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RESEARCH PAPER

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Collisions with power lines and electrocutions in birds —an analysis based on Swedish ringing recoveries 1990–2017

Kollisioner med ledningar och elströmsolyckor – en analys baserad på återfynd av ringmärkta fåglar i Sverige 1990–2017

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RECOVERIES OF BIRDS ringed in Sweden from the period 1990–2017 were used to analyse the occurrence of collisions with power lines and electrocutions. Out of more than 10,000 recoveries of birds found dead with finding circumstances mentioned, 8.6 % was associated with power line constructions. The number of species involved was 51 and high proportions were especially evident in some species of owls and raptors. The overall proportion of recoveries caused by collision/electrocution shows a significant decrease over time. A decrease over time in the proportions of electrocution and collision was also evident when analysing finding circumstances in four species where corpses were sent to the Swedish Museum of Natural History. Information about the power line system in Sweden during the period 2007–2016 shows that the length of local power lines has decreased with about 21 % during a ten-year period and that underground cables have increased with 28 % during the same period. The results show that collisions with power lines have decreased more than electrocutions and this may imply that there are still many places where birds are at risk of being electrocuted.

Keywords: power lines | electrocution | collision | bird ringing | ring recoveries

Introduction

Birds have been subject to anthropogenic mortality in many ways for a long time. One of these human induced mortality factors is caused by power line constructions, both through collisions and electrocutions, and it has since many years been highlighted as a conservation issue in North America, Europe and South Africa (e.g. Scott *et al.* 1972, Andersen-Harild & Bloch 1973, Bevanger 1994, Loss *et al.* 2014). It has been claimed that the expected growth of the energy demand globally in the future will result in an extension of power lines in parts of Asia, Africa, and Latin America and that this in turn will increase the bird mortality (Bernardino *et al.* 2018). Efforts have been made in order to find ways to mitigate the risk of collisions and electrocutions at power lines (e.g. Bevanger 1994, Lehman 2001, Manville 2005, Jenkins *et al.* 2010, Tintó *et al.* 2010). An analysis of the amount of birds killed at US power lines shows that between 12 and 64 million birds are killed each year (Loss *et al.* 2014).

An investigation of the occurrence of collisions and electrocutions at power lines was conducted in Sweden in 1985 by using recoveries of ringed birds reported during the period 1960–1985 (Stolt et al. 1986, Stolt & Fransson 1987). The results indicated that during this period the frequency of mortality caused by these circumstances increased by 17 %. The results from this study highlighted the problem with electrocution at transformers and a method for insulating transformers was developed. This study was later followed up by an investigation of recoveries reported during the period 1960–1999 (Fransson & Stolt 2000) where it was found that the increase levelled off and no increase in the frequency of recoveries caused by collisions or electrocutions was found during the 1990s. In the present study we have analysed recoveries reported during the period 1990–2017 in order to investigate the extent of these circumstances and to see how the proportion of these circumstances among the recoveries has developed over time. We have also investigated the finding circumstances in birds of four species where dead birds were sent to the museum during this period.

Material and methods

Recoveries of birds ringed in Sweden with a finding date within the period 1990–2017 and processed at the Swedish Bird Ringing Centre until 6 February 2018 have been included in the analysis. When recovery reports are processed and registered in the database, finding circumstances mentioned in the reports are coded according to Euring Exchange code (http://www.euring.org). As a first selection we extracted all recoveries of birds found dead in Sweden during the study period (20,974 recoveries). This data set includes a mixture of recoveries, for example birds found dead without any information about circumstances and recoveries caused intentionally by man (e.g. shot). We therefore made a second selection where circumstances such as recoveries accidentally caused by man or through human agency as well as natural causes were selected (Euring codes 30–78 and 91). In this selection, we included both recoveries with assured and presumed circumstances. After making those selections we ended up with 10,714 recoveries found in Sweden during the period 1990–2017. The selection used for the present analysis differs slightly from the earlier analyses performed on Swedish recoveries where also birds found dead without any information about circumstances were included.

Electrocution has a unique code (35) and in the code instruction it is written that if a bird collides with power lines and gets electrocuted, the code for electrocution shall be used. It is however rare that a bird that collides with power lines also becomes electrocuted (cf. Bevanger & Overskaug 1998). Collision with power lines has no unique code and this finding circumstance is included in the code described as collision with thin man-made structure (43). In the database there is in many cases extra information given as text and we have manually excluded recoveries when information given show that the collision was not against a power line and this amounts to 10 % of the recoveries coded as collision with thin man-made structure. When analysing the distribution on age we have used only birds ringed as nestlings.

To investigate the extent of collisions and electrocutions in birds during the study period further, birds of some species sent to the museum have been analysed regarding finding details. Several species of birds and mammals in Sweden are treated as State game and if found dead, they shall according to legislation be sent to the National Veterinary Institute or to the Swedish

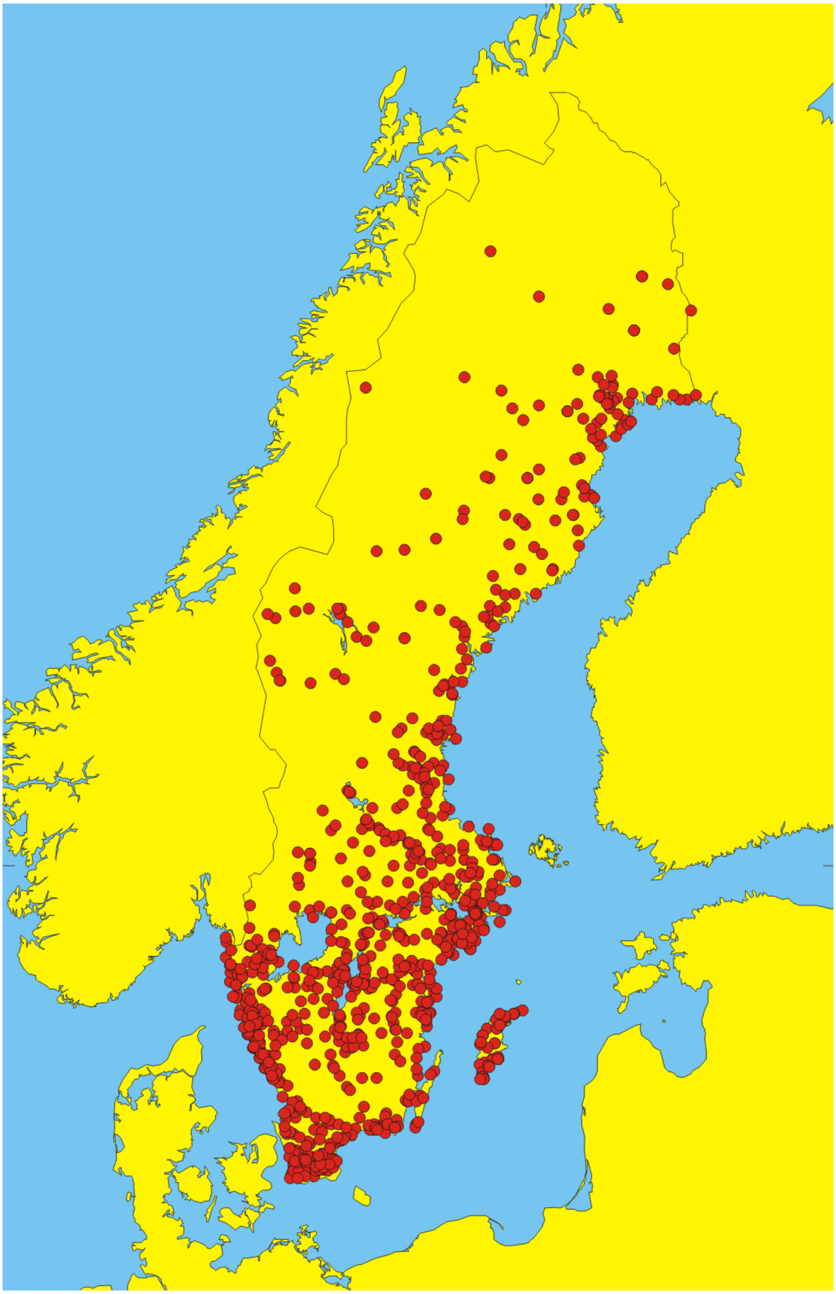


FIGURE 1. Map showing the locations of recoveries of ringed birds reported as collisions with power lines and electrocutions in Sweden during the period 1990–2017 (n=921).
— *Karta som visar platser i Sverige där ringmärkta fåglar rapporterats påträffade efter att ha kolliderat med elledning eller råkat ut för elström under perioden 1990–2017 (n=921).*

Museum of Natural History. The species investigated in this study are the White-tailed Eagle *Haliaetus albicilla*, Golden Eagle *Aquila chrysaetos*, Eagle Owl *Bubo bubo* and the Ural Owl *Strix uralensis*, species known to be prone to power line mortality and with large sample sizes. The total number of those four species registered at the museum as found during the period 1990–2017 amounts to 3,839. Some of the birds sent to the museum have been ringed and in order not to include individuals twice they have been excluded from this analysis if they have been treated by the ringing centre and included in the database of recovered ringed birds. We have also excluded reports without any information about circumstances or condition of the bird, in line with how we treated recoveries. After this selection we ended up with 1,590 birds of the four species involved. It is important to recognize that this sample differs somewhat from the ringing recoveries since many of the birds have passed the National Veterinary Institute and undergone an autopsy and hence have a veterinary statement.

Information about the annual existing length of different kind of power lines as well as underground power cables in Sweden was received from the Swedish Energy Markets Inspectorate for the last 10–15 years depending on types. The power companies are obliged to report this information to the Swedish Energy Markets Inspectorate on an annual basis. Annual information about the complete length of power lines in Sweden is available from the period 2007–2016 and for some types of power lines from a few years before that. The length of underground power cables is available for the period 2000–2016. The local electricity network includes the most extensive stretches, and the voltage transferred in those power lines varies between 0.4–24 kV and both insulated and uninsulated power lines exist. Regional power lines (30–150 kV) and national power lines (>150 kV) exist as well.

Results

RECOVERIES OF RINGED BIRDS

There are 921 recoveries of ringed birds found dead in Sweden during the period 1990–2017 where the reports include information that collision with overhead wires or electrocution have, or presumed to have, caused the deaths (Table 1). This is 8.6 % of all recoveries with information about cause of death (10,714) handled during this period. The number of species involved is 51 and the proportion of the recoveries caused by power lines varies much between species. The sample sizes are, however, small in some of the species with high proportion. Species with somewhat larger number of recoveries, owls, raptors, swans, Common Crane *Grus grus* and White Stork *Ciconia ciconia* show high proportions (Table 1). Among species with more than 50 recoveries caused by collision/electrocution, Golden Eagle (49 %), Eagle Owl (39 %) and Ural Owl (29 %) show the highest proportions of those circumstances. Out of the recoveries caused by power lines, 38 % have been reported by the finder as caused by electrocution. In some species, electrocution is involved in a large proportion of the recoveries and this holds especially true for several species of owls and raptors (Table 1) and in the Ural Owl, a majority (76 %) of the recoveries has electrocution mentioned in the recovery reports. The reports sometimes include information about how the birds have been electrocuted and in owls it often happens when perching on pole-mounted transformers. In some other species like the Mute Swan *Cygnus olor* and the Grey Heron *Ardea cinerea*, electrocution is not noted at all while it is involved in one third of the recoveries of White Stork (Table 1).

The geographical distribution shows that most of the recoveries are reported in the southern part of Sweden and along the coast in the north, with concentrations of recoveries in densely populated areas (Figure 1). The reports of collisions and electrocutions are not evenly distributed over the year (Figure 2) and show peaks during autumn (July–October) and spring (March–May). During winter (November–February) and early summer (June), incidents are less common.

TABLE 1. The number of recoveries of ringed birds found dead with circumstances mentioned in Sweden during the period 1990–2017, the number of recoveries involving collision with power lines/electrocution, the proportion of collision/electrocution recoveries of the total number of recoveries, and the proportion caused by electrocution of the total number of recoveries.
— Antalet återfynd av ringmärkta fåglar funna döda med angiven orsak i Sverige under perioden 1990–2017, antalet återfynd där kollision med kraftledning eller elström angetts som orsak, andelen kollisioner/elström i förhållande till samtliga fynd, samt andelen där elström angetts som dödsorsak.

Species *Art*			Total number of recoveries	N involving collision / electrocution	Percent collision / electrocution	Percent electro-cution
English name *Engelskt namn*	Swedish name *Svenskt namn*	Scientfic name *Vetenskapligt namn*	*Totalt antal återfynd*	*Antal kollision / elström*	*Procent kollision / elström*	*Procent elström*
Canada Goose	kanadagås	*Branta canadensis*	11	1	9.1	
Barnacle Goose	vitkindad gås	*Branta leucopsis*	32	1	3.1	
Greylag Goose	grågås	*Anser anser*	19	6	31.6	
Taiga Bean Goose	tajgasädgås	*Anser fabalis*	2	1	50.0	
Mute Swan	knölsvan	*Cygnus olor*	202	36	17.8	
Whooper Swan	sångsvan	*Cygnus cygnus*	6	2	33.3	16.7
Common Shelduck	gravand	*Tadorna tadorna*	5	1	20.0	
Mallard	gräsand	*Anas platyrhynchos*	139	1	0.7	
Common Goldeneye	knipa	*Bucephala clangula*	3	1	33.3	
Western Capercaillie	tjäder	*Tetrao urogallus*	7	1	14.3	
Red-throated Loon	smålom	*Gavia stellata*	17	1	5.9	
White Stork	vit stork	*Ciconia ciconia*	13	6	46.2	15.4
Grey Heron	gråhäger	*Ardea cinerea*	45	13	28.9	
Great Cormorant	storskarv	*Phalacrocorax carbo*	370	1	0.3	
Western Osprey	fiskgjuse	*Pandion haliaetus*	45	4	8.9	2.2
European Honey Buzzard	bivråk	*Pernis apivorus*	4	2	50.0	25.0
Golden Eagle	kungsörn	*Aquila chrysaetos*	105	51	48.6	23.8
Eurasian Sparrowhawk	sparvhök	*Accipiter nisus*	194	4	2.1	
Northern Goshawk	duvhök	*Accipiter gentilis*	423	61	14.4	2.1
Western Marsh Harrier	brun kärrhök	*Circus aeruginosus*	13	6	46.2	
Red Kite	röd glada	*Milvus milvus*	26	8	30.8	11.5
White-tailed Eagle	havsörn	*Haliaeetus albicilla*	315	58	18.4	6.0
Rough-legged Buzzard	fjällvråk	*Buteo lagopus*	13	1	7.7	
Common Buzzard	ormvråk	*Buteo buteo*	167	33	19.8	3.0
Corn Crake	kornknarr	*Crex crex*	1	1	100.0	
Common Moorhen	rörhöna	*Gallinula chloropus*	1	1	100.0	
Common Crane	trana	*Grus grus*	11	6	54.5	9.1
Eurasian Oystercatcher	strandskata	*Haematopus ostralegus*	11	2	18.2	9.1
Black-headed Gull	skrattmås	*Chroicocephalus ridibundus*	155	5	3.2	
Mew Gull	fiskmås	*Larus canus*	94	3	3.2	
Great Black-backed Gull	havstrut	*Larus marinus*	51	2	3.9	
European Herring Gull	gråtrut	*Larus argentatus*	161	6	3.7	0.6
Stock Dove	skogsduva	*Columba oenas*	5	1	20.0	
Eurasian Eagle-Owl	berguv	*Bubo bubo*	1,004	393	39.1	17.3
Tawny Owl	kattuggla	*Strix aluco*	764	76	9.9	5.9

TABLE 1 continued | *Tabell 1 fortsatt.*

Species *Art*			Total number of recoveries	N involving collision/ electrocution	Percent collision/ electrocution	Percent electro-cution
English name *Engelskt namn*	Swedish name *Svenskt namn*	Scientfic name *Vetenskapligt namn*	*Totalt antal återfynd*	*Antal kollision/ elström*	*Procent kollision/ elström*	*Procent elström*
Ural Owl	slaguggla	*Strix uralensis*	199	55	27.6	21.1
Great Grey Owl	lappuggla	*Strix nebulosa*	73	7	9.6	1.4
Common Swift	tornseglare	*Apus apus*	12	1	8.3	
Common Kestrel	tornfalk	*Falco tinnunculus*	432	38	8.8	3.7
Merlin	stenfalk	*Falco columbarius*	5	1	20.0	
Peregrine Falcon	pilgrimsfalk	*Falco peregrinus*	57	7	12.3	3.5
Eurasian Jay	nötskrika	*Garrulus glandarius*	19	1	5.3	
Eurasian Magpie	skata	*Pica pica*	31	1	3.2	
Spotted Nutcracker	nötkråka	*Nucifraga caryocatactes*	6	1	16.7	
Rook	råka	*Corvus frugilegus*	8	1	12.5	
Northern Raven	korp	*Corvus corax*	42	7	16.7	2.4
Common Starling	stare	*Sturnus vulgaris*	124	1	0.8	
Common Blackbird	koltrast	*Turdus merula*	202	1	0.5	
Common Redstart	rödstjärt	*Phoenicurus phoenicurus*	39	1	2.6	
Eurasian Tree Sparrow	pilfink	*Passer montanus*	81	1	1.2	
Common Redpoll	gråsiska	*Acanthis flammea*	55	1	1.8	
Total *Totalt*			**10,714**	**921**	**8.6**	**3.3**

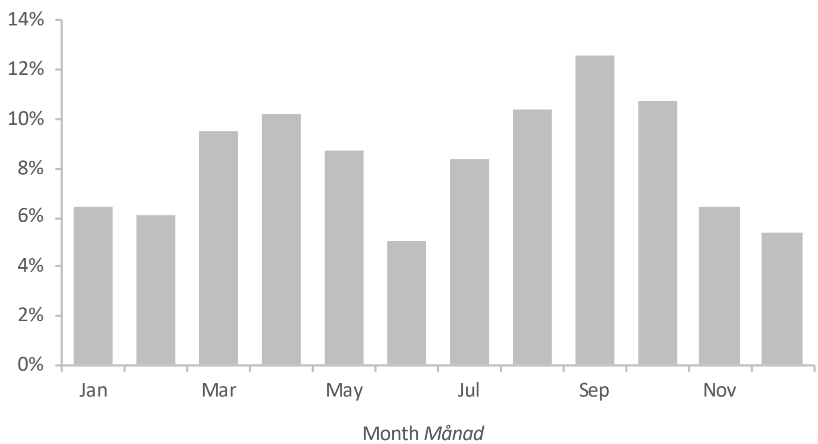
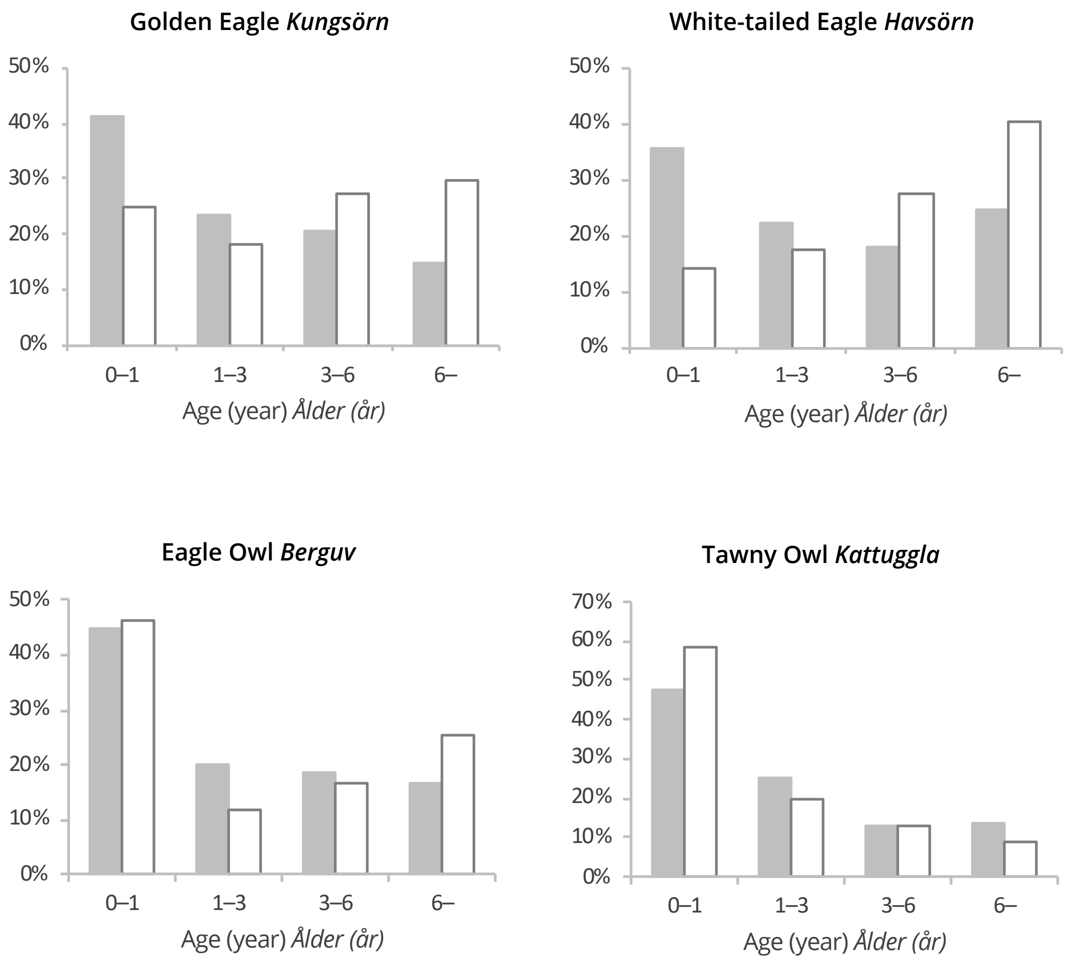


FIGURE 2. The seasonal distribution of recoveries caused by collision with power lines and electrocution reported during the period 1990–2017.
— Den säsongsmässiga fördelningen av återfynd orsakade av kollisioner med ledning och elström under perioden 1990–2017.



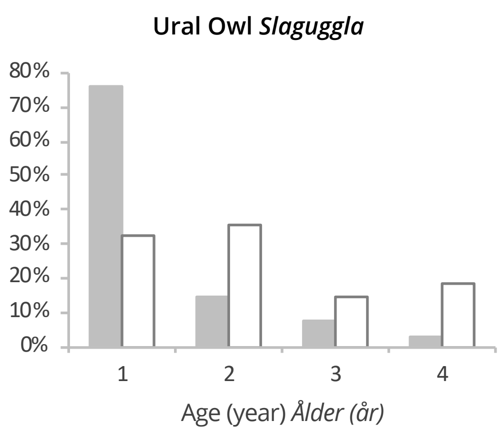


FIGURE 3. Distribution on age-classes of recoveries reported as collisions with power lines and electrocutions (filled bars) compared with the distribution of recoveries reported with other known finding circumstances (open bars). Golden Eagle *Aquila chrysaetos* (collisions and electrocutions n=34 and other known circumstances n=44), White-tailed Eagle *Haliaeetus albicilla* (n=45 and n=232), Eagle Owl *Bubo bubo* (n=168 and n=248), Tawny Owl *Strix aluco* (n=55 and n=469) and Ural Owl *Strix uralensis* (n=42 and n=105). Note different scales of the y-axes.
— Fördelningen av återfynd orsakade av kollisioner med ledning och elström på olika åldersklasser (fyllda staplar) jämfört med fördelningen av återfynd med andra kända fyndorsaker (öppna staplar). Kungsörn (kollisioner med ledning och elström n=34 och andra kända fyndorsaker n=44), havsörn (n=45 och n=232), berguv (n=168 och n=248), kattuggla (n=55 och n=469) och slaguggla (n=42 och n=105). Notera att y-axlarna har olika skalor.

The age distributions in recoveries reported as caused by collision and electrocution compared with recoveries caused by other circumstances in five species varied between species (Figure 3). In some of the species it is clear that power line recoveries are more common among younger birds compared to what is found in other circumstances: White-tailed Eagle (χ^2=14.1, df=3, p=0.002), Eagle Owl (χ^2=8.6, df=3, p=0.04) and Ural Owl (χ^2=24.0, df=3, p=0.0002). This is not the case in some other species: Golden Eagle (χ^2=4.0, df=3, p=0.26) and Tawny Owl (χ^2=2.5, df=3, p=0.48). Even if recoveries during the first year of life are predominant among recoveries caused by power lines it is clear that older birds are affected as well. The proportion of recoveries reported from birds three years or older varies between 2 and 24 % in the five species studied (Figure 3).

The overall proportion of recoveries caused by collision and electrocution during the period 1990–2017 shows a significant decrease over time (R_s=−0.82, n=28, p<0.05; Figure 4). The decrease in power line recoveries during the study period is also evident at the species level (Figure 5) even if the amount of decrease varies somewhat between species. When recoveries of birds are separated into collision and electrocution, both circumstances have decreased during the period 1990–2017 even though electrocution have decreased less than collision (collision: R_s=−0.80, n=28, p<0.001, electrocution: R_s=−0.40, n=28, p<0.05; Figure 6).

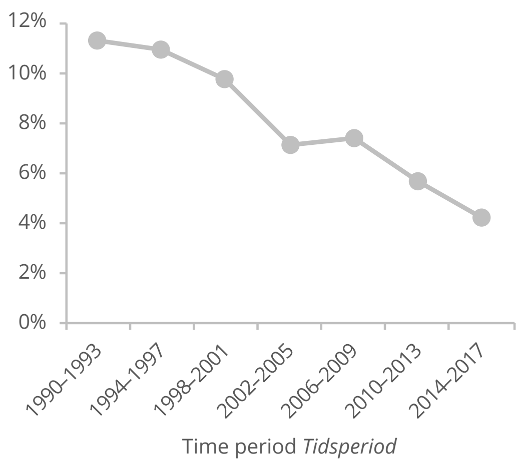


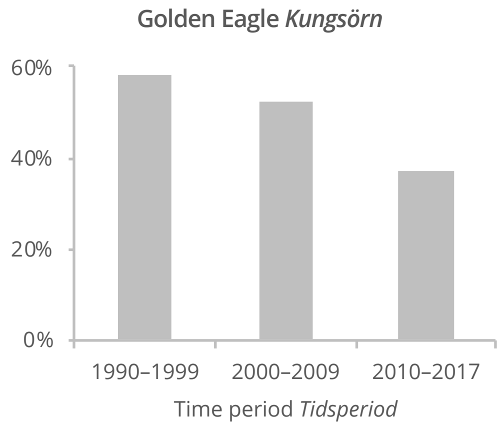
FIGURE 4. The proportion of ringing recoveries caused by collision with power lines and electrocution of the total number of ringed birds found dead in Sweden with known finding circumstances in four-year periods during 1990–2017.
— Andelen återfynd som orsakats av kollision med ledning och elström av fåglar påträffade döda i Sverige med känd fyndorsak under perioden 1990–2017, fördelade på fyraårsperioder.

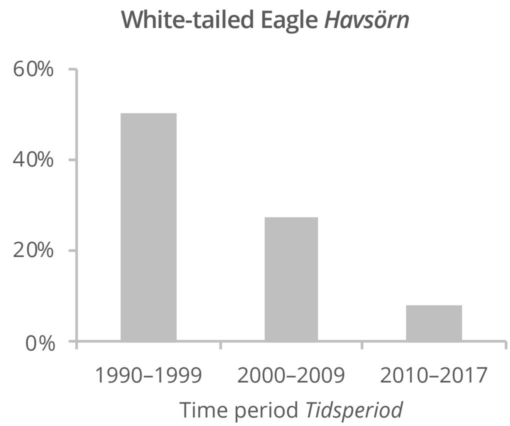
BIRDS SENT TO THE SWEDISH MUSEUM OF NATURAL HISTORY

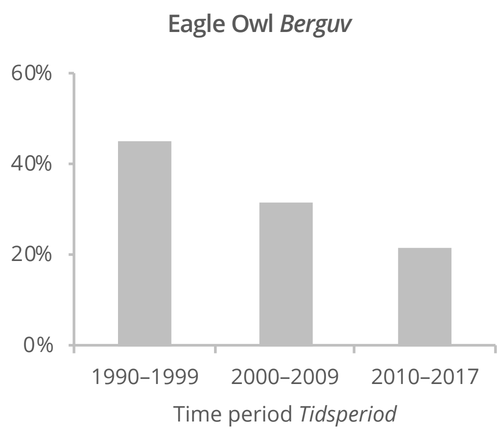
In the four species sent to the museum during the period 1990–2017, where information about cause of death have been registered, it is also clear that the proportions of birds found dead as a result of collision and electrocution have decreased over time (Figure 7). The proportions differ slightly compared with the results from recoveries of ringed birds, and this is especially evident for the eagles where lower proportions of collisions and electrocutions are found in birds sent to the museum. This is most certainly a result of that some causes of death are based on veterinary examinations, for example lead poisoning and illegal hunting, which is normally not possible to conclude when birds are found dead and reported by the public.

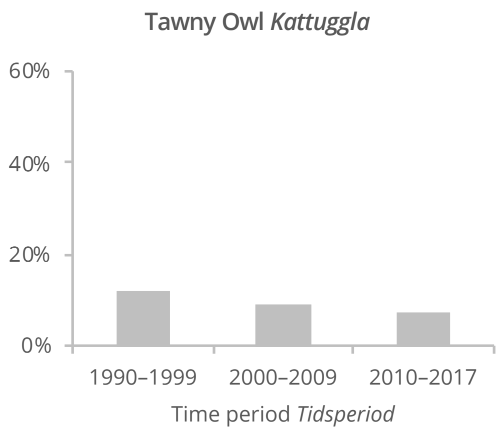
CHANGES IN THE ELECTRICITY NETWORK

The total length of overhead power lines in Sweden decreased by 21 % over ten years, from 230 694 km in 2007 to 182 167 km in 2016 (Table 2). The local electricity network includes power lines with lower voltage (0.4 kV) as well as power lines with higher voltage (10–24 kV). Both the length of the uninsulated and the insulated low voltage power lines in the local electricity network have decreased slightly during the period 2007–2016 and in 2016, 92 % was isolated (Table 2). Uninsulated power lines with higher voltage in the local electricity network show a decrease in length with 43 % during the period 2007–2016 while the length of the insulated power lines increased by 70 % during the same period and in 2016, 36 % was isolated (Table 2). The length of the underground power cables has increased from 296,853 km in 2007 to 380,369 km in 2016 (+28 %). The increase is larger in the higher voltage cables (55 %) compared with low voltage cables (18 %). Very small changes have occurred in the regional and in the national electricity networks (Table 2).









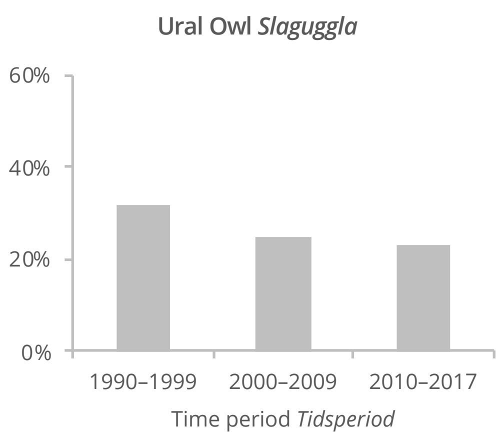


FIGURE 5. The proportion of ringing recoveries caused by collision with power lines and electrocution of the total number of ringed birds found dead in Sweden, with known finding circumstances, in five species during three time periods over 1990–2017.
— Andelen återfynd av fem arter som orsakats av kollision med ledning och elström av fåglar påträffade döda i Sverige, med känd fyndorsak, under perioden 1990–2017 fördelade på tre tidsperioder.

Discussion

Most studies about mortality caused by power lines have been based on monitoring of stretches of power lines or surveys of poles (e.g. Scott *et al.* 1972, Lehman *et al.* 2007, Jenkins *et al.* 2010, Tintó *et al* 2010, Dwyer *et al.* 2013, Bevanger *et al.* 2014), but as far as we know this has not been carried out in an organised way in Sweden. To use recoveries of ringed birds, as in this study, has been done less frequently in other countries. One problem when using recoveries of ringed birds is that the probability of finding a dead individual depends on the cause of death as well as size and colour of the bird, which means that the proportions found cannot be used as mortality estimates (Schaub & Pradel 2004). A bird found with wounded wings or legs might very well have collided with power lines, but if this is not obvious to the finder and not mentioned as a possible cause of the wounds they are not included as victims of power lines. Another problem is that finders might not always look very careful for signs of electrocutions, but notice the vicinity of a power line and report that the bird have died from collision with power lines resulting in an underestimation of the proportion of electrocutions. Even if problems exist, comparing proportions found between species and over time can give important insights in the mortality caused by the electricity network.

Collisions and electrocutions at power lines involve a great variety of bird species and in this study, we found it to have occurred in 51 different species. An earlier study, using the same method and covering the period 1911–1999, included 141 different species (Fransson & Stolt 2000). An Italian study based on over 1,300 reported individual power line casualties included 95 species, comprising 19 % of the Italian bird species (Rubolini *et al.* 2005). Several species of raptors, owls, swans as well as Grey Heron, Crane and White Stork are among the species with the highest proportions of mortality caused by power lines in our study. This is in line with results found in many studies around the world (e.g. Rubolini *et al.* 2005, Manville 2005, Jenkins *et al.* 2010, Bevanger 1998, Harness & Wilson 2001). Those groups include many endangered and vulnerable species and this mortality factor have therefore been highlighted as a nature conservation issue. It is, however, important to have in mind that some groups of birds are ringed only in low numbers and/or not included in the State game in Sweden and some species that run a high risk of colliding with power lines might be missed in this analysis. Species with high wing loading and low aspect ratio have been considered especially vulnerable to collisions with power lines (Bevanger 1998, Janss 2000, Bernardino *et al.* 2018). The Galliformes (including for example grouses, partridges and quails) are characterised by high wing loading and low aspect ratio and is a group of birds ringed in low numbers in Sweden.

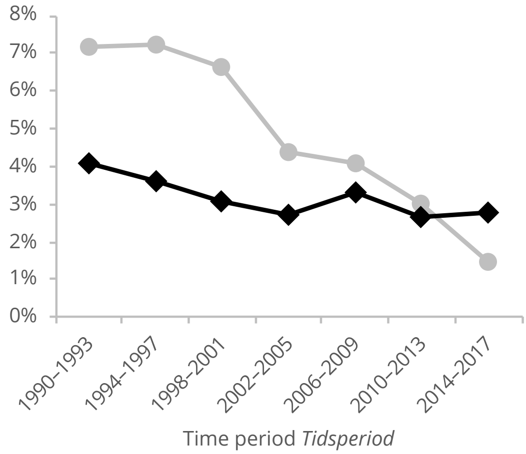


FIGURE 6. The proportion of ringing recoveries of birds found dead in Sweden with known finding circumstances caused by collisions with power lines (grey line; circles) and electrocutions (black line; diamonds) during the period 1990–2017, divided on four-year periods. — *Andelen återfynd som orsakats av kollision med ledning (grå linje; cirklar) eller elström (svart linje; fyrkanter) av fåglar påträffade döda i Sverige under perioden 1990–2017, fördelat på fyraårsperioder.*

Electrocution is common in some species of owls and raptors and the reason for this is probably mainly incidents when birds are landing or taking off from poles and when birds are resting on pole-mounted transformers with uninsulated cables attached. Since detailed information in most cases is missing on how the bird has been electrocuted or what kind of power line that has been involved, it is not possible to make any detailed conclusions about those aspects. It is striking, however, that a great majority of the reported Ural Owls has been reported as electrocuted and this is most certainly related to the species habit of resting on pole-mounted transformers. In addition, Eagle Owl and Tawny Owl show high proportions of electrocution

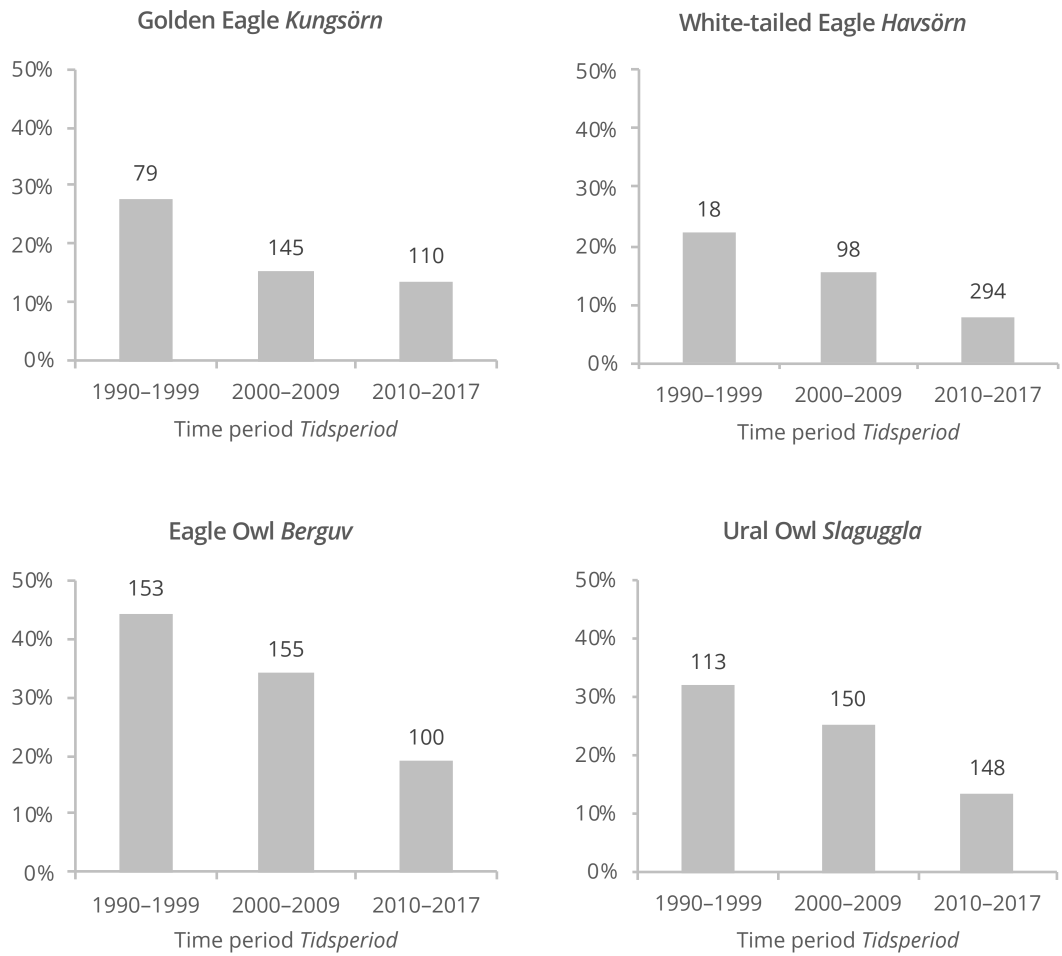


FIGURE 7. The proportion of birds sent to the Swedish Museum of Natural History with known finding circumstances in four different species caused by collision with power lines and electrocution during the period 1990–2017. Sample sizes of birds included in each period are given above the bars.
— Andelen fåglar av fyra arter med fyndorsaken kollision med ledning och elström av fåglar med kända fyndorsaker som inkommit till Naturhistoriska riksmuseet under perioden 1990–2017, fördelat på tre tidsperioder. Antalet fåglar som inkluderats anges ovanför staplarna för varje period.

among the recoveries probably for the same reason. Golden Eagle also show a high proportion of electrocution and this has also been observed in western United States (Harness & Wilson 2001). White Stork, in contrast to Mute Swan and Grey Heron, show both collisions and electrocution which is in line with a study from Spain (Garrido & Fernández-Cruz 2003). The Spanish study shows that, beside the risk of collision with power lines in flight, the habit of roosting on poles make White Storks also vulnerable to electricity. White Stork is a species that is known to be strongly affected by power lines in Europe and, based on data from Switzerland, Schaub & Pradel (2004) estimated that about one in four juveniles and one in 17 adults are dying each year because of power lines.

The distribution on age classes in five species show that the power line recoveries differ from other known finding circumstances in three species. This indicates that, at least in some species, younger birds are more affected by power lines than other circumstances and this might reflect behavioural differences between species. The comparisons have been made with other known finding circumstances and the distribution on age of those recoveries are not necessarily reflecting the age structure in the population, since there might exist other finding circumstances where young birds are overrepresented. Stolt *et al.* (1986) found no obvious difference in three species between the proportions found during the first year of life in recoveries caused by power lines compared with other recoveries. In a study in western United States it was found that 66 % out of 90 Golden Eagles found electrocuted were juvenile birds (Harness & Wilson 2001). Most of the incidents with the electricity network in Sweden involve younger birds, but it is also clear that adult birds belonging to the breeding population regularly are involved as well.

The seasonal distribution of recoveries caused by power lines shows a peak in autumn (July–October) and a slightly smaller peak in spring (March–May). Less incidents seem to occur during breeding time (June) and during winter (November–February). Several studies have shown a peak of collisions and electrocutions in autumn and this has been explained by the dispersal of young birds (Sergio *et al.* 2004, Harness & Wilson 2001). Dwyer *et al.* (2013) found a different pattern, where incidents with power lines in western United States were more common during breeding season. The seasonal distribution with less incidents in winter might also be a result of people not spending as much time outdoors as during the rest of the year and another problem could be that dead birds during winter may be covered by snow. The peak of occurrence found in spring in this study might at least partly be a result of birds being on migration and hence more vulnerable. It is, however, surprising that the proportion of recoveries found in spring is not very different from the one found in autumn considering the large number of young birds existing in autumn.

By comparing the proportion of recoveries reported as caused by the electricity network with other reported causes this study shows that the mortality among recovered ringed birds reported as caused by overhead wires (collisions and electrocutions) has decreased during the period 1990–2017. Earlier studies performed in Sweden based on ringing recoveries showed an increase in this mortality among recoveries during the period 1960–1985 (Stolt *et al.* 1986) while a follow up showed that the mortality levelled off during the 1990s (Fransson & Stolt 2000). In this study, the decrease in the proportion of recoveries caused by overhead wires is also more evident after the year 2000. Decreases in the proportion of power line incidents were also evident in the four species of birds found dead and sent to the Swedish Museum of Natural History during the

TABLE 2. Length (km) of the Swedish electricity network in 2007, 2011, and 2016 based on figures from to the Swedish Energy Markets Inspectorate. Some stretches of underground cables with higher voltage exist as well, but the length is less than 2,000 km.
— Det svenska elnätets längd (km) 2007, 2011 och 2016 baserat på uppgifter från Energimarknadsinspektionen. Markkabel med högre spänning förekommer, men längden på denna är mindre än 2 000 km.

	Voltage (kV)	Length (km) *Längd (km)*		
	Spänning (kV)	2007	2011	2016
Local electricity network *Lokalnät*				
Uninsulated power lines *Oisolerade ledningar*	0.4	12,880	7,569	5,095
Insulated power lines *Isolerade ledningar*	0.4	69,061	62,407	55,199
Uninsulated power lines *Oisolerade ledningar*	10–24	87,576	68,133	49,829
Insulated power lines *Isolerade ledningar*	10–24	16,530	22,292	28,111
Underground power cable *Markkabel*	0.4	217,505	236,249	257,108
Underground power cable *Markkabel*	10–24	79,348	102,204	123,261
Regional electricity network *Regionnät*	30–150	29,519	33,386	29,273
National electricity network *Stamnät*	>150	15,128	15,190	14,660

period 1990–2017. This material consisted of close to 1,600 birds with known or presumed cause of death.

Complete information about the Swedish power line system has only been possible to obtain back to 2007 and during this period, it is clear that large changes have taken place. These changes are most certainly behind the decrease in mortality caused by the electricity network observed in recoveries of ringed birds as well as in birds sent to the museum during the last 20 years. The total length of overhead power lines have decreased in length with 21 % during the period 2007–2016 and the proportions of insulated power lines have increased. An insulated power line is more visible than an uninsulated and this might decrease the risk that birds should collide. During the same period, the length of underground cables increased with more than 80,000 km. It is clear that the change in the electricity network in Sweden started earlier than 2007 and estimates concerning 1981 show that the total length of overhead power lines was 276,400 km while the length of underground power cables was 163,600 km (Statens Planverk 1985). This can be compared with 230,694 km of overhead power lines in 2007 and 182,167 km in 2016 as well as 297,548 km of underground power cables in 2007 and 382,130 km in 2016. Several winter storms, especially the one named Gudrun in January 2005, resulting in power failure in large areas are most certainly something that intensified the changes made in the Swedish power system in order to make it more weather proof, for example power lines being insulated and underground cabling. We have no information about changes in numbers of pole-mounted transformers during the same time, constructions where birds regularly have been reported electrocuted. It is reasonable to believe that the number of pole-mounted transformers has decreased, started to become insulated, or changed into other constructions during the last ten years. The proportion of recoveries where the finders have mentioned electrocution has decreased less than collisions and this may imply that there are still many places where birds are at risk for being electrocuted.

Several studies have investigated what kind of constructions that cause collisions and electrocutions and in what habitat incidents frequently occur (e.g. Ferrer *et al.* 1991, Bevanger 1994, Tintó *et al.* 2010, Shaw *et al.* 2018). The importance of considering the risk of bird collisions when planning new routes for power lines has been stressed (e.g. Bevanger 1994). A survey in northeast Spain including 3,869 poles was conducted in order to find out details about the most dangerous poles. Tintó *et al.* (2010) made a predictive model and found that 9.2 % of the poles accounted for 53.2 % of the mortality in the study area. By correcting 222 poles they found a clear reduction of incidents in the area. A similar pattern was found on the island Smøla in Norway where a survey of 742 poles showed that 50 % of the 142 dead birds were found at 2.8 % of the poles (Bevanger *et al.* 2014). In a study of Eagle Owl in northern Italy, it was shown that territories near to power lines were progressively abandoned during a ten-year period and the authors suggested that insulation of particular uninsulated poles should be prioritised (Sergio *et al.* 2004). The fact that some places are more dangerous than others was also mentioned by Stolt *et al.* (1986), where several Ural Owls were reported as electrocuted in the same pole-mounted transformers within short time. This shows that an important measure of mitigation can be to find and secure particular places where birds experience a high risk.

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Svensk sammanfattning

Att fåglar råkar ut för kollisioner med ledningar och elström har varit känt under lång tid och på flera håll i världen uppmärksammats som ett fågelskyddsproblem. Det har uppskattats att mellan 12 och 64 miljoner fåglar dödas av ledningsnätet i USA varje år. Förekomsten av kollisioner med ledningar och fåglar som råkat ut för elström i Sverige baserat på återfynd av ringmärkta fåglar har tidigare analyserats för perioden 1960–1985 och under den perioden visade det sig att återfynd orsakade av ledningar ökade med 17 %. I en uppföljande studie av återfynd från perioden 1960–1999 visade resultaten att återfynd orsakade av ledningar under 1990-talet inte uppvisade någon ökning. För att studera hur förekomsten av återfynd orsakade av ledningar och elström utvecklats under senare år har återfynd av ringmärkta fåglar under perioden 1990–2017 analyserats.

Materialet utgörs av återfynd av fåglar påträffade döda i Sverige och där upphittaren angett en säker eller trolig dödsorsak. Det betyder att återfynd där upphittaren endast angett att fågeln hittats död inte inkluderats eftersom det i denna grupp också finns fåglar som kolliderat med ledning eller råkat ut för elström utan att det uppmärksammats av upphittaren. Antalet återfynd av fåglar påträffade döda med angiven dödsorsak under period 1990–2017 (behandlade av ringmärkningscentralen t.o.m. 6 februari 2018) uppgår till 10 714.

Fyra arter av Statens vilt (havsörn, kungsörn, berguv och slaguggla) som inkommit till Naturhistoriska riksmuseet under perioden 1990–2017 har också analyserats med avseende på fyndorsaker. I detta material har, i linje med hur återfynden hanterats, fåglar som inte har någon angiven dödsorsak sorterats bort och materialet omfattar totalt 1 590 fåglar. Uppgifter om längden luftburna elledningar och längden nedgrävd elkabel i Sverige har erhållits från Energimarknadsinspektionen dit detta årligen rapporteras och där information från de senaste tio åren använts.

Antalet återfynd där upphittaren angett att kollision med ledning eller elström varit orsak, eller trolig orsak, uppgår till 921 under den studerade perioden, vilket innebär 8,6 % av samtliga fynd (10 714) med fyndorsak angiven (tabell 1). Antalet arter som ingår är 51 och det visar att många olika arter är inblandade. För en del arter är materialet litet, men för arter med lite större material förekommer höga andelar hos flera rovfåglar, ugglor och svanar samt trana och vit stork. Bland arter med fler än 50 fynd orsakade av ledningar uppvisar kungsörn (49 %), berguv (39 %) och slaguggla (29 %) de högsta andelarna. Av ledningsfynden har 38 % angetts vara orsakade av elström och för en del arter utgör elström en stor del av ledningsfynden (tabell 1). Om fåglar råkat ut för elström i samband med kollisionen har fyndet kodats som elström, men det är ovanligt att fåglar i samband med en kollision också råkar ut för elström. Ibland innehåller fyndrapporten uppgift om vad som inträffat och det framgår att många som råkat ut för elström har kommit i kontakt med oisolerade ledningar vid stolptransformatorer. För en art, slaguggla, har huvudparten av fynden (76 %) orsakats av elström.

Den geografiska spridningen visar att förekomsten av kollisioner/elström är spridd över en stor del av landet, men med koncentrationer till tätbefolkade områden i södra Sverige och längs Norrlandskusten (figur 1). Fyndens fördelning under året visar en tydlig topp under hösten som säkerligen sammanfaller med årets ungfåglar och deras rörelser. Under våren förekommer också en tydlig topp som inte är så mycket mindre än höstens topp och som förmodligen åtminstone till del är ett resultat av rörelser under vårflyttningen. Färre fynd är rapporterade under vintern och det kan delvis bero på att färre människor då befinner sig i skog och mark samt att döda fåglar kan döljas av snö.

Åldersfördelningen bland återfynden orsakade av kollisioner och elström visar att dessa orsaker är vanligare bland yngre fåglar än bland andra kända fyndorsaker hos några arter (havsörn, berguv och slaguggla) (figur 3). Hos några andra arter (kungsörn och kattuggla) kunde någon skillnad inte påvisas. Det är möjligt att det även i kategorin andra kända fyndorsaker finns orsaker där yngre fåglar är överrepresenterade, vilket gör jämförelsen svår att tolka, men skillnaderna kan spegla olikheter i arternas beteenden. Även om andelen yngre fåglar är stor bland ledningsfynden så är det klart att även äldre fåglar ingår och hos de studerade fem arterna varierar andelen fåglar äldre än tre år från 2–24 %.

Andelen återfynd orsakade av kollisioner med ledningar och elström uppvisar en signifikant minskning under perioden 1990–2017 ($R_s = -0.82$, $n = 28$, $p < 0.05$, figur 4). Denna minskning är tydlig också hos enskilda arter även om graden av minskning varierar något mellan olika arter (figur 5). Delas återfynden upp på de som orsakats av kollisioner och de som orsakats av elström så uppvisar båda en minskande andel under perioden, men fynden orsakade av elström har minskat i en långsammare takt (kollisioner: $R_s = -0.80$, $n = 28$, $p < 0.001$, elström: $R_s = -0.40$, $n = 28$, $p < 0.05$, figur 6). I det studerade materialet av fyra arter som tillhör Statens vilt som inkommit till museet under perioden 1990–2017 kan också en minskande andel orsakade av kollisioner och elström noteras (figur 7). Andelarna skiljer sig något från vad återfynden visar, men detta beror till viss del på att många av fåglarna obducerats av veterinärer på SVA (Statens veterinärmedicinska anstalt) och då fått en fyndorsak som inte lika lätt kunnat upptäckas av en privat upphittare.

Den totala längden på det svenska elnätet i form av luftledningar var 230 694 km 2007, vilket kan jämföras med 182 167 km tio år senare, en minskning med 21 %. Under samma period minskade längden oisolerad luftledning för medelhög spänning (10–24 kV) med 43 % medan längden isolerad ökade något (tabell 2). Längden ledning med lägre spänning (0,4 kV), både isolerad och oisolerad luftledning, minskade något under tioårsperioden och en stor del (92 %) av lågspänningsnätet utgjordes 2016 av isolerade ledningar (tabell 2). Både minskningen av den totala ledningslängden och ökningen av isolerade ledningar (som är mer synliga) har säkerligen bidragit till den minskning av andelen återfynd orsakade av ledningsnätet som denna studie visar. Mycket av förändringen är sannolikt ett resultat av att man arbetat med att vädersäkra ledningsnätet, inte minst efter stormen Gudrun som inträffade 2005 och som orsakade stor skada på ledningsnätet. Under de senaste tio åren har dessutom längden nedgrävd elkabel i landet ökat med 80 000 km.

Det faktum att fynd orsakade av elström minskat långsammare än kollisioner med ledning antyder att det fortfarande finns många platser där fåglar riskerar att drabbas av elström. En studie i Spanien av 3 869 elstolpar visade att 9,2 % av stolparna orsakade 53,2 % av dödligheten och genom att säkra 222 stolpar erhölls en tydlig minskning av olyckorna. Liknande resultat har erhållits från ön Smøla i Norge där en studie av 742 elstolpar resulterade i 142 döda fåglar varav 50 % påträffades vid 2,8 % av stolparna. En viktig åtgärd för att minska olyckorna kan därför vara att lokalisera och åtgärda platser där det finns en stor risk att fåglar kan drabbas av kollisioner och elström.

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