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Map of bird sensitivities to wind farms in Scotland: A tool to aid planning and conservation

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ARTICLE INFO

Article history:
Received 23 October 2007
Received in revised form
29 May 2008
Accepted 27 June 2008
Available online 28 August 2008

Keywords:
Renewable energy
Wind turbine
Collision
Disturbance
Bird conservation

ABSTRACT

Government targets for renewable energy have led to a huge increase in wind farm proposals. Because of its high wind resource, Scotland has more proposed wind farms than any other UK country. Scotland's upland habitats support many birds of conservation concern, leading to potential conflict with wind farms.

To help reduce this conflict, a map of bird sensitivities has been created to guide the location of onshore wind farms in Scotland, based on distributions of 16 bird species of conservation priority and statutory Special Protection Areas. The likely sensitivity of each species to wind farms was assessed from literature, based on foraging ranges, collision risk and sensitivity to disturbance. This information was used to buffer species' locations to identify areas of 'high' or 'medium' sensitivity. Individual species maps were converted to 1-km square resolution, and a composite map for all species created by selecting the highest sensitivity rating for each square.

The map indicates greater bird sensitivity in northwest Scotland, particularly the Highlands, Western and Northern Isles. Overall, 37% of Scotland is classified as 'high', 25% as 'medium' and 38% as 'low/unknown' sensitivity. The overlap of the mapped species with proposed and existing wind farm developments was assessed and species for which cumulative effects of multiple wind farms are of particular concern identified. Within a Scottish context, bean goose, red kite and hen harrier showed the greatest overlap. Applications and limitations of the approach are discussed.

1. Introduction

Climate change is considered the single greatest long-term threat to birds and other wildlife, with mid-range climate warming scenarios predicting that 15% to 37% of species world-wide will be 'committed to extinction' by 2050 (Thomas et al., 2004).

In an attempt to reduce the effects of climate change, the proposed EU Renewable Energy Directive has set a target of 20% of energy consumption across member states to come

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0006-3207/$ - see front matter
doi:10.1016/j.biocon.2008.06.029

from renewable sources by 2020, with the UK allocated a target of 15% (EU, 2008). The Scottish Government has set a revised target of 50% of electricity from renewable sources by 2020 (Scottish Executive, 2007). This paper presents an approach to minimise the potential conflict between wind farms, proposed as one climate change mitigation measure, and bird conservation.

Onshore wind is currently one of the cheapest and most technologically advanced forms of renewable energy, and thus government targets have resulted in an increased number of wind farm proposals. A high wind resource and reluctance to have wind farms close to habitation, has led to many wind farms being proposed in the uplands. Scotland contains a large area of upland habitat, and one of the best wind resources in Western Europe, and as a result, 42% of proposed UK wind farms are in Scotland (British Wind Energy Association (BWEA), 2008).

Scotland's upland habitat supports many bird species of conservation importance, including many listed on Annex I of the EU Birds Directive (EC Directive on the Conservation of Wild Birds, 79/409/EEC). Whilst some of these are concentrated in Special Protection Areas (SPAs), most are dispersed.

Wind farms affect birds mainly through collision with turbines and associated power lines (e.g. Drewitt and Langston, 2006; Hötker et al., 2006; Everaert and Stienen, 2006; Lekuona and Ursúa, 2007; Smallwood, 2006; Thelander and Smallwood, 2007), or disturbance displacement (e.g. Drewitt and Langston, 2006; Hötker et al., 2006). Effects can be site and species-specific, but remain poorly understood. Although low collision rates have been recorded at many wind farms (e.g. Erickson et al., 2001; Percival, 2005; Drewitt and Langston, 2006), some poorly-sited wind farms have had high collision mortality. For example, estimates have been made of 67 golden eagles *Aquila chrysaetos* killed annually at Altamont Pass in California (Smallwood and Thelander, 2008), and 36 common kestrels *Falco tinnunculus* and 30 griffon vultures *Gyps fulvus* killed per year at Tarifa in southern Spain (Barrios and Rodríguez, 2004, 2007). It should be noted that wind farms in both Altamont Pass and Tarifa comprise a range of wind turbine designs, including lattice towers and windwalls of closely spaced turbines that do not feature in modern wind farms. Raptors appear particularly susceptible to collision (Hötker et al., 2006), although other groups also may be vulnerable, for example estimates of around 165 collisions of several species of tern per year were made at a 25-turbine wind farm at Zeebrugge, Belgium (Everaert and Stienen, 2006). Meta-analysis indicated reduced abundances of many bird species at wind farm sites, particularly of wildfowl and waders (Stewart et al., 2007). It is important to quantify the population level consequences of such effects. Although this is rarely achieved, due to cost and practicalities (Morrison and Pollock, 1997; Sterner et al., 2007), potential population level effects (i.e. population declines) were associated with several of the examples above (Everaert and Stienen, 2006; Sterner et al., 2007; Thelander and Smallwood, 2007). For species of conservation concern, even small increases in mortality may be significant either from individual wind farms or the cumulative effects of multiple wind farms.

Careful location of wind farms is key to minimising negative effects on birds, especially those of high conservation concern (Drewitt and Langston, 2006; Stewart et al., 2007; Langston et al., 2006). For example, Madders and Whitfield (2006) consider that 'spatial models that attempt to predict areas of greatest sensitivity for birds at the landscape scale can be useful design tools, enabling developments to be located so as to minimise the potential effects on identified key species'.

Within the UK, wind farms have not yet been associated with high collision rates, because generally they have been constructed in areas with little bird activity (Percival, 2005; Madders and Whitfield, 2006). Given the increasing demand for wind farms within the UK, and particularly Scotland, a strategic approach to locating wind farms is necessary to safeguard species of conservation concern. We undertook this by creating a bird sensitivity map to help plan onshore wind farms in Scotland. The overlap between the mapped sensitivities of each species with proposed and existing wind farms was then assessed. At a time of rapidly increasing global exploitation of renewable energy resources, sensitivity mapping has wider applicability to other countries.

2. Methods

2.1. Species list

SPAs were included because these sites are classified under Article 4 of the Birds Directive (EC Directive on the Conservation of Wild Birds, 79/409/EEC) as "most suitable territories" to deliver the conservation of Annex I and regularly occurring migratory birds. Annex I species require "special conservation measures concerning their habitat". SPAs were used as a surrogate for congregational species of wintering geese and other waterbirds, and colonial nesting seabirds, as designation criteria include populations exceeding 20,000 birds as well as individual species criteria (Stroud et al., 2001). This was because, for most species, a high proportion of their populations occur within the SPAs (Stroud et al., 2001). However, the SPA network alone is not sufficient to represent all selected species because designated sites tend to include small proportions of dispersed (especially upland) species. For example, only 15% of the UK breeding population of golden eagle occurs within SPAs (Stroud et al., 2001).

Therefore, distributions were included of a further 16 species of conservation concern (see Table 1 for species) for which the literature indicated sensitivity to collision risk, disturbance or changes in habitat, especially in relation to wind farms.

Twelve of these species are listed on Annex I. We included four additional species because, whilst not listed on Annex I, they are either very localised in their UK distribution, or undergoing a rapid population decline and are not well represented by the SPA network (see above). Bean geese were included as they regularly occur at only one site in Scotland, which was not an SPA at the time of the study, and geese are potentially vulnerable to both disturbance displacement (Kruckenberg and Jaene, 1999) and collision risk (Hötker et al., 2006). Common scoter has a small, localised breeding distribution, is a red-listed "Bird of Conservation Concern (BoCC)" (Gregory et al., 2002), and potentially affected by disturbance displacement, with evidence of sensitivity to sources of

Table 1 – Summary of buffering distances and sensitivity ratings (1 = high sensitivity, 2 = medium sensitivity)

Species	Data used	Coverage	Units	Spatial resolution	Buffer	Sensitivity	Key references
Red-throated diver *Gavia stellata*	National Survey 1994 (Gibbons et al., 1997), various regional datasets since 1994	National survey: Comprehensive on Shetland and Orkney, 11% of remaining breeding range. Regional surveys: unknown	Possible/probable/confirmed breeding records	100 m/1-km squares	1 km	1	D Jackson (pers. comm.)
Black-throated diver *Gavia arctica*	Annual monitoring from last 10 years (for methods see Whyte et al., 1995), knowledge of commonly used feeding lochs (lakes)	Comprehensive	Apparently occupied territories	Loch boundary	1 km	1	Lehtonen (1970), Petterssen (1985), Gotmark et al. (1989) and Jackson (2003)
Slavonian grebe *Podiceps auritus*	Breeding lochs used 1995–2005 (RSPB data unit)	Comprehensive	Lochs with pair(s) present	Loch boundary	1 km	1	Summers et al. (1994) and RSPB, unpublished data
	Breeding lochs used 1990–1995 (RSPB data unit)	Comprehensive	Lochs with pair(s) present	Loch boundary	1 km	2	
[*]Bean goose *Anser fabalis*	All fields used on Slammanan Plateau (see Simpson and Maciver, 2005 for methods)	Comprehensive	Fields	Field boundary	0.6 km	1	Kruckenberg and Jaene (1999) and Simpson and Maciver (2005)
[*]Common scoter *Melanitta nigra*	National Survey 1995 (Underhill et al., 1998)	Comprehensive	Possible/probable/confirmed breeding records	100 m/1-km squares	1 km	1	Mitschke et al. (2001) and Kaiser et al. (2006)
Red kite *Milvus milvus*	All data since re-introduction (RSPB data unit)	Comprehensive	Nest locations	100 m/1-km squares	3 km	1	Davis and Davis (1981), Ward (1996) and D Orr-Ewing (pers. comm.)
	All data since re-introduction (RSPB data unit)	Comprehensive	Roost sites	100 m/1-km squares	5 km	1	
White-tailed eagle *Haliaeetus albicilla*	All data since re-introduction (Evans and Wilson, unpublished)	Comprehensive	All territory centres plus known nest locations	1-km square	5 km	1	Struwe-Juhl (1996a,b) and Masterov (2003)
Hen harrier *Circus cyaneus*	National Survey 2004 (Sim et al., 2007)	Comprehensive on Orkney, 72% of remaining Scottish population	Sightings/nest locations	100 m/1-km squares	2 km	1	Watson (1977), Picozzi (1978), Martin (1987) and Arroyo et al. (2005)

	National Survey 1998 (Sim et al., 2001)	Comprehensive on Orkney, 77% of remaining Scottish population	Sightings/nest locations	100 m/1-km squares	2 km	2	
Golden eagle *Aquila chrysaetos*	National Survey 2003 (Eaton et al., 2007a)	Comprehensive	Nest locations/territories	100 m/1-km squares	2.5 km	1	McGrady et al. (1997, 2002)
	National Survey 2003		Nest locations/territories	100 m/1-km squares	2.5 km to 6 km	2	
	National Survey 1992 Green, 1996	Comprehensive	Nest locations/territories	100 m/1-km squares	6 km	2	
Peregrine falcon *Falco peregrinus*	National Survey 2002 (Banks et al., 2003)	92% of UK population	Nest locations/territories	100 m/1-km squares	2 km	2	Weir (1977, 1978)
Black grouse *Tetrao tetrix*	Perthshire study group data (see Robinson et al., 1993 for methods), various regional datasets, National Survey 2005 (Sim et al., in press)	National survey: 8% of range in Scotland/ northern England Others: unknown	Lek sites	100 m/1-km squares	1.5 km	2	Johnstone (1969), Cayford (1993), Anon (2003) and Warren and Baines (2004)
Capercaillie *Tetrao urogallus*	Upper survey strata used for the 2003–04 National Survey (Eaton et al., 2007b). Confirmed breeding/present in 2003, present in 2000	Comprehensive	Forest blocks over 0.5 ha containing capercaillie since 2000	Boundaries of forest blocks over 0.5 ha	0 km	1	Eaton et al. (2007b)
Corncrake *Crex crex*	National Surveys 1993 to 2003 (for methods see Green, 1995; O'Brien et al., 2006)	Comprehensive in 1993 and 2003, over 90% of Scottish population for other years	Singing males	100 m/1-km squares	0.85 km	1	Hudson et al. (1990) and Green and Stowe (1993)
*Arctic skua *Stercorarius parasiticus*	Seabird 2000 (Mitchell et al., 2004)	Comprehensive	Colonies of 10 or more birds	1-km square	0 km	1	Mitchell et al. (2004) and JNCC (2006)
Nightjar *Caprimulgus europaeus*	National Survey 2004 (Conway et al., 2007)	54% of suitable habitat in Scotland	Churring males	1-km square	1 km	1	Bowden and Green (1994), Alexander and Cresswell (1990),

(continued on next page)

Table 1 – *continued*

Species	Data used	Coverage	Units	Spatial resolution	Buffer	Sensitivity	Key references
	National Survey 2004		Churring males	1-km square	1 km to 2.5 km	2	Wichmann (2004), Palmer (pers. comm.), Rollie (pers. comm.) and Wotton (pers. comm.)
Chough *Pyrrhocorax pyrrhocorax*	National Survey 2002 (Finney and Jardine, 2003)	Comprehensive	Nest locations	1-km square	1 km	1	Bignal et al. (1996), Gray et al. (2004), and Whitehead et al. (2006)
SPAs	All SPAs		SPAs	boundary	0 km	1	

* – Species not listed on Annex I of the EU Birds Directive.

offshore disturbance including wind farms (Kaiser, 2004; Petersen et al., 2006). Arctic skua has shown a substantial decline (37%) in population and SPA coverage is relatively low (24%), whereas the few other species of seabird with comparatively low SPA coverage are not loch in rapid decline (Stroud et al., 2001; Mitchell et al., 2004; Joint Nature Conservation Committee (JNCC), 2006). The UK population of black grouse is declining rapidly (Sim et al., in press), it is a red-listed BoCC (Gregory et al., 2002), with low dispersive ability and is susceptible to disturbance displacement and collision risk (Bevanger, 1995; Anon, 2003; Hötker et al., 2006).

2.2. *Data sources*

National surveys for many of the species take place at regular intervals as part of the Statutory Conservation Agency/RSPB Breeding Bird Scheme (SCARABBS, Baker et al., 2006).

Survey coverage for most species was comprehensive (Table 1). However, for red-throated diver and black grouse national survey coverage was low, so was supplemented with data collected regionally (Table 1). Whilst some data were from fairly comprehensive regional surveys, others were collations of ad hoc records, and so national coverage could not be estimated for these species.

The most recent data available were used, but their age varied between species. Data from surveys spanning a range of years were used for red-throated diver, black-throated diver, Slavonian grebe and corncrake, as these species are likely to use alternate breeding locations in different years. For red kite and white-tailed eagle, all data since the start of the re-introduction programmes were used, due to their very small population sizes. Persecution is likely to be limiting the current distribution of hen harrier and golden eagle (Whitfield et al., 2003), and so data from penultimate national surveys were included as medium sensitivity for these species, to highlight unoccupied locations that could be recolonised.

Most national surveys occurred in the breeding season. Survey units varied (Table 1). Nest locations were used for some species, whereas calling males were used as an indication of breeding activity (Gibbons et al., 1993) for secretive nesting species. For hen harrier, locations of nests and sightings of birds were added to the map because the data did not distinguish between them, although the locations of communal roost sites were not made available to us for this analysis because of concerns regarding raptor persecution. Red kite roost locations were included due to their importance to a large number of birds from the small, reintroduced population. Fields used for feeding and roosting by wintering bean geese were also included due to their highly restricted distribution.

2.3. *Creation of the map*

The map was created in MapInfo Professional version 6.0. Distribution was mapped separately for each bird species. Most data were available at 100-m resolution, but some were available only within 1-km.

The distributional data were buffered according to species (e.g. as circles drawn around nest locations, or lines at a set distance around loch margins), and sensitivity ratings were applied to these buffered areas (Table 1). Buffer radii and sensitivity ratings were determined on the basis of territory size, foraging ranges, sensitivity to disturbance, collision risk and other relevant features of behavioural or population ecology for each species. Literature searches were conducted using species' names as keywords, as well as searches under 'wind farm', wind turbine', 'collision' and 'disturbance' on ISI Web of Knowledge, and web-sites of various research bodies. Information from peer-reviewed published literature was given a greater weight than that from 'grey' literature.

Species' sensitivities and buffer distances were determined on the basis of information relating to collision risk and foraging ranges. In the absence of this, information relating to disturbance displacement from turbines, or failing that, other forms of disturbance, was used. Disturbance distances were interpreted with caution, as individual responses to disturbance depend on a number of factors, such as the quality of the site, distance to other suitable sites, and investment made in a site (Gill et al., 2001). Finally, in the absence of adequate documented information, relevant species' experts were consulted. Once completed, the literature reviews, proposed buffers and sensitivity ratings for each species were circulated amongst species' experts for comment (see Bright et al., 2006 for further details of methods).

For nightjar, corncrake, chough, and all raptor species, buffers were based upon estimated foraging ranges. For golden eagle and nightjar, the foraging range was divided into a core area, rated 'high sensitivity', and an outer area, rated 'medium sensitivity', to reflect estimated proportional use of the range (and thus risk of collision or disturbance displacement). For loch breeding species, foraging flight routes were not estimated, as these are likely to be largely site-specific 'flight corridors' to other lochs or the sea. In these cases, buffers reflect disturbance distances around breeding lochs.

Buffered areas were assigned a rating of 'high' or 'medium' sensitivity for each species (Table 1). Maps of buffered areas for each species were converted to 1-km square grids, by selecting the sensitivity rating of the centre of each 1-km square. However, where buffers were less than 1-km radius and the unit being buffered was smaller than a 1-km square, or an irregular shape (e.g. a loch or forest boundary), all 1-km squares intersecting the buffered area were selected to ensure capture of smaller sites.

Individual species' maps were combined to produce a composite map. This was done by choosing the highest sensitivity rating of any species for each 1-km square. This was the preferred method for the production of the final sensitivity map, as the protective legislation applies equally to each species of conservation priority. Due to the shortage of information available on species-specific effects, a three-level scale of sensitivity ratings was used, as follows:

(1) 'High sensitivity' or within an SPA.
(2) 'Medium sensitivity'.
(3) 'Low/unknown sensitivity'.

An alternative method would be to create a cumulative map indicating the number of species present in each square with either a high or medium sensitivity rating and this is also shown here for comparison.

2.4. Overlap of bird distributions with wind farms

The overlap of bird species' distributions with proposed and existing wind farms was assessed using wind farm locations from Scottish Natural Heritage (SNH)'s renewable energy database (February 2007 version, SNH unpublished). Wind farms were classified as installed (operational); approved (planning consent granted); application (planning permission sought), and scoping (registered with the planning authority in order to seek direction for environmental assessment).

Locations of wind farms were given as single central point references. For analysis, the wind farm 'footprints' were estimated from their energy outputs. This relationship was quantified using turbine locations extracted from available Environmental Statements for 46 wind farms in the UK. The turbine locations were plotted, and buffered by 100 m (to prevent linear arrays or single turbines from having no area). The outer edges of buffers within 1-km of each other were then joined for each wind farm to create its footprint. Linear regression (Minitab, 2007) derived the following predictive relationship (where output is measured in MW): Footprint $(km^2) = (7E-05 \times Output^2) + (0.0505 \times Output) + 0.0295$ $(R^2 = 0.98)$. This was used to estimate the areas of all wind farms in the SNH database, and circular buffers of the appropriate areas were then drawn around the central points to represent estimated footprint size. In some cases (installed 6/38; approved 4/39; application 73/159; scoping 42/91), the output of the wind farm was not given, and so the median value for wind farms at the relevant stage in the planning process was used (installed = 7.5 MW; approved = 17.5 MW; application = 30 MW; scoping = 33 MW). Wind farms with an output of less than 1-MW ($n = 18$), generally single turbines, were excluded from the analyses.

The wind farm map was overlaid on the buffered single species maps to determine the number of buffered areas for each species overlapping proposed and existing wind farms, providing an index of the proportion of birds affected because each buffered area generally refers to a single nest or bird record.

3. Results

3.1. Sensitivity map

The composite sensitivity map is presented here for illustration at the tetrad (2-km square) scale of resolution (Fig. 1), based on the 1-km square map. The underlying 1-km square sensitivity ratings are not presented, to protect locations of species particularly vulnerable to persecution. The map indicates a greater incidence of bird sensitivities in northwest Scotland, particularly in the Highlands, Western and Northern Isles. Overall, 37% of the 84,589 1-km squares were classified as 'high sensitivity', 25% as 'medium' and 38% as 'low/unknown sensitivity'.

The cumulative map is also produced at the tetrad scale, for comparison. The depth of colour increases with

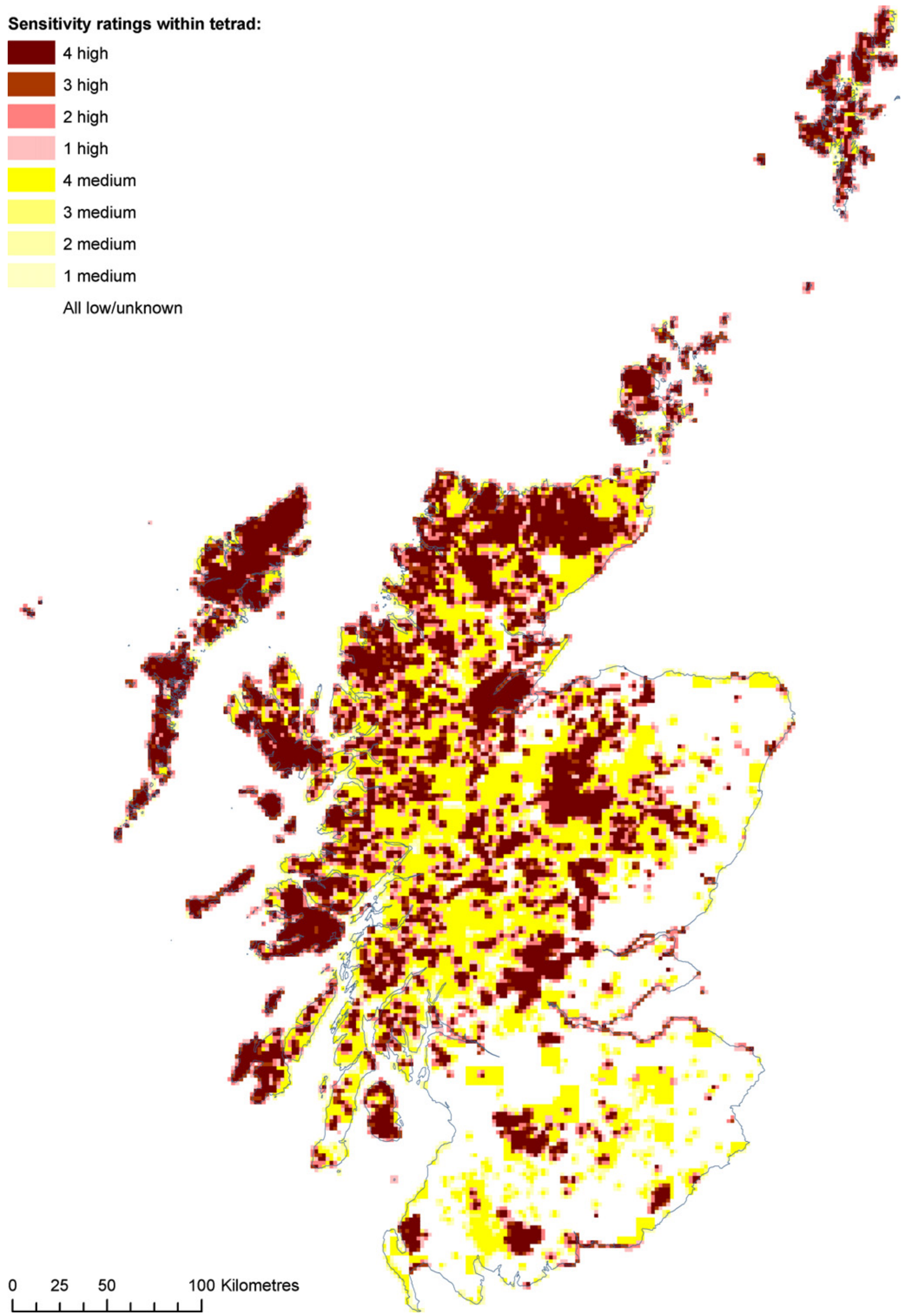

Fig. 1 – Composite map of Scotland showing wind farm sensitivity ratings for bird species of conservation concern (2 km × 2 km resolution). Based on the highest sensitivity rating, for any of the species included, in each constituent 1-km square.

the total number of high or medium sensitivity ratings for all species, highlighting areas that are sensitive for a suite of species. As with the composite sensitivity map, the Northern and Western Isles, Caithness and Sutherland, and parts of the mainland west coast and Highlands contain the greatest concentrations of sensitive species (Fig. 2).

3.2. *Overlap of bird distributions with wind farms*

No proposed or existing wind farms fell within the buffered areas around Slavonian grebe or common scoter breeding sites, and overlap for white-tailed eagle, capercaillie, Arctic skua and chough was low (⩽3% of buffered areas, Table 2). The species with the greatest overlap with all proposed and existing wind

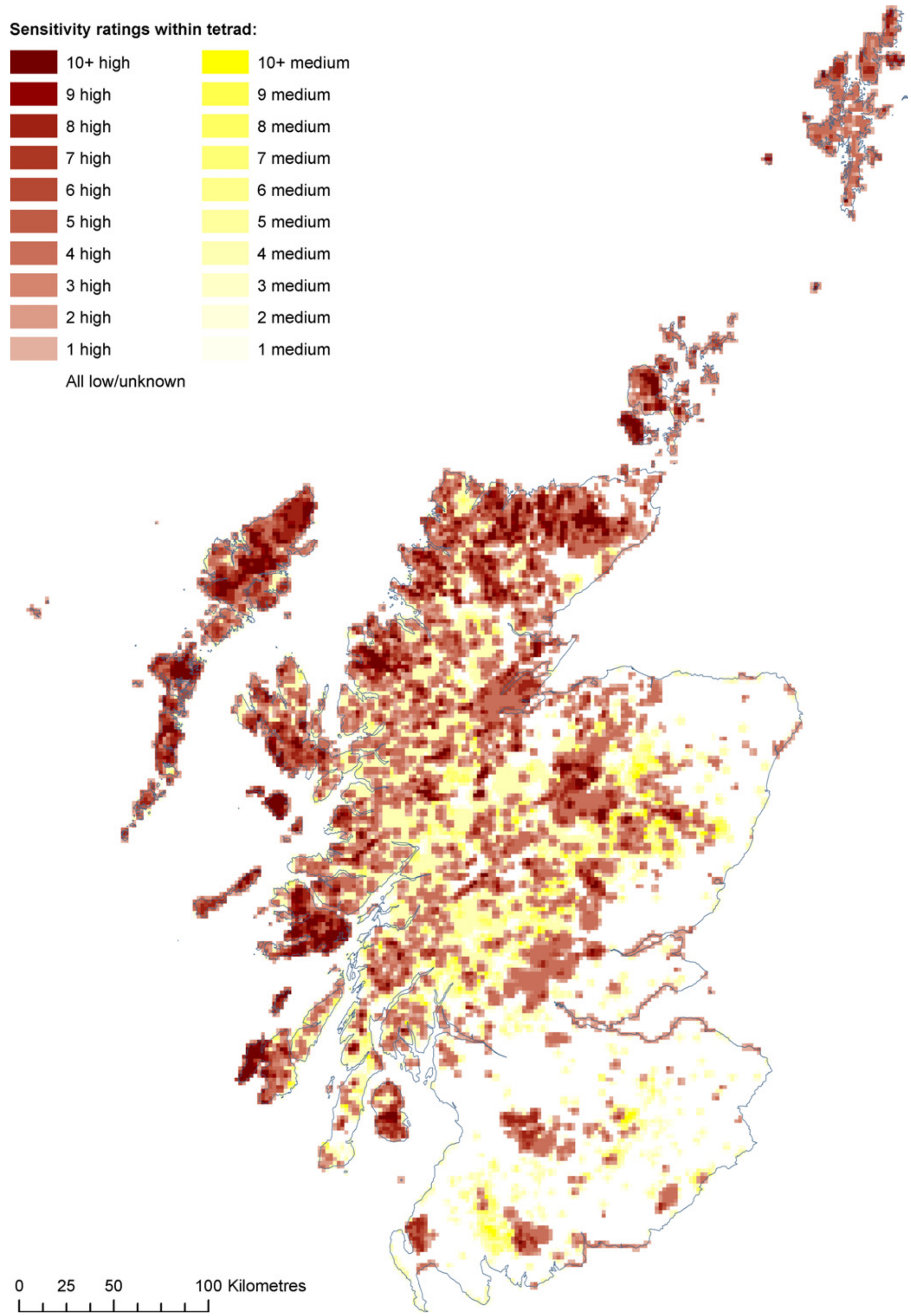

Fig. 2 – Map of Scotland showing cumulative sensitivity to wind farms weighted by sensitivity ratings for a suite of bird species of conservation concern (2 km × 2 km resolution). Based on the total number of high or medium sensitivity ratings, for all mapped species, for each constituent 1-km square.

farms were bean goose, red kite and hen harrier, each with >10% of high sensitivity buffered areas overlapping wind farms.

4. Discussion and conclusions

Locational guidance such as that presented here is valuable in light of the rapid increase in the number of wind farms proposed in Scotland. SNH published strategic locational guidance for onshore wind farms in Scotland in 2001 (SNH, 2005) based on natural heritage, including landscape, designated sites, recreation, earth science, and sensitive bird areas. However, their map of sensitive bird areas was at the 10-km square resolution, based on data from Gibbons et al. (1993) for just eight species of Annex I birds. The composite sensitiv-

Table 2 – Overlap of species buffers with proposed and existing wind farm developments

Species	Number (%) of buffered areas for birds overlapping with wind farms[a]					Number of buffered areas	Estimate of size of Scottish population
	Installed	Approved	Application	Scoping	Total buffered areas affected		
Red-throated diver	10 (<1)	8 (0)	29 (1)	37 (2)	79 (4)	2021 breeding locations	935 breeding pairs Gibbons et al. (1997)
Black-throated diver	0 (0)	2 (1)	10 (3)	7 (2)	18 (6)	305 breeding/key feeding lochs	180 summering pairs (Whyte et al., 1995)
Slavonian grebe: high sensitivity	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	56 breeding lochs	44 pairs (RSPB unpublished data, 2005)
Bean goose	0 (0)	0 (0)	0 (0)	1 (100)	1 (100)	1 wintering area	300 birds (2005/06, M Trubridge, pers. comm.)
Common scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	88 probable/confirmed breeding records	95 pairs (Underhill et al., 1998)
Red kite	0 (0)	13 (8)	5 (3)	0 (0)	18 (11)	166 (140 territory and 26 roost locations)	82 pairs (RSPB, unpublished data)
White-tailed eagle	0 (0)	0 (0)	1 (3)	0 (0)	1 (3)	37 territory locations	Over 30 pairs (Evans and Wilson, unpublished)
Hen harrier: high sensitivity	17 (3)	15 (3)	237 (7)	12 (2)	67 (13)	499 nest sites/territory locations/sightings	633 breeding pairs (Sim et al., 2007)
Golden eagle: high sensitivity	1 (<1)	1 (<1)	11 (3)	2 (<1)	15 (3)	438 home range centres	430 breeding pairs Eaton et al. (2007a)
Golden eagle: medium sensitivity: outer part of range 2003	6 (1)	12 (3)	33 (8)	25 (6)	61 (14)	438 home range centres	430 breeding pairs Eaton et al. (2007a)
Peregrine falcon	5 (1)	4 (1)	25 (4)	17 (3)	48 (8)	609 nest sites/territory locations/sightings	542 breeding pairs (Banks et al., 2003)
Black grouse	4 (0)	11 (1)	52 (4)	32 (2)	90 (6)	1444 lek sites	3344 displaying males (Sim et al., unpublished)
Capercaillie	0 (0)	0 (0)	1 (0)	3 (<1)	3 (<1)	3231 occupied forest blocks	1980 males Eaton et al. (2007b)
Corncrake: buffers around 2003 data only	0 (0)	11 (1)	12 (2)	0 (0)	23 (3)	797 calling males	1067 calling males (O'Brien et al., 2006)
Arctic skua	0 (0)	1 (1)	1 (1)	0 (0)	2 (2)	84 1-km squares containing 10 or more Apparently Occupied Territories	2136 Apparently Occupied Territories (Mitchell et al., 2004)
Nightjar: high sensitivity	0 (0)	0 (0)	1 (6)	0 (0)	1 (6)	17 1-km squares containing Nightjar	27 churring males (Conway et al., 2007)
Nightjar: medium sensitivity	0 (0)	1 (6)	1 (6)	0 (0)	2 (12)	17 1-km squares containing Nightjar	27 churring males (Conway et al., 2007)
Chough	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	82 nest locations	83 pairs (Finney and Jardine, 2003)
SPAs	0 (0)	3 (2)	10 (7)	2 (1)	14 (9)	150	150

For buffer sizes see Table 1, for full explanation of what buffered areas represent see Bright et al., 2006.

Population estimates are given for comparison with number of buffers. The two do not necessarily correspond, as mapping units were not always the same as survey units, survey coverage was not always comprehensive. In addition, for some species, data from more than one year were used, for example, for Slavonian grebe, lochs used over a number of years were plotted, due to the high turnover of loch use in this species. Likewise, for red-throated diver, black-throated diver, red kite, white-tailed eagle, black grouse and capercaillie data were from more than one year (Table 1). For common scoter, peregrine falcon, Arctic skua, nightjar and chough data from a single national survey were used. Although historical data were included on the map for hen harrier, golden eagle and corncrake, only data from the most recent survey were used in the overlap analysis to provide data more contemporary with the available data for wind farms.

a Numbers of buffered areas for birds do not necessarily add up to the total number affected, as wind farms at different stages in the planning process may intersect with the same buffered areas for birds.

ity map described here takes forward the mapping for a wider range of sensitive bird species, using a much finer resolution, more recent distribution/ abundance data, and species-specific buffers.

The map has two uses. Firstly, it indicates at a national level the regions where wind farm development is most likely to affect sensitive birds (parts of the Highlands, Western and Northern Isles), and the cumulative map further highlights areas that are particularly sensitive for a suite of species within these regions. These regions are amongst the windiest parts of Europe, and therefore have considerable potential for wind energy generation (Fig. 3, see also Risø National Laboratory, Denmark, 1989). However, any deleterious impacts of wind farms on the high conservation interest of

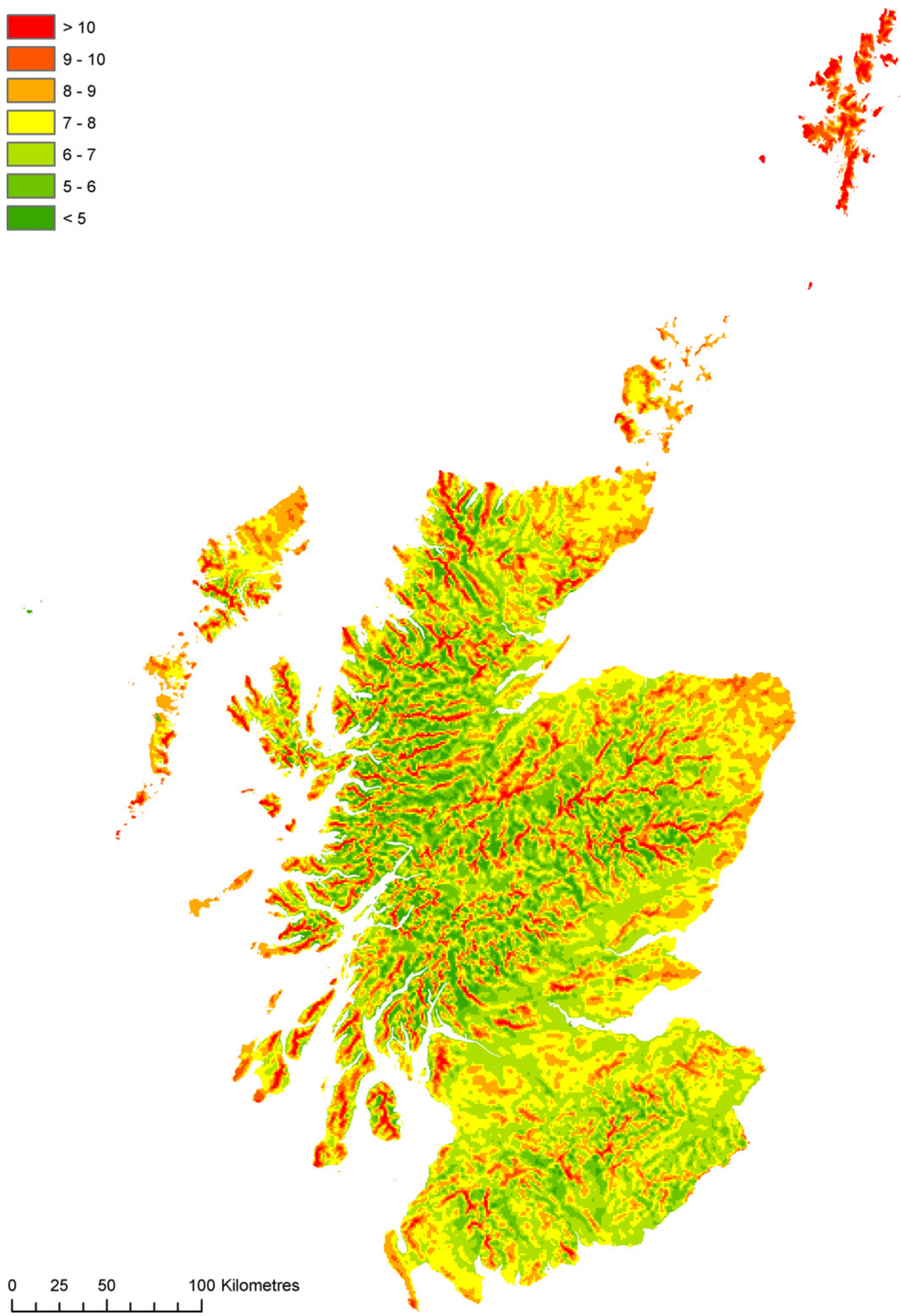

Fig. 3 – Annual mean wind speed (m/s) by 1-km square at 45 m above ground level (BERR, 2007).

these areas must be avoided by careful planning. As shown by Fig. 3, there is also considerable wind resource outside these areas.

Secondly, the map can be used at a regional level, to indicate where wind farm development is less likely to conflict with bird conservation, and therefore facilitate the planning process. Current and potential wind farm developments frequently occur outside the most sensitive areas (Fig. 4). The sensitivity map should be a useful tool to maintain this situation.

Fielding et al. (2006) used a similar approach and found relatively little potential for conflict between golden eagles and

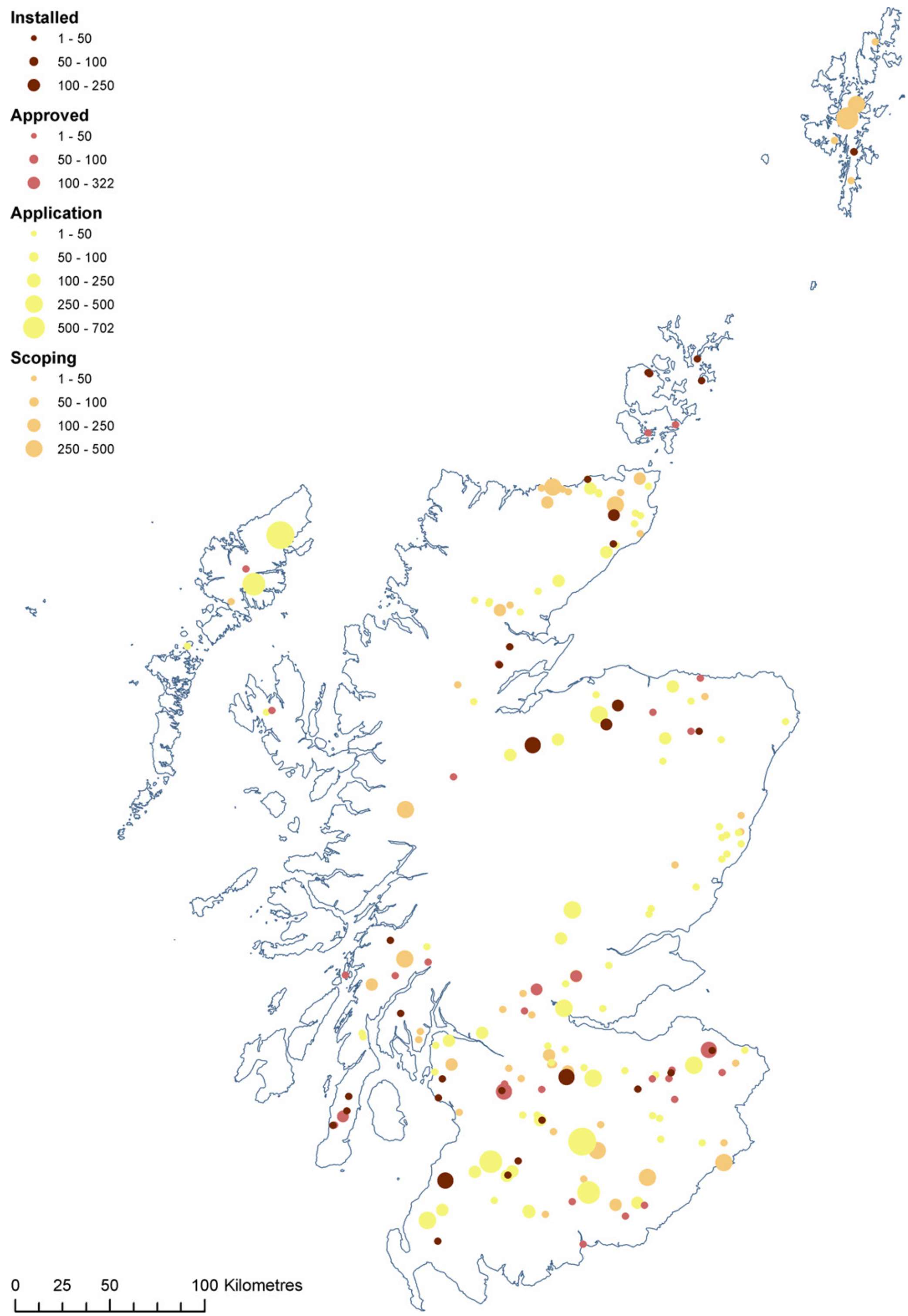

Fig. 4 – Wind farm developments at different stages in the application process (SNH unpublished, February 2007). Size of circle indicates energy output in MW.

wind farm development in Scotland (4% of territory centres within 3 km of wind farm proposals). We found a similarly low number of territories within 2.5 km of proposed wind farms. However, 14% of territories were within 6 km (the range within which golden eagles spend an estimated 97% of their time; McGrady et al., 1997, 2002), and therefore may be at risk (Walker et al., 2005).

Of the other 15 species, 12 had relatively little overlap with proposed and existing wind farm development at the national scale. The level of overlap was higher (>10% of high sensitivity buffered areas), for bean goose, red kite and hen harrier. For bean goose and red kite, a small number of wind farm developments could affect significant proportions of their national populations. Both species are potentially susceptible to collision, with red kite collisions being recorded at several wind farms in Europe (Hötker et al., 2006). Further, both red kite and hen harrier have vulnerable populations in Scotland recovering from historical persecution (Watson, 1977; Carter et al., 1998; Sim et al., 2007), and have received considerable conservation effort, including three red kite re-introduction programmes (O'Toole et al., 2000; Wotton et al., 2002). Nightjar, peregrine falcon, black grouse, and black-throated diver, also had percentage overlaps of 5–10% between buffered areas and proposed and existing wind farms. Cumulative effects from multiple wind farms may impose significant pressures nationally and locally. It is essential that factors such as cumulative effects, population size and conservation status are evaluated when considering the effects of wind farms.

The map was created using the best data and information currently available, but there are inevitably caveats that apply to its use. Unfortunately, data deficiency and gaps in survey coverage precluded a distinction between 'low' and 'unknown' sensitivity squares. Many of these areas will not be within the range of the species of interest, or will not contain suitable habitat for them, but some will be sensitive. Thus, the map is not a substitute for site-specific Environmental Impact Assessment. Some sensitive species were not included due to lack of recent, comprehensive data (merlin *Falco columbarius* and short-eared owl *Asio flammeus*), or problems with data access (osprey *Pandion haliaetus*). The most recent comprehensive data for breeding waders were at a relatively coarse (10-km square) resolution and nearly 20 years old (Gibbons et al., 1993), and so it was not considered appropriate to include them in the map used for these analyses. However, golden plover and dunlin were included as medium sensitivity on a previous version of the map provided to local authorities (Bright et al., 2006), to identify areas that may contain high densities of these species and therefore require further assessment. Likely impacts of wind farms on golden plover in mainland Scotland and the Western Isles have been assessed at a coarser scale by Pearce-Higgins et al. (2008), demonstrating high densities on Lewis and in Caithness and Sutherland, further emphasising the potential sensitivity of these areas to wind farm development, and also parts of the Highlands and Southern Uplands. In most cases, it was not possible to include locations of immature and non-breeding (including wintering and migrating) birds. The map needs to be updated regularly to incorporate new data, either for species already on the map, or the additional species mentioned above.

An additional source of variation between species was the information available on which to base the buffer distances and sensitivity ratings. As there is little information concerning the effects of wind farms on the selected species, we took a precautionary approach based on behavioural ecology. For some species, this information, e.g. disturbance distances and home range sizes, was sparse, or lacking. However, for others, such as golden eagle, radio-telemetry studies have been used to create models predicting the percentage time spent within different distances of territory centres (McGrady et al., 1997, 2002), providing a useful assessment of likely sensitivity. The development of habitat-based models may aid interpolation of species distributions beyond the range covered by sample surveys. More detailed research is necessary to elucidate the impacts of wind farms on birds, and our assessments of sensitivity should be revised in light of this.

SPAs were included on the sensitivity map as a surrogate for concentrations of certain bird species (see Section 2). The requirements for protection of these sites include avoiding adverse impacts on the sites, habitats or species for which they are designated (Stroud et al., 2001). SPAs were not buffered, as a standard buffer was considered inappropriate due to site- and species-specificity of effects. Fourteen (9%) of Scotland's 150 SPAs overlap a proposed or existing wind farm. Given that only approximately 8% of Scotland is within an SPA (Bright, unpublished data), this overlap is perhaps surprising as fewer wind farms might be expected to overlap with SPAs.

Constraints mapping, combining the bird sensitivity map with factors such as wind speed, technical feasibility and cost could be used by planners and developers to identify preferred areas for wind farm development within a region. The Highland Renewable Energy Strategy is an example of this (Aquatera, 2006). Extension of constraints mapping to other consenting authorities would be a valuable aid to strategic planning of wind energy.

Scotland was considered a priority for a sensitivity map, as it has the highest number of onshore schemes currently being considered for planning approval within the UK. The approach is currently being extended to England. Increasing demands for wind energy development globally to combat greenhouse gas emissions (IPCC, 2007), merit strategic planning across international boundaries, for example coastal areas of Europe in relation to offshore wind farms, which are likely to contribute substantially to future renewable energy (Crown Estate, 2003). Sensitivity mapping is a useful tool to assist strategic planning.

Acknowledgements

The authors would like to thank the RSPB and SNH for jointly funding this project. Richard Bradbury Dave Dawson, Gavin Stewart, Jeremy Wilson and two unnamed reviewers provided useful comments on an earlier draft of this paper. Ellen Wilson and Colin Campbell provided advice and technical expertise during the project.

We are grateful to the following for providing data: Bean Goose Action Group, Capercaillie Biodiversity Action Plan Steering Group, Join Nature Conservation Committee, Perthshire Black Grouse Study Group, Rare Breeding Birds Panel and Scottish Raptor Study Groups, and the many individuals who contributed data and expertise to the project, please see Bright et al., 2006 for full details.

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