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# Wind Farms and Power Lines Reduced the Territory Status and Probability of Fledgling Production in the Eurasian Goshawk *Accipiter gentilis*

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**Abstract:** Wind power is commonly used to reduce greenhouse gas emissions but often has negative effects on biodiversity. In this study, I investigated the effects of wind farm and power line construction on the territory status of the Eurasian goshawk *Accipiter gentilis*, whether fledglings were produced or not, and the number of fledglings. Included were 55 goshawk territories investigated before and after the construction period. I found that the territory status declined significantly in the influence area within 3 km from the disturbance compared to the control area more than 7 km away. Interestingly, the decline in territory status was similar in the distance categories 0–1 km, 1–2 km, and 2–3 km, while there was nearly no change in territory status in the control area, thus indicating that the influence area from this kind of disturbance was minimum 3 km from the nest. The number of breeding pairs declined significantly during the construction period only in the influence area. Possible reasons might be higher mortality caused by collisions with power lines, desertion, avoidance of the areas with noise and disturbance from the constructions, and possible indirect effects caused by reductions in prey species. I found no effects of the construction on the number of fledglings.

**Keywords:** anthropogenic disturbance; explosions; influence area; raptor; road construction; wind energy

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## 1. Introduction

We are, for the moment, facing the biggest global energy crisis in history, and short-term strategies to reduce the problem have benefited the fossil fuel industry so that the world is dangerously locking into even faster global warming [1]. Human industrial activities, perhaps in combination with natural variation, have already warmed the earth's atmosphere, oceans, and land. Global surface temperature has increased very fast in the last 50 years, and strong reductions in $CO_2$ and other greenhouse gas emissions in the coming decades are needed to reduce global warming [2]. With global warming of 1.5–2 °C, the majority of terrestrial species ranges are projected to shrink dramatically [3], but the precision of many distribution models varies [4,5]. Many species in different taxa have already experienced population declines caused by global warming [6–8], including many bird species [9,10]. Especially farmland birds have declined strongly because of agricultural intensification, and some of the changes in farmland practice have been possible because of climate change [11–15].

Solar and wind energy were responsible for 10% of the electricity generation in 2021 compared with 2% in 2011, and 28% of all electricity was in 2021 produced by renewable sources [1]. The increased part of wind power is a useful mitigation action to reduce greenhouse gas emissions [16], which is necessary to halt global warming and biodiversity loss. On the other hand, the construction and use of wind farms and power lines imply disturbance and land use that is detrimental to biodiversity. Altogether, humans occupy, use, and influence huge areas to such an extent that only 23% of land area globally is classified as wilderness [3], and mitigation actions are needed not only to halt climate change but also to halt the decline in biodiversity [17]. Investigations have shown the negative effects of landscape disturbance and land use on many bird populations [18–20]. Our experience with birds and wildlife in general indicates that the construction and operation of wind-power plants may impact birds negatively by (1) habitat loss and alteration [18,21–23], (2) disturbance, especially noise, during the construction period [24–30], (3) direct mortality [20,23,31–35], and (4) disturbance due to increased human presence [29,36,37]. Farmland birds decline more near urban areas compared with rural areas with less anthropogenic impact [15].

Eurasian goshawks (*Accipiter gentilis*) might be skeptical about approaching humans in areas where they have been heavily persecuted, as they earlier have been in Norway. That is probably one important factor resulting in former declining populations [38–41]. The goshawk population in Norway is estimated at 1384–1856 pairs, and the population is still declining [42]. Goshawks are classified as vulnerable (VU) on the Norwegian red list [43]. However, globally, the goshawks are classified as least concern (LC) in 2021 (IUCN red list).

Habitat losses and alterations are important factors, directly or indirectly, responsible for the goshawk population's continued decline in Norway. In the middle part of Norway, goshawks most often breed in ripe conifer forests [44], and modern forestry in the breeding areas is suspected to be the most important cause of population decline [42,45]. Not much has been published about the goshawks' tolerance to noise. Investigations indicate that noise caused by timber harvesting had only alert effects on neighboring breeders [46–48]. However, nests close to roads were less often used than nests further away [49]. The mean distance from nest sites to human habituation in the Donetsk region in Ukraine was more than 1.7 km in the 75 goshawk nests investigated, and the goshawks were among the raptors with the highest demands for virgin habitats [50]. A greater frequency of human visits in the surroundings of the nest areas resulted in an infrequent use of the nest sites by the goshawks compared with areas with few humans [49].

Some species of raptors suffer high mortality caused by wind turbines, but the goshawks are not mentioned among the victims in these publications [23,35,51–54]. Wind farms are constructed in open and windy areas, and even during display flights, goshawks are normally in forested areas [55], and they therefore most often avoid areas with wind turbines. However, the power lines are often constructed in forests where goshawks live and hunt, and they are found as victims both because of collisions and by electrocution [56]. In my study area, the new power lines and poles are constructed with long distances between the wires and between the polyons (towers) and the wires, so that electrocution is not possible for goshawks or other raptors, but there is always a possibility for collisions.

The home ranges of breeding goshawks vary considerably between areas and territories, depending on the amount of woodland edge and prey availability [57]. Some individuals might have home ranges of more than 3 km from the nest site [45,58], also in and near my study area [59], and hunting range is recorded up to 6 km from the nest [40] and even longer outside the breeding season [55]. I therefore started this investigation by defining all areas within 3 km from the closest wind farm or power line to belong to the influence area (Figure 1) and other areas to be in the control area. As no territories were detected 3–7 km away from the closest disturbance (wind turbine or power line), it is not possible for me to investigate how far away the disturbances have a negative effect if this effect is further than 3 km.

The present study investigates the effects of noise and other disturbances on goshawks in Norway during the construction of both wind farms and power lines and a short period with active wind turbines and operative power lines. I investigated territories with goshawks before the disturbance started and in the first breeding season after the wind turbines and power lines were built and activated. According to the literature introduced above, I expected to (1) find reduced territory status (no goshawks detected, goshawks detected, and confirmed breeding) after the construction period compared with before the construction started in the influence area but not in the control area further away. In addition, I (2) expected fewer territories with fledglings (successful breeding) and (3) reduced number of fledglings per territory within the influence area compared with the control area.

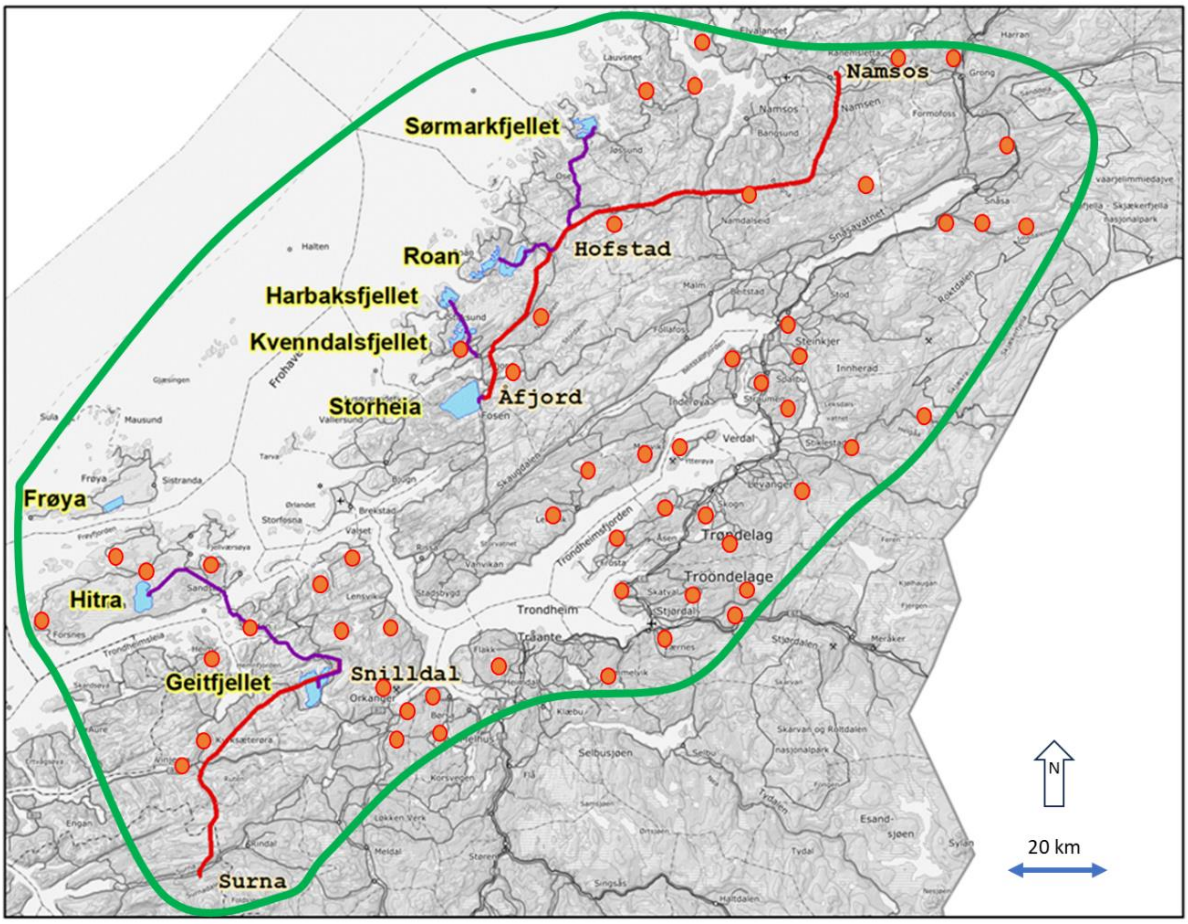

**Figure 1.** The study area with the eight wind farms (blue) with area names (yellow marking) and 420 kV (red) and 132 kV (violet) power lines in the middle part of Norway. Nearly no new power lines were constructed on Frøya. The investigated area for goshawk territories is within the green marking. The red circles are the approximate placement of the latest used nest in 55 territories with goshawks before the disturbance started.

## 2. Materials and Methods

### 2.1. Study Area

The study area comprises eight wind farms and associated power lines in the central part of Norway (Figure 1). In 2014–2016, I investigated a total of 76 areas known for having goshawks registered during the last decade, and areas with old and large spruce or pine forests that seemed suitable as breeding areas. Areas without known goshawks during the five-year period before the preliminary study and with no goshawks detected in the preliminary study ($n$ = 15) were excluded from the project. Likewise, I excluded areas with no detected goshawks during both the preliminary investigation and after disturbance during 2019–2022 ($n$ = 6). Therefore, the data consisted of a total of 55 active territories, meaning a territory with goshawks present and/or breeding at least one of the two periods. All territories included in this investigation had a new or old nest.

The preferred breeding habitat for goshawks in Fennoscandia, including the territories in this investigation, is ripe spruce *Picea abies* forests, some ripe pine *Pinus sylvestris* forests, and sometimes in mixtures with deciduous trees [38,60]. Parts of the study area are mountains without forests, farmland areas, bogs, lakes, and rivers, and some spread human settlements and cities. Despite the fact that these areas are not suited for breeding goshawks in this study area, they are still used for hunting [60]. Islands with breeding goshawks in the study area lack the mammalian predators common on the mainland, like, for example, red fox (*Vulpes vulpes*), Eurasian lynx (*Lynx lynx*), European badger (*Meles meles*) and pine marten (*Martes martes*). No goshawks are breeding in cities or close to dense human settlements in the study area.

The goshawk diet shows a wide variety of prey, especially various species of birds and mammals, depending on the habitat [61]. A major proportion of the diet of the goshawk in Fennoscandia is woodland grouse (Tetraonidae), corvids, Columbidae, Turdidae, and red squirrels (*Sciurus vulgaris*) [38,61–64]. The prey species mentioned here are all common in the investigated areas.

### 2.2. Construction Disturbance

The main disturbances are noise in connection with the wind farm and road construction, transport, installation of the turbines with the use of cranes and large trucks, and construction of the power lines. Information about the wind farms is given in Table 1. Disturbance along the power line network involves clearing a belt free of trees in the power line gate by use of logging machines or manually using chain saws, use of helicopters to transport materials, and installing the electric lines. Several rig areas and storage spaces are constructed along the power line areas. There were no restrictions during the construction execution, despite disturbance caused by, for example, the usage of mechanical diggers and dynamite.

**Table 1.** Information about the wind farms. Max height is the height when one rotor blade is in the highest position. The information is found on the Internet or received from the concessionaires.

| Wind Farm | N of Turbines | Max Height (m) | Area (km$^2$) | Road Length (km) |
|---|---|---|---|---|
| Sørmarkfjellet | 31 | 145.5 | 9.3 | 27 |
| Roan | 71 | 145.5 | 24.5 | 50.5 |
| Harbaksfjellet | 30 | 145.5 | 9.4 | 19 |
| Kvenndalsfjellet | 27 | 145.5 | 9.0 | 21 |
| Storheia | 80 | 145.5 | 37.9 | 59 |
| Frøya | 14 | 180 | 6.6 | 10 |
| Hitra 2 | 26 | 145.5 | 18.3 | 18 |
| Geitfjellet | 43 | 154 | 25.4 | 42 |
| Total | 322 | 145.5–180 | 140.4 | 246.5 |

During the construction period, there was more human activity than usual, but this change is not quantified. That, together with the construction disturbance, we most likely will have reduced preferred habitats for the goshawk and for some of the prey species. After the construction period, the wind turbines started to produce electricity and generated a different but significant type of noise. The disturbance in the influence areas is therefore 2–3 years with the construction period and a few months with active wind turbines and power lines. It was not possible to start the investigations immediately after the construction period because I had to wait until the first breeding season afterward. After construction, the power lines might also have caused mortality by collisions [65]. According to the goshawk habitat preferences, nearly all nests in the influence area were situated closer to a power line than to a wind turbine, with only one exception.

The construction activities in the present study were performed throughout the year, including the goshawk breeding period. Many adult goshawks stay in or close to the territory during the winter, but some birds also leave the territory [66]. That means that at least some of the birds were exposed to the disturbances continuously the whole year for about three years.

### 2.3. Observing Territory Status and Production of Fledglings

I investigated possible and known breeding areas and nest sites in March–April before the construction period to find the territory status, categorized as 0 = not registered ($n$ = 5), 1 = registered but no breeding proved, meaning that prey remnants, fresh green branches most often from spruce or pine were added to the nest, feathers were found, or that the birds were heard ($n$ = 6), and 2 = breeding proved ($n$ = 44). The numbers in brackets refer to the number of territories included in the final investigation. If no goshawks were detected during the territory control, Wildlife Acoustic Sound Meters (SM 2+, SM4, and SM Mini) were used, programmed to record from one hour before sunrise and continuously for four hours daily for about 14 days. This increased the probability of detecting any present goshawks. Only territories with detected goshawks in at least one of the two periods are included in this project. The sound recordings were analyzed by the programs Audacity(R) editing software (v. 2.4.2), Kaleidoscope (Pro Analysis Software v. 5.1.9g, Wildlife Acoustics), and Raven (Pro v. 1.6, Cornell Lab of Ornithology).

The production of fledglings was investigated at the end of June and the beginning of July. That is just prior to the nest leaving stage, and the fledglings are sitting on the nest or on the branches close to the nest. Chicks lying flat in the bottom of the nest might be overlooked, but the same method was used in all territories, and the observations are therefore comparable between nests and years.

Different territories were investigated in different years. The preliminary investigation was in 2014–2016, and the first year after the construction period was 2019–2022, thus giving time laps from the first to the second investigation of mainly 5–7 years, plus one territory with 3 and one with 4-year time laps. I measured the distance from the nest in use when the nest was investigated in this project for the first time to both the closest wind turbine (ranging from 2.5 to 96.2 km) and the shortest distance to a new power line (ranging from 0.1 to 77.1 km).

### 2.4. Statistics

To test the hypotheses, I used Generalized Linear Mixed Model (GLMM) analysis (IBM Statistics v. 27). I used three different target variables to test the hypotheses: (1) Change in territory status. Alternative categories were 1 = reduced territory status ($n$ = 19); 2 = no change, meaning the same status in both periods ($n$ = 29); and 3 = higher territory status in the last period ($n$ = 7). (2) Change in breeding success. Categories were 1 = no fledglings produced, 2 = at least one fledgling produced, and (3) change in number of fledglings produced. Any change in a target variable was from before (2014–2016) to after (2019–2022) the construction period.

Explanatory variables were (1) within or outside the influence area of 3 km (values 1 and 2, respectively), (2) the distance between the nest and the closest wind turbine, and (3) the shortest distance between the nest and a new power line, and (4) the shortest distance from the nest to the construction disturbance (either wind turbine or power line). All distances were measured to the nearest 0.1 km. Each wind turbine and the powerlines are visible on norgeskart.no that have a tool for measuring distances. In addition, (5) I included island and mainland with values 1 and 2, respectively, and (6) time laps between the two investigation periods as explanatory variables. The type of power line with 132 kV (category 1) and 420 kV (category 2) were included as random factors. It was a similar disturbance during the construction of the two types of power lines, but in case the bigger 420 kV lines affected the goshawks more than the smaller line, I wanted to reset a potential difference.

In the data exploration before the GLMM analysis, we first used Spearman rank correlations between all explanatory variables. The distance variables (continuous or categorized) correlated quite high ($r_s$ = 0.4–1.0) and for many correlations above the suggested maximum limit of 0.7 [67]. Therefore, many of the explanatory variables include the same or similar information, for example, the correlation between the distance to the closest wind turbine and the closest new power line ($r_s$ = 0.787, $n$ = 55, $p$ < 0.001). Some of the goshawk territories were far away from the wind farm area but were close to a new power line. The distance to the closest of the two constructions was chosen because it gives more data close to the construction areas (Table 2), and this variable is nearly identical to the distance to new power lines ($r_s = 0.999$, $n = 55$, $p < 0.001$). The effect of the explanatory variable island–mainland was far from significant and was therefore excluded from the final model.

**Table 2.** The number of goshawk nests or most probable nest places in different distance categories to the closest wind turbine, the closest new powerline, or the closest of the two constructions.

| Distance Category | Wind Turbine | Powerline | Both Constructions |
|---|---|---|---|
| <1 km | 0 | 4 | 4 |
| 1–2 | 0 | 4 | 4 |
| 2–3 | 2 | 3 | 4 |
| ≥3 km | 53 | 44 | 43 |

I compared the different models using the Akaike Information Criteria (AIC). With $\Delta$AIC > 2 from the best model, the other models are normally rejected [68]. The two best and equally good models were found by including two or three explanatory variables, including the closest distance to either the wind turbine or power line, within or outside the influence area and with or without time-lapse in the investigation periods. All three explanatory variables were included in further analyses. Variation Inflation Factor (VIF) values were <2, which is within acceptable values in most recommendations [68,69]. The GLMM analyses with categorical target variables were run with multinomial probability distribution with cumulative logit link function.

GLMM was used because it removes variability in responses that are associated with random factors rather than the conditions of experimental interest, thus reducing the Type I error rate [70]. GLMM may be the best tool for analyzing non-normal data that involve random effects [71].

I used the nonparametric Mann–Whitney U-test to compare the distances from the nesting place to the nearest disturbance source (wind turbine or power line). Changes in the number of nests of different categories were tested with Pearson Chi-square tests ($\chi^2$) or a nonparametric Fisher–Freeman–Halton Exact Test (FFHET) if some numbers were ≤5.

Because of the expected strong probabilities of negative effects of the disturbances to this shy raptor, all statistical tests are one-tailed with an $\alpha$-level of 0.05.

## 3. Results

### 3.1. Observed Goshawks and Territory Status

During the construction period, the number of territories with observed goshawks declined from 12 to 8 (33%) in the influence area within 3 km from the disturbance and from 38 to 31 (18%) in the control area further away, meaning >7 km away because no nests were found between 3 and 7 km. The number of territories with observed goshawks was significantly lower after disturbance both in the influence area (FFHET: $p = 0.023$) and in the control area ($\chi^2 = 3.592$, df = 1, $p = 0.029$) compared with before disturbance.

Before the construction period, there were no differences in territory status between territories in the influence area compared with the control area (Figure 2, Mann–Whitney U-test: $z = -0.263$, $n = 55$, $p = 0.396$). Table 3 shows that the territory status declined most in the influence area during the construction, and this decline was significant (Figure 2, Mann–Whitney U-test: $z = -2.053$, $n = 12$, $p = 0.040$), while the decline in the control area was not significant (Figure 2, Mann–Whitney U-test: $z = -1.222$, $n = 43$, $p = 0.222$). The territory status declined significantly more in the influence area compared with the control area during the construction period (Figure 3, Mann–Whitney U-test: $z = -2.173$, $n = 55$, $p = 0.030$).

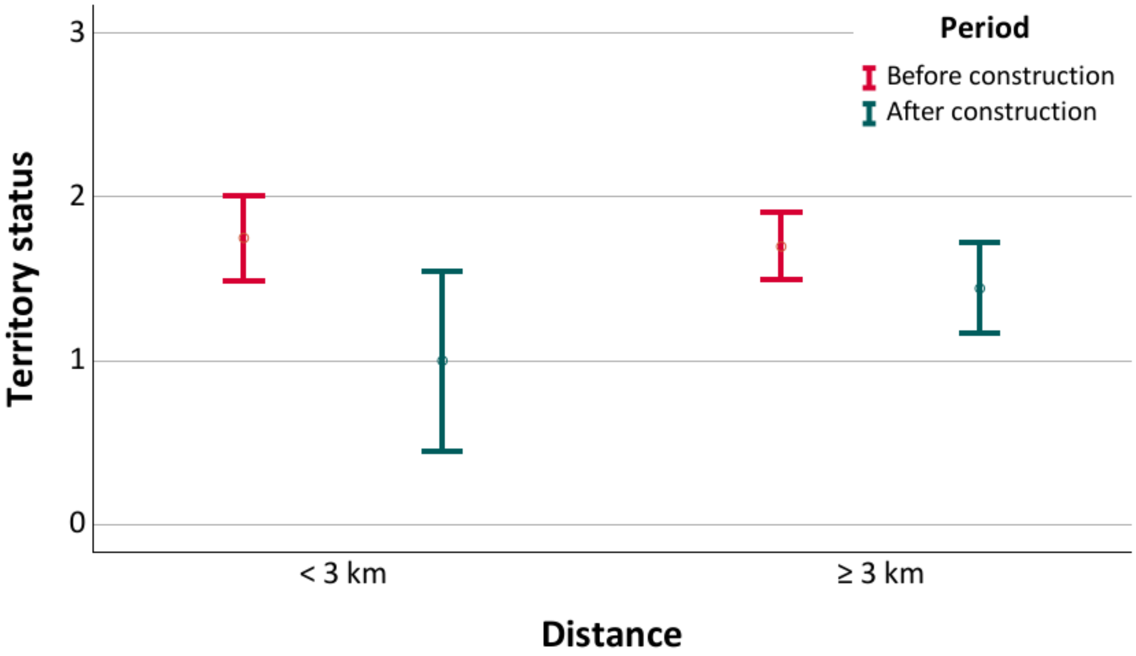

**Figure 2.** Territory status (±2 SE) with 0 = no goshawks registered, 1 = goshawks registered but breeding not confirmed, and 2 = breeding confirmed, in relation to the categorized distance between the goshawk nest and the closest construction (wind turbine or power line) and period. The number of territories in each distance category is 12 and 43, respectively.

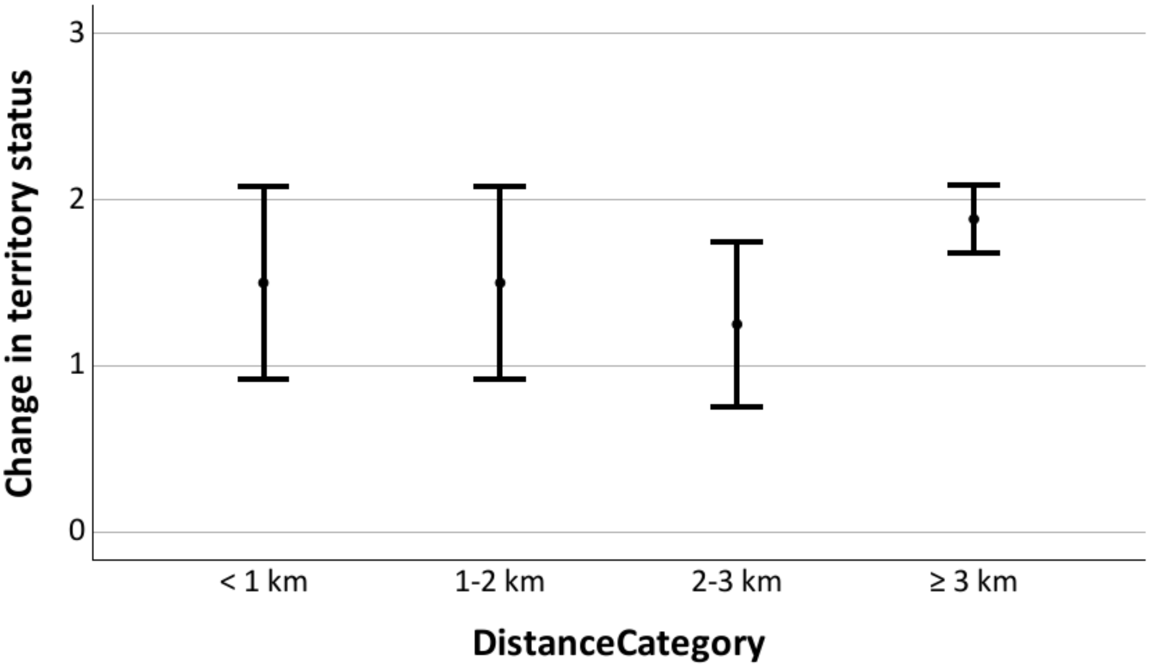

**Figure 3.** Change in territory status (±2 SE) with 1 = reduced, 2 = no change, and 3 = increased during the construction period in relation to the closest distance between the nest and the construction area (wind turbine or power line). The number of nests in each distance category is 4, 4, 4, and 43, respectively.

**Table 3.** Change in territory status (adult goshawks not detected, detected but no breeding attempt confirmed, breeding confirmed), change in breeding success (fledglings produced or not), and change in number of fledglings during the construction period in relation to categorized distance between the goshawk nest and closest disturbance (wind turbine or power line).

| Change | Territory Status | | | Breeding Success | | | N of Fledglings | | |
|---|---|---|---|---|---|---|---|---|---|
| | $<3$ km | $\geq3$ km | Total | $<3$ km | $\geq3$ km | Total | $<3$ km | $\geq3$ km | Total |
| Lower/fewer | 7 | 12 | 19 | 4 | 10 | 14 | 4 | 17 | 21 |
| Stable | 5 | 24 | 29 | 7 | 22 | 29 | 5 | 10 | 15 |
| Increased/more | 0 | 7 | 7 | 1 | 8 | 9 | 3 | 13 | 16 |
| Unknown | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 3 | 3 |
| Total number | 12 | 43 | 55 | 12 | 43 | 55 | 12 | 43 | 55 |

The reduction in territory status was quite similar in all three distance categories within the influence area, which means distances of <1 km, 1–2 km, and 2–3 km (Figure 3). In the territories in the control area, there was nearly no change in territory status (Figure 3).

The GLMM analysis with change in territory status as the target variable and the nearest distance to the disturbance (wind turbine or power line) as the explanatory variable was nearly significant, and for categorized distances as explanatory variables, the decline in territory status was significant (Table 4).

**Table 4.** GLMM analyses with the target variables change in territory status (no goshawks observed, observed, breeding), change in breeding success (nestlings produced or not), and number of fledglings. Changes mean less/fewer, stable, or more/better. Explanatory variables were A: distance to disturbance as continuous variable or B: categorized distance within 3 km or 3 km or more to disturbance, and time laps between the two investigation periods. The type of power line is a random factor. Time laps were always far from significantly influencing the breeding, and the values were not included. Significant results (1-sided test) are written in bold.

| Target Variable | Coefficient | SE | t | *n* | *p* |
|---|---|---|---|---|---|
| A: Change in territory status | 0.026 | 0.016 | 1.647 | 55 | 0.053 |
| B: Change in territory status | 1.331 | 0.774 | 1.721 | 55 | **0.046** |
| A: Change in breeding success | 0.024 | 0.016 | 1.523 | 52 | 0.067 |
| B: Change in breeding success | 0.020 | 0.014 | 1.428 | 52 | 0.080 |
| A: Change in number of fledglings | 0.011 | 0.617 | 0.018 | 52 | 0.493 |
| B: Change in number of fledglings | 0.003 | 0.012 | 0.206 | 52 | 0.419 |

The territories where goshawks were observed both before and after disturbance or only after disturbance ($n = 38$) had a significantly longer distance between the nests and the closest disturbance compared with nests where goshawks were observed only before the disturbance ($n = 17$) (Mann–Whitney U-test: $z = -2.550$, $p = 0.006$).

### 3.2. Breeding

During the construction period, the number of breeding pairs declined from nine to five (44%) in the influence area and from 35 to 31 (11%) in the control area. It was significantly fewer territories with breeding after disturbance compared with before disturbance in the influence area (FFHET: $p = 0.041$), but not in the control area ($\chi^2 = 1.131$, df = 1, $p = 0.143$) during the construction period. Among the 51 territories with breeding at least one of the two periods, there was not a significant difference between influence and control area in how many territories were abandoned or not ($\chi^2 = 1.585$ df = 1, $p = 0.104$).

Before the construction period, there were no differences in breeding success (fledglings produced or not) between the influence and control area (Mann–Whitney U-test: $z = -0.099$, $n = 55$, $p = 0.460$). The breeding success did not change significantly between the influence area and control area (Mann–Whitney U-test: $z = -1.111$, $n = 52$, $p = 0.185$), and there was no significant difference in breeding success in the influence area compared with the control area after the disturbance period (Mann–Whitney U-test: z = −1.111, $n$ = 52, $p$ = 0.133).

Of 12 territories in the influence area, four (33%) had lower breeding success after the construction period compared with 10 of 40 (25%) in the control area (Table 3). The GLMM analysis with change in breeding success as the target variable and the nearest distance to the disturbance (wind turbine or power line) as the explanatory variable was not significant (Table 4).

The territories that had a stable or better breeding success ($n$ = 40) had a significantly longer distance between the nests and the closest disturbance than nests with reduced breeding success ($n$ = 12) during the construction period (Mann–Whitney U-test: z = −2.010, $p$ = 0.022).

### 3.3. Number of Fledglings

The mean number of fledglings in nests with confirmed breeding in the influence area was 2.2 before the construction period ($n$ = 9, SE = 0.364) and 2.4 after the construction period ($n$ = 5, SE = 0.245). This difference was not significant (Mann–Whitney U-test: z = −0.299, $p$ = 0.382). In the control areas, the mean number of fledglings was 1.7 ($n$ = 35, SE = 0.199) before the construction period and 2.6 ($n$ = 31, SE = 0.425) after, but this difference was not significant (Mann–Whitney U-test: z = −1.091, $p$ = 0.137).

There was no significant relationship between the number of fledglings and if the nest was inside or outside the influence area neither before the construction period (Mann–Whitney U-test: z = −0.099, $n$ = 12 and 43, $p$ = 0.461) nor after the construction (Mann–Whitney U-test: z = −1.111, $n$ = 12 and 40, $p$ = 0.234). The distance between the nest and the disturbance did not differ between territories that produced the same number or more fledglings ($n$ = 31) compared with territories with fewer fledglings ($n$ = 21) (Mann–Whitney U-test: z = −0.755, $p$ = 0.225). The GLMM analyses gave no significant differences in the change in number of fledglings during the construction period (Table 4).

That means that there were no significant effects of the disturbance on the number of fledglings.

## 4. Discussion

The present investigation focuses on the immediate response of goshawks to disturbances from the construction period and a short period with operative wind farms and power lines. I found that the territory status declined significantly in the influence area within 3 km from the disturbance compared to the control area further away (Figures 2 and 3, Table 4). Interestingly, the decline in territory status was similar in the distance categories 0–1 km, 1–2 km, and 2–3 km, while there was nearly no change in territory status in the control area. This indicates that the influence area from the disturbance was at least 3 km from the nest. However, there were no nests 3–7 km away from the disturbance, so it is unfortunately not possible to find out if the influence area was longer than 3 km from the nest. In addition to the decline in territory status, territories with observations of goshawks after the disturbance had significantly longer distances between the nest and the closest disturbance compared to territories that were abandoned. The results show a negative effect of the disturbance on territory status in accordance with hypothesis 1.

The number of breeding pairs declined significantly during the construction period within the influence area, but the change was not significant outside. For territories that had a stable or better breeding success (fledglings produced or not), the distance between the nest and the closest disturbance was significantly longer than for nests with reduced breeding success, thus indicating a negative effect of the disturbances also on the breeding success in support of hypothesis 2.

Opposite to hypothesis 3, I found no evidence that the construction period affected the number of fledglings. Others have found that territory occupancy frequency is a good indicator of territory quality and reproductive success in goshawks [49], but a review paper shows that there is not always a strong correlation between nest site occupancy and the production of fledglings [72].

Knowledge about the size of the influence area is required in conservation action. Figure 3 indicates that the effect of the disturbance is a minimum of 3 km away from the disturbance. It might have been more, but there were no nests 3–7 km away from the disturbance, so there is no data on nests in this distance interval. In Norway, the recommended distance between disturbances like explosions, vehicles, and human pedestrians is 500 m [73]. In a review, disturbance-free zones of 500 m and less are being proposed, but the investigations referred to seemed to have less anthropogenic disturbance than in my investigated area [74]. Other investigations suggest that goshawk protection has been insufficient regarding anthropogenic disturbance, but no clear advice about minimum distances between the disturbance and goshawk nests is given [49]. A relatively new review of wind turbine influence on *Accipitriformes* found a maximum distance with an influence of 2250 m [75]. However, active wind turbines have a disturbance quite different from the construction period. More investigations in areas with a similar type of year-round disturbance are recommended to unveil the size of the influence area.

Disturbance along the power line network involves clearing a belt free of trees in the power line gate by use of logging machines or manually using chain saws, use of helicopters to transport materials, and installing the electric lines. The clearing belt in this investigation did not reduce the proportion of forests below critical levels in the territories, as judged from an investigation of the goshawk's territory demands [60]. I therefore believe that the reduced amount of forest habitat is not responsible for the declines in goshawks' breeding performances found here. There might have been three main explanations related to the constructions. First, the increased mortality of goshawks is caused by the power lines and the wind turbines. In this area, the closest wind turbine is most often further away from the goshawk nests than power lines, and there is no investigation showing that goshawks are killed by wind turbines [51,76]. However, power lines are killing many goshawks in Norway [56]. Second, desertion and avoidance of wind power areas by goshawks caused by the noise and disturbance from the constructions. Several publications show the negative effects of noise and human disturbance on bird populations [24–26,29,30,36,55]. Third, possible indirect effects are that prey species of the goshawks might die or leave the area [31,32] and that the goshawks also leave because less prey is available, but I have no data on the effects of the construction on the abundance of prey species. However, investigations show that the amount of prey species has a significant effect on goshawk density and/or hunting area [55,77], but the reduction in one type of prey might cause the goshawks to hunt other species [58]. Even though goshawks might take quite high portions of available prey [38,55], they might also reduce nest predation rates on some prey species by scaring nest predators away from the goshawk nest surroundings [78]. The total effect of goshawks on the prey species is therefore not easy to say, but the fact that goshawks can use the same territory in decades [38] indicates quite sustainable effects on their prey species. A potential decline in prey species is therefore most probably caused by the construction and not by the goshawk itself. There is experimental evidence that goshawk reproduction can be limited by food availability [79–81]. As I found no effects of the constructions on a number of fledglings might be because the reduction in the number of neighboring goshawks gave the ones that did not abandon their territories more space to hunt on and therefore access to sufficient resources, thus camouflaging any decline in prey numbers within the original territory.

The construction disturbance in the investigated area is finished, but the disturbance from rotating wind turbines and their sounds might also deter the goshawks and their prey, and the power lines might kill both goshawks and their prey. This will be investigated in the ongoing study of all territories. There are many other threats to the goshawk population [55], but they are equally relevant in the influence area as well as in the control area.

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