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Nesting of the black stork (*Ciconia nigra*) and white-tailed eagle (*Haliaeetus albicilla*) in relation to forest management

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Abstract

Since 1957, 200 m zones around known nests of the black stork (*Ciconia nigra*) and white-tailed eagle (*Haliaeetus albicilla*) have been strictly protected in Estonia. Yet, the black stork population has recently suffered a large decline, which coincides with the intensification of forestry. To check whether higher disturbance levels could have caused the decline, we related the extent of forestry operations and mature forest near black stork nests to their occupancy, treating the increasing eagle population as a comparison. For both species, we studied 1 km zone around 38 nest sites and, for each nest site, around two random points 2 km away. The total annually cut and reforested area was used to quantify forestry activity, since this single variable explained most of the variability in the extent of different forestry operations. Management was significantly more extensive in the landscapes inhabited by black storks than those inhabited by white-tailed eagles, but the periods of nest occupancy and unoccupancy did not differ significantly in either species. There were neither species-specific nor occupancy-related differences in the total area of mature forest. We conclude that, compared with the white-tailed eagle, the black stork is more vulnerable to disturbance and landscape change due to forestry operations, but these processes are probably not responsible for the recent decline of the stork population.

Keywords: *Ciconia nigra*; Estonia; *Haliaeetus albicilla*; Human disturbance; Mature forests; Nest site protection

1. Introduction

Forest management has a major impact on wildlife populations by influencing habitat structure, resource availability and populations of interacting species (e.g., Sjöberg and Lennartsson, 1995; Hunter, 1999). Additionally, some species suffer from the management activities per se—disturbance and killing during harvesting, planting, road building etc. The latter taxa include several large disturbance-prone birds (Newton, 1979; Tucker and Heath, 1994; Petty, 1996, 1998).

Case studies about forestry-caused disturbance in relation to breeding of large birds (Mathisen, 1968; Levenson and Koplin, 1984; Anderson, 1985; Anthony and Isaacs, 1989; Mooney and Taylor, 1996; Newton et al., 1996; Toyne, 1997; García-Dios and Viñuela, 2000; see also reviews by Peterson, 1986; Vana-Miller, 1987; Watson, 1997) have produced controversial results, probably because of different study methods, types and intensities of forest management, as well as true differences between populations.

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For example, out of four sub-populations of the bald eagle (*Haliaeetus leucocephalus*) in the northeastern United States, timber harvests were significantly correlated with the distribution of only one (Livingston et al., 1990). However, taking a precautionary approach, researchers have frequently recommended establishing disturbance-free buffer zones around nests or other activity centres of the birds (a review by Richardson and Miller, 1997). Today, buffer zones (often combined with habitat reserves) are considered in many countries (e.g., Petty, 1998; Schäffer and Gallo-Orsi, 2001), but their effects remain virtually unexplored. A notable exception is the report about the success of 500 m disturbance-free zones around wedge-tailed eagle (*Aquila audax*) nests in Tasmania (Mooney and Taylor, 1996). In contrast, Crocker-Bedford (1990) found that unharvested buffers with a mean size of 70 ha were insufficient for the goshawk (*Accipiter gentilis*) in Arizona, but he attributed this failure to factors other than disturbance.

Logically, the importance of buffer zones may depend on the intensity of forest management. When the intensity is low, human activities are infrequent near nests simply because of chance, and the impact on bird populations may be negligible. Inadequacy of protection zones may become evident when management intensifies. In this study, we explore whether such a process has taken place in Estonia, where (1) 200 m zones around known nests of the black stork (*Ciconia nigra*), eagles and the osprey (*Pandion haliaetus*) have been strictly protected since 1957; (2) forestry has sharply intensified since the early 1990s—felling volumes grew from 2.4 million m^3 in 1993 to 10.8 million m^3 in 2000, and in recent years coniferous trees have been harvested at intensities greater than can be replaced by annual growth (Kuuba, 2001); (3) the national black stork population has recently declined more than twofold, probably as an effect of depressed productivity (Sellis, 2000).

First of all, we are interested in determining whether the decline in the black stork population may be caused by forestry disturbance, since a preliminary report has suggested that human disturbance is the main factor influencing its breeding success in the neighbouring Latvian population (Strazds et al., 1996). The black stork is a forest interior species in Estonia (A. Lõhmus, U. Sellis, R. Rosenvald, unpublished analysis) and fragmenting its habitat by clear-cutting and road-building may introduce other disturbance sources, such as human recreation uses. Therefore, we relate the extent of cuttings and reforestation within 1 km around the black stork nests to their occupancy, treating the similarly protected, but increasing, white-tailed eagle (*Haliaeetus albicilla*) population as a comparison. We ask two questions: (1) are the forestry operations more frequent near the stork nests than near the eagle nests; (2) is the extent of the operations related to the occupancy of nest sites. Additionally, we explored the surrounding area of mature forests (i.e. potential breeding habitat for both species), which may enable the birds to build new nests in the region even if disturbed.

2. Material and methods

2.1. Nest sites and their history

For both species, we sampled 38 nest sites in 12 of the 15 Estonian counties (Hiiu, Ida-Viru and Valga counties were excluded mainly because of scarce data). A ‘nest site’ included all nests of one pair. The selected sites had at least 60% of forest area within 3 km on state-owned lands because management information was limited for private forests. This approach could exclude the most disturbed areas, because the sharp increase in felling volumes in the 1990s has mostly taken place in private forests (Kuuba, 2001), which currently cover 40% of Estonian forests. However, the bias is probably not serious, since (1) state forests host over 70% of national populations of the considered species and the black stork population has decreased all over Estonia (Sellis, 2000; U. Sellis, pers. commun.); (2) the matched-pair design (see below) removed between-site effects by comparing occupancy and non-occupancy periods only if both were known in a given site.

In Estonia, the black stork has been annually monitored since 1961 (Mank, 1967) and the white-tailed eagle since 1964 (Randla and Tammur, 1996). These monitoring data (stored in the archives of the Eagle Club and the nature conservation society “Kotkas”) were used to map nests and to explore their history. Given that both studied species are extremely site-tenacious, the occupancy of nest sites was explored over approximately 10-year periods, according to the official forest inventories (see Section 2.2). The criterion of occupancy was an occupied nest (breeding or at least nest-building by a territorial bird observed; Sellis, 2000) in at least 1 year. Within a period, a nest site was classified as either unoccupied (including abandonment during the period) or occupied (including establishment during the period). A few ephemeral sites, which were established and abandoned in the same period, were classified to both categories. Finally, the periods of the same category were pooled for each site. As a result, 30 black stork sites and 23 eagle sites were represented by both an occupied and an unoccupied period.

2.2. Measuring the area under forestry operations

The history of forestry operations was studied in circular plots (radius 1 km) around nest sites and two random points in forest land 2 km away from each nest site. If a nest site contained several nests, the nest plot was centred between the nests or, if the nests were more than 1 km from each other, separate plots were explored. The two random plots were not allowed to overlap, and their data were averaged and used to characterise broader landscapes in the home-ranges of the two species. Forestry operations in these distant areas were not influenced by the nest protection rules.

The information about forestry operations and stand structure was obtained from official forestry planning maps (scale 1:10,000), which are prepared approximately every 10 (6–15) years. Originally, the maps included stand borders and structural parameters, but foresters use them for mapping forestry operations up to the next planning period. Depending on the quality of local archives, up to four maps (for the 1960s, 1970s, 1980s and 1990s planning periods) were used in our study.

For each study plot and period, we measured the annual area (ha) of three silvicultural activities per square kilometre of total area: (1) clear-cutting; (2) all types of thinnings and sanitary-cutting (hereafter: thinning); and (3) reforestation (planting or sowing). Total area was used as a reference because we were interested in total disturbance and landscape change levels rather than their intensity per forest area. Additionally, we explored the extent and fate of mature stands (at least 70 years for deciduous or 140 years for coniferous trees), which could support breeding black storks or white-tailed eagles: (4) the total area of mature stands in the beginning of the period; (5) the annual loss (%) of these stands due to clear-cutting. All areas were measured with a digital planimeter. When the plots contained private-owned forests (for which there were usually no relevant data), we extrapolated the intensities found for state forests also to these areas. The error from this procedure is probably small because largely private-owned sites were avoided in sampling (see above).

2.3. Statistical methods

We checked for strong ($r > 0.6$) correlations between original variables and reduced their number in principal component analysis, based on correlations and including varimax rotation. For factor extraction, only random plots data were used (in the nest sites, some intrinsically uncorrelated characteristics may co-occur due to the preferences of the birds or management restrictions). Components with eigenvalues greater than 1.0 were accepted for the further analysis, and their factor scores were calculated for both random plots and nest sites.

We used one-way ANOVA or (if variances were significantly heterogeneous) Kruskal–Wallis ANOVA for comparing means between species, and paired *t*-tests for comparing occupancy and unoccupancy periods of nest sites. Prior to analyses, the distributions of all variables were checked for normality (Kolmogorov–Smirnov test) and transformed where appropriate (arcsine-square-root transformation used for proportions, logarithmic or square-root transformations for other variables). However, for ease of interpretation, means and standard deviations are presented in their untransformed states throughout the paper. Levene's test was used to explore the homogeneity of variances in ANOVA. The tests of differences in the area of forest operations between occupied and unoccupied nest sites were one-tailed, since any positive effects of these activities were unlikely—both species avoid humans, and use clear-cuts only occasionally for foraging (Lõhmus, 2001; Lõhmus and Sellis, 2001). All other tests were two-tailed. The calculations were performed with Statistica 6.0 software. For power analyses of paired *t*-tests, we used the program PS (Dupont and Plummer, 1990).

3. Results

3.1. Principal component analysis

The total area of mature forest was treated as an independent variable, since it was only weakly ($0.2 < r < 0.36$) although significantly ($0.001 < P < 0.086$) correlated with the other variables in the 76 random plots. In contrast, the remaining four variables (the areas annually cleared, thinned and reforested, the annual % loss of mature forest) were strongly intercorrelated ($r > 0.6$, $P < 0.001$, $N = 76$) and were reduced to a single principal component (PC), which explained 70% of their total variance. The PC had strong negative correlations with the original variables (Table 1) and thus reflected the general extent of forest management. However, we found that the total area of forestry activities (annual sum of clear-cuts, thinnings and reforestation activities per square kilometre of total area; TOT) captured most of the variability of the PC (linear regression: $\text{TOT} = -0.51(\text{PC}) + 0.79$; $R^2 = 0.88$; $N = 76$; $P < 0.0001$), and in further analyses we used the easily interpretable total area instead of principal component scores.

3.2. Nest site use in relation to forest management

Comparison of nest sites and random plots around the nests of both studied species indicated that forestry operations took place over larger areas in the landscapes inhabited by black storks than those inhabited by the white-tailed eagle (Fig. 1; ANOVA: $F_{3,144} = 14.3$, $P < 0.0001$). According to Tukey's HSD post-hoc tests, random plots did not differ significantly from the nest sites within species ($P > 0.9$), but both the nest sites and random plots differed between species ($P < 0.0001$). In contrast, there were no significant differences between species, and nest sites versus random plots in the total area of mature forest (Kruskal–Wallis ANOVA: $H_{3,144} = 6.1$, $P = 0.11$), although the high variability of this variable around the eagle's nests was distinct (Fig. 1; Levene's test: $F = 2.91$, $P = 0.04$).

Neither the total area annually under forestry operations nor the total area of mature forests differed significantly between occupied and unoccupied nests of either species (Table 2). However, the low power of tests may have hidden quite large differences—compared to occupied nests, the real area of forestry operations may be up to 32–42% larger and the area of mature forests 58% less around unoccupied nests (Table 2).

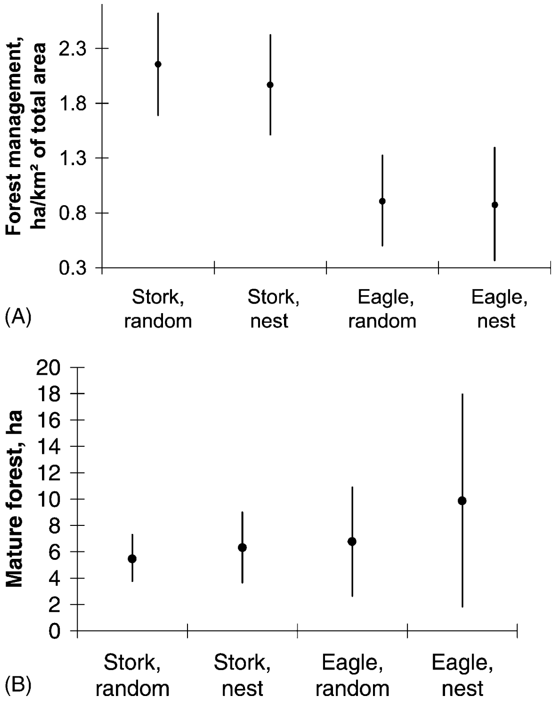

Fig. 1. The annual area of forestry operations (A) and the area of mature forests (B) within 1 km of nest sites and surrounding random plots in the black stork and white-tailed eagle (mean ± 95% confidence interval). The sample size is 40 for random plots near black stork nests, and 36 for all other categories.

Table 1
Correlation coefficients of the four variables measuring the annual extent of forestry operations (ha/km^2 of total area) with the first principal component from a principal components analysis ($N = 76$ random plots)[a]

Variables	Correlation coefficient
Clear-cut area (log)	−0.87
Thinned area (log)	−0.83
Reforested area (square-root)	−0.83
Loss of old-growth (arcsin(square-root))	−0.81
Explained variation (%)	69.6

[a] Prior to analysis, the original variables were transformed as shown in brackets.

Table 2
Comparison of the mean annual area of forest operations and the area of mature forests around unoccupied and occupied nests of the black stork and the white-tailed eagle

Variable	Mean ± S.D.		Difference in means[a]		Detectable difference[b] (%)
	Occupied	Unoccupied	t	P	
Black stork ($N = 30$)					
Forestry operations (ha/km^2 of total area × year)	2.05 ± 1.21	2.26 ± 1.58	0.82	0.21[c]	32
Mature forest (ha)	4.79 ± 6.15	4.47 ± 5.05	0.13	0.90	58
White-tailed eagle ($N = 23$)					
Forestry operations (ha/km^2 of total area × year)	0.66 ± 1.03	0.70 ± 0.97	0.61	0.27[c]	42
Mature forest (ha)	4.26 ± 7.04	5.61 ± 14.37	0.37	0.28	58

[a] Paired t-test.
[b] Minimum detectable difference between means (% of occupied nests' sample mean) in the given sample at $\alpha = 0.05$ and power $\beta = 0.8$.
[c] One-tailed test.

4. Discussion

We noticed that the extent of forest management differed significantly between the studied species but not between their occupied and unoccupied nest sites. The species difference can be explained by their habitats—the nest stands of the black stork are preferably situated on fertile soils (Drobelis, 1993; Sellis and Lõhmus, 2001), whereas the white-tailed eagle uses all forest types (Leibak et al., 1994). Consequently, the tendency to establish forest reserves on unproductive lands (Lõhmus et al., 2003) has resulted in that 50–60% of the Estonian white-tailed eagles breed in protected areas, while that share is 30–45% for the black stork (Lõhmus et al., 2001). Hence, although the 200 m buffers have been established also to the nest sites outside reserves, forest management could disturb the storks more seriously than the eagles.

The similarity in the extent of forest management during nest occupancy and unoccupancy periods, however, did not support the idea that the black stork population has declined mostly because of disturbance. In principle, this result can be an error if (1) the measured variables were poorly related to true disturbance levels, or (2) the tests did not have enough power to reject the null hypotheses.

Probably, our approach to measure the whole area of the most extensive forestry operations reveals adequately the rate of landscape change. However, several studies have indicated that forest management is most disturbing to birds at their early stage of breeding (Levenson and Koplin, 1984; Vana-Miller, 1987; Newton et al., 1996; Toyne, 1997). The raw data did not allow us to determine the season of the activities but spring has been traditionally the time for reforestation and seasonal break in cuttings in Estonia. Given the strong positive correlations between the levels of different activities (partly due to the period-long pooling of data, which effectively captured both clear-cutting and the following reforestation), we suggest that the analysed total area of activities is closely related to the relative management level in spring. A more serious problem can be the possible impact of occasional, heavy disturbance (e.g., people visiting the nest or working nearby during a specific time), which cannot be discovered from average levels of management.

Regarding the power of tests, there are two aspects to consider. First, our non-significant results may hide real differences as large as shown in Table 2 only when we assume to have sampled very large populations. However, if the decline in the black stork population has been driven by local factors (Sellis, 2000), such as the national system of forest management, the large sampling fractions (40% of the national black stork population, 30% in the white-tailed eagle) would allow one to reduce confidence intervals for means (e.g., Krebs, 1989) and, thereby, to detect smaller differences. Secondly, despite whether the extent of forestry operations around unoccupied black stork nests could have exceeded those around occupied nests by 10% (difference between sample means) or up to 32% (the smallest statistically detectable difference), nothing is known about the biological impacts of such differences. Based on our experience with the species, we doubt whether even a 30% increase in forestry extent could have caused the rapid twofold decrease of the black stork population. Yet, given that non-linear responses of bird populations to habitat change have been often theoretically predicted (e.g., Fahrig, 2001) and also documented in nature (e.g., Swindle et al., 1999), we recommend a precautionary management approach.

Our data does not allow speculation about minimum area of mature forests required by the species since (because of technical reasons) the lower limit of 'mature forest' was set quite high for coniferous forests. The lack of differences between nests and random plots, as well as occupied and unoccupied nests, suggests that both species may occupy landscapes with very different amounts of old stands.

5. Conclusions

We conclude that compared with the white-tailed eagle, the black stork is more vulnerable to forestry-related disturbance and landscape change due to a higher intensity of such activities in its breeding areas. It is not clear whether the 200 m buffer zones around nests are sufficient, and a precautionary approach could be to avoid any potentially disturbing activities within 1 km of black stork nests in the early breeding season (April–May). However, the recent decline of the black stork population is not likely explained by the growing disturbance by forest management. Since we have previously rejected the hypothesis that the species suffers from changed forest structure (A. Lõhmus, U. Sellis, R. Rosenvald, unpublished analysis), we suggest that the species' depressed productivity may result from gradual degradation of foraging habitat (permanent water courses in forests) as a long-term impact of forest drainage (Lõhmus and Sellis, 2001). However, this latter hypothesis has yet to be tested.

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