Impact of power lines on bird mortality in a subalpine area

K. Bevanger & H. Brøseth

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Abstract

Impact of power lines on bird mortality in a subalpine area.— Four sections of power lines, amounting to 4,000 km, in a subalpine area of southern Norway were patrolled from April 1989 to June 1995 to record birds killed when colliding with the overhead wires. A total of 399 dead birds and bird remains were identified as collision victims. At least 24 species were identified among the victims, the majority only represented by a few individuals. Ptarmigan (*Lagopus* spp.), particularly Willow ptarmigan (*Lagopus lagopus*), made up 80% of the victims. Season, power–line section and ptarmigan abundance affected the collision rate of this species. The highest rate was found in winter, marginally higher than in spring. Few collided with the power lines in autumn, and none were identified as victims in summer. On average, the annual minimum ptarmigan collision rate was found to be 5.3 birds km^{-1} power line. The only parameter with a predictable effect on the probability of ptarmigan collisions was the height of the trees, as collision spots tended to be in places with low trees. Mortality due to power lines was, on average, at least 2.4 times higher than the annual ptarmigan hunting bag in the area during this 6–year study.

Key words: Collision, Hunting, *Lagopus* spp., Norway, Wildlife management.

Resumen

Impacto del tendido eléctrico de alta tensión en la mortalidad de las aves de una región subalpina.— Entre abril de 1989 y junio de 1995, se estudiaron cuatro secciones de tendido eléctrico de alta tensión de una zona subalpina de Noruega meridional, con una extensión total de 4.000 km. El objetivo era registrar el número de aves que habían perecido tras haber colisionado con los cables aéreos. Se identificaron un total de 399 de cadáveres y restos de aves como víctimas de colisiones. Se determinaron un mínimo de 24 especies distintas, que en la mayoría de los casos sólo estaban representadas por unos pocos individuos. Los lagópodos (*Lagopus* spp.), en especial el lagópodo común (*Lagopus lagopus*), constituyeron el 80% de las víctimas. La estación del año, la sección del tendido eléctrico y la abundancia de lagópodos influyeron en la tasa de colisión de esta especie. La tasa más elevada se registró en invierno, con valores marginalmente más altos que en primavera. En otoño, fueron pocos los lagópodos que colisionaron con el tendido eléctrico, mientras que en verano no se registró ninguna víctima. Por término medio, la tasa mínima anual de colisión de lagópodos fue de 5,3 aves por km^{-1} de tendido eléctrico. El único parámetro con un efecto predecible sobre la probabilidad de colisión de los lagópodos fue la altura de los árboles, puesto que en los lugares donde se registró un mayor número de colisiones abundaban los árboles de poca altura. Durante los sies años que duró el estudio, la mortalidad de lagópodos ocasionada por el tendido eléctrico de alta tensión fue, por término medio, 2,4 veces mayor que aquélla generada por la caza.

Palabras clave: Colisión, Caza, *Lagopus* spp., Noruega, Gestión de la Fauna.

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Introduction

Flying birds generally depend on free air space for their movements. Over time, several species have evolved sophisticated behavioural and biomechanical adaptations for moving around in structurally complex habitats, although flight in obstructed terrain is a finely tuned balance, with an ever-present risk of collisions taking place. Over more than 100 years, a steadily growing number of man–made obstacles have increased the collision hazards for birds, particularly through the erection of overhead wires for energy transmission and telecommunication (Avery et al., 1980; Hebert et al., 1995; Trapp, 1998).

Research on bird mortality caused by collisions with power lines has been published around the world, for instance in Australia (Winning & Murray, 1997), India (Sundar & Choudhury, 2001), Europe (Scott et al., 1972; Renssen et al., 1975; Heijnis, 1980; Ferrer & Riva, 1987; Rose & Baillie, 1992; Bevanger et al., 1998; Janss, 2001), Southern Africa (Royen & Ledger, 1999), South America (Zerda & Rosselli, 1997) and the United States (Brown & Drewien, 1995; Savereno et al., 1996). The results of these studies confirm earlier data indicating that many different species are involved in collisions with overhead wires, and there is increasing evidence of a disproportionate representation of species with restricted biomechanical qualities ("poor flyers" sensu Rayner, 1988), for instance gallinaceous birds (Bevanger, 1998).

Several studies in Europe have confirmed that resident tetraonid species, like ptarmigan (*Lagopus* spp.), are particularly prone to collide with overhead wires (Watson, 1982; Bevanger, 1988, 1993a, 1995a; Miquet, 1990; Bevanger et al., 1998), and fences (Baines & Summers, 1997; Bevanger & Brøseth, 2000). The ecological, economic and recreational importance of these birds (Bevanger, 1995b) has prioritized the need to understand the effect of collision mortality at the population level. More knowledge about the factors that trigger collisions would provide essential guidelines for routing and constructing power lines that would be optimal from an ornithological point of view.

In general, bird deaths due to collisions with power lines have been considered an unimportant source of mortality at the population level (Bevanger, 1994). Awareness is now increasing regarding the possible additive effects of human related mortality factors. For example, whether hunting mortality is compensated for, or whether it occurs in addition to natural mortality (Bergerud, 1985; Ellison, 1991). New research on ptarmigan in Scandinavia does not support the idea of compensation of hunting mortality under the conditions studied (Smith & Willebrand, 1999; Pedersen, in press). There is little reason to believe that mortality caused by collisions with power lines should differ, given the same conditions.

We initiated a long–term study in subalpine habitats in southern Norway in 1989, primarily to assess the extent of bird collision mortality and, specifically for ptarmigan populations, its possible implications compared with mortality from hunting. We also tried to identify possible connections between collisions and ptarmigan behaviour, topographical characteristics and power–line configuration or technical construction.

Material and methods

Study area

The study area is located in Mørkedalen, a valley in the county of Buskerud, southern Norway (61° 54' N, 8° 30' E), in an approximately 50 km^2 area where small–game hunting takes place each autumn (fig. 1). About half of the area is typical Willow ptarmigan (*Lagopus lagopus*) habitat, located below the tree line, which is at about 1200 m a.s.l. here; the higher parts of the area are a more typical Rock ptarmigan (*Lagopus mutus*) habitat. The power–line sections patrolled to assess the extent of bird collisions are located 950–1000 m a.s.l. in subalpine habitats dominated by northern boreal birch woodland mixed with small mires (Bevanger, 1990a; Bevanger & Sandaker, 1993; Bevanger et al., 1998).

Power–line characteristics

Three power lines with a total length of 30 km cross the study area, a single circuit 300 kV high–tension transmission line and two distribution lines (22 and 66 kV, single circuit). All the lines have flat configurations with simplex phase conductors. The transmission line has two parallel earth wires about three meters above the phase conductors and the 22 kV distribution line has one earth wire about two meters below the phase conductors (table 1).

Data recording

Four selected sections of the power lines were patrolled from April 1989 to June 1995 to assess the impact on bird mortality. Section one was a five km segment of the 300 kV power line, section two was a 2.5 km segment of the 66 kV power line, and sections three and four were segments of 2.5 and 1 km, respectively, of the 22 kV power line (fig. 1, table 1). Patrols were carried out at five–day intervals from September to May and 10–day intervals from June to August. During the study period about 4000 km of power lines were patrolled. The data–collecting routine was to patrol the power-line corridor to find and collect dead birds and their remains (Bevanger, 1999). One person accompanied by pointer dogs searched the area beneath the power line and 5–10 m on each side of the terminal phase conductor, that is a 16–32 m transect (table 1). The use of pointers obviously increased the efficiency of the search for collision victims. It should be stressed that the dogs should be specially trained for the task, as pointers are generally most interested in

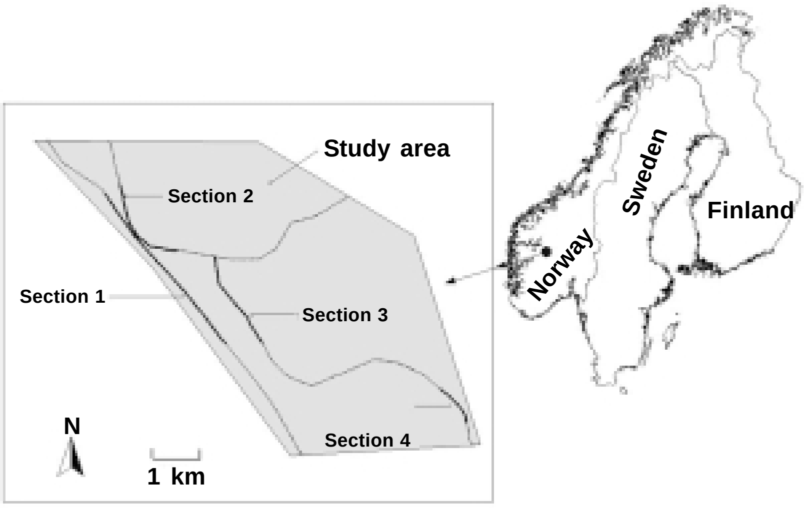

Fig. 1. The subalpine area in southern Norway used to study bird collisions with power lines. Patrolled power–line sections are shown and the limit of the ptarmigan hunting area is indicated in grey.

Fig. 1. La zona subalpina de Noruega meridional donde se han estudiado las colisiones de aves con el tendido eléctrico de alta tensión. Se muestran las secciones de tendido eléctrico que fueron estudiadas se indican en negrita, mientras que el límite del área de caza de lagópodos se indica en gris.

Table 1. Technical specifications for the four power–line sections searched for bird collision victims in southern Norway in 1989–1995.

Tabla 1. Especificaciones técnicas de las cuatro secciones de tendido eléctrico de alta tensión en la Noruega meridional donde se habían estudiado las muertes de aves por colisión entre los años 1989 y 1995.

	Power–line section			
	1	2	3	4
Voltage (kV)	300	66	22	22
Distance patrolled (m)	5000	2500	2500	1000
Patrols	376	376	375	279
Time and distance patrolled (km)				
April–May	405.5	204.1	205.0	56.0
June–August	320.0	158.7	160.0	37.0
September–October	323.0	160.7	160.0	51.0
November–March	809.4	407.5	412.5	134.9
Total distance patrolled (km)	1857.9	931.0	937.5	278.9
Patrol period (first/last patrol)	1 IV 1989/ 31 V 1995	1 IV 1989/ 31 V 1995	1 IV 1989/ 31 V 1995	5 X 1990/ 31 V 1995
Phase conductors/levels	3/1	3/1	3/1	3/1
Earth wires/levels	2/1	0/0	1/1	1/1
Phase conductor diameter (mm)	35.10	12.33	12.33	12.33
Earth wire diameter (mm)	18.27	–	12.33	12.33
Pylon/pole height (m)	20–30	10–12	8–10	8–10
Distance between phase conductors (m)	9.2	3.0	1.5	1.5
Construction year	1974	1971/1972	1977	1990
Width of clear–felled area (m)	35	20	10	10

Table 2. Ptarmigan collision rates (*n* collisions per km^{-1} per $month^{-1}$) recorded during patrols beneath four power–line sections in southern Norway in 1989–1995. A total of 279 ptarmigan were recorded as casualties of collisions with the power lines. During April–June 1989, another 39 ptarmigan found along sections 1, 2 and 3 were classified as having collided during the winter of 1988–1989. The winter (November–March) collision rate is given from one year to the next (i.e. 1989 = 1989–90, 1990 = 1990–91, etc.): * Collision rates affected by an experimental removal of the earth wire on power–line section 3 in this period (Bevanger & Brøseth, 2001).

*Tabla 2. Tasas de colisión de lagópodos (*n* colisiones por km^{-1} por mes^{-1}) registradas durante los estudios llevados a cabo en cuatro secciones de tendido eléctrico de alta tensión de la Noruega meridional entre 1989 y 1995. Se registraron un total de 279 lagópodos como víctimas por colisión con el tendido eléctrico de alta tensión. Entre abril y junio de 1989, se determinó que otros 39 lagópodos encontrados a lo largo de las secciones 1, 2 y 3 habían colisionado con las líneas de alta tensión durante el invierno de 1988–1989. La tasa de colisiones correspondiente a la estación invernal (noviembre–marzo) se expresa de un año para otro (es decir, 1989 = 1989–90, 1990 = 1990–91, etc.): * Tasas de colisión afectadas por una eliminación experimental del alambre de tierra en la sección 3 de las líneas de tendido electrico de alta tensión durante este periodo (Bevanger & Brøseth, 2001).*

	Season															
	Spring				Summer				Autumn				Winter			
Year/Section	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1989	0.2	0.2	0.4	–	0	0	0	–	0	0	0.6	–	0.6	0.6	0.5	–
1990	0.2	0.2	0.4	–	0	0	0	–	0	0	0.2	0	0.8	0.3	1.2	2.2
1991	0.2	0.2	1.4	0	0	0	0	0	0.1	0	0.4	0	0.8	0.5	0.9	1.8
1992	0.3	0.2	0.2*	0	0	0*	0	0	0	0.4	0.4*	0.5	0.5	0.6	0.3*	0.6
1993	0.2	0.4	0.6*	1.5	0	0*	0	0	0.1	0	0.4*	0	0.2	0.6	0.2*	0.2
1994	1.0	1.0	1.2*	2.5	0	0*	0	0	0.5	0	0.2*	1.0	0.5	0.2	0.2*	0.4
1995	0.4	0.4	0.6*	1.0	–	–	–	–	–	–	–	–	–	–	–	–

live birds. However, young, inexperienced dogs can be useful, as they are curious about dead animals lying on the ground.

All bird remains were collected for detailed examination. It may be difficult to distinguish collision victims from raptor kills by visual examination at a collision site. However, only the Golden Eagle (*Aquila chrysaetos*) and Gyrfalcon (*Falco rusticolus*) are present in winter in mountainous areas of Norway, and only the Golden Eeagle was observed in the study area. This heavy bird will always leave its footprints in snow. The Golden Eagle was never observed to scavenge birds killed by the power line beneath the conductors, although its footprints and feather–tip marks were occasionally observed in the snow beneath the conductors, indicating that some power–line victims could have been removed. The topographical and technical parameters of the power line were recorded at each collision spot.

We calculated the ptarmigan collision rate as the number of victims found per kilometre of power line per month for each power–line section each year (table 2). To assess the impact of a potential seasonal effect on the collision rate we separated the material into four biologically meaningful seasons (spring: April–May; summer: June–August; autumn: September–October; winter: November–March).

Live birds flushed by the observer or the pointer in the transect and in adjacent sites were recorded and used to calculate a ptarmigan population index as the number of observations per 10 km of patrol (table 3). Willow ptarmigan may form flocks, and 50 or more birds can sometimes be seen together in winter. When a large flock was flushed by the observer, it was impossible to count the number of birds exactly. Therefore, when calculating the number of observations, single birds and flocks were treated as one observation in the ptarmigan population index, which may have decreased the accuracy of the index.

To assess the relative impact of ptarmigan mortality caused by power lines in this area, we compared it with another anthropogenic mortality factor, hunting, by recording the number of ptarmigan shot in the study area during the hunting season each year.

Table 3. Ptarmigan population index (*n* observations per 10 km^{-1} per patrol) along four power–line sections patrolled in southern Norway in April 1989–June 1995.

*Tabla 3. Índice poblacional de lagópodos (*n *observaciones por 10 km^{-1} por patrulla) a lo largo de cuatro secciones de tendido eléctrico de alta tensión estudiadas en la Noruega meridional entre abril de 1989 y junio de 1995.*

	Season															
	Spring				Summer				Autumn				Winter			
Year/Section	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1989	1.8	1.2	7.1	–	0.1	0.4	3.8	–	0.2	0	2.2	–	1.3	0.6	1.0	–
1990	1.8	0	1.3	–	1.6	0	1.8	–	1.0	0	2.3	0	2.2	1.5	3.7	6.4
1991	2.7	1.3	3.7	3.3	1.6	0.8	1.6	0	0.6	0.4	1.8	0	3.1	1.2	3.1	1.3
1992	2.8	2.0	7.7	2.5	0.2	0	2.7	0	0	0	0.7	0	2.3	1.5	2.6	3.2
1993	1.4	2.3	9.0	2.7	0.9	0.5	4.9	0	0.7	0	2.0	0	1.4	0.9	4.8	3.6
1994	1.7	1.4	5.0	4.2	1.6	0.9	4.0	0	1.5	0	4.4	0	1.8	1.1	2.6	0
1995	2.7	2.2	5.8	2.2	–	–	–	–	–	–	–	–	–	–	–	–

Factors affecting the rate of collisions with power lines

To test for the effect of different factors on the rate of ptarmigan collisions with power lines, we applied a GLM–Univariate analysis procedure (SPSS for Windows, Release 10.0.5, © 1999 SPSS Inc., Chicago, Illinois) with power–line section, season (spring, summer, autumn or winter), and power–line category (300 kV, 66 kV or 22 kV) as fixed factors, year as a random factor, and the ptarmigan population index as a covariate. We tested for both the main effects and the interaction effects of all the parameters. To find the best model, we applied the model–building strategy of stepwise forward inclusion or alternate exclusion of independent variables. Only variables significant at $P < 0.05$ were accepted in the model. The collision rate on powerline section three in 1992–1995 was excluded from the GLM–analysis because the collision hazard on this section was influenced by the experimental removal of the earth wire during this period (table 2; Bevanger et al., 1998; Bevanger & Brøseth, 2001).

Factors affecting the probability of collisions with power lines

To test whether we were able to predict the probability of ptarmigan colliding with the power lines using the power–line characteristics, vegetation, and topography as parameters, we performed a binary logistic regression analysis based on a comparison of collision spots and stratified random places without any recorded collisions (SPSS for Windows, Release 10.0.5, © 1999 SPSS INC., Chicago, Illinois). A stepwise forward conditional model–building strategy was applied to find the best logistic model

Table 4. Seasonal bias correction factors used to adjust the estimate of the number of Ptarmigan killed by colliding with high–tension power–lines in southern Norway: spring, April–May; autumn, September–October; winter, November–March. Total correction denotes the cumulative correction used to adjust the absolute minimum number of collision victims found during the patrols (tdb) (Bevanger, 1995b).

Tabla 4. Factores de corrección del sesgo estacional empleados para ajustar la estimación del número de lagópodos que perecieron al colisionar con el tendido eléctrico de alta tensión en la Noruega meridional: primavera, abril–mayo; otoño, septiembre–octubre; invierno, noviembre–marzo. La corrección total indica la corrección acumulativa empleada para ajustar el número mínimo absoluto de victimas por colisión encontradas durante el estudio (tdb) (Bevanger, 1995b).

	Seasonal correction factors		
	Spring	Autumn	Winter
Search bias	0.05	0.05	0.05
Scavenger bias	0.25	0.30	0.20
Habitat bias	0.20	0.20	0.20
Crippling bias	0.05	0.05	0.05
Total correction	1.85 tdb	1.98 tdb	1.73 tdb

to predict ptarmigan collisions based on the parameters tested. In the logistic analysis, we tested whether the height of the earth wire above the ground, the distance to the woodland and the height of trees affected the probability of collision taking place. We also tested whether topographical parameters like slope and habitat type had a significant effect on the probability of collision.

Estimating total losses

The numbers of dead ptarmigan found during power–line patrols are absolute minimum values, no matter how frequently patrols are performed, or how thoroughly the corridor is searched for victims (Bevanger, 1999). Therefore, several important biasing factors connected with the fieldwork procedure have to be taken into account when trying to estimate the real number of collision victims (Aplic, 1994; Bevanger, 1995b, 1999).

The four biasing factors commonly accounted for are crippling, habitat, scavenger and search biases (review in Bevanger, 1999). Let N denote the total number of collision victims along a patrolled power-line section, and 1–pbk the proportion of these that are undetected because of the crippling bias (pbk = "percentage of birds colliding that were killed and fell on the search area" (Meyer, 1978)). Let 1–ps denote the proportion of the remaining pbk × N victims that are undetected because of the habitat bias (ps = "proportion of line section which is searchable" (James & Haak, 1979)). Let 1–pnr denote the proportion of the remaining ps × pbk × N victims that are undetected because of the scavenger bias (pnr = "percentage of dead birds not removed by scavengers–derived from a removal rate study" (Meyer, 1978)). Finally, let 1–pbf denote the proportion of the remaining pnr × ps × pbk × N victims that are undetected because of the search bias (pbf = "percentage of dead birds found based on a dead bird plant study" (Meyer, 1978)). The total number of dead birds found, tdb, is given by the equation tdb = pbf × pnr × ps × pbk × N. Thus, the real, total loss, N, is tdb / (pbf × pnr × ps × pbk).

To estimate the total annual losses in the area, we applied the estimating procedure and correction factors used in earlier studies on ptarmigan collisions to adjust the observed collision rate recorded during the patrols (table 4; Bevanger et al., 1994, 1998; Bevanger, 1995b, 1999; Bevanger & Brøseth, 2000). Year–round fieldwork in Norwegian alpine habitats is difficult due to bad weather and snow conditions for about six months of the year. We performed experiments in the study area to improve the scavenger removal bias, which is site specific and quite important in some areas (Bevanger et al., 1998). The results showed that 15% of the dummy ptarmigan were removed within five days, and tracks indicated that the Red fox (*Vulpes vulpes*), Stoat (*Mustela erminea*) and Golden eagle were the most active scavengers, particular the Red fox.

Results

Species composition of collision victims

A total of 399 dead collision victims were recorded during the six–year study, 390 of which were identified at the species or genus level. At least 24 different species were identified among the collision victims, 318 (80%) of which were ptarmigan. Most species were represented by a few individuals: Mallard (*Anas plathyrhynchos*), Rough–legged buzzard (*Buteo lagopus*), Kestrel (*Falco tinnunculus*), Black grouse (*Tetrao tetrix*), Golden plover (*Pluvialis apricaria*), *Tringa* sp., Lapwing (*Vanellus vanellus*), Ruff (*Philomachus pugnax*), Snipe (*Gallinago gallinago*), Arctic tern (*Sterna paradisea*), Wood pigeon (*Columba palumbus*), Long–eared owl (*Asio otus*), *Anthus* sp., Blackcap (*Sylvia atricapilla*), Bluethroat (*Luscinia svecica*), Fieldfare (*Turdus pilaris*), Ring ouzel (*Turdus torquatus*), Blackbird (*Turdus merula*), Redwing (*Turdus iliacus*), Song thrush (*Turdus philomelos*), Wheatear (*Oenanthe oenanthe*), and Redpoll (*Carduelis flammea*). It was rarely possible to identify the species of ptarmigan as most consisted of feather clusters and other remains. However, 42 undisturbed ptarmigan bodies were found, the majority (95%) of which were Willow ptarmigan.

Ptarmigan mortality due to power lines

The observed variation in the ptarmigan collision rate was significantly affected by the season and power–line section, together with the ptarmigan population index which also entered the GLM model (table 2 and table 3, $F_{7,81} = 9.0$, $P < 0.001$). These three parameters accounted for 46% of the observed variation. We found no significant interaction effect between the parameters tested, and nor did the power–line category or year explain a significant part of the observed variation ($P > 0.10$). On average, the annual minimum ptarmigan collision rate was estimated to be 5.3 ± 1.1 SE birds per kilometre of power line (section one: 3.7, section two: 3.1, section three: 6.5 and section four: 7.8).

The ptarmigan collision rate peaked in the winter with 0.7 birds per km^{-1} per $month^{-1}$ (fig. 2, seasonal effect: $F_{3,81} = 4.8$, $P < 0.01$). However, there was also a high collision rate in spring (0.6 birds per km^{-1} per $month^{-1}$), whereas far fewer ptarmigan collided in autumn (0.2 birds per km^{-1} per $month^{-1}$). During the summer months, we found no ptarmigan collision victims. Of the four power-line sections, section four had a much higher ptarmigan collision rate than the other three, which were quite similar (fig. 3, section effect: $F_{3,81} = 4.8$, $P < 0.01$). In general, the collision rate increased as the population index increased (population index covariate effect: $F_{1,81} = 9.0$, $P < 0.01$).

Based on the recorded collision rate of the patrolled sections, we found that, on average, collisions with power lines killed at least 159 ptarmigan annually in this area. When the observed collision

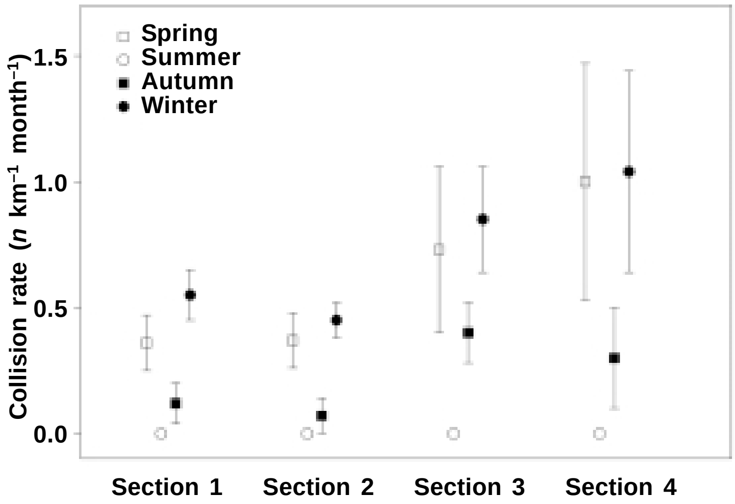

Fig. 2. Seasonal variation in ptarmigan collision rates (*n* collisions per km^{-1} per month^{-1}) ± SE for the four power–line sections studied in a subalpine area in southern Norway during a 6–year period from April 1989 to June 1995.

*Fig. 2. Variación estacional en las tasas de colisión de los lagópodos (*n *colisiones por km^{-1} por mes^{-1}) ± EE para las cuatro secciones de tendido eléctrico de alta tensión de una zona subalpina de Noruega meridional estudiadas durante un período de 6 años comprendido entre abril de 1989 y junio de 1995.*

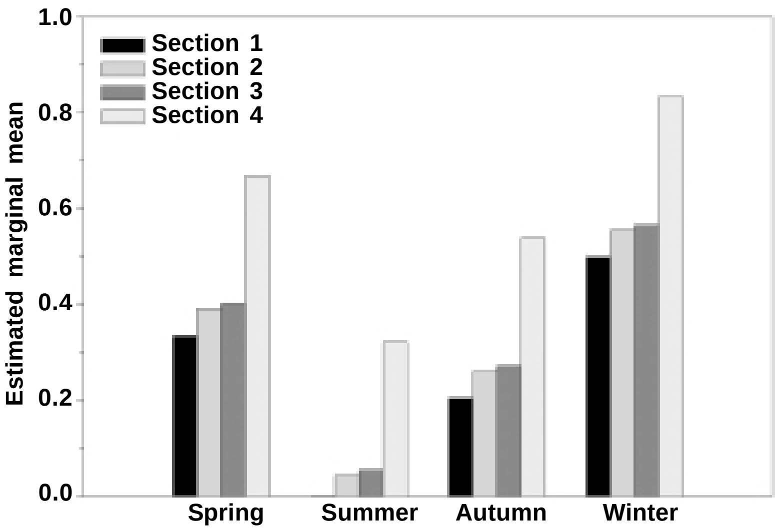

Fig. 3. Estimated marginal means of ptarmigan collision rates (*n* collisions per km^{-1} per month^{-1}) in different seasons to compare the four power–line sections studied. These mean values are adjusted for the ptarmigan population index as a covariate in the GLM analysis in a fixed–effects model.

*Fig. 3. Medias marginales estimadas de las tasas de colisión de los lagópodos (*n *colisiones por km^{-1} por mes^{-1}) en distintas estaciones del año para comparar las cuatro secciones de tendido eléctrico estudiadas. Estos valores medios se han ajustado para el índice poblacional de los lagópodos como una covarianza en el análisis GLM de un modelo de efectos fijos.*

Table 5. The absolute minimum annual number of ptarmigan collision victims recorded during patrols beneath four power–line sections in southern Norway in 1989–1995, and the total hunting yield in 1989–1994 in the same area. The number is given from one year to the next, i.e. 1989–1990, 1990–1991, etc.

Tabla 5. El número mínimo absoluto anual de víctimas de lagópodos por colisión registrado durante el estudio realizado entre 1989 y 1995 en cuatro secciones de tendido eléctrico de alta tensión de la Noruega meridional, y el rendimiento total de caza entre 1989 y 1994 en la misma área. El número se indica de un año para otro; es decir, 1989–1990, 1990–1991, etc.

	Year					
	1989	1990	1991	1992	1993	1994
Minimum no. of collision victims	108	216	183	117	107	173
Hunting bag	86	101	94	28	49	64

rate was adjusted for biasing factors connected with the fieldwork procedure (table 4), we estimated that, on average, collisions killed 282 ptarmigan annually. This indicates that the annual collision rate was probably was as high as 9.4 birds per kilometre of power line during the study period.

The only significant parameter in the binary logistic regression analysis affecting the probability of ptarmigan colliding was the height of trees ($P^2_1 = 13.5$, $P < 0.001$). Collision spots generally had lower trees than places along power lines without any recorded ptarmigan collisions. Neither the height of power-line wires, the distance to woodland, the slope nor the habitat type had any significant predictive effect on the probability of collision.

Power line versus hunting mortality

During the six hunting seasons (1989–1994), 422 ptarmigan were shot in the study area (table 5). The minimum power–line collision mortality recorded each year was on average at least 2.4 times higher than the hunting mortality during this period (range 1.3–4.2 times higher). The estimated mean minimum number of ptarmigan killed annually by colliding with the power lines during 1989–1994 was 151 birds, whereas only 70 were harvested each year (table 5). Compared with the estimated total losses due to power lines in the area (289 birds year^{-1}), this is, on average, as much as four times higher than the hunting mortality.

Discussion

Few bird species are adapted to survive the harsh environmental conditions in Norwegian alpine habitats during the winter. In summer, however, migrants increase the number of species significantly. The majority of bird species run a risk of colliding with man–made obstacles like overhead wires, although in most species only a few individuals are recorded (Avery, 1980; Bevanger, 1993a, 1995a, 1998; Brown & Drewien, 1995; Munkejord 1996). A similar pattern occurs also in the present study where ptarmigans are the dominating victims. The migrant Fieldfare was the only species other than the ptarmigan that had a noticeable collision mortality (6% of the victims). The Fieldfare is quite common, and numerous individuals gather in flocks during autumn when the southward migration starts. The migrant species of collision victims was mainly found during restricted periods in spring and autumn, reflecting the fact that the valley is draining an east–west bird migration in autumn and a west–east migration in the spring. The victim number of these species is, however, too small and fragmental for an assessment based on statistical treatment.

The considerable number of ptarmigan victims found confirms the findings of earlier studies, which showed that tetraonid species are particularly prone to collide with man–made obstacles (Watson, 1982; Bevanger, 1988, 1993a, 1995a; Miquet, 1990; Baines & Summers, 1997; Bevanger & Brøseth, 2000). The majority of the ptarmigan we were able to classify to the species level were Willow ptarmigan, and only two verified Rock ptarmigan victims were found. Rock ptarmigan only temporarily migrate from higher altitudes down to Willow ptarmigan habitats in the birch woods, where the four power–line sections were located, when snowstorms and icing of food resources occur in their alpine habitat. Willow ptarmigan and Rock ptarmigan are monogamous, territorial, medium sized grouse (0.4–0.6 kg), with a circumpolar distribution inhabiting mainly heather moor, treeless tundra and alpine habitats of North America and northern parts of Eurasia (Johnsgard, 1983). Ptarmigan populations exhibit major fluctuations in numbers, with large spatio–temporal variations in density of the breeding and autumn population (Myrberget, 1988; Hudson, 1992; Lindström, 1994).

The number of ptarmigan victims found during spring (April–May) and winter (November–March) indicates that these are the most dangerous periods of the year with respect to collisions. The winter and early spring activity of the species combined with the poor light and bad weather conditions in this period particularly seem to contribute to the collision hazard. During the winter, ptarmigan make short, preferably gliding, flights downhill, from one food patch to another, depending on the combination of prevailing winds and falling and drifting snow covering the vegetation. The males have a display period in April and May flying between the boundaries of their territory, the activity peaking during evening twilight. In summer, ptarmigan scarcely fly at all because food is plentiful and the birds are caring for their chicks. Autumn, before snow covers the vegetation, is also a period with abundant food resources and the birds may stay within restricted areas.

The data collected on topography and vegetation structure indicate some highly hazardous situations. The tree height effect on collision probability supports the assumption that ptarmigan prefer open terrain when flying between food patches. Thus, the collision hazard must be expected to decrease if a power line is routed through dense woodland or forest with tall trees, forcing the birds to fly above the wires (Thompson, 1978; Bevanger, 1990b, 1993a). Northern boreal birch woodland does not develop into tall trees (normally less than 7–8 m high), but the distribution and height of trees play an important role in regulating the flight lanes of birds. It would, however, have been preferable to use multidimensional terrain models to get a better picture of how to route a power line to minimize the collision hazard.

The high mortality values on section four are interesting, as the section was built in 1990 (Bevanger & Sandaker, 1993). It has earlier been suggested that power lines are particularly dangerous for birds shortly after they are constructed, implying that birds may "learn" to avoid collisions with air obstacles in the area they inhabit. An alternative hypothesis would be that a possible decrease in collisions over time reflects a reduction in the population size due to increased mortality caused by the power lines.

Power lines may negatively influence the population development, and contribute to population limitation. Watson (1982) reported the local extinction of Rock Ptarmigan in Scotland due to overhead ski–lift cables, and in France cables have been reported to be a threat to Black grouse populations (Miquet, 1990). Whether such mortality is compensatory or additive to natural mortality is questionable (Ellison, 1991). Traditionally, wildlife biologists have rejected density independent mortality factors like hunting and power lines as being important for species with a short life span and high reproduction potential. However, this has recently been questioned, and hunting has been shown to be important for the population trajectory (Pedersen, in press).

The present study indicates that the majority of ptarmigan are killed in winter and spring, i.e. when most natural mortality occurs (Hudson, 1992), and these birds would be going to reproduce. Hence, power–line induced mortality may have a significant demographic effect. Hunting, on the other hand, takes place in September and October (Kastdalen, 1992). Moreover, hunting mortality can be spread over a much wider area (Brøseth & Pedersen, 2000), whereas birds in the vicinity of a power line run a greater risk of becoming collision victims than an "average" bird. However, the impact area, i.e. the area where power lines have a behavioural or ecological effect (Cassel, 1978), must be considered according to species-specific movement patterns.

These two mortality factors might thus affect a local population in two ways. An interesting aspect of the present findings, particularly from a management point of view, is that the mortality caused by the power lines was 2–3 times higher than that caused by hunting. It is, however, difficult to assess the significance of hunting and power-line induced mortality in the area because the present data are insufficient for judging the population development in the study period.

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