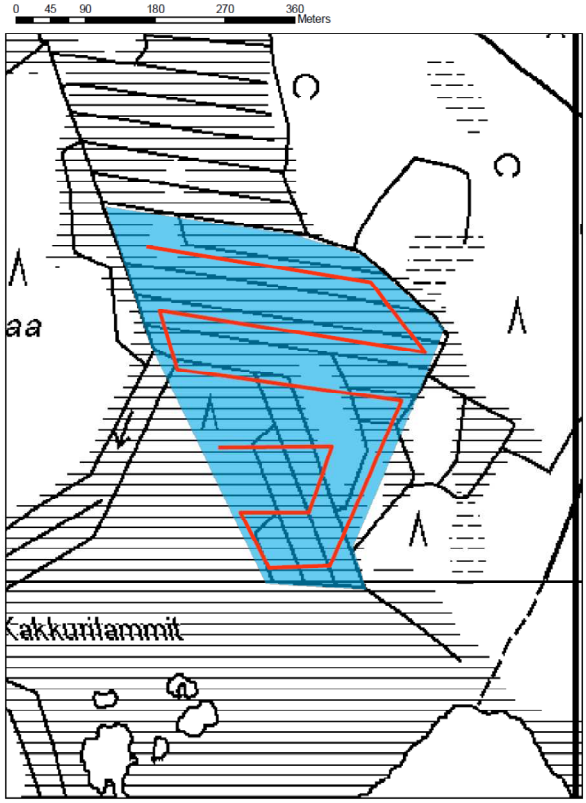
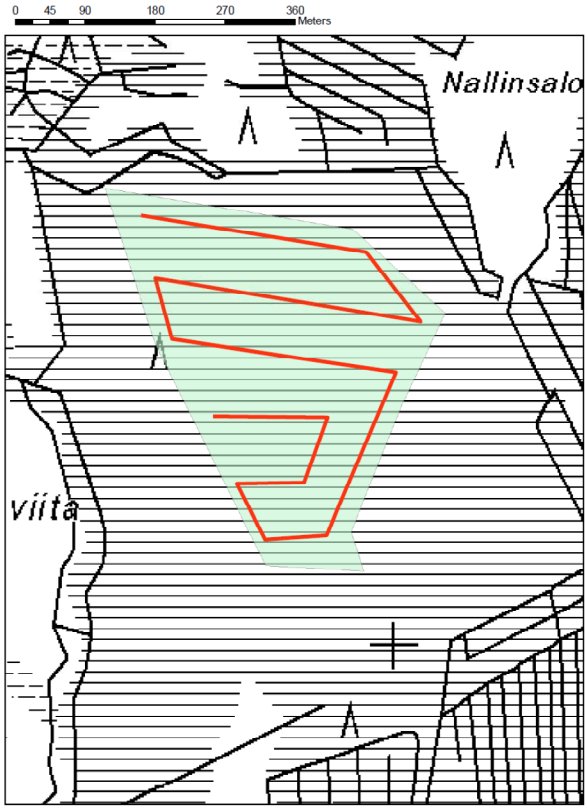
Appendix 1. Treatment site (above) and pristine site with transect line in Haapakeidas.

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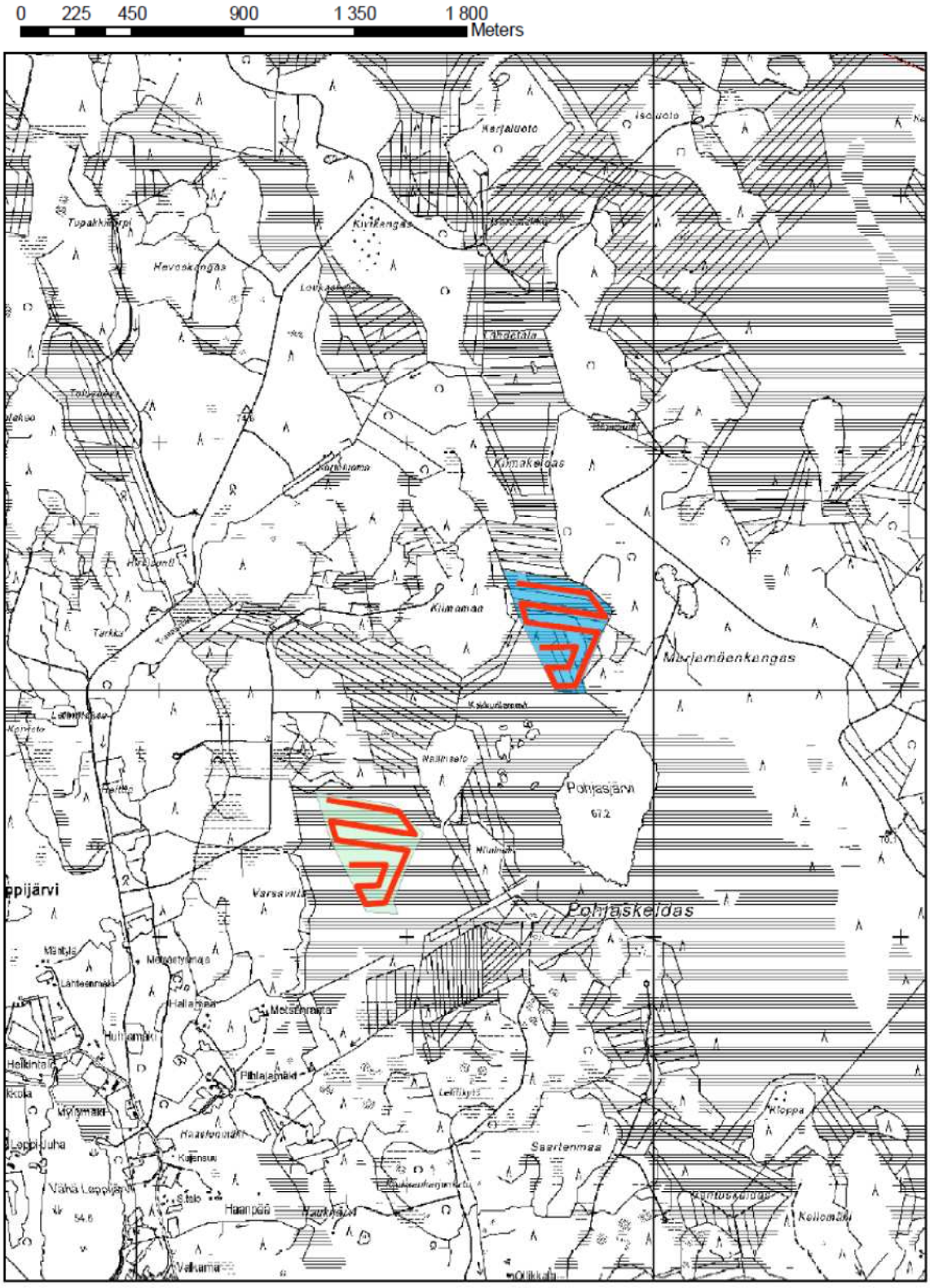

Suoverkosto-LIFE
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Ylimääräinen karttapohja, jos koko alue tulee näkyä.

Bird species	2010 (11 sites)	2011 (2 sites)	2012 (5 sites)	2013 (9 sites)	2014 (10 sites)
Alauda arvensis	0	1	1	1	0
Anas crecca	1	1	5	10	5
Anas platyrhynchos	0	0	0	0	1
*Anthus pratensis** NT	22	11	9	7	5
Anthus trivialis	40	8	7	33	51
Bucephala clangula	0	0	0	0	1
Carduelis chloris	0	1	0	0	0
Carduelis flammea	0	0	1	0	0
Carduelis spinus	12	0	1	2	3
Columba palumbus	0	0	0	1	1
Cuculus canorus	5	1	2	2	3
Cygnus cygnus	0	0	1	0	0
Dryocopus martius	0	0	1	0	0
Emberiza citrinella	2	1	1	2	2
Emberiza rustica	0	0	0	1	1
*Emberiza pusilla**	0	0	0	1	0
Emberiza schoeniclus	0	1	3	2	1
Erithacus rubecula	8	0	0	1	4
Ficedula hypoleuca	5	0	0	1	4
Fringilla coelebs	56	0	12	14	49
Fringilla montifringilla	1	1	0	1	3
*Gallinago gallinago**	3	2	4	12	7
*Grus grus**	1	0	1	2	2
*Lagopus lagopus** NT	4	0	1	3	1
Lanius collurio	0	0	2	0	1
Lanius excubitor	0	0	0	0	1
Larus canus	1	0	0	0	0
Lyrurus tetrix	2	1	0	0	6
Motacilla alba	3	0	2	5	6
*Motacilla flava** VU	20	4	10	15	10
Muscicapa striata	6	0	0	2	7
*Numenius arquata**	4	3	6	2	3
*Numenius phaeopus**	6	0	0	3	4
Parus cristatus	5	0	0	0	2
Parus major	1	0	0	2	8
Parus montanus	7	0	0	0	5

Phoenicurus phoenicurus	0	0	1	0	1
Phylloscopus trochilus	26	6	5	16	29
*Pluvialis apricaria**	11	1	9	13	12
Regulus regulus	0	0	0	0	1
Saxicola rubetra	5	3	3	4	13
Sylvia atricapilla	1	0	0	0	0
Tetrastes bonasia	1	0	0	0	0
Tetrao urogallus	0	0	0	0	1
*Tringa glareola**	19	8	13	19	14
*Tringa nebularia**	6	1	2	1	7
Tringa ochropus	1	0	1	12	8
Troglodytes troglodytes	0	0	0	1	0
Turdus iliacus	0	0	0	0	1
Turdus merula	0	0	2	1	0
Turdus pilaris	1	0	0	0	7
Turdus philomelos	1	0	1	1	2
Turdus viscivorus	3	0	0	0	3
*Vanellus vanellus**	3	1	1	2	1

Appendix 2. List of bird species and number of territories observed during Boreal Peatland Life-project. Species marked with * are considered as mire bird species. For mire species, nationally threatened and near threatened species are also specified (Rassi et. al. 2010), NT = Near Threatened, VU = Vulnerable.