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EXTENDED ABSTRACT

Advances in impact assessment of offshore wind farms upon seabirds: insights from studies of terns (*Sterna* and *Sternula* spp.)

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The UK is internationally important for five species of tern in the following order of abundance: Arctic *Sterna paradisaea*, Sandwich *S. sandvicensis*, Common *S. hirundo*, Little *Sternula albifrons* and Roseate *Sterna dougallii*. There is potential for some species to interact with offshore wind farms (OWFs) on their breeding grounds, with all species possibly affected when on passage. Our intensive studies upon different species at different breeding colonies around the UK suggest that a number of advances at different stages of the environmental impact assessment (EIA) process are required to increase confidence in evaluating impacts of OWFs upon terns. The techniques suggested could also apply to species such as gulls, skuas and Northern Gannet *Morus bassanus* that also spend considerable time in flight whilst foraging.

The first step in ornithological EIA requires description of abundance and distribution of birds of a potential OWF, preferably relative to the wider area (Fig. 1). Both boat- and aeroplane-based (aerial) surveys provide a means of estimating density and population size of flying birds in surveyed areas (Camphuysen *et al.* 2004). Aerial surveys are typically used over large areas (e.g. a region-based approach) as a result of the speed of the survey platform. However, a low level of species identification, lack of behavioural information and generally low survey frequency (as a result of expense) hinder the value of aerial surveys. Temporal and spatial patterns of abundance of important bird species may be difficult to interpret as a result. In comparison, boat-based surveys offer a high level of species identification in conjunction with behavioural information. However, the assumption of the standard snapshot methodology that flying birds are detected to 300 m from the survey platform is likely to be violated (Barbraud & Thiebot 2009), especially on smaller vessels of lower eye-height (*c.* < 8 m). In our experience, relatively small vessels are typically used to reduce costs. In turn, the cost of vessels over multiple surveys (a minimum of 24 surveys over a 2-year period is standard) is an important financial consideration. Our ongoing analyses suggests that a distance sampling approach (Thomas *et al.* 2010) is required to estimate the density and thus population size of flying birds in a similar manner to that currently in use for birds on the water surface. Without distance correction there is a risk of underestimating the importance of the site. Underestimation of density may also lead to underestimation of the birds at risk of collision.

In the absence of comparative boat-based surveys of other nearby OWF sites or other areas likely to be used by birds from breeding colonies, the relative importance of the site to the wider area may be difficult to determine. Individual-based methodologies such as radiotelemetry (e.g. on Little Terns, Perrow *et al.* 2006) or visual tracking from a fast-moving (>30 knots h^{-1}) boat such as a rigid-hulled inflatable (Perrow *et al.* 2010b) provide the best means of identifying foraging range from colonies and developing understanding of patterns of use. Our tracking of Sandwich, Common and Arctic terns showed colony-specific patterns and different potential for interaction with OWFs that was difficult to predict in advance (Perrow *et al*. 2010a).

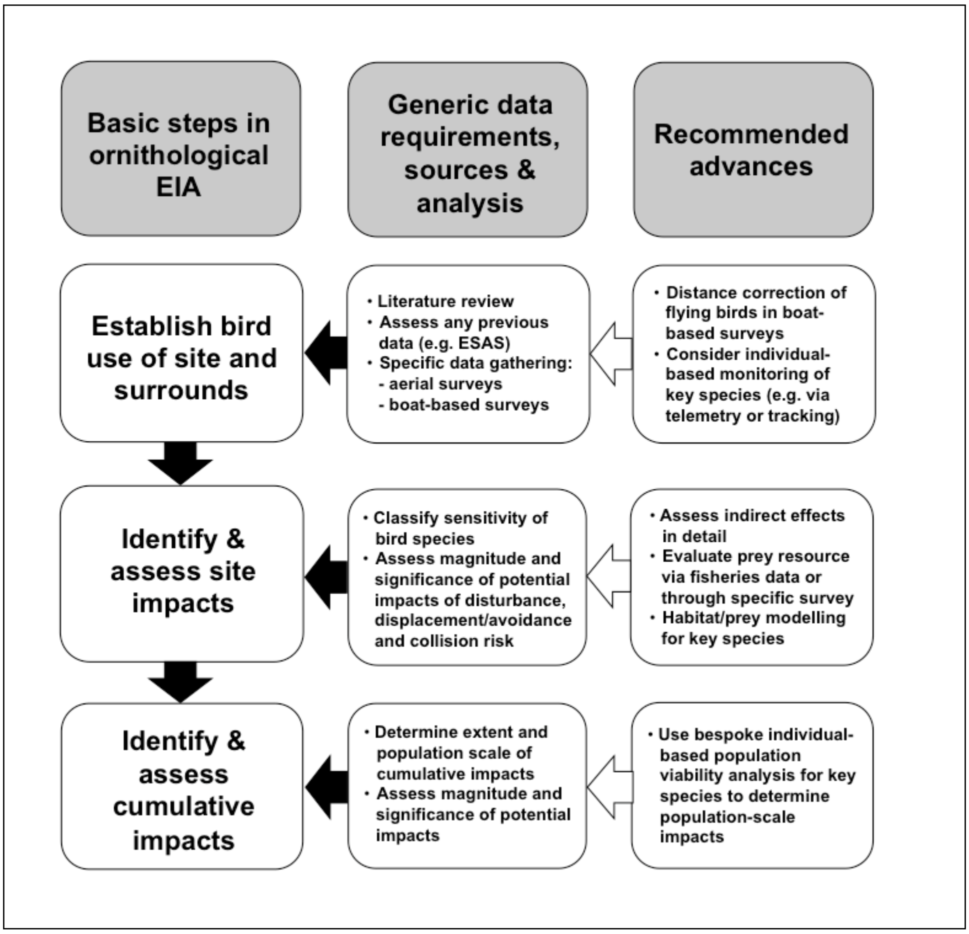

Figure 1. Basic steps and information flow in ornithological EIA. Filled arrows show established pathways, whereas open arrows illustrate how recommended advances in data gathering and assessment may be incorporated.

Detailed information increases confidence in the output of the second step of EIA where key impacts are identified and rigorously assessed (Fig. 1). As well as the potential for disturbance/displacement and the risk of collision, we stress that it is essential that indirect trophic impacts upon prey as well as possible changes in habitat conditions are carefully considered. Thomsen *et al.* (2006), amongst others, illustrate the potentially significant impact of construction noise especially pile driving upon hearing-specialist fish species such as Herring *Clupea harengus*. Any impact upon fish abundance and distribution may knock-on to birds dependent on such prey, changing foraging success and perhaps breeding productivity (Perrow *et al.* 2006). Targeted monitoring of fish of importance to birds may prove invaluable in assessing impacts as well as improving understanding of the trophic links and dynamics in the system that may be affected.

Thorough understanding of the habitat variables gained through individual-based monitoring or even from extensive observations in boat-based surveys (Schwemmer *et al.* 2009) may also enable predictions of relative use of different areas. In our case of Sandwich Terns at two colonies (Blakeney Point and Scolt Head) in north

Norfolk, information from individual tracks was scaled to the colony level through development of a simulation model. The number of movements from (and to) the colony was estimated at *c.* 1 million through use of boat-based transects parallel and close (~300 m) to the shore designed to intercept virtually all birds leaving and arriving at the colony on/from foraging trips to sea in any direction. Individual tracks of Sandwich Terns typically showed little deviation from an initial course adopted from the colony, suggesting birds headed directly to specific foraging areas. In our model, each of 10 000 simulated birds flying from the colony was randomly allocated a flight direction according to the proportion sampled from colony-based transects. The distance flown by each individual model bird was drawn from a direction-specific Weibull distribution, the parameters of which were determined by reference to data from tracked birds. The distribution allowed for a small proportion of individuals that travel a longer distance, and generally reflected the observed dispersal distances during tracking. The model indicated high use of inshore areas with declining use of OWFs further from the colonies and from shore with the exception of sites along the Lincolnshire coast. A prediction of the passage rate across different OWFs was used to generate estimates of collision risk, which were in broad agreement with those derived from boat-based surveys of individual sites.

Collision risk modelling remains a key component of EIA, both for an individual site and in a cumulative context in the third key step of EIA (Fig. 1). Meaningful prediction of the number of potential collisions remains problematic without specific information on avoidance rate from actual sites. Assessment thus typically relies on precautionary estimates designed to reduce risk in the decision-making process. However, this introduces the prospect of the impact of OWFs being overestimated. The use of individual-based techniques such as visual tracking may be useful in determining avoidance rate at constructed sites, which may then guide assessment of similar sites. But even with this information it may still be difficult to assess potential impacts upon important populations (e.g. within Special Protection Areas). To better assess population-scale impacts we have used bespoke individual-based population viability analysis (PVA) using data specific to the colonies wherever possible. Scenarios with and without additional mortality from OWFs may be compared. Different combinations of sites may also produce different impacts upon populations. Not surprisingly, modelling shows that selection of an appropriate avoidance rate may be critical in separating significant from non-significant impacts. As a result of our positive experiences using PVA in a predictive capacity, we anticipate that PVA will become an increasingly important tool especially in relation to cumulative impacts, particularly as the recently let Round 3 zones often containing multiple sites come into planning.

Acknowledgements

Much of the work described was undertaken for Centrica Renewable Energy Limited. Subsequent work was undertaken during the COWRIE project (Tern 07-08). We are grateful to those organizations and S. King (AMEC) and T. Norman (Crown Estate) in particular for their support. Tracking was dependent on our drivers, including P. Lines, R. Brookin, A. Diggle and P. Turkentine.

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CITATION: Perrow, M.R., Gilroy, J.J., Mackenzie, A. & Skeate, E.R. 2010. Advances in impact assessment of offshore wind farms upon seabirds: insights from studies of terns (*Sterna* and *Sternula* spp.). *BOU Proceedings – Climate Change and Birds*. http://www.bou.org.uk/bouproc-net/ccb/perrow-etal.pdf