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Short Communication

Incorporating data uncertainty when estimating potential vulnerability of Scottish seabirds to marine renewable energy developments

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ABSTRACT

The effects of marine renewable energy developments (MREDs) on seabirds are uncertain because of the relative infancy of the industry. This uncertainty can delay the consenting process as regulators adopt a precautionary approach. This study uses novel methods to demonstrate uncertainty in two indices that ranked the vulnerability of seabird populations to MREDs. The study also consolidates recently available data with information from the two indices to consider developments in our understanding of how seabirds respond to MREDs and to present up-to-date vulnerability predictions. Results indicate greater uncertainty in data regarding displacement caused by vessels and/or helicopters, and use of tidal races by seabirds, than in data regarding the percentage of flight overlapping with wind turbine blades and the level of displacement caused by structures. Results also indicate varying uncertainty among species. Overall vulnerability rankings remained broadly the same, with some minor changes. The uncertainty indices highlight areas lacking data, identify robust predictions, and indicate where particular caution in interpreting vulnerability indices should be adopted. They are a useful tool to inform impact assessment and identify strategic research and monitoring priorities.

1. Introduction

Marine renewable energy developments (MREDs) are increasing worldwide to provide an alternative to fossil fuels, increase energy security and mitigate against climatic change [6,7,19]. Scotland has valuable marine renewable energy resources [1,21] and has developed a marine plan, including offshore wind, wave and tidal-stream technologies, to contribute to generating 100% of Scotland's electricity through renewable sources by 2020 [19]. Scotland is internationally important for seabirds [2,16], with special protection areas (SPAs) designated to safeguard breeding colonies [9,18,20]. With several leased and proposed Scottish MRED sites located close to SPAs for breeding seabirds, consideration of the potential consequences for seabirds is necessary.

The effects of MREDs on seabirds are uncertain because of the relative infancy of the industry, the early stage of some environmental monitoring programmes [25] and a limited ability to effectively monitor post-construction effects [13,14,17]. Uncertainty over effects can delay the consenting process as regulators adopt a precautionary approach [15]; for example, by using avoidance rates that may overestimate collision risk. In the absence of information regarding specific effects of MREDs on seabirds, a common approach is to use existing knowledge of seabird behaviour and ecology to derive estimates of seabird vulnerability (e.g. [3–5]). Uncertainty in the contributing data is, however, rarely presented, but is vital information, as the reliability of results and confidence in interpretations can be affected by the quality, quantity and relevance of contributing data [15]. These measures of data uncertainty identify where evidence supporting vulnerability rankings is more robust; where caution in interpreting results may be required; and where additional monitoring and research could prove beneficial [22].

Using Furness et al. [3,4] as examples, this study developed novel methods to incorporate uncertainty into indices ranking the vulnerability of Scottish seabird populations to MREDs. Furness et al. [3,4] developed four indices ranking vulnerability to i) collision with offshore wind turbines, ii) displacement caused by offshore wind farms, iii) wave energy, and iv) tidal-stream energy developments. These indices have been used by MRED regulators and developers during initial scoping and impact assessment (e.g.

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[8]) but measures of uncertainty in data contributing to rankings were not explicitly included. This study develops uncertainty indices to aid transparent and consistent application of vulnerability index predictions. Recently available data were consolidated with information in Furness et al. [3,4], to account for new developments in our understanding of how seabirds respond to i) structures and ii) vessels and helicopters, and to incorporate a reduced risk of collision with offshore wind turbines for species displaced by structures. The development of uncertainty indices and modified vulnerability indices more accurately represent the risks posed by MREDs to seabirds.

2. Methods

2.1. Calculating uncertainty

Four vulnerability factors were identified as important in driving seabird vulnerability to MREDs [3,4]: i) percentage of flight overlapping with wind turbine blades, ii) displacement caused by structures, iii) displacement caused by vessels and/or helicopters, and iv) use of tidal races. The quality, quantity and relevance of data contributing to these factors were assessed for each of 38 Scottish seabird species to estimate data uncertainty (see Supplementary Table 1 for scientific names). Data uncertainty was assessed using five criteria, with greater scores reflecting a greater quantity and quality of data, and therefore indicating lower levels of uncertainty:

1) **Species Score**: Did data refer to the target species or a related species? Species were scored 3 if $\geq 50\%$ of data sources referred to the target species, 2 if data referred to a related species or to higher taxa, and 1 if no published data were available.
2) **Number of Sites**: How many sites contributed data?
3) **Number of Studies**: How many studies are included?
4) **Mean Years**: What was the mean period of years over which data were collected?
5) **Method Score**: What level of uncertainty was associated with the methods used to collect data? For a full explanation of the Methods Score, Method Categories and associated Uncertainty Levels see Section 2.1.1 and Table 1.

The five criteria scores derived for each species, in each vulnerability factor, are shown in Supplementary Tables 2–5.

2.1.1. Method Score

To generate a Method Score for each species, in each vulnerability factor, the number of studies in each Method Category (with different Method Categories considered relevant for the four vulnerability factors; Table 1) were multiplied by the Uncertainty Score under which the Method Category was located (Table 1). Greater weight was given to studies using more reliable and robust methods; for example, before-after-control-impact studies and studies collecting data on flight altitudes using bird-borne GPS devices. These more reliable methods were associated with greater scores to reflect a greater quality of data, and therefore a corresponding lower Uncertainty Level (Table 1; Eqs. (1) and (2)). The Method Score reflects the reliability of the methods used in all studies considered for each species in each vulnerability factor, and the uncertainty inherent in those data. Eq. (1) was used to

Table 1
Uncertainty Levels and Scores indicating the level of uncertainty associated with data contributing to species vulnerability rankings. Five categories with associated ranking scores indicate the level of uncertainty: very high (score 1), high (score 2), moderate (score 3), low (score 4) and very low uncertainty (score 5). Capital letters in brackets refer to the Method Categories included in Eqs. (1) and (2). The table indicates the Uncertainty Level and Score assigned to each Method Category and outlines the range of values included in the Combined Score at each Uncertainty Level, which differs among vulnerability factors. Greater scores reflect a greater quantity and quality of data, and therefore correspond to lower levels of uncertainty.

Vulnerability factor	Vulnerability factor attributes	Uncertainty Level (Uncertainty Scores)				
		Very high (1)	**High (2)**	**Moderate (3)**	**Low (4)**	**Very low (5)**
% Time flying at turbine height	**Method Category**	Anecdotal observation (or unknown method) **(A)**	Observations not recorded in the presence of turbines (indirect study 2) **(B)**	Observations recorded in the presence of turbines (indirect study 1) **(C)**	Study combining results from 5 or more studies/ sites to produce modelled flight information **(D)**	GPS or radar (direct study) **(E)**
	Combined Score	0.0 – 28.5	29.0 – 56.5	57.0 – 84.5	85.0 – 112.5	113.0–140.5
Disturbance by structures	**Method Category**	Anecdotal observation (or unknown method) **(A)**	Observation **(B)**	Before-After- Control-Impact study (BACI) **(C)**		
	Combined Score	0.0–12.5	13.0–24.5	25.0–36.5	37.0–48.5	49.0–60.5
Disturbance by vessel and/or helicopter activity	**Method Category**	Anecdotal observation (or unknown method) **(A)**	Observation **(B)**	BACI or experimental method **(C)**		
	Combined Score	0.0–8.5	9.0–16.5	17.0–24.5	25.0–32.5	33.0–40.5
Use of tidal races	**Method Category**	Anecdotal observation (or unknown method) **(A)**	Observation without current data **(B)**	Observation with modelled or inferred current data **(C)**	Study combining results from 5 or more studies/ sites with modelled or inferred current data **(D)**	Observation with concurrent current data **(E)**
	Combined Score	0.0–8.5	9.0–16.5	17.0–24.5	25.0–32.5	33.0–41.5