Scottish Natural Heritage
Archive Report No. 050

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ARCHIVE REPORT

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For further information on this report please contact:

George Lees
Scottish Natural Heritage
Battleby
Redgorton
PERTH
PH1 3EW
Telephone: 01738 458621
E-mail: george.lees@nature.scot

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ARCHIVE REPORT

Summary

Assessment methodology for determining cumulative impacts of wave and tidal marine renewables energy devices on marine birds

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marine renewables; wave energy; tidal energy; cumulative impact assessment; environmental impact assessment

Background

As part of the second round of wave and tidal development, search areas across north and north western Scotland have been identified by the Scottish Government as potentially suitable for wave and tidal energy development. In the context of marine ornithology, an increase in planned and proposed offshore energy developments has raised concerns over cumulative effects, primarily because of potential collision risk, disturbance and displacement.

To date no guidance has been published on cumulative impact assessment for birds in relation to wave and tidal devices. Scottish Natural Heritage (SNH) commissioned research funded by Marine Scotland (MS) to provide guidance on this issue, specifically wave and tidal devices on marine birds in Scottish Territorial Waters (STW), and to outline possible approaches to the assessment process whereby cumulative impacts can be determined.

Main findings

The approach recommended to SNH and MS for identification of marine bird species and/or protected areas likely to be affected by cumulative impacts from particular wave and tidal projects is as follows:

1. Establish proposed spatial scale to be used through consultation (e.g. Regional Sea).
2. List all marine/coastal bird species on that spatial scale - a possible list of species is provided in the SEA (Scottish Executive, 2007).
3. List SPAs, mSPAs and SSSIs (with a coastal component) as well as other designated sites that support important numbers of seabirds within the project's zone of influence as established under step 1.
4. Obtain data on foraging ranges for species identified in Step 2 (see e.g. Langston, 2010), apply these as buffer zones around the relevant protected sites identified under Step 3.
5. Based on Step 4 confirm default spatial scale (e.g. Regional Sea) still relevant or in need of extension in case of migratory / passage species or species with large foraging ranges.

6. Obtain information on all other relevant development projects within the established spatial scale.
7. Reduce species list to those species with a development area within their maximum foraging range.
8. Identify the number of other projects (development areas) within the i) maximum and ii) median foraging range of each species.
9. Estimate the sensitivity of species using a sensitivity index incorporating indicators of demographic sensitivity such as adult survival rate or conservation status as well as indicators of vulnerability to devices (e.g. dive depth), prey preferences (Garthe & Hüppop, 2004; Desholm, 2009; and Stelzenmüller *et al.,* 2010).
10. Assess significance based on established guidelines (e.g. IEEM EIA guidance).

For further information on this project contact:
George Lees, Scottish Natural Heritage, Battleby, Redgorton, Perth, PH1 3EW.
Tel: 01738 458621 or george.lees@nature.scot
For further information on the SNH Research & Technical Support Programme contact:
Research Coordinator, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW.
Tel: 01463 725000 or research@nature.scot

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1. INTRODUCTION

As part of the second round of the wave and tidal development, search areas across north and north western Scotland have been identified by the Scottish Government as potentially suitable for wave energy and tidal stream development. The areas identified to date are off Islay, Kintyre, the Inner and Outer Hebrides as well as the Pentland Firth, Orkney and Shetland.

In the context of marine ornithology, an increase in planned and proposed offshore energy developments has raised concerns over cumulative effects, primarily because of potential collision risk, disturbance and displacement.

Within the European legislative framework, the Habitats Regulations (EC Directive 92/43/EEC) require an assessment of in-combination effects of development projects of features within Special Protection Areas (SPA) or Special Areas of Conservation (SAC). Under UK law the consideration of cumulative effects of projects is integrated into the Environmental Impact Assessment (EIA) Regulations (EC Directive 97/11/EC), of which it forms an essential feature.

1.1 Cumulative impact - definition

Whilst individual projects may affect the environment, the combined or cumulative effects of multiple projects may be greater than the sum of the individual parts (Canter & Kamath, 1995). Although there has been some confusion surrounding the definition of cumulative effects/impacts (Masden *et al*., 2010), for the purpose of this document, cumulative effects are defined as:

“The additional changes caused by a proposed development in conjunction with other similar developments or as the combined effect of a set of developments, taken together” (SNH, 2009).

A cumulative impact assessment (hereafter CIA) is therefore intended to estimate the impact of a planned project on a receptor, in combination with other projects, and to inform whether specified thresholds are exceeded are not (Canter & Kamath, 1995).

Cumulative impacts assessments to date

To date, initial guidance has been published on CIA for birds in relation to on- or offshore developments. The two main examples relevant to Scotland involve guidance on birds and onshore wind farms (SNH, 2000; 2009), and birds and offshore wind farms (Norman *et al*., 2007; King *et al*., 2009).

No guidance exists for cumulative effects of wave and tidal developments on marine birds at this stage. SNH is currently drawing up a guideline document to this effect, which is likely to be finalised in late 2010.

The lack of established guidelines is likely to have contributed to inadequacies of approach to CIA for a range of offshore wind projects, with assessments varying considerably in scope and quality (Piper *et al*., 2001; King *et al*., 2009; Masden *et al*., 2010). This, in turn, further compounds the issue as it restricts the acquisition of basic knowledge about the cumulative impacts of wind farms on bird populations (Masden *et al*., 2010).

A review of a number of CIA documents identified the main issues as:

- inadequate scoping;

- lack of understanding of the species involved;
- difficulties in assigning the range of species which should be included in the assessment; and
- difficulties in choosing the methods by which CIA should be undertaken (Norman *et al*., 2007).

Consequences of an inadequate CIA approach could include a failure to identify potentially significant impacts and could cause significant delays in the development process through a lack of clarity in the process among stakeholders (King *et al*., 2009).

Cumulative effects are often complex, with a multitude of factors involved. The fact that, in some circumstances, underlying ecological mechanisms affecting seabird distribution and abundance are not fully understood, introduces significant uncertainties and leads to the need for various assumptions to be made. Given the level of complexity as well as uncertainties involved, it is paramount that CIA requires a transparent, structural and detailed assessment to identify and distinguish the overall effects which could arise from a group of projects as well as the contribution of individual projects to these.

These issues highlight the need for CIA guidelines for wave and tidal devices to be developed as soon as possible.

1.2 Objectives

The aim of this document is to provide guidance on the issue of assessing the cumulative impacts of marine renewable energy developments, specifically wave and tidal devices (excluding offshore wind farms) on marine birds in Scottish Territorial Waters (STW), and to outline possible approaches to the assessment process so that cumulative impacts can be determined.

This document will provide a short overview of existing knowledge on potential impacts of wave and tidal technology, and a review of existing guidelines for CIA assessment of offshore developments. These will form the basis for the construction of draft guidelines for the assessment and determination of cumulative impacts on marine birds from wave and tidal developments.

2. POTENTIAL IMPACTS OF OFFSHORE WAVE AND TIDAL DEVELOPMENTS

Potential cumulative effects of wave and tidal developments are difficult to assess and even harder to determine, as the underlying ecological mechanisms for individual factors and the associated likelihood of significant impacts on birds of each of these are often poorly or only partially understood.

Several uncertainties have been identified (OEER, 2008; Simas *et al*., 2009), and it is postulated that effects on biodiversity may be both positive and negative (Inger *et al*., 2009). It is likely that impacts will be specific to the individual devices (RPS, 2010), but also species, age-, and sex-specific, as well as temporally and spatially variable. For example, the magnitude of impacts for diving birds will depend on the dive profile of the species (i.e. depth and shape of dive) and the operational depth of the devices. The effects will also be specific to the separate development phases: construction, operation and decommissioning of wave and tidal installations (Scottish Executive, 2007). For ease of reference potential impacts have been grouped into three main categories: collision, disturbance and displacement.

A large number of marine underwater energy devices are under development or potential deployment. There is a wide variation in the design of these devices, and most are still at the developmental stage. This means that it is not possible to be specific about any negative (or positive) impacts on diving birds. However, with the caveat that each device in each different location will need individual rigorous assessments, an examination of generic theoretical potential impacts is the first step towards evolving a CIA approach.

2.1 Potential negative effects

Marine underwater energy devices pose six theoretical categories of risk to diving birds, inherent to their mode of operation or construction. These can be divided into direct effects and indirect effects:

- Direct loss of habitat for diving birds due to installation of devices;
- direct risk of collision between diving birds and moving parts of the device;
- direct risk of entrapment within enclosed parts of the device;
- direct impacts of construction/operational noise and pressure changes;
- indirect impacts due to construction/maintenance/operational disturbance; and
- indirect impacts due to habitat change for prey, depletion (as a result of collision), displacement or aggregation of prey.

The potential theoretical risk from most of the categories mentioned above is likely to increase with the scale of the project, i.e. the larger the array of renewable devices, the greater the rotor swept volume of water and the greater the potential risk to diving birds. However, it is unknown which one of the two factors of i) the size, or ii) speed, of the rotors will present a greater potential risk to birds.

Habitat loss

Installation of underwater energy devices would result in habitat lost from the foraging range of diving birds and physically prevent dives taking place in part of the water column. This loss comprises both the two-dimensional footprint of the device, i.e. on the seabed, as well as the three-dimensional foraging volume occupied by the device in the water column. This direct habitat loss is however usually of very low extent compared to the overall foraging range of an individual. As such the potential for a significant direct effect resulting from such limited loss is considered to be very low.

Collision risk

Potential collision risk will vary between renewable devices according to the extent to which turbine blades or oscillating arms are exposed to the surrounding water.

Horizontal-axis turbines are renewable devices that resemble wind turbines. These could have the same type of collision effect as wind turbines on underwater wildlife, including diving birds. Some of these devices are mounted on towers which are anchored or mono-piled into the seabed so that the rotors sit just below the water surface. Therefore in these cases the fast-moving blades of horizontal-axis turbines will be the first parts of the device to be encountered by birds diving from the surface. Other horizontal-axis devices are mounted in frames that sit on the seabed, which due to their position in the water column may present less of a risk to diving birds (but may still pose a hazard to fish and mammals).

Risk of entrapment

The potential risk to diving birds posed by energy devices is different in that although the device has no submerged moving parts, birds may be vulnerable to becoming trapped in the turbine chamber and injured or killed by the powerful propulsion of water within.

Impacts of noise and pressure changes

The potential impact of operational noise on the animals that utilise wave and tidal sites will be most significant during construction and subsequent maintenance activities (Madsen *et al.*, 2006). Developments capable of floating or resting on the seabed rather than being fixed in the seabed would minimise the impact of noise during the construction process, as pile driving would be unnecessary. The machinery involved in pile driving has the potential to cause auditory damage to birds and marine mammals in the vicinity (Thomsen *et al.*, 2006).

Devices may exclude birds from suitable foraging habitat by producing noise that results in avoidance behaviour (Scottish Executive, 2007). Depending on the type of device deployed, underwater noise during the operational lifetime of an array could have a significant long-term impact on local habitat utilisation by seabirds as well.

Recent research on bats suggests that sudden changes in pressure can cause barotraumas (Baerwauld *et al.*, 2008). Birds were considered less susceptible to barotrauma because of their different respiratory system, however the possibility of direct mortality or drowning as a result of these effects cannot be ruled out.

Indirect impacts of disturbance to birds

There may be indirect impacts at development sites due to construction, maintenance or operational disturbance. This may either be due to a reaction of the birds themselves (which may be only temporary) in displaying avoidance behaviour from arrays that provide a physical or perceptual barrier (Scottish Executive, 2007) or in combination with impacts on their prey species (see also next section), for example through water contamination or increased levels of suspended sediment and turbidity during any stage of a development.

Exclusion may limit other device interactions, such as collisions, but will also limit the available habitat on a local level, with potential associated impacts on access to food resources and breeding success, stress on individuals and energy budgets. Typical array sizes are likely to be 4 km^2 for wave and 0.5 km^2 for tidal arrays (Scottish Executive, 2007).

Evidence from wind farm projects indicates that several species, most notably divers and seaducks, have shown increased avoidance of up to 2 – 4 km from wind farm areas (Petersen *et al.* 2004; Petersen, 2005). Wave and tidal arrays might incur a similar impact and whilst it is considered that alternative foraging areas may be available to displaced species, significant displacement might be compounded by an effect on nearby bird populations arising from increased competition for prey species in areas adjacent to a development. The magnitude of such an impact likely depends on the means of securing the device to the seabed (i.e. its footprint).

In order to assess the potential impacts of disturbance on diving birds, the presence of breeding colonies and favoured feeding areas along with the foraging ranges and behaviour of the relevant species would have to be taken into account.

Indirect impacts on diving birds through impacts on their prey

Given that birds will only come into potential conflict with underwater devices when diving for prey, understanding the distribution and behaviour of prey species is critical in assessing the potential risk to diving birds from devices.

Diving birds may be at risk from indirect negative impacts on their fish or shellfish prey through the following scenarios:

- Local prey abundance could become depleted or displaced by the deployment of energy devices, reducing the resources of the area and causing diving birds to seek alternative foraging grounds;
- prey could habituate to energy devices and aggregate around the structures, attracting diving birds and increasing risk to the birds; and
- fish prey species could fall victim to collision with energy devices, or entrapment within reservoirs, attracting diving birds to trapped fish, or fish carrion, increasing overall collision risk for birds.

2.2 Potential positive effects

Marine underwater energy devices could positively affect seabirds as well, for example through the creation of reef-like habitat on underwater structures, which could potentially be colonised by benthic species, subsequently increasing the availability of prey species in the vicinity of turbines.

There are also theoretical positive effects of the presence of devices on seabirds, especially if fishing activities are excluded from an operational wave or tidal site. Although in the short term this might not be important, it could have longer-term benefits (Inger *et al.,* 2009). Potentially of importance are possible benefits of roosting/resting sites above the water surface as well as an increase in underwater habitat complexity leading to enhanced fish recruitment. Any benefits would have to be offset by the costs of potential collision risk, although all potential impacts (negative and positive) are considered theoretical at this stage.

2.3 Measuring the impacts

There is a lack of information on the vertical distribution and swimming behaviour of marine birds within the water column as well as reactive behaviour of birds to devices, once detected in the water (i.e. avoidance behaviour). Furthermore, although there is some information on dive profiles and diving constraints of breeding adult birds for a variety of species (e.g. RPS, 2010), such information is often scarce for birds outside the breeding season. Consequently, at present it is difficult to estimate, with confidence, collision risk posed to marine birds by wave and tidal devices (Scottish Executive, 2007; RPS, 2010).

Technologies potentially available to assess underwater behaviour and collision rates for marine birds include:

- Strain gauges (although these rely on body mass and so may be more relevant for marine mammals and not as practical for some of the smaller diving birds);
- sonar and acoustic camera systems; and
- encounter models (Wilson *et al.*, 2007).

A further constraint is the limited understanding of the effects of changes in flow characteristics on marine birds and their prey, as well as the extent to which devices affect turbidity and the subsequent effect on species' ability to detect prey visually. It also remains largely unknown how birds respond to and are affected by underwater noise. For more detailed information on knowledge gaps see Wilson *et al.* (2007), Linley *et al.* (2009) and MASTS (2010).

In spatial terms, little is known about the small-scale distribution of individuals in proposed wave and tidal search areas, or of fine-scale population variability in population size. Connectivity between SPAs and foraging areas other than those in the immediate vicinity of such protected areas is lacking in detailed information for most species as well.

Techniques and technologies available to address some of these issues include:

- Ship-based surveys of marine birds distribution, behaviour and prey distribution;
- aerial surveys of marine birds distribution – particularly outwith the breeding season;
- water column characterisation (including noise profiles);
- tagging studies; and
- Before-After-Control-Impact survey framework.

Population modelling

If cumulative impacts are highlighted as a significant potential problem for a species of concern, then more detailed research might be required to determine the magnitude and significance of the impacts. One such approach could be through population modelling: population viability analyses (PVA) are methods used to assess the probability of extinction and evaluate management strategies. Population projection modelling and individual-based models (IBMs) are two useful PVA techniques that can be used to ask questions regarding threats to species as well as the potential effectiveness of mitigation measures.

Population projection modelling

Models can be written specifically for individual projects or off-the-shelf software can be used. Maclean *et al.* (2007) reviewed five software packages (ULM, VORTEX, RAMAS, INMAT and GAPPS) available for population viability analysis and concluded that ULM (Unified Life Models) was the most appropriate package for PVAs for seabirds because it allows the inclusion of age- and density-dependent differences in demographic parameters. They also concluded that there were data available on seabird populations for at least basic population viability analyses (Maclean *et al.*, 2007).

Another method of population modelling that has been suggested for assessing the population consequences of effects is Potential Biological Removal (PBR) which has been used for marine mammals in the U.S. and could be used for marine birds (Wade, 1998; MASTS, 2010).

Individual-based models

Individuals are the building blocks of ecological systems and so IBMs can be used to investigate the population consequences of individual interactions and behaviours, and may include spatial components such as movement. Individuals in IBMs are autonomous units defined by their characteristic behaviours and parameters, whilst being tracked through time, but interact with other members of the population and their environment. Due to the fact that simulation models can often differentiate between additive and interactive processes, IBMs offer the best prospects for analysing cumulative environmental impacts (Hyder, 1999).

An IBM was used to assess the cumulative impacts of displacement on common scoter *Melanita nigra* due to wind farms in Liverpool Bay (Kaiser *et al.* 2002). Such models could be used to investigate the population impacts of wave and tidal renewable energy devices on marine birds through the integration of behavioural mechanisms with regard to displacement and collision risk into the models. Although such models are data-intensive, for most species likely to be affected by offshore wind farms sufficient demographic data exist to carry out population *viability* analyses (Maclean & Rehfisch, 2008).

The types of data required to parameterise such models would include, but are not limited to:

- Baseline age-dependent survival;
- productivity;
- population abundance;
- incidence of non-breeding;
- movements between meta-populations;
- prey availability;
- foraging information;
- breeding behaviour; and
- spatial distribution.

3. OVERVIEW OF EXISTING GUIDELINES

Only limited information is available on the assessment of cumulative impacts of renewable energy devices on birds, and due to the infancy of marine renewable energy, no projects have specifically concentrated on the cumulative impacts of wave and tidal devices. In a UK context, two main attempts have been made to establish guidelines focussed on the cumulative impacts of wind turbines on birds both onshore (SNH, 2009) and offshore (King *et al.* 2009), with a third providing a conceptual framework for considering cumulative impact assessments (Masden *et al.* 2010).

The approach taken by both SNH (2009) and King *et al.* (2009) is broadly based around identifying the bird species at risk from cumulative impacts, using a matrix approach and a set of selection criteria. In these two documents the selection of species to include for assessment was mainly qualitative, although the approach suggested by King *et al.* (2009) provided much more detail in a 'key features' table. The species included were selected according to priority criteria based upon the level of species protection such as whether they were on Annex 1 of the EC Birds Directive, Schedule 1 of the Wildlife and Countryside Act (as amended) or featured on a Birds of Conservation Concern list. However King *et al.* (2009) take this further and consider potential temporal variability of impacts depending on whether the birds are breeding, wintering, on passage, or a combination of these. Spatial variability of habitat use and foraging ranges of species are also considered. In both approaches, the overall impact is partitioned into the effects of displacement, collision, barrier effects, indirect effects (e.g. prey species) or habitat loss, and the vulnerability of each species to these effects scored accordingly (i.e. low, medium, or high).

Both SNH (2009) and King *et al.* (2009) highlight spatial scale as an important consideration for CIA. Only the latter guidance, however, suggests inclusion of all regulated projects (including oil and gas activities and aggregates projects) and their associated impacts within the area of search. SNH includes only wind farms in its cumulative assessment guidelines. Masden *et al.* (2010) highlight scale as well as actions (i.e. projects) and impacts as important components that should be clearly defined within an assessment of cumulative impacts to overcome the current lack of consistency between projects. In an offshore context, King *et al.* (2009) provide the first detailed attempt to establish guidelines that incorporate a set sequence of steps and definitions of spatial scale with the aim to provide a solid, consistent and auditable foundation for offshore CIA. Many recommendations for the identification of key factors that should be considered within CIA presented in this document follow those suggested in the guidelines by King *et al.* (2009), but have been adapted for impacts associated with wave and tidal devices where relevant.

4. PROPOSED APPROACH TO CUMULATIVE IMPACT ASSESSMENT

4.1 Data collection

It is considered that the standard boat-based and aerial survey methods of data collection for offshore EIA purposes (Camphuysen *et al.,* 2004; WWT, 2005) form a core survey element to provide robust project-specific datasets. It is essential that survey recommendations made by Maclean *et al.* (2009) are incorporated into study design, methodology etc. where relevant.

Behavioural data, recorded in categories as described in Camphuysen *et al*. (2004), are essential and should always be gathered during surveys. In particular, where feeding or loafing behaviour is observed, this should be recorded. Similarly, other factors which may assist in interpreting bird distributions, such as whether the birds are carrying prey, associations with other birds or ships and the presence of fishing and commercial vessels should be recorded.

Offshore boat and aerial survey protocols will however, need to be tailored to the specifics of a given project, whilst at the same time maintaining the essence of established guidelines, to ensure the collection of high quality data in a scientifically robust manner, as well as inter-project consistency in general approach.

Experiments with other or adapted methods of data collection are also underway, notably at the European Marine Energy Centre (EMEC) and Strangford Lough, where shore-based monitoring using a grid framework has been used to assess surface distribution of seabird activity. RPS is also involved, as are other specialists, in evolving survey methods for specific offshore marine energy developments (see RPS, 2010). In summary, these combine shore-based surveys with modified boat-based line transects and point counts.

For tidal search areas in particular, it is evident that it is extremely valuable to gather behavioural data through a dedicated effort as opposed to line transect methodology, where such data is of secondary interest. As mentioned this could for example be done by combining line transects with stationary point counts at predefined locations.

At such locations, observers could for example select target individuals (diving birds on the sea, or quartering birds in the air) and record their behaviour. Data collected should include species, age, feeding behaviour, dive duration and frequency. Such an approach would significantly aid our understanding of species distribution and abundance as well as insight in the reasons behind these patterns, in turn enabling more precise CIAs.

4.2 Species selection

For each project species selection should be based on the spatial distribution and underwater ecology of all diving bird species likely to be regularly present within the study area, and therefore potentially at risk from underwater marine renewable devices. To that purpose the following factors should be reviewed at the scoping stage of each project:

- Species occurrence (spatial and temporal distribution);
- species sensitivity (foraging behaviour including feeding depth, dive profile, underwater vision, prey species preferences); and
- species of conservation importance.

Species occurrence

Species selection could, for example, be based on the list of species provided in the SEA (Scottish Executive, 2007), or on a larger scale the list compiled by the Marine Protected Areas Technical Group, focusing on all birds which make significant use of the marine environment around the UK and Gibraltar (JNCC, 2007).

Determination of marine bird species occurrence in a study area should, as a starting point, be based on (i) species distribution maps from e.g. Stone *et al.* (1995) and Mitchell *et al.* (2004) and (ii) site-specific baseline data collected for EIA purposes through tailored monitoring programmes by boat-, aerial- and land-based surveys.

Species sensitivity

There will likely be varying degrees of overlap between the proposed locations of underwater energy devices and seabird foraging areas. Tidal stream devices in particular will be proposed for areas favoured by diving birds, which preferentially forage in regions of high tidal activity. Diving birds are therefore potentially at risk through the processes described in Section 2.

Species sensitivity will depend on:

- The extent of overlap between devices and diving bird foraging areas on the surface;
- the extent of overlap between devices and diving bird foraging areas below the surface;
- the foraging ecology of diving bird species at risk, including diving depth and swimming speed;
- diurnal / nocturnal routine of foraging;
- seasonality of species presence;
- species which are known or thought to be at particular risk from offshore developments (see Garthe & Hüppop 2004); and
- the extent to which the species is attracted to the development, e.g. for perching / nesting / foraging / moulting (underwater structures may act as reefs, attracting prey species).

In assessing risk, the species selection should focus on the potential risk of collision or entrapment, as well as potential disturbance and displacement. Starting points for species-specific sensitivities to offshore developments are Garthe & Hüppop (2004), Maclean & Rehfisch (2008) and Langston (2010). Although all of these focus on wind farms, they do provide good examples of an approach to species-specific sensitivities.

Conservation importance

Any cumulative impact assessment must refer to the conservation importance of a species, based on its UK and European legal protection status and qualification for inclusion in nearby designated sites: Special Protection Areas (SPAs), Marine SPAs (mSPAs) and Sites of Special Scientific Interest (SSSIs).

Species selection based on conservation importance level should be based on the following criteria:

- species of conservation importance, e.g. Annex 1 of the EU Birds Directive, Wildlife and Countryside Act 1981 (or Wildlife (Northern Ireland) Order 1985) Schedule 1 species and Birds of Conservation Concern red list species (BirdLife International *et al.* 2008); and

- species whose population within the study area at any time exceeds 1% of the national population including breeding, passage and wintering species.

Selection of protected sites for inclusion into a CIA should in the first instance look at all SPAs, mSPAs, RAMSAR sites and SSSIs (with a coastal component) within the entire zone of possible influence (e.g. at the Regional Sea level).

4.3 Spatial scale

It is fundamental to determine the area to be included in an analysis and it must be large enough to cover the processes likely affected (Krebs 2002). If an action affects a whole population, including only a sub-sample of the population in the assessment will not estimate the true effect.

Although in many cases the ideal spatial scale of assessment may be the global range of a population, logistical impracticalities associated with large-scale data collection and analysis is likely to limit such an approach. As such it is recommended to use existing, smaller bio-geographic units for CIA. Although often arbitrary, such units are emerging or established, and may have associated data archives (Masden *et al.,* 2010).

King *et al.* (2009) recommend the relevant strategic wind farm area to be considered as the default boundary of the CIA study area. These areas may be extended for migratory species and species with large foraging ranges. Maclean & Rehfisch (2008) propose for CIA areas to be defined on a case-by-case basis, following the same principles as applied for SPA designation, with strategic areas only to be used as an alternative in case the former approach is not possible. In the context of the wave and tidal development areas in Scottish waters, a workable alternative is the use of Regional Seas areas 7 and 8, as all current search areas lie within both regions. Where foraging birds are likely to originate from SPAs outside these regions, boundaries could be extended to include such areas.

Another alternative would be to use ICES (International Council for the Exploration of the Sea) fishing areas, or some other method of partitioning the sea into management areas such as Marine Scotland planning areas. In specific cases it may be a requirement to include projects outside of the UK in a CIA when such projects potentially impact upon species, for example offshore developments in Ireland or non-British sections of the North Sea where these installations could impact bird populations that breed at SPAs in the UK.

Both King *et al.* (2009) and SNH (2009) strongly recommended that the spatial scale of reference for a given project is discussed early on and agreed on with statutory advisors. It is important to note that assessment may have to take place at several different spatial scales, depending on spatial and temporal differences of study area utilisation by the bird populations involved.

4.4 Other development types to be included into CIA

There are no current guidelines which specify which types of developments should be considered in a CIA. Consequently, it is often the case that only the effects of similar projects or developments are included, for example a wind farm proposal will consider only other wind farms nearby. A comprehensive assessment is often more appropriate and should consider all other projects which may have cumulative impacts on birds. When considering marine birds potentially affected by wave and tidal energy devices, this should include impacts from offshore and onshore wind, oil and gas and any other regulated activities both current and in planning. King *et al.* (2009) propose for the following project types to be included into a CIA assessment:

- Projects that have been consented but which are yet to be constructed;
- projects for which application has been made;
- projects that are reasonably foreseeable;
- non-wind farm projects subject to EIA; and
- existing projects that have yet to exert a predicted effect (i.e. an effect that is not covered in the baseline).

4.5 Assessing significance

It is recommended that the significance of most cumulative effects is assessed by summing the impacts from each component development. The exception to summing should be in assessing cumulative impacts of disturbance and barrier-effects where the impacts accrue in a non-linear manner (King *et al.* 2009). The authors propose that these are first considered in a qualitative manner making best use of available information. If the cumulative impacts are subsequently thought to be significant, then a more detailed quantitative study should be carried out.

King *et al.* (2009) state that consideration of cumulative impacts should not only be given to those species for which there is a significant impact at any one of the component developments, but should also include species that narrowly miss this category as it is entirely plausible that the accumulation of non-significant impacts could, over time, become significant.

Furthermore, the authors recommend that the significance of cumulative impacts is initially assessed using the same matrix approach as that routinely used for EIA. This should be supported by detailed discussion of the predicted impact to substantiate the conclusion of a significant or non-significant effect, as recommended by the established Institute of Ecology and Environmental Management (IEEM) guidelines (IEEM 2008).

4.6 Example of a possible CIA sequence

To identify marine bird species and/or protected areas likely to be affected by cumulative impacts from particular wave and tidal projects we propose the following approach:

1. Establish proposed spatial scale to be used through consultation (e.g. Regional Sea);
2. list all marine/coastal bird species on that spatial scale - a possible list of species is provided in the SEA (Scottish Executive, 2007);
3. list SPAs, mSPAs and SSSIs (with a coastal component) as well as other designated sites that support important numbers of seabirds within the project's zone of influence as established under step 1;
4. obtain data on foraging ranges for species identified in Step 2 (see e.g. Langston 2010), apply these as buffer zones around the relevant protected sites identified under Step 3;
5. based on Step 4 confirm default spatial scale (e.g. Regional Sea) still relevant or in need of extension in case of migratory / passage species or species with large foraging ranges;
6. obtain information on all other relevant development projects within the established spatial scale;
7. reduce species list to those species with a development area within their maximum foraging range;
8. identify the number of other projects (development areas) within the i) maximum and ii) median foraging range of each species;

9. estimate the sensitivity of species using a sensitivity index incorporating indicators of demographic sensitivity such as adult survival rate or conservation status as well as indicators of vulnerability to devices (e.g. dive depth), prey preferences (Garthe & Hüppop, 2004; Desholm, 2009 and Stelzenmüller *et al.,* 2010); and
10. assess significance based on established guidelines (e.g. IEEM EIA guidance).

5. DISCUSSION

Although cumulative impacts are increasingly included within environmental impact assessments, research has concluded that the quality of several have been far from adequate (Piper, 2001). As previously highlighted, one of the suggested reasons for this is the lack of guidance on the requirements of cumulative impact assessments. In trying to improve the technical robustness of CIA, however, both spatial and temporal variability confound the problem of assessment (Masden *et al.*, 2010). There is limited availability of bird movement data (although this is increasing) and the majority of sources report only maximum foraging ranges. It is evident that individuals do not utilise space evenly across their foraging range and more likely that space use will be patchy or occur along a gradient. Use over different years can vary widely as well. Whilst foraging range data are helpful, application of these to help define scale for CIA is problematic in practice, as it is unlikely that foraging areas are circular. Without data detailing space use as a function of its explanatory variables, for example distance from a nest site, it is not possible to assume anything other than uniform use out to a radius of maximum range. An alternative may be to include a series of scenarios in an assessment that range from assuming 100% use of a given area down to 50% and 0%.

Temporal variance also poses challenges when assessing cumulative impacts. Firstly, the effects of a project may not be realised immediately but rather the effects may be lagged due to the ecology of a species such as delayed sexual maturity. Consequently the temporal scale of an assessment would need to be greater to incorporate this variance. It is also possible that the behaviour of individuals, and thus the impact of a project, may change over the lifetime of the project. For example, habituation has been observed in pink-footed geese *Anser brachyrhynchus* at terrestrial wind farms in Denmark (Madsen & Boertmann, 2008). Temporal variability in population dynamics may also confound cumulative assessments, especially when determining the significance of impacts because without baseline data on the underlying variability in a system it may be difficult to assess the impacts of a project.

Another common problem when assessing cumulative impacts is the lack of a common currency or unit of measure for the different effects and impacts. This is important when trying to compare and combine impacts from different projects. Birds colliding with marine renewable energy devices may have a direct impact on population size through increased mortality but it is more difficult to translate displacement from feeding habitat (i.e. effective habitat loss), into an impact on population size. The latter is only possible with an understanding of how devices affect biological processes, for example the links between displacement, food requirements and availability, and reproduction. Using modelling techniques it is then possible to estimate the cumulative impact of the different effects (collision and displacement) of projects acting on a population.

Despite the global growth of the renewable energy industry (particularly wind energy) and the associated increase in knowledge of impacts of wind turbines on birds, little is known of the ecological impacts of wave and tidal devices, as few devices have actually been deployed. Consequently, any discussions on the cumulative impacts of such devices are still speculative, and at best based on similarities with wind turbines. It has been suggested that when capability and resources for assessing cumulative impacts are limited, a greater proportion of effort should be assigned to minimise the impacts of single actions (MacDonald, 2000). For that reason, at present it may be most productive to concentrate efforts on understanding and minimising the individual effects of wave and tidal devices and identifying areas/populations where cumulative impacts may be a problem, before attempting to determine the cumulative impacts.

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