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Assessing the vulnerability of breeding bird populations to onshore wind-energy developments in Finland

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Wind-energy expansion raises concerns over its potential impacts on bird populations. Birds may be affected directly via collision with turbines or indirectly via habitat loss or displacement due to disturbance. Species with long generation times, low reproductive output or high habitat specialisation are more likely to be impacted. Using national-scale breeding bird distributions, we applied a quantitative prioritisation method to assess the vulnerability of species to onshore wind-energy developments in Finland. We assessed 214 species that regularly breed in the country. Each species was assigned a priority score based on a combination of life-history traits, habitat specialisation, exposure to wind energy and conservation status. We found that the priority scores varied markedly between species, allowing a distinction between a minority of high-ranked species and a majority of low-ranked species. High-ranked species included terns (*e.g.*, *Sternula albifrons*), raptors (*e.g.*, *Aquila chrysaetos*), gulls (*e.g.*, *Larus fuscus*), some forest-dwelling passerines (*e.g.*, *Poecile montanus*) and ducks (*e.g.*, *Aythya ferina*). Low-ranked species included woodpeckers (*e.g.*, *Picus canus*) and many passerines. Our results indicate that the priority species are not limited to the more highly regarded large raptors, and that wind-energy impact assessments need to pay special attention to high-ranked species inhabiting coastal areas.

1. Introduction

Efforts to curb climate change and its dire consequences require, among other things, a rapid transformation of the energy system (IPCC, 2018). Wind energy has a low life-cycle carbon footprint (Wiser *et al.*, 2011), being one of the fastest-growing renewable energy sources in the world (REN21, 2020). Wind energy met 5.9% of global electricity demand in 2019 (REN21, 2020) and 16.4% of the demand in the European Union (including the United Kingdom) in 2020 (WindEurope, 2021).

Despite its climate change-related benefits, the construction of wind farms can be accompanied by negative effects on co-occurring wildlife. In birds, the main negative effects are collision mortality, displacement due to disturbance, habitat loss or degradation and barrier to movements (Kuvlesky *et al.*, 2007). The degree to which a species is affected depends on a range of factors, including biology, morphology, ecology, response to turbines, landscape features and season (Schuster *et al.*, 2015). Regarding collision mortality, there is growing concern for long-lived species with low reproductive rates and small population sizes. If collision mortality rate surpasses even slightly a critical threshold, local populations of such species (*e.g.*, large-soaring raptors) may experience a sudden decline and face an increased risk of becoming extinct or a sink (Erickson *et al.*, 2015). Displacement due to disturbance (*e.g.*, by turbines installed in proximity to nests) translates into habitat loss and has the potential to impact breeding productivity and survival (Drewitt & Langston, 2006). Wind energy, compared to other energy sources, has an intermediate land footprint per unit energy (*e.g.*, 72.1 km^2/TWh/yr; McDonald *et al.*, 2009). However, with its rapid expansion, appropriate site selection is crucial to reduce impacts on both habitats and species that use wind-farm areas for feeding, breeding and movement purposes. Barrier effects are a particular concern for migrating birds, which may be forced to spend extra energy to actively avoid wind farms along migration routes (Masden *et al.*, 2009, 2010).

Population-level impacts caused by wind energy are challenging to quantify, and thus remain largely unknown (Schuster *et al.*, 2015). Strategic planning is a necessary tool for ensuring that wind-energy targets are achieved without compromising vulnerable wildlife (European Commission, 2011). In this context, a knowledge of species vulnerability or population sensitivity to wind energy has several implications for conservation practice. Such knowledge can help to direct resources towards top priority species in *e.g.*, risk assessment, landscape planning and monitoring efforts. It can also help to identify potential conflicts in an early phase of the planning process, and, if needed, to select less damaging sites for construction. A useful approach for setting priorities is to develop indices of vulnerability (Garthe & Hüppop, 2004; Desholm, 2009; Furness *et al.*, 2013; Diffendorfer *et al.*, 2015; Beston *et al.*, 2016), particularly when large-scale assessments with many species are involved. Index-based models yield a list of species-specific scores that indicate which species should be prioritised when developing wind energy. Index-based models often rely on information that is relatively easy to find in the literature, and thus are not constrained by high data requirements (Laranjeiro *et al.*, 2018). In this study, we follow the index-based and quantitative method for species prioritisation proposed by Beston *et al.* (2016). Their method has the advantage of incorporating both direct and indirect effects of wind energy, prioritising species for their risk of population decline as a function of life-history traits, habitat specialisation, exposure to wind energy and conservation status.

Wind energy is an integral part of Finland's National Energy and Climate Strategy, expected to contribute to long-term plans for a substantial reduction in greenhouse gas emissions (Huttunen, 2017). In 2020, a total of 821 turbines with a cumulative capacity of 2586 MW (2515 MW onshore and 71 MW offshore) supplied 9% (7.8 TWh) of the electricity consumed in the country (Finnish Wind Power Association, 2021; WindEurope, 2021). In view of the growing number of wind farms, research is needed to understand the risks faced by different bird species (Meller, 2017). Here, we apply the aforementioned prioritisation method to more than 200 bird species that regularly breed in Finland, focusing on their breeding distribution in relation to existing onshore (*i.e.*, located on land) wind turbines and wind-farm projects.

2. Materials and methods

2.1. Datasets

2.1.1. The Third Finnish Breeding Bird Atlas

We used the Third Finnish Breeding Bird Atlas (hereafter, the Bird Atlas) to estimate the exposure of breeding bird populations to wind energy (see Section 2.2.). The Bird Atlas (which is based on surveys in 2006–2010) is the result of coordinated monitoring by a network of researchers, associations and thousands of volunteers (Valkama *et al.*, 2011). Based on field evidence, breeding was classified as *confirmed*, *probable*, *possible* or *unlikely*. For example, the detection of an incubating bird was confirmed breeding; a single bird or a pair observed building a nest was probable breeding; a pair detected only once in a suitable habitat/area was possible breeding; a bird detected in migration flight was unlikely breeding. Here, we focused on confirmed and probable breeding. *Anser erythropus* was excluded at this stage because it was an unlikely breeder in all records. Further information on the degrees of breeding evidence is available at http://atlas3.lintuatlas.fi/background/indices.

2.1.2. Existing onshore wind turbines and wind-farm projects

We extracted existing wind turbine locations from a topographic map (updated in June 2020) of the National Land Survey of Finland. We identified 765 onshore wind turbines after carefully checking the data for misclassification (Fig. 1a). To obtain the coordinates of wind-farm projects, we relied on a database (updated in February 2020) maintained by Etha Wind Oy and the Finnish Wind Power Association (Table S1; [Etha Wind Oy, 2021]). In addition to coordinates, this database contained details such as development phase and (minimum and maximum) number of turbines. Here, we focused on wind farms that were already at an advanced development phase, namely *Environmental Impact Assessment (EIA) done*, *Land Use Plan Proposal*, *STR Process Ongoing*, *Land Use Plan or STR done*, *Fully Permitted* or *Under Construction* (Fig 1b; Table 1); the mean number of turbines was used in the calculations. These six phases were assumed to represent a realistic wind-energy scenario for the near future.

2.1.3. Variables for the calculation of wind-energy risk metrics

The species prioritisation method proposed by Beston *et al.* (2016) is based on three wind-energy risk metrics: (1) Proportion of fatalities due to turbines (FT), (2) Fatality Risk Index (FRI) and (3) Indirect Risk Index (IRI). FT relies on estimates of individuals killed by turbines per year. In the absence of such information (which is often unavailable or even unreliable for certain

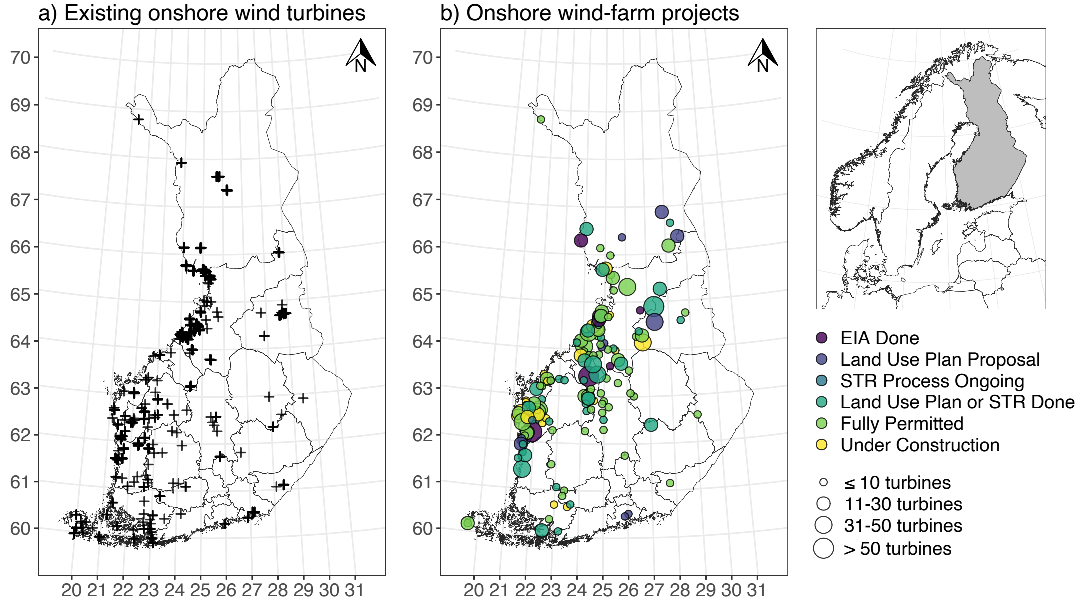


Fig. 1. Location of the assessed (a) existing onshore wind turbines and (b) wind-farm projects in Finland. The number of turbines per wind-farm project is the mean between estimated minimum and maximum numbers.

Table 1. Details of the assessed wind-farm projects in Finland (updated in February 2020). The assessment includes only projects with an estimated location and minimum or maximum number of turbines. Some projects have an unspecified nominal capacity.

Phase	Min./max. turbines	Mean turbines	Min./max. capacity (MW)	Mean capacity (MW)	No. projects
EIA Done	153/187	170	909/1434	1172	8
Land Use Plan Proposal	114/181	148	738/1043	890	11
STR Process Ongoing	3/3	3	15/15	15	1
Land Use Plan or STR Done	432/810	621	854/2788	1821	44
Fully Permitted	638/845	742	2204/3839	3022	69
Under Construction	268/278	273	866/1347	1106	22
Total	1608/2304	1957	5585/10466	8026	155

species), FRI can be used as an alternative to FT. Since fatality estimates for Finnish wind farms are scarce, we focused only on FRI and IRI (for which data could be adequately compiled).

FRI was developed on the assumption that species that are slow-maturing and highly exposed to wind energy are more susceptible to direct effects (Diffendorfer *et al.*, 2015; Beston *et al.*, 2016). For FRI, the following variables were required: (1) age at first reproduction, (2) number of broods per year, (3) clutch size, (4) hatching success and (5) nest success. Here, hatching success is the proportion of eggs laid that hatched; nest success is the proportion of nests that fledged at least one young. We obtained these variables from specialised books, identification guides, a research database, reports, theses and more than 100 peer-reviewed articles restricted to the Western Palaearctic realm. When confronted with multiple values for the same variable, we retained either the minimum typical value (variables 1–3) or the mean (variables 4–5). IRI was developed on the assumption that species that are habitat-specialist and highly exposed to wind energy are more susceptible to indirect effects. For IRI, the (6) number of suitable habitats was required, which we obtained from the Red List of Finnish Species (level-2 habitat classes; Lehikoinen *et al.*, 2019). For species with missing information, we filled in the gaps with the mode (14 species missing any of variables 1–3 and 6) or the mean (136 species missing either variable 4 or 5) of the corresponding taxonomic family or order. All variables and corresponding sources may be found in Table S2.

2.2. Wind-energy exposure: the overlap between breeding bird populations and wind energy

Using the Bird Atlas, we recorded the presence or absence of each bird species on a grid of 10-km square cells. When recording presence, we selected the highest degree of breeding evidence detected in the field. For example, a species with both confirmed and probable breeding in the same grid cell was treated as confirmed breeding. To estimate the exposure of breeding populations to wind energy, we recorded the presence or absence of existing wind turbines and wind-farm projects, as well as the number of turbines, on a grid with the same specifications as above. Wind-energy exposure (p) for each species was expressed as the product of the mean number of turbines per grid cell occupied by ≥ 1 breeding pair and the proportion of grid cells with ≥ 1 turbine.

2.3. Wind-energy risk metrics

2.3.1. Fatality Risk Index (FRI)

We derived species-specific FRIs from life-history traits and wind-energy exposure (p; see Section 2.2.). Maternity (m) was calculated as the product of number of broods, clutch size,

Table 2. Priority scores and associated metrics for 214 bird species that regularly breed in Finland. Species are ranked in decreasing order according to priority scores.

Species	Wind-energy exposure	Wind-energy exposure	FRI (ranking)	IRI (ranking)	Status	Priority score
	Confirmed breeding	Probable breeding				
Sternula albifrons	447.1	45.5	159.7 (2)	469.8 (1)	EN	14.0
Aquila chrysaetos	49.2	72.2	253.6 (1)	51.2 (101)	VU	13.0
Streptopelia decaocto	305.3	198.6	16.8 (55)	404.5 (2)	EN	12.6
Larus fuscus	43.2	44.8	153.6 (3)	32.8 (144)	EN	10.2
Apus apus	105.2	88.7	116.9 (8)	149.5 (23)	EN	9.8
Bubo bubo	112.7	152.7	133.8 (4)	94.5 (44)	EN	9.7
Poecile montanus	95.9	53.7	4.9 (105)	245.5 (10)	EN	9.3
Buteo buteo	85.6	101.2	29.5 (30)	272.4 (5)	VU	9.1
Chlidonias niger	0.0	170.0	14.3 (60)	169.9 (16)	CR	8.8
Emberiza hortulana	237.5	128.9	18.6 (52)	151.0 (22)	CR	8.6
Accipiter gentilis	105.7	73.4	19.3 (48)	284.8 (4)	NT	8.3
Pernis apivorus	72.3	121.3	67.2 (14)	132.9 (28)	EN	8.2
Nucifraga caryocatactes	74.4	181.1	8.9 (77)	329.7 (3)	LC	8.1
Passer domesticus	99.0	163.8	4.3 (123)	180.9 (13)	EN	7.9
Aythya ferina	49.1	97.7	2.9 (146)	97.9 (39)	CR	7.1
Larus argentatus	60.8	112.8	102.4 (11)	16.7 (177)	VU	7.1
Lanius excubitor	217.7	86.9	15.8 (58)	261.2 (7)	LC	6.8
Lyrurus tetrix	95.3	75.9	1.8 (166)	266.5 (6)	LC	6.8
Podiceps auritus	173.8	75.1	19.5 (47)	105.7 (37)	EN	6.7
Loxia curvirostra	75.2	107.2	6.8 (88)	257.5 (9)	LC	6.6
Tetrao urogallus	91.6	76.2	3.2 (141)	259.5 (8)	LC	6.6
Perisoreus infaustus	58.4	79.7	29.1 (32)	196.4 (11)	NT	6.5
Lophophanes cristatus	120.4	66.3	3.6 (134)	153.6 (20)	VU	6.3
Grus grus	110.6	78.3	129.2 (6)	30.0 (149)	LC	6.2
Aythya marila	19.5	153.8	2.7 (150)	96.4 (41)	EN	6.1
Haliaeetus albicilla	44.3	123.1	131.0 (5)	35.3 (139)	LC	6.1
Calidris pugnax	25.0	162.2	7.1 (85)	35.4 (137)	CR	5.9
Circus cyaneus	145.5	180.4	44.9 (20)	78.5 (55)	VU	5.9
Larus canus	72.3	126.9	125.9 (7)	17.0 (176)	LC	5.9
Anser fabalis	128.1	78.7	39.0 (23)	19.7 (170)	EN	5.8
Limosa limosa	0.0	376.9	47.8 (19)	75.3 (57)	VU	5.8
Chloris chloris	92.3	92.2	5.3 (97)	69.2 (64)	EN	5.6
Garrulus glandarius	124.1	73.1	8.8 (78)	160.6 (17)	NT	5.6
Buteo lagopus	62.7	140.2	23.0 (39)	37.9 (127)	EN	5.5
Delichon urbicum	89.0	78.4	4.6 (116)	64.1 (72)	EN	5.4
Coturnix coturnix	0.0	125.9	1.9 (164)	62.9 (77)	EN	5.4
Hirundo rustica	90.7	42.1	2.4 (154)	111.7 (36)	VU	5.4
Fulica atra	61.1	41.0	12.3 (64)	40.8 (120)	EN	5.3
Perdix perdix	207.8	194.3	2.7 (150)	152.5 (21)	NT	5.3
Corvus corax	89.6	62.1	104.7 (9)	26.8 (156)	LC	5.3
Hydroprogne caspia	40.9	67.9	104.6 (10)	37.4 (133)	LC	5.3
Panurus biarmicus	132.7	154.2	1.4 (176)	104.9 (38)	VU	5.2
Anser anser	121.6	185.5	96.8 (12)	53.6 (93)	LC	5.2
Calidris alpina schinzii	30.8	26.7	4.8 (110)	44.1 (114)	EN	5.1
Glaucidium passerinum	96.7	87.3	3.9 (129)	93.5 (45)	VU	5.1
Riparia riparia	118.6	77.0	4.3 (123)	39.3 (124)	EN	5.0
Larus marinus	86.5	12.9	44.8 (21)	15.5 (180)	VU	5.0
Melanitta fusca	41.9	98.4	1.6 (171)	91.1 (47)	VU	5.0
Caprimulgus europaeus	218.5	83.1	22.9 (40)	173.3 (15)	LC	5.0
Aythya fuligula	79.7	70.0	2.9 (146)	38.2 (126)	EN	4.9
Acrocephalus arundinaceus	64.3	43.7	2.3 (156)	86.1 (49)	VU	4.9
Strix uralensis	107.0	142.4	10.7 (70)	178.2 (14)	LC	4.9
Tarsiger cyanurus	91.1	0.0	4.4 (120)	182.2 (12)	LC	4.9
Falco peregrinus	75.8	75.8	31.3 (28)	37.9 (127)	VU	4.8
Tetrastes bonasia	92.4	63.1	1.3 (179)	82.6 (52)	VU	4.8
Chroicocephalus ridibundus	79.8	99.8	29.5 (30)	32.4 (145)	VU	4.7
Oriolus oriolus	21.6	22.2	3.1 (143)	21.8 (167)	EN	4.6
Podiceps grisegena	31.2	53.7	3.9 (129)	115.9 (33)	NT	4.5
Sterna paradisaea	69.4	51.2	85.4 (13)	11.9 (187)	LC	4.5
Asio flammeus	256.1	158.8	27.0 (34)	134.2 (24)	LC	4.4
Strix nebulosa	188.2	84.7	5.9 (92)	153.7 (19)	LC	4.4
Dryocopus martius	122.2	73.4	1.0 (183)	158.9 (18)	LC	4.4
Lagopus lagopus	51.7	197.2	1.5 (174)	60.1 (85)	VU	4.3
Calidris temminckii	3.3	42.2	1.6 (171)	7.0 (192)	EN	4.2
Saxicola rubetra	100.8	88.6	4.3 (123)	48.4 (103)	VU	4.1
Pica pica	94.6	60.5	25.5 (36)	62.4 (78)	NT	4.1
Spatula querquedula	51.7	82.1	1.8 (166)	46.4 (108)	VU	4.0
Pyrrhula pyrrhula	89.7	87.6	6.9 (87)	133.4 (27)	LC	4.0
Spinus spinus	69.4	129.6	9.2 (73)	134.1 (25)	LC	4.0
Aegolius funereus	122.6	91.0	4.9 (105)	84.0 (50)	NT	3.9

Table 2. Continues...

Species	Wind-energy exposure	Wind-energy exposure	FRI (ranking)	IRI (ranking)	Status	Priority score
	Confirmed breeding	Probable breeding				
Haematopus ostralegus	77.0	145.8	64.1 (15)	37.5 (130)	LC	3.9
Coccothraustes coccothraustes	81.1	84.7	11.4 (68)	123.4 (32)	LC	3.9
Erithacus rubecula	98.8	66.7	5.2 (98)	132.1 (29)	LC	3.9
Regulus regulus	93.0	81.1	1.5 (174)	133.6 (26)	LC	3.9
Turdus viscivorus	90.8	78.2	4.8 (110)	129.9 (20)	LC	3.9
Anas acuta	69.2	156.7	1.0 (183)	36.9 (135)	VU	3.8
Mareca penelope	67.8	81.1	1.4 (176)	36.1 (136)	VU	3.8
Columba livia	116.1	84.6	39.2 (22)	79.2 (54)	LC	3.8
Corvus frugilegus	85.7	77.8	50.3 (18)	62.3 (80)	LC	3.8
Periparus ater	86.0	84.0	4.2 (126)	128.0 (31)	LC	3.8
Podiceps cristatus	49.4	42.6	8.7 (79)	70.7 (62)	NT	3.7
Gallinula chloropus	5.9	87.8	2.9 (146)	24.9 (162)	VU	3.6
Charadrius dubius	184.4	183.8	5.9 (92)	69.1 (65)	NT	3.6
Scolopax rusticola	120.3	89.7	38.2 (25)	66.1 (68)	LC	3.6
Branta leucopsis	57.1	248.7	52.7 (17)	45.4 (109)	LC	3.6
Schoeniclus schoeniclus	86.7	69.8	2.6 (153)	17.4 (175)	VU	3.5
Schoeniclus rusticus	76.2	114.3	3.5 (136)	66.7 (67)	NT	3.5
Phoenicurus ochruros	32.4	77.8	1.3 (179)	71.2 (60)	NT	3.5
Loxia pytyopsittacus	63.1	101.5	3.8 (131)	113.9 (34)	LC	3.5
Numenius arquata	124.9	78.7	22.6 (42)	27.4 (154)	NT	3.4
Columba palumbus	96.3	95.0	30.1 (29)	71.9 (59)	LC	3.4
Turdus merula	109.2	69.8	12.6 (63)	96.0 (42)	LC	3.4
Rhadina sibilatrix	64.5	95.9	3.6 (134)	112.4 (35)	LC	3.4
Cinclus cinclus	9.5	14.6	0.2 (199)	11.2 (190)	VU	3.3
Dendrocopos leucotos	4.8	38.9	0.3 (194)	16.2 (178)	VU	3.3
Jynx torquilla	88.8	112.1	2.3 (156)	57.9 (89)	NT	3.3
Bombycilla garrulus	30.7	127.9	11.6 (67)	94.6 (43)	LC	3.3
Sterna hirundo	50.3	112.1	52.8 (16)	15.2 (183)	LC	3.2
Motacilla cinerea	6.9	0.0	0.4 (190)	2.3 (200)	VU	3.1
Phalaropus lobatus	13.3	0.0	0.4 (190)	3.3 (198)	VU	3.1
Turdus torquatus	0.0	11.1	0.1 (201)	5.6 (194)	VU	3.1
Tringa totanus	101.1	147.4	13.8 (61)	29.1 (152)	NT	3.1
Prunella modularis	97.2	83.1	4.4 (120)	92.5 (46)	LC	3.1
Sylvia borin	79.7	105.2	25.5 (36)	66.1 (68)	LC	3.1
Phylloscopus collybita	100.0	93.1	3.3 (140)	97.7 (40)	LC	3.1
Acrocephalus schoenobaenus	85.6	93.0	11.7 (66)	26.4 (158)	NT	3.0
Tringa nebularia	107.7	81.1	5.7 (95)	37.1 (134)	NT	3.0
Erythrina erythrina	89.1	103.3	4.1 (127)	40.2 (122)	NT	3.0
Fringilla montifringilla	43.2	123.6	5.4 (96)	42.0 (118)	NT	3.0
Mergus merganser	65.6	45.8	1.6 (171)	44.2 (113)	NT	3.0
Tringa glareola	88.5	105.4	8.5 (81)	35.3 (139)	NT	3.0
Falco subbuteo	101.3	80.9	17.2 (54)	70.9 (61)	LC	3.0
Sturnus vulgaris	101.7	78.5	17.8 (53)	70.5 (63)	LC	3.0
Columba oenas	111.2	110.2	7.3 (84)	83.2 (51)	LC	3.0
Alauda arvensis	118.3	115.0	4.9 (105)	35.1 (142)	NT	2.9
Mergus serrator	48.5	66.7	2.2 (160)	40.9 (119)	NT	2.9
Corvus monedula	105.3	105.7	20.7 (46)	63.3 (76)	LC	2.9
Gavia stellata	57.6	167.9	34.5 (26)	35.4 (137)	LC	2.9
Vanellus vanellus	105.7	96.6	38.3 (24)	25.7 (160)	LC	2.9
Certhia familiaris	98.6	72.4	1.1 (182)	89.9 (48)	LC	2.9
Curruca communis	56.7	91.4	4.0 (128)	29.2 (150)	NT	2.8
Tringa ochropus	145.5	83.4	15.8 (58)	62.4 (78)	LC	2.8
Accipiter nisus	117.7	71.3	9.0 (76)	76.7 (56)	LC	2.8
Gallinago gallinago	66.0	94.1	8.6 (80)	18.8 (173)	NT	2.7
Lullula arborea	82.0	48.1	4.5 (118)	26.5 (157)	NT	2.7
Cygnus olor	71.8	18.7	25.7 (35)	40.6 (121)	LC	2.7
Pluvialis apricaria	146.4	120.6	19.0 (49)	51.7 (100)	LC	2.7
Anthus trivialis	96.8	62.1	12.1 (65)	63.9 (73)	LC	2.7
Cygnus cygnus	82.5	81.7	32.7 (27)	30.8 (148)	LC	2.7
Troglodytes troglodytes	74.8	69.4	5.1 (100)	72.9 (58)	LC	2.7
Phoenicurus phoenicurus	81.7	75.0	2.3 (156)	79.5 (53)	LC	2.7
Asio otus	79.7	96.0	9.2 (73)	63.8 (74)	LC	2.6
Corvus corone	90.6	45.7	21.1 (45)	45.4 (109)	LC	2.6
Fringilla coelebs	92.6	53.4	10.9 (69)	59.6 (87)	LC	2.6
Gavia arctica	44.5	34.8	24.7 (38)	30.9 (147)	LC	2.5
Numenius phaeopus	114.3	88.8	16.4 (56)	45.3 (111)	LC	2.5
Parus major	89.7	31.5	13.5 (62)	52.7 (97)	LC	2.5
Cyanistes caeruleus	98.8	63.2	6.4 (90)	65.2 (70)	LC	2.5
Falco columbarius	67.2	90.7	21.8 (43)	37.5 (130)	LC	2.5
Spatula clypeata	104.5	63.7	2.0 (163)	68.2 (66)	LC	2.5
Sylvia atricapilla	73.2	86.4	10.3 (72)	58.2 (88)	LC	2.5
Turdus philomelos	88.7	71.0	6.7 (89)	62.1 (82)	LC	2.5

Table 2. Continues...

Species	Wind-energy exposure	Wind-energy exposure	FRI (ranking)	IRI (ranking)	Status	Priority score
	Confirmed breeding	Probable breeding				
Motacilla alba	78.9	20.2	5.0 (103)	8.5 (191)	NT	2.4
Poecile cinctus	6.1	18.4	0.5 (188)	15.3 (182)	NT	2.4
Botaurus stellaris	78.8	55.1	9.1 (75)	53.1 (96)	LC	2.4
Circus aeruginosus	69.8	64.2	18.9 (51)	33.9 (143)	LC	2.4
Cuculus canorus	78.3	84.7	3.2 (141)	60.3 (84)	LC	2.4
Hydrocoloeus minutus	111.8	50.7	22.9 (40)	27.4 (154)	LC	2.4
Pandion haliaetus	59.4	76.9	16.2 (57)	39.1 (125)	LC	2.4
Phalacrocorax carbo	34.3	54.7	4.5 (118)	61.6 (83)	LC	2.4
Picoides tridactylus	88.2	84.6	1.2 (181)	65.2 (70)	LC	2.4
Strix aluco	47.2	96.7	2.1 (161)	63.7 (75)	LC	2.4
Ficedula hypoleuca	90.2	40.7	5.1 (100)	55.3 (90)	LC	2.3
Linaria cannabina	108.5	99.1	7.0 (86)	52.7 (97)	LC	2.3
Actitis hypoleucos	77.7	83.2	2.7 (150)	59.7 (86)	LC	2.3
Anthus pratensis	97.5	81.8	27.3 (33)	15.4 (181)	LC	2.3
Surnia ulula	77.3	94.4	1.7 (168)	62.3 (80)	LC	2.3
Dendrocopos major	95.1	51.6	4.9 (105)	48.4 (103)	LC	2.2
Falco tinnunculus	119.5	53.8	21.6 (44)	20.9 (169)	LC	2.2
Ficedula parva	51.5	60.2	3.5 (136)	54.4 (92)	LC	2.2
Locustella fluviatilis	75.0	59.1	5.0 (103)	52.3 (99)	LC	2.2
Mareca strepera	66.2	86.7	2.1 (161)	54.8 (91)	LC	2.2
Passer montanus	100.0	121.2	4.9 (105)	53.5 (94)	LC	2.2
Turdus iliacus	78.8	55.4	3.0 (144)	53.2 (95)	LC	2.2
Stercorarius longicaudus	0.0	7.6	0.5 (188)	3.8 (197)	NT	2.1
Tringa erythropus	0.0	12.9	0.4 (190)	4.3 (196)	NT	2.1
Ardea cinerea	71.4	94.9	8.4 (82)	39.6 (123)	LC	2.1
Emberiza citrinella	105.7	60.0	4.6 (116)	45.2 (112)	LC	2.1
Turdus pilaris	81.7	51.6	4.7 (115)	43.0 (117)	LC	2.1
Acrocephalus scirpaceus	61.7	74.2	4.8 (110)	49.4 (102)	LC	2.1
Charadrius hiaticula	47.2	91.0	19.0 (49)	23.2 (166)	LC	2.1
Curruca curruca	54.2	112.0	7.8 (83)	44.1 (114)	LC	2.1
Dendrocopos minor	99.3	83.7	6.1 (91)	47.0 (106)	LC	2.1
Hippolais icterina	41.3	59.1	5.2 (98)	47.2 (105)	LC	2.1
Calidris falcinellus	0.0	5.7	0.3 (194)	0.9 (202)	NT	2.0
Calcarius lapponicus	0.0	8.2	0.1 (201)	1.0 (201)	NT	2.0
Acanthis flammea	30.3	112.9	4.8 (110)	43.4 (116)	LC	2.0
Aegithalos caudatus	59.4	68.2	1.9 (164)	46.7 (107)	LC	2.0
Carduelis carduelis	47.7	94.0	3.0 (144)	37.9 (127)	LC	1.9
Luscinia luscinia	54.2	78.9	1.7 (168)	37.5 (130)	LC	1.9
Phylloscopus trochilus	81.6	47.8	2.4 (154)	35.2 (141)	LC	1.9
Lanius collurio	99.5	61.0	10.5 (71)	21.7 (168)	LC	1.8
Lymnocryptes minimus	0.0	169.9	4.8 (110)	28.3 (153)	LC	1.8
Muscicapa striata	86.0	51.2	3.5 (136)	31.9 (146)	LC	1.8
Motacilla flava	85.6	92.0	2.3 (156)	29.2 (150)	LC	1.7
Rallus aquaticus	46.2	65.0	3.5 (136)	26.2 (159)	LC	1.7
Acrocephalus palustris	56.7	76.8	4.4 (120)	19.0 (172)	LC	1.6
Bucephala clangula	80.7	44.1	1.4 (176)	25.7 (160)	LC	1.6
Oenanthe oenanthe	88.3	83.6	3.8 (131)	23.6 (164)	LC	1.6
Anas platyrhynchos	83.0	72.8	5.1 (100)	13.3 (185)	LC	1.5
Crex crex	18.2	88.4	5.8 (94)	15.6 (179)	LC	1.5
Seicercus trochiloides	2.3	53.8	0.8 (185)	19.5 (171)	LC	1.5
Melanitta nigra	47.2	0.0	0.4 (190)	23.6 (164)	LC	1.5
Mergellus albellus	8.8	78.6	0.7 (186)	24.0 (163)	LC	1.5
Acrocephalus dumetorum	31.6	77.3	3.7 (133)	11.7 (189)	LC	1.4
Anas crecca	88.9	83.4	1.7 (168)	14.5 (184)	LC	1.4
Picus canus	14.9	23.9	0.3 (194)	17.9 (174)	LC	1.4
Porzana porzana	0.0	73.0	0.6 (187)	12.2 (186)	LC	1.3
Locustella naevia	4.4	85.3	2.8 (149)	11.8 (188)	LC	1.3
Pinicola enucleator	0.0	6.6	0.3 (194)	6.6 (193)	LC	1.2
Schoeniclus pusillus	0.0	4.9	0.1 (201)	2.5 (199)	LC	1.1
Luscinia svecica	7.0	0.0	0.2 (199)	4.7 (195)	LC	1.1
Falco rusticolus	0.0	0.0	0.0 (204)	0.0 (204)	CR	1.0
Anthus cervinus	0.0	0.0	0.0 (204)	0.0 (204)	EN	1.0
Seicercus borealis	0.0	0.0	0.0 (204)	0.0 (204)	EN	1.0
Eudromias morinellus	0.0	0.0	0.0 (204)	0.0 (204)	VU	1.0
Iduna caligata	0.0	0.0	0.0 (204)	0.0 (204)	VU	1.0
Plectrophenax nivalis	0.0	0.0	0.0 (204)	0.0 (204)	VU	1.0
Calidris alpina alpina	0.0	0.0	0.0 (204)	0.0 (204)	NT	1.0
Clangula hyemalis	0.0	0.0	0.0 (204)	0.0 (204)	NT	1.0
Limosa lapponica	0.0	0.0	0.0 (204)	0.0 (204)	NT	1.0
Lagopus muta	0.0	0.0	0.0 (204)	0.0 (204)	LC	1.0
Loxia leucoptera	0.0	0.0	0.0 (204)	0.0 (204)	LC	1.0
Acanthis hornemanni	0.0	7.7	0.3 (194)	0.7 (203)	LC	1.0

hatching success, nest success and an assumed proportion of female offspring of 0.5. The ratio of maternity (m) to the age at first reproduction (a) measures species sensitivity relative to life-history speed (Diffendorfer *et al.*, 2015). Everything else being equal, FRI increases with a slower life-history speed.

$$\mathrm{FRI} = \sum_{b=1}^{2} \left[\left(\frac{p}{m/a} \right) \times c \right] \times w_{\mathrm{b}}$$

To account for species vulnerability to collision mortality (and thus improve our direct-risk metric), we incorporated collision rate estimates (c; number of collisions/turbine/year) predicted from a global-scale assessment (supplementary material from Thaxter *et al.*, 2017). For the few species with missing information ($n = 5$), we filled in the gaps with the mean collision rate across species. Assuming confirmed breeding to be more important (by an unknown degree) than probable breeding, we placed different weights (w_{b}) to the degrees of breeding evidence. We generated 1000 random numbers (between 0.1 and 0.9) to be used as weights for probable breeding. The weight assigned to confirmed breeding was always 1. The final FRI was the mean FRI across iterations.

2.3.2. Indirect Risk Index (IRI)

We derived species-specific IRIs from habitat specialisation and wind-energy exposure (p; see Section 2.2.). Everything else being equal, IRI increases with a decreasing number of suitable habitats (h).

$$\mathrm{IRI} = \sum_{b=1}^{2} \left[\left(\frac{p}{h} \right) + f \right] \times w_{\mathrm{b}}$$

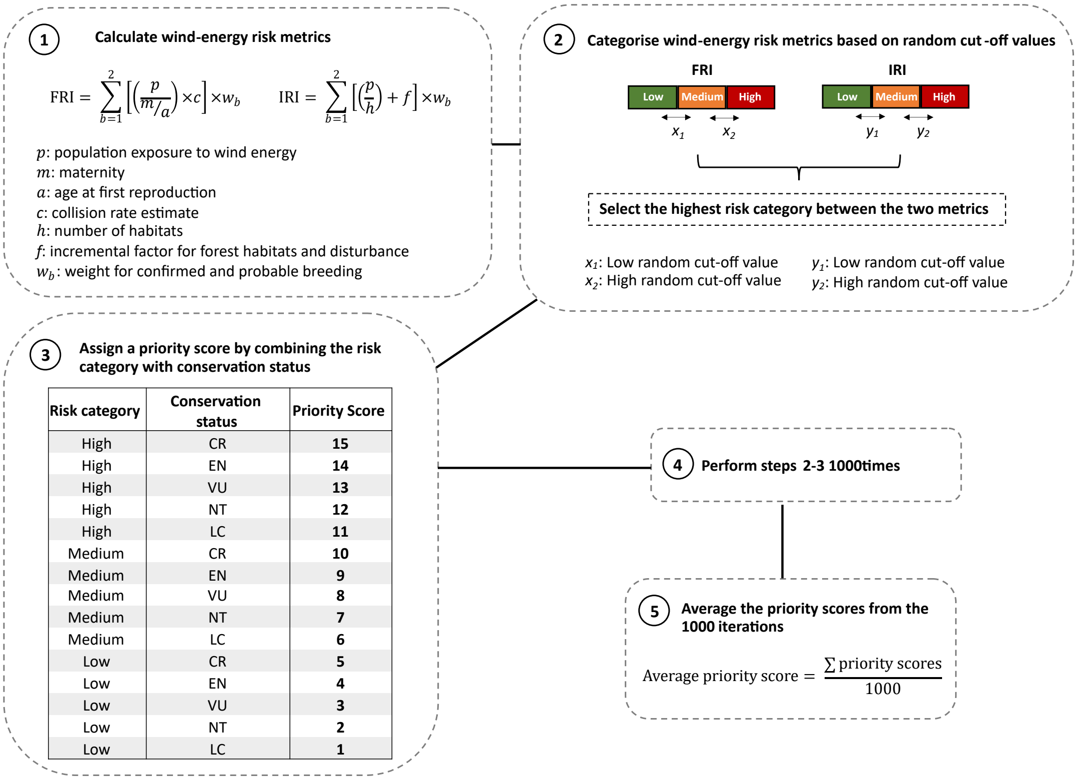
In Finland, forests have been the most targeted environment for wind-energy development (Fig. S1). This means that forest-dwelling species may be at greater risk, especially if they are sensitive to disturbance. IRI is thus increased by a factor f depending on whether the species is a forest dweller and/or sensitive to disturbance (see current threats in the 2019 Red List of Finnish Species; p. 146). For example, a species that is both present in forests and sensitive to disturbance has the metric increased by 2. The weights applied to the two degrees of breeding evidence (w_{b}) were the same as above. The final IRI was the mean IRI across iterations.

2.4. Priority scores

We generated species-specific priority scores by combining FRI, IRI and national conservation status in an iterative process. Firstly, we separately assigned FRI and IRI to one of three risk categories: Low, Medium or High. To avoid arbitrarily choosing what constituted a Low, Medium or High risk, we separately generated for FRI and IRI 1000 pairs of random numbers (bounded by minimum and maximum values) to be used as cut-off values. The low value of the pair separated Low from Medium risk category, and the high value separated Medium from High risk category. In each iteration, we retained the highest risk category between FRI and IRI. For example, a species with Low FRI and Medium IRI was treated as Medium risk. Secondly, we combined the retained risk category with conservation status to assign a priority score. The final priority score was the mean priority score across iterations (Fig. 2). We used R (Version 4.0.2; R Core Team 2020) for all spatial and non-spatial operations and graphical displays.

2.5. Species selection

Our selection initially included all bird species assessed in the 2019 Red List of Finnish Species for which breeding distributional data were available. However, we firstly narrowed down our selection to species with ≥ 25 breeding pairs (based on estimates in Väisänen *et al.*, 2011). We judged this threshold appropriate to exclude species that are not representative of the Finnish avifauna, and retain those with a small but a well-established population such as *Motacilla cinerea* and *Chlidonias niger*. Species below the threshold were *Alcedo atthis*, *Anser caerulescens*, *Anthus campestris*, *Calidris maritima*, *Calidris minuta*, *Circus macrourus*, *Circus pygargus*, *Clanga clanga*, *Cyanistes cyanus*, *Eremophila alpestris*, *Falco vespertinus*, *Gallinago media*, *Linaria*



Risk category	Conservation status	Priority Score
High	CR	**15**
High	EN	**14**
High	VU	**13**
High	NT	**12**
High	LC	**11**
Medium	CR	**10**
Medium	EN	**9**
Medium	VU	**8**
Medium	NT	**7**
Medium	LC	**6**
Low	CR	**5**
Low	EN	**4**
Low	VU	**3**
Low	NT	**2**
Low	LC	**1**

Fig. 2. Flowchart of the steps followed to generate priority scores for 214 bird species that regularly breed in Finland. The priority scores rely on a combination of two wind-energy risk metrics (FRI and IRI) and national conservation status.

flavirostris, *Locustella luscinioides*, *Milvus migrans*, *Motacilla citreola*, *Remiz pendulinus*, *Schoeniclus aureolus*, *Serinus serinus*, *Sitta europaea*, *Streptopelia turtur*, *Tachybaptus ruficollis*, *Tringa stagnatilis*, *Xenus cinereus* and *Zapornia parva*. Species that have a breeding distribution strictly limited to the archipelago of the Baltic Sea and rarely fly over land or travel very short distances inland are unlikely to approach the onshore developments studied here (despite occurring in the same coastal grid cells). To avoid artificially high wind-energy exposure and priority scores, the following species were excluded: *Alca torda*, *Anthus petrosus*, *Arenaria interpres*, *Cepphus grylle*, *Curruca nisoria*, *Somateria mollissima*, *Stercorarius parasiticus*, *Tadorna tadorna* and *Uria aalge*. We further excluded species with unreported conservation status in the 2019 Red List of Finnish Species, namely *Branta canadensis* and *Phasianus colchicus*. *Calidris alpina alpina* and *Calidris alpina schinzii* were treated as separate taxa due to their distinctive spatial distribution: the former breeds in northernmost Lapland and the latter primarily along the west coast. We assessed a total of 214 species distributed among 15 taxonomic orders (Fig. 3).

3. Results

There was a marked variation between species in terms of breeding population exposure to wind energy, FRI, IRI and priority scores (Table 2). The distribution of FRI and IRI was skewed to the right (Fig. 4a–b), meaning that a small number of species were found at the high end of the risk spectrum. Species with the highest FRI were *Aquila chrysaetos* (Vulnerable; VU), *Sternula albifrons* (Endangered; EN), *Larus fuscus* (EN), *Bubo bubo* (EN) and *Haliaeetus albicilla* (Least Concern; LC). Species with the highest IRI were

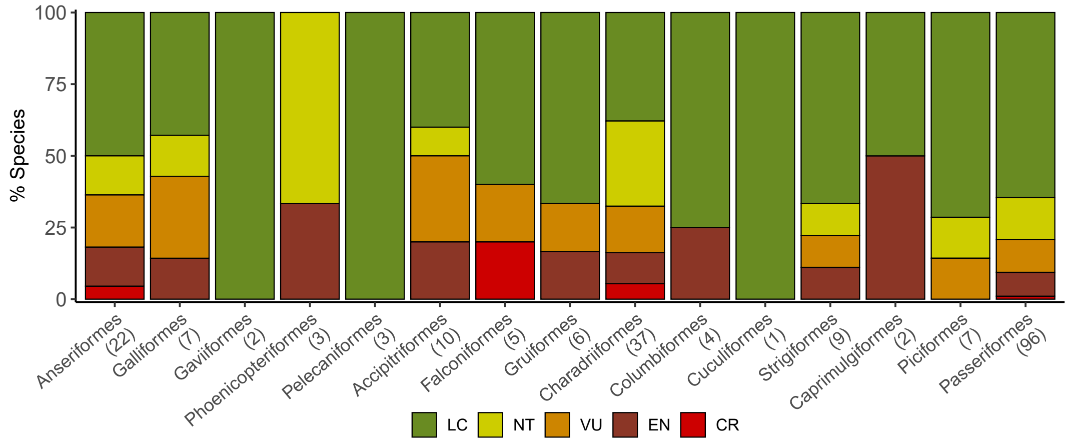


Fig. 3. Number of assessed species per taxonomic order with relative proportion of different conservation status (LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered).

Sternula albifrons, *Streptopelia decaocto* (EN), *Nucifraga caryocatactes* (LC), *Accipiter gentilis* (Near Threatened; NT) and *Buteo buteo* (VU), all of which are found in one or two habitats. The distribution of the priority scores was also skewed to the right (Fig. 4c), though less pronounced than that of FRI and IRI. *Sternula albifrons* was assigned the highest priority score. Many of the top priority species were Charadriiformes that are restricted to or mostly distributed in coastal areas, including two tern species. High-ranked species also included medium- to large-sized raptors, some forest-dwelling passerines and ducks. Low-ranked species included woodpeckers and many passerines. Eleven species had no exposure at all: *Clangula hyemalis*, *Lagopus muta*, *Falco rusticolus*, *Eudromias morinellus*, *Calidris alpina alpina*, *Limosa lapponica*, *Anthus cervinus*, *Iduna caligata*, *Seicercus borealis*, *Loxia leucoptera* and *Plectrophenax nivalis*. Most of these species have a small population in Lapland, where wind energy is a more recent development. Further details on the priority scores and related variables at the species level may be found in Table S2.

The FRI, IRI and priority scores varied markedly within most taxonomic orders (Table 3). Hence, the results at the order level are not representative of the species level. For example, Charadriiformes was not among the top priority orders. Caprimulgiformes, Accipitriformes and Galliformes had the highest median priority scores. Piciformes, Pelecaniformes and single-species Cuculiformes had the lowest median priority scores. Further details on the priority scores and related variables at the order level may be found in Table S3.

4. Discussion

We applied a quantitative prioritisation method to assess the potential population-level consequences faced by 214 bird species from the currently existing onshore wind turbines and wind-farm projects in Finland. The priority scores were shown to vary markedly between species, with a minority placed at the high end of the risk spectrum. Only 16 species had a score higher than seven, *i.e.*, half of the maximum priority score. Despite methodological differences, this pattern is consistent with results from similar studies (Garthe & Hüppop, 2004; Desholm, 2009; Furness *et al.*, 2013; Robinson Willmott *et al.*, 2013; Beston *et al.*, 2016), reflecting interspecific variation in terms of *e.g.*, flight behaviour, natural history, habitat use, population sensitivity to additive mortality and conservation status. The skewed distribution of the priority scores should help researchers, conservationists, developers and consenting authorities to focus on species that are most likely to be impacted by poorly-sited wind farms. In particular, coastal and forested areas

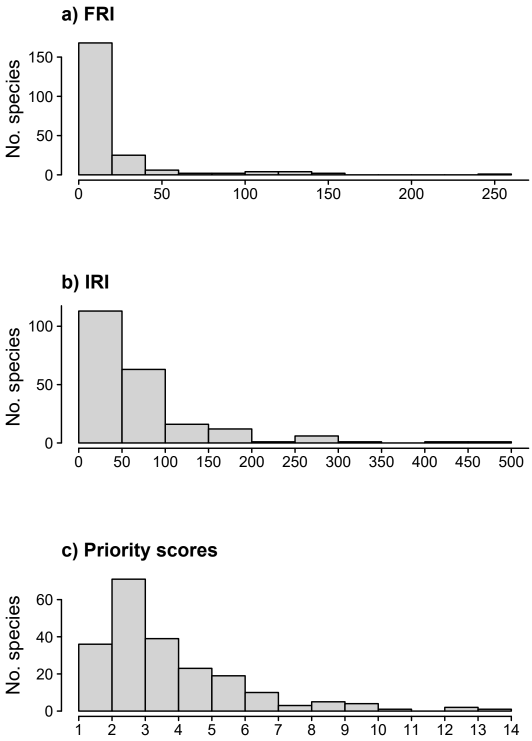


Fig. 4. Frequency distribution of (a) FRI, (b) IRI and (c) priority scores for 214 bird species that regularly breed in Finland.

with sensitive species require careful assessment.

The wind-energy risk metrics, although not providing an absolute measure of risk (see next paragraph), did identify species that are likely to be affected. Regarding direct effects, many of the top species belong to groups that suffer disproportionately high fatalities, such as terns, gulls and raptors (Rydell *et al.*, 2012). For example, *Sternula albifrons* (EN) and *Sterna hirundo* (LC) can be significantly impacted by wind turbines installed near a breeding colony or along flight paths; and *Larus fuscus* (EN), *Larus canus* (LC) and *Larus argentatus* (VU) can collide in large numbers (Everaert, 2014). Collisions among *Aquila chrysaetos* (VU) and *Haliaeetus albicilla* (LC) highlight the need to divert large-scale development from important breeding areas (Dahl *et al.*, 2012), high-quality habitats (Heuck *et al.*, 2019) or migration routes (Katzner *et al.*, 2012). In Finland, these two raptor species have hitherto been a primary focus in wind-energy research (Balotari-Chiebao *et al.*, 2016; Tikkanen *et al.*, 2018). Many raptorial species are long lived, have long generation times, low reproductive rates and small population sizes (Newton, 1998). Such features make them sensitive to additive mortality and population decline. However, other bird groups (*e.g.*, swans, geese, ducks and waders) are potentially vulnerable to collision (Tosh *et al.*, 2014), and thus deserve greater attention. Regarding indirect effects, studies on reduced bird density due to turbine avoidance have reported contrasting results, making it difficult to draw general conclusions. However, geese, ducks and waders are predominant among species with a negative response; also partridges and pheasants appear to be affected during the breeding season (Rydell *et al.*, 2012). From our study, notable examples from these groups include *Aythya ferina* (CR), *Aythya marila* (EN), *Anser fabalis* (EN) and *Limosa limosa* (VU). Examples from other bird groups include *Accipiter gentilis* (NT), *Buteo buteo* (VU) and *Poecile montanus* (EN). Raptors and passerines generally exhibit a weak avoidance of turbines (Madders & Whitfield, 2006; Rydell *et al.*, 2012), but those species (already threatened by *e.g.*, reduction of old-growth forests and large trees [Lehikoinen *et al.* 2019; Byholm *et al.* 2020]) can be further impacted by wind-farm establishment in forests.

The fatality-risk metric assumed that species with a high exposure to wind energy, a slow life-history speed and a high collision rate should be prioritised. However, given the resolution of the grid cells, an assumed exposure to wind energy does not necessarily mean a true overlap on a finer spatial scale (in which case, the exposure and associated metrics are overestimated to an unknown degree). Furthermore, bird collisions with turbines depend on multiple factors and species behaviour (*e.g.*, turbine attraction or avoidance) is challenging to predict (Schuster *et al.*, 2015). The incorporation of collision rates was intended to address this issue. The use of fatality estimates from Finland, rather than collision rates from a global assessment, may have yielded more realistic results. At present, however, there are no public databases for bird fatalities from Finnish wind farms. Similarly, the indirect-effect metric assumed that species with a high exposure to wind

Table 3. Priority scores and associated metrics for 15 taxonomic bird orders, including 214 species that regularly breed in Finland. Orders are ranked in decreasing order according to priority scores. Summary statistics are based on the median and interquartile range.

Order	Wind-energy exposure	Wind-energy exposure	FRI	IRI	Priority score
	Confirmed breeding	Probable breeding			
Caprimulgiformes	161.8 ± 56.7	85.9 ± 2.8	69.9 ± 47.0	161.4 ± 11.9	7.4 ± 2.4
Accipitriformes	71.0 ± 40.5	89.1 ± 50.1	26.2 ± 42.6	64.0 ± 81.1	6.0 ± 4.8
Galliformes	91.6 ± 68.0	76.2 ± 90.6	1.8 ± 0.9	82.6 ± 144.5	5.3 ± 1.5
Phoenicopteriformes	49.4 ± 71.3	53.7 ± 16.2	8.7 ± 7.8	105.7 ± 22.6	4.5 ± 1.5
Strigiformes	107.0 ± 42.9	96.0 ± 51.4	5.9 ± 6.8	93.5 ± 70.4	4.4 ± 2.3
Columbiformes	113.7 ± 55.9	102.6 ± 39.9	23.5 ± 18.0	81.2 ± 86.2	3.6 ± 2.7
Charadriiformes	66.0 ± 102.4	83.4 ± 70.6	15.8 ± 40.0	28.3 ± 28.9	3.1 ± 2.6
Anseriformes	67.0 ± 33.4	79.9 ± 30.5	2.0 ± 3.1	39.4 ± 27.4	3.0 ± 2.9
Passeriformes	81.7 ± 44.4	73.7 ± 41.1	4.4 ± 4.8	52.7 ± 67.3	2.8 ± 1.8
Gaviiformes	51.0 ± 6.6	101.3 ± 66.6	29.6 ± 4.9	33.1 ± 2.2	2.7 ± 0.2
Gruiformes	32.2 ± 48.4	75.7 ± 18.4	4.7 ± 7.6	25.5 ± 11.1	2.6 ± 3.3
Falconiformes	75.8 ± 34.1	75.8 ± 27.1	21.6 ± 4.6	37.5 ± 17.0	2.5 ± 0.8
Cuculiformes	78.3 ± 0.0	84.7 ± 0.0	3.2 ± 0.0	60.3 ± 0.0	2.4 ± 0.0
Pelecaniformes	71.4 ± 22.2	55.1 ± 20.1	8.4 ± 2.3	53.1 ± 11.0	2.4 ± 0.1
Piciformes	88.8 ± 45.6	73.4 ± 38.9	1.2 ± 3.0	48.4 ± 29.1	2.4 ± 1.1

energy and a high degree of habitat specialisation (dependent on forests, in particular) should be prioritised. Again, the resolution of the grid cells hampers our ability to verify the overlap between wind energy and habitats occupied by a focal species. For example, *Streptopelia decaocto* (EN) had the second highest IRI due to a combination of (an artificially) high wind-energy exposure, high habitat specialisation and unfavourable conservation status. This species occurs in parks, yards and gardens, places typically excluded for wind energy. We note, however, that even a higher spatial resolution (which is unfeasible with the Bird Atlas) would not be enough to address other data-related limitations (see last paragraph). In a preliminary assessment, species with a high wind-energy risk metric need to be carefully evaluated for their collision risk or habitat preferences.

Wind-derived electricity generation in Finland is targeted to reach 7–9 TWh by 2030 (Huttunen, 2017). As of February 2020, the combined capacity of proposed wind farms with at least a concluded EIA ranges from 5585 to 10466 MW (Table 1), which exceeds the amount needed to reach that target. Wind farms have been mostly built in coastal areas, where wind conditions are among the most favourable (Tammelin *et al.*, 2011). Many current proposals are also located in coastal areas, although development efforts can be seen elsewhere. Some of the species identified here as top priority (*e.g.*, *Sternula albifrons*) are restricted to or largely occur in coastal areas, have small population sizes and unfavourable conservation status. Site selection is crucial to reduce impacts on bird populations (Arnett & May, 2016), and even wind-farm configuration (*i.e.*, the spatial distribution of turbines within the same wind farm) can influence collision risk (Marques *et al.*, 2014). Careful landscape planning is required for the future protection of those species. When referring to our study for preliminary guidance, we recommend the use of priority scores at the species level rather than the order level (due to the large variation within most orders). For example, *Charadriiformes*, despite having many high-ranked species, was not among the top ranking orders. This was to be expected of such orders with many species with *e.g.*, different breeding distribution, life-history traits and conservation status.

A species prioritisation method without high data requirements has the advantage of quickly identifying species that deserve greater attention. This is important when considering the rapid expansion of wind energy, which outpaces the ability of researchers to assess its true impacts (Stewart *et al.*, 2007). However, there are data-related limitations that may restrict the usefulness of our wind-energy risk metrics and priority scores. For example, the number of existing wind turbines, obtained from a national topographic database, seems to be lower than the real number (to judge from figures reported in Finnish Wind Power Association (2021). Also, there is uncertainty as to the outcome, location and number of turbines of wind-farm projects. Regarding the Bird Atlas, this comprehensive dataset is concerned primarily with breeding birds and thus contains little or no information on non-breeders, stopover sites to migrating birds and overwintering sites. Furthermore, it does not include abundance estimates (grid cells with unequal numbers of breeding pairs were treated simply as occupied cells). The combined effect of the forementioned limitations could lead to minor or major changes in the breeding population exposure to wind energy and associated metrics. Despite these shortcomings, our findings clearly show that certain species, in addition to *e.g.*, large raptors (which are often of primary concern), need to be given special attention in wind-energy impact assessments.

Vilka häckfågelarter är i riskzonen att påverkas negativt av utbyggnaden av landbaserad vindkraft i Finland?

Expansionen av vindkraft väcker oro genom dess potentiella påverkan på fågelpopulationer. Fåglar kan påverkas direkt via kollision med turbiner och tillhörande infrastruktur eller indirekt, t.ex. via den förlust av livsmiljöer som utbyggnationen orsakar eller som en direkt respons på den störning som vindkraftsinfrastruktur kan åsamka. Arter med långa generationstider, långsam förökningstakt och hög grad av habitatspecialisering är mest benägna att påverkas negativt. Med hjälp av uppgifter över häckfågelbeståndets utbredning nationellt använde vi en kvantitativ prioriteringsmetod för att rangordna arter enligt risken att deras populationer minskar till följd av pågående utbyggnation av landbaserad vindkraft i Finland. Vår studie inkluderar 214 arter som regelbundet häckar i landet. Varje art tilldelades en prioritetspoäng baserad på en kombination av artens livshistoriska egenskaper, grad av habitatspecialisering, hur stor del av populationen som exponeras för vindkraft samt dess bevarandestatus. Prioritetspoängen varierade markant mellan arter, vilket resulterade i en tydlig skillnad mellan arter med hög respektive låg risk för populationsminskning som följd av utbyggnad av vindkraft. Högt rankade arter inkluderade tärnor (t.ex. *Sternula albifrons*), rovfåglar (t.ex. *Aquila chrysaetos*), måsar (t.ex. *Larus fuscus*), en del skogslevande tättingar (t.ex. *Poecile montanus*) och änder (t.ex. *Aythya ferina*). Lågt rankade arter var bland annat hackspettar (t.ex. *Picus canus*) och många tättingar. Våra resultat indikerar att det i konsekvensbedömningar av vindkraftsinverkan inte är tillräckligt att man likt nu långt begränsar sig till enbart stora rovfåglar, utan att man även måste ägna uppmärksamhet till andra högt rankade arter vars utbredning koncentreras till kustområden.

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