Received: 13 December 2023 | Accepted: 5 January 2025

DOI: 10.1002/2688-8319.70010

PERSPECTIVE

Ecological Solutions and Evidence

The Global Energy Transition: Ecological Impact, Mitigation and Restoration

Cumulative barriers to renewable energy development: Can we adjust our perspective and approach to benefit biodiversity?

Aonghais S. C. P. Cook[1,2] | Elizabeth A. Masden[3] | Elizabeth M. Humphreys[4] | James W. Pearce-Higgins[1,5,6]

[1]British Trust for Ornithology, The Nunnery, Norfolk, UK

[2]The Biodiversity Consultancy, 3e Kings Parade, Cambridge, UK

[3]Environmental Research Institute, UHI North, West and Hebrides, University of the Highlands and Islands, Thurso, UK

[4]British Trust for Ornithology Scotland, Stirling University Innovation Park, Stirling, UK

[5]Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge, UK

[6]School of Biological Sciences, University of East Anglia, Norwich, UK

Correspondence
Elizabeth A. Masden
Email: elizabeth.masden@uhi.ac.uk

Funding information
Scottish Wind Farm Bird Steering Group

Handling Editor: Dave Augeri

Abstract

1. Renewable energy development is rapidly increasing in efforts to mitigate climate change. Whilst the impact of individual projects on biological diversity may be limited, there is a risk of significant cumulative impacts across projects, resulting in a conflict between our needs for renewable energy and to preserve biodiversity.
2. A range of approaches have been developed for cumulative impact assessment (CIA). Biologically realistic approaches advocated in the peer-reviewed literature have challenging data requirements and are more complex than those widely used by practitioners and regulators to inform assessments.
3. Projected cumulative impacts are approaching levels where future development of the industry is at risk, with concerns that this is driven by an overly precautionary approach, a direct consequence of insufficient data.
4. A 'race to submission', whereby developers aim to submit their assessments as early as possible in an attempt to avoid being the project that triggers an unacceptable cumulative impact, exacerbates this problem. This leads to situations whereby consented projects may not reflect the optimal balance between minimising biodiversity impacts and delivery of renewable energy targets.
5. *Solution*. There is an urgent need to shift the focus of CIA from the anthropogenic activities, which drive the need for assessments, to the populations concerned. This will require international agreement on minimum standards for robust assessment and coordination of data collection. A failure to achieve this may mean that delivering the renewable energy required to minimise the impacts of climate change in an ecologically sustainable manner becomes a regulatory impossibility.

KEYWORDS
biodiversity crisis, birds, CEA, CIA, climate crisis, population approach, sustainable development, wind energy

Aonghais S. C. P. Cook and Elizabeth A. Masden—Joint first authors contributed equally and have given permission for either to be listed first where beneficial for example for the purposes of grant applications.

1 | INTRODUCTION

The climate and biodiversity crises can be viewed as the greatest challenges to ecosystem health and services (Pörtner et al., 2023). Large-scale renewable energy deployment can make a large contribution to climate change mitigation. However, if not carefully implemented, the scale of energy infrastructure deployment, and associated land-use change, required to mitigate climate change risks exacerbating biodiversity declines, many of which are linked to existing anthropogenic developments (Jaureguiberry et al., 2022; Spillias et al., 2020). Considering the renewable energy targets already set by governments, in combination with other existing and predicted human activities and developments, it is clear that a holistic approach is required, particularly when considering highly mobile species such as seabirds (O'Hanlon et al., 2023). Such an approach should include key aspects such as being centred on the biodiversity features concerned, considering more than a restricted part of their life cycle, and include all anthropogenic activities to which the biodiversity features are exposed.

Cumulative impacts (CI) can be defined as “Impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project” (Hyder, 1999). Cumulative impact assessment (CIA) is therefore a systematic procedure for identifying and evaluating the significance of any impact from multiple pressures on single or multiple receptors (Judd et al., 2015). Consequently, if we are to find ‘win-win’ solutions, CIA for renewable energy must balance the climate and biodiversity crises (Gorman et al., 2023), which have both been described as ‘wicked’ problems due to their complexity and the lack of clarity relating to their aims and solutions (Walls, 2018).

We are at a point where the consequences for biodiversity projected from CIAs are starting to delay progression towards renewable energy targets (Broadbent & Nixon, 2019; Caine, 2020), often in response to concerns being raised in relation to the sustainability of projected cumulative impacts on vulnerable populations (Busch & Garthe, 2017; Diffendorfer et al., 2021; Peschko et al., 2024). However, it is often far from clear whether the projected CIs presented in Environmental Impact Assessments (EIA) for renewable energy projects are based on robust methodologies using the best scientific evidence (Caine, 2020; Willsteed et al., 2018). We discuss impact assessments and the CIA approaches that have been used to date, before highlighting the challenges to developing effective CIA methodology that considers the combined impacts of renewable energy, and other anthropogenic pressures, on biodiversity. Whilst we focus on the biodiversity impacts of renewable energy, many of these challenges are common to other anthropogenic impacts, for example, those from roads, agriculture, forestry and coastal development (Foley et al., 2017). The urgency of the joint biodiversity and climate crises necessitates an approach that is not overly obstructive. However, we argue that to address these twin crises appropriately, it is imperative to develop methods that are reliable, robust and can be standardised across all forms of renewable energy, and other anthropogenic developments, to ensure consistency and comparability of assessments.

2 | ENVIRONMENTAL IMPACT ASSESSMENTS AND CUMULATIVE IMPACTS

Whilst the outcomes from CIA are seen as a crucial part of the EIA process, the methodologies used to assess CIs are an acknowledged weakness, often contributing to substantial delays in regulatory decision-making (Willsteed et al., 2018). When carried out as part of an EIA, CIAs should consider the cumulation of impacts associated with the project itself in combination with the impacts associated with all other existing, approved and reasonably foreseeable projects (Durning & Broderick, 2019). As such, it is important to ensure that spatial scales appropriate to the biodiversity feature concerned are identified when selecting projects for inclusion in CIAs. Increased understanding of species movements and distributions gained through technology such as biotelemetry makes defining these spatial scales easier (Woodward et al., 2024), which is reflected by the fact that CIA carried out as part of EIA generally define appropriate spatial scales well (Willsteed et al., 2018). However, having identified sites for inclusion, access to the necessary data to enable assessment of CIs becomes a significant challenge. This is the case for older projects, for which the lack of a centralised, online repository, makes storing and accessing data challenging. However, it is also an issue in relation to more contemporary projects, particularly when, as is often the case in the UK, multiple projects, often involving competing developers, are going through the consenting process at the same time, and regardless of intention, it becomes challenging to ensure data and information are available within the timescales demanded by each project. As a consequence, assessments of the significance of CIA are often made in qualitative, rather than quantitative, fashion, contributing to decision-maker concerns over the robustness of assessments (Willsteed et al., 2018). Furthermore, such approaches do not offer the detail required to determine the extent of any mitigation or compensation required in relation to projects in order to conform to the mitigation hierarchy (Croll et al., 2022).

3 | APPROACHES TO CIA

Given the challenges identified above, a variety of CIA approaches have been used for renewable energy projects; these approaches become progressively more complex as additional information is incorporated (Figure 1).

At a most basic level, cumulative impacts are assessed qualitatively (Figure 1a), drawing inferences about the significance of impacts based on species potential exposure (e.g. Goodale & Milman, 2020). Where impacts have been estimated for individual projects, a cumulative impact may be derived through summation

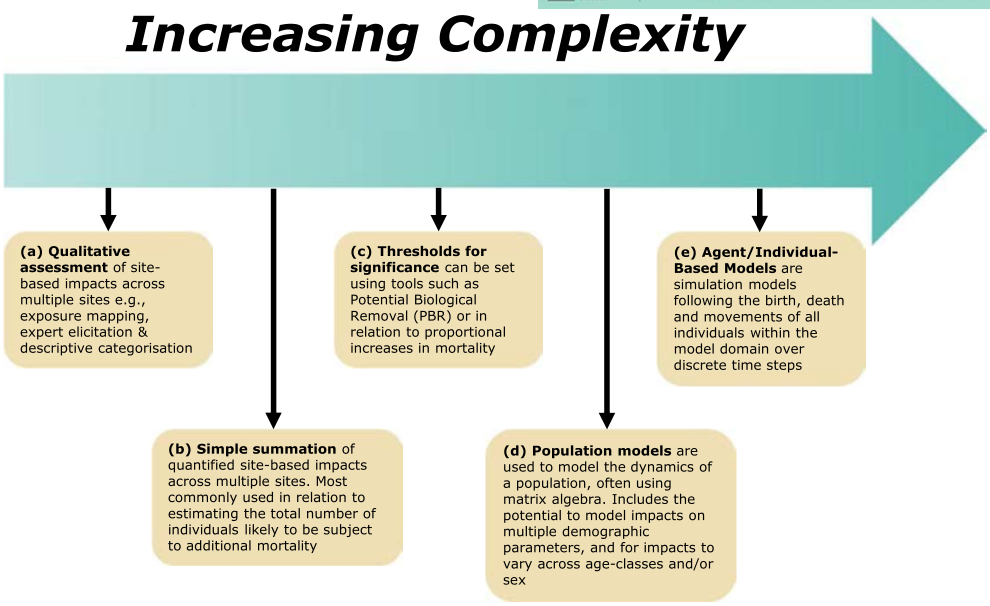

FIGURE 1 The complexity of approaches used for cumulative impact assessment increases as additional information is incorporated, often with a view to making models more biologically realistic.

(Figure 1b), for example in relation to collision mortality with wind turbines (Vasilakis et al., 2017). However, these approaches provide information about impact magnitude, but not significance; this requires considering impacts within the wider context of the population(s) concerned, using approaches such as estimating the resulting proportional mortality increase across the population (e.g. Brabant et al., 2015), or considering whether thresholds, like those set using potential biological removal (PBR), are exceeded (Busch & Garthe, 2016) (Figure 1c).

Assessing cumulative impacts in relation to proportional mortality increases, or thresholds such as PBR, do not account for the multiplicative effect of impacts across multiple years. Mortality thresholds also fail to account for impacts beyond mortality, for example reduced productivity (Balotari-Chiebao et al., 2016). By incorporating these impacts within a (meta-) population model (Figure 1d), impacts can be projected over the lifetime of a project, incorporating effects on other demographic parameters, like productivity, in addition to survival (Cook & Robinson, 2017; Ruiz et al., 2021). The biological realism of such models can be improved by incorporating factors including habitat effects (Bastos et al., 2016), underlying trends in demography (Horswill et al., 2022) and density-dependence (Horswill et al., 2017). These approaches typically consider impacts on the (meta-) population, rather than on individuals which may have important differences in relation to their exposure to, and interactions with, different pressures. Alternatively, individual-based models (Figure 1e) consider impacts at an individual level, and then scale up to the population level (Van Bemmelen et al., 2021), potentially the most biologically realistic, such approaches are typically "data-hungry", making them complex to implement.

4 | CHALLENGES TO APPLYING CIA

4.1 | Lack of concept

Key to a successful CIA is being clear about both its intention and purpose, though this is often overlooked (Willsteed et al., 2023). CI may be assessed in relation to an increasing range of metrics following advances in technology and monitoring outputs (Niemi & McDonald, 2004). These metrics vary in relation to data requirements and their relevance to biodiversity, habitats and anthropogenic pressures. Consequently, without a clear definition of the features covered by the CIA, the spatial and temporal extent, and the pressures included, identifying suitable metrics, and therefore appropriate impact thresholds, becomes an impossible challenge (Masden et al., 2010).

4.2 | Lack of evidence for impact pathways

As the industry has developed, there is increasing evidence about the potential impacts of individual projects (e.g. Dierschke et al., 2016) but combining impacts from multiple wind farms remains challenging. In part this is because these impacts may affect different aspects of species ecology and demography (e.g. distribution, survival or productivity), which need to be scaled up to the population level, but also because of the potential for the consequences of these impacts to interact with one another. Whether stressors or responses should be considered additively (i.e. combined effect is the sum of their effects), synergistically (i.e. combined effect is larger than the sum of their effects) or antagonistically (i.e. combined effect is smaller than the sum of their effects) will be important for the predicted impacts (Mantyka-Pringle et al., 2019). Taking the example of displacement from a wind farm and collision from that same wind farm, the cumulative impact of these two effects could simply be considered additive. However, as an individual bird cannot be both displaced from a wind farm and at risk of colliding with the turbines, the cumulative impact of the two combined must be antagonistic. This is a relatively simplistic example but in reality, a range of impacts and habitat changes may be associated with renewable energy deployment, with complex interactions between them.

Quantifying impact pathways is further complicated for populations of long-distance migrants, many of which are declining in numbers. The broad ranges across which these species move poses significant challenges in relation to identifying all the projects individuals may interact with throughout the year and around understanding how their responses may vary according to stages of the annual cycle (O'Hanlon et al., 2023). However, approaching the scoping and screening process for project inclusion in CIA (Durning & Broderick, 2019) from the perspective of animal ranges, rather than human imposed boundaries, would provide a starting point for improvements in the assessment. Failing to account for these patterns may give a misleading impression about the sustainability of any resulting population-level impacts (Tyack et al., 2022).

4.3 | Lack of data

Access to data is a key challenge for a robust CIA. In an ideal world, CIAs for renewable energy developments would be based on a detailed understanding of the population(s) concerned. This means understanding not just baseline population sizes and demography (e.g. survival and productivity) but also demographic processes impacting a population (e.g. density-dependence, source-sink dynamics, immigration and emigration (Reed et al., 1998)) and any existing anthropogenic pressures impacting the population, including climate change (Horswill et al., 2022). Demographic data may vary in both space and time (Frederiksen et al., 2005), but such data are rarely available at the required resolution, even for relatively well-studied species (O'Hanlon et al., 2023); a problem that will be magnified as the renewable energy industry expands in regions where biodiversity data are even more limited.

There are concerns that failing to accurately account for existing pressures, underlying trends and demographic processes may lead to unreliable assessments at a population level (Horswill et al., 2022). However, assumptions surrounding these parameters can have important implications when assessing the acceptability of any impacts (Miller et al., 2019). Precautionary principle guiding assessments lead to conservative assumptions, but that precaution is then magnified through the CIA process, leading to concerns that consenting decisions are unduly precautionary (Searle et al., 2023).

4.4 | Lack of decision-making frameworks

Given the trans-boundary movements of many of the species and populations of relevance to CIA (e.g. seabirds during migration; Gauld et al., 2022; O'Hanlon et al., 2023), it is important that the purpose, guidance and approaches used for CIA are agreed across all jurisdictions concerned. For example, CIAs for offshore wind farms in Scotland are based on estimated impacts from wind farms once they have been built. By contrast, in England the estimated impacts are included from the point the wind farms were consented, as developers may retain the option to add further capacity once a project has been completed. Consequently, CIAs carried out in these two adjacent jurisdictions, with many overlapping seabird populations, are based on different, and potentially, incompatible, scenarios. Inconsistencies in CIA guidance and legislation like this hinder progress in practice.

Challenges also arise from the leasing and tendering process since there is often a 'race to submission' as a consequence of the 'building block' approach in which applications are considered sequentially (Broadbent & Nixon, 2019). Developers therefore aim to submit their environmental assessments as early as possible, in an attempt to avoid being the project that triggers an unacceptable cumulative impact. The resulting haste with which CIAs are completed may contribute to concerns about their quality (Caine, 2020; Willsteed et al., 2018), and limit opportunity for innovation around more robust approaches that are likely to be slower to implement. Furthermore, it is likely to lead to situations whereby consented projects may not reflect the optimal balance between impacts to biodiversity and progress towards renewable energy targets, as opposed to if all applications were assessed at the same time.

5 | RISK OF BUSINESS AS USUAL

To date, uncertainty over projected cumulative impacts has contributed to the refusal of planning consent for one wind farm (Broadbent & Nixon, 2019) and legal challenges to the consent granted for others (Caine, 2020; Scottish Courts and Tribunals, 2016, 2017). As the renewable energy industry continues to expand apace, not just in the UK but globally, there is a risk that the uncertainty inherent in current CIA approaches, particularly where approaches are inadequate, results in further legal challenges at significant cost to all concerned, delaying efforts to meet emissions targets. This uncertainty will only be exacerbated by the 'race to submission'.

The perception that assessments are not fit for purpose, resulting in predictions that may be unduly precautionary (Searle et al., 2023; Willsteed et al., 2018), may lead governments to focus on the more easily quantifiable climate mitigation potential of renewable energy, at the expense of considering the biodiversity impacts of those technologies (Spillias et al., 2020), particularly given the stated policy of many governments to accelerate the deployment of renewable energy infrastructure. Recent European Union directives aimed at expediting the consenting process for renewable energy may be examples of this (Durá-Alemañ et al., 2023). This is in stark contrast to a growing recognition of the need to view the climate and biodiversity crises as two inter-linked challenges that cannot be addressed in isolation from one another (Pörtner et al., 2023). Indeed, through careful planning, and using a "Right Action, Right Place" approach, win-win scenarios which maximise the benefits for both climate change mitigation and biodiversity may be possible (Gorman et al., 2023). However, unless current approaches to CIA can be improved, such opportunities are likely to be missed, and the need to develop renewable energy may take precedence to the equally urgent need to preserve biodiversity.

6 | CONCLUSIONS AND RECOMMENDATIONS

Despite advances in the range of analytical methods available, many applications of CIA remain relatively simplistic, lacking a clear intention and purpose (Willsteed et al., 2023), with differences between jurisdictions due to the lack of a common decision-making framework. This often arises due to a lack of available data and a limited understanding of how impacts interact with one another and may vary in importance across space and time (Willsteed et al., 2023). As a consequence, assessments are perceived to be of poor quality, overly precautionary and fail to reflect biological reality (Searle et al., 2023; Willsteed et al., 2018). This leaves the decision-making process open to legal challenge, and risks delaying efforts to mitigate climate change through the expansion of renewable energy (Broadbent & Nixon, 2019; Caine, 2020).

At present, CIA is generally considered from a fixed and predetermined frame of reference, encapsulating the human developments and activities of interest (e.g. a wind farm development and other surrounding wind farms), and the biodiversity features affected by these (Willsteed et al., 2023). However, it may be that approaching the problem in this way adds to the challenge of assessing impacts because biodiversity is not placed at the centre of the process; rather the focus is on the human activities. As the focus for many governments and developers shifts from ensuring no net loss to delivering net positive impacts for biodiversity from renewable energy developments (Jacob et al., 2020), placing biodiversity at the centre of the process will become ever more important. This will mean moving beyond some of the simplistic approaches used to date (Figure 1) and incorporating the impacts associated with developments, other potential pressures on those populations, and any measures taken to offset these impacts, into population models that account for existing pressures on those populations (Horswill et al., 2022; Ruiz et al., 2021). Whilst it may be desirable that these models are as biologically realistic as possible, this is unlikely to be feasible in the first instance in many cases. Consequently, in the short-term, the focus should be on ensuring the models are good enough to be useful for the consenting process, informed by outputs from sensitivity analyses (Cook & Robinson, 2017; Miller et al., 2019) to determine which demographic parameters and processes most strongly influence conclusions, which data are required or are lacking, and communicating the implications of any resulting uncertainty for decisions. Through time these models should be validated and improved by ongoing monitoring and evaluation of populations potentially impacted by developments. As part of this process, and as has previously been advocated (e.g. Caine, 2020; Durning & Broderick, 2019), there is a need for mandated data-sharing at an early stage to ensure that CIA can be carried out across multiple projects using a common, and agreed set of data, in an open and transparent manner.

O'Hanlon et al. (2023) provide a framework with a stepped holistic approach to identify and prioritise data collection and determine actions required to inform decision making. Such a framework can be followed as an appropriate conceptual model to address the challenges to applying CIA, particularly lack of data, that we highlight above, and to aid in moving from the left (qualitative methods) towards the right (agent/individual-based models) in Figure 1. This approach is further developed by Secor et al. (2024), who advocate the use of the flyways concept when assessing anthropogenic impacts across broad spatial scales.

Over the medium-long term, the aim should be to develop the evidence base to enable a more holistic population-based approach to CIA based on a detailed understanding of demography and the structure and functioning of the ecosystems concerned. Industry-wide investment in demographic and environmental monitoring may achieve this most efficiently. In the marine environment where there are particular offshore wind challenges, given the global ranges of many of the species concerned (O'Hanlon et al., 2023), this will require a more strategic approach to the collection and analysis of abundance (including obtaining robust population estimates for key species at appropriate national and regional scales), movement and demographic data than has been applied to date, and ensuring such data are made available at appropriate spatial scales. It will also require international coordination on CIA definition, purpose and approach. Delivering this will be a substantial undertaking, with a significant financial cost (Tyack et al., 2022). However, current spending on environmental protection and biodiversity in relation to renewable energy has been insufficient (Caglar & Yavuz, 2023) and has contributed to the current challenges facing the industry. To maximise the value of these data, both in relation to the consenting process for renewable energy, and to conservation more generally, it is vital that they are made publicly available. This will facilitate a more holistic approach to CIA based on improved methods and more comprehensive data, reducing the ecological uncertainty that is contributing to delays and increasing costs in the delivery of renewable energy projects and therefore also costing money (Broadbent & Nixon, 2019; Spillias et al., 2020). By taking a carefully designed, holistic approach it will be possible to more rapidly overcome some of the regulatory barriers to achieving net zero whilst minimising the risk of biodiversity loss.

AUTHOR CONTRIBUTIONS

Aonghais S. C. P. Cook, Elizabeth A. Masden, Elizabeth M. Humphreys and James W. Pearce-Higgins jointly conceived the ideas. James W. Pearce-Higgins led the proposal and supervised the work that informed this paper. Aonghais S. C. P. Cook and Elizabeth A. Masden led the writing of the manuscript; all authors contributed critically to the drafts and gave final approval for publication.

ACKNOWLEDGEMENTS

The original report that led to the discussions and thinking around this work was funded by the Scottish Wind Farm Bird Steering Group. We would like to thank reviewers and editors for their constructive comments which have benefitted the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.70010.

DATA AVAILABILITY STATEMENT

This manuscript does not include any data.

RELEVANT GREY LITERATURE

You can find related grey literature on the topics below on Applied Ecology Resources: Wind energy, Population approach, Sustainable development, Birds.

ORCID

Elizabeth A. Masden https://orcid.org/0000-0002-1995-3712

James W. Pearce-Higgins https://orcid.org/0000-0003-1341-5080

REFERENCES

Balotari-Chiebao, F., Villers, A., Ijäs, A., Ovaskainen, O., Repka, S., & Laaksonen, T. (2016). Post-fledging movements of white-tailed eagles: Conservation implications for wind-energy development. *Ambio*, *45*(7), 831–840.

Bastos, R., Pinhanços, A., Santos, M., Fernandes, R. F., Vicente, J. R., Morinha, F., Honrado, J. P., Travassos, P., Barros, P., & Cabral, J. A. (2016). Evaluating the regional cumulative impact of wind farms on birds: How can spatially explicit dynamic modelling improve impact assessments and monitoring? *Journal of Applied Ecology*, *53*(5), 1330–1340.

Brabant, R., Vanermen, N., Stienen, E. W. M., & Degraer, S. (2015). Towards a cumulative collision risk assessment of local and migrating birds in North Sea offshore wind farms. *Hydrobiologia*, *756*(1), 63–74.

Broadbent, I. D., & Nixon, C. L. B. (2019). Refusal of planning consent for the docking shoal offshore wind farm: Stakeholder perspectives and lessons learned. *Marine Policy*, *110*, 103529.

Busch, M., & Garthe, S. (2016). Approaching population thresholds in presence of uncertainty: Assessing displacement of seabirds from offshore wind farms. *Environmental Impact Assessment Review*, *56*, 31–42.

Busch, M., & Garthe, S. (2017). Looking at the bigger picture: The importance of considering annual cycles in impact assessments illustrated in a migratory seabird species. *ICES Journal of Marine Science*, *75*, 690–700.

Caglar, A. E., & Yavuz, E. (2023). The role of environmental protection expenditures and renewable energy consumption in the context of ecological challenges: Insights from the European Union with the novel panel econometric approach. *Journal of Environmental Management*, *331*, 117317.

Caine, C. A. (2020). The race to the water for offshore renewable energy: Assessing cumulative and in-combination impacts for offshore renewable energy developments. *Journal of Environmental Law*, *32*, 83–109.

Cook, A. S. C. P., & Robinson, R. A. (2017). Towards a framework for quantifying the population-level consequences of anthropogenic pressures on the environment: The case of seabirds and windfarms. *Journal of Environmental Management*, *190*, 113–121.

Croll, D. A., Ellis, A. A., Adams, J., Cook, A. S. C. P., Garthe, S., Goodale, M. W., Hall, C. S., Hazen, E., Keitt, B. S., Kelsey, E. C., Leirness, J. B., Lyons, D. E., McKown, M. W., Potiek, A., Searle, K. R., Soudijn, F. H., Rockwood, R. C., Tershy, B. R., Tinker, M., … Zilliacus, K. (2022). Framework for assessing and mitigating the impacts of offshore wind energy development on marine birds. *Biological Conservation*, *276*, 109795.

Dierschke, V., Furness, R. W., & Garthe, S. (2016). Seabirds and offshore wind farms in European waters: Avoidance and attraction. *Biological Conservation*, *202*, 59–68.

Diffendorfer, J. E., Stanton, J. C., Beston, J. A., Thogmartin, W. E., Loss, S. R., Katzner, T. E., Johnson, D. H., Erickson, R. A., Merrill, M. D., & Corum, M. D. (2021). Demographic and potential biological removal models identify raptor species sensitive to current and future wind energy. *Ecosphere*, *12*, e03531. https://doi.org/10.1002/ecs2.3531

Durá-Alemañ, C. J., Moleón, M., Pérez-García, J. M., Serrano, D., & Sánchez-Zapata, J. A. (2023). Climate change and energy crisis drive an unprecedented EU environmental law regression. *Conservation Letters*, *16*, e12958.

Durning, B., & Broderick, M. (2019). Development of cumulative impact assessment guidelines for offshore wind farms and evaluation of use in project making. *Impact Assessment and Project Appraisal*, *37*(2), 124–138. https://doi.org/10.1080/14615517.2018.1498186

Foley, M. M., Mease, L. A., Martone, R. G., Prahler, E. E., Morrison, T. H., Murray, C. C., & Wojcik, D. (2017). The challenges and opportunities in cumulative effects assessment. *Environmental Impact Assessment Review*, *62*, 122–134. https://doi.org/10.1016/j.eiar.2016.06.008

Frederiksen, M., Harris, M. P., & Wanless, S. (2005). Inter-population variation in demographic parameters: A neglected subject? *Oikos*, *111*, 209–214.

Gauld, J. G., Silva, J. P., Atkinson, P. W., Record, P., Acácio, M., Arkumarev, V., Blas, J., Bouten, W., Burton, N., Catry, I., Champagnon, J., Clewley, G. D., Dagys, M., Duriez, O., Exo, K.-M., Fiedler, W., Flack, A., Friedemann, G., Fritz, J., … Franco, A. M. A. (2022). Hotspots in the grid: Avian sensitivity and vulnerability to collision risk from energy infrastructure interactions in Europe and North Africa. *Journal of Applied Ecology*, *59*, 1496–1512. https://doi.org/10.1111/1365-2664.14160

Goodale, M. W., & Milman, A. (2020). Assessing cumulative exposure of northern gannets to offshore wind farms. *Wildlife Society Bulletin*, *44*(2), 252–259.

Gorman, C. E., Torsney, A., Gaughran, A., McKeon, C. M., Farrell, C. A., White, C., Donohue, I., Stout, J. C., & Buckley, Y. M. (2023). Reconciling climate action with the need for biodiversity protection, restoration and rehabilitation. *Science of the Total Environment*, *857*, 159316. https://doi.org/10.1016/j.scitotenv.2022.159316

Horswill, C., Miller, J. A. O., & Wood, M. J. (2022). Impact assessments of wind farms on seabird populations that overlook existing drivers of demographic change should be treated with caution. *Conservation Science and Practice*, *4*(4), e12644.

Horswill, C., O'Brien, S. H., & Robinson, R. A. (2017). Density dependence and marine bird populations: are wind farm assessments precautionary?. *Applied Ecology*, *54*: 1406–1414.

Hyder. (1999). *Final report on the study on the assessment of indirect and cumulative impacts, as well as impact interactions within the Environmental Impact Assessment (EIA) process. Volume 2: Research study and findings*. https://ec.europa.eu/environment/archives/eia/eia-studies-and-reports/pdf/volume2.pdf

Jacob, C., van Bochove, J.-W., Livingstone, S., White, T., Pilgrim, J., & Bennun, L. (2020). Marine biodiversity offsets: Pragmatic approaches toward better conservation outcomes. *Conservation Letters*, *13*(3), e12711.

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances*, *8*, eabm9982. https://doi.org/10.1126/sciadv.abm9982

Judd, A., Backhaus, T., & Goodsir, F. (2015). An effective set of principles for practical implementation of marine cumulative effects assessment. *Environmental Science & Policy*, *54*, 254–262.

Mantyka-Pringle, C., Leston, L., Messmer, D., Asong, E., Bayne, E. M., Bortolotti, L. E., Sekulic, G., Wheater, H., Howerter, D. W., & Clark, R. G. (2019). Antagonistic, synergistic and direct effects of land use and climate on Prairie wetland ecosystems: Ghosts of the past or present? *Diversity and Distributions*, *25*(12), 1924–1940.

Masden, E. A., Fox, A. D., Furness, R. W., Bullman, R., & Haydon, D. T. (2010). Cumulative impact assessments and bird/wind farm interactions: Developing a conceptual framework. *Environmental Impact Assessment Review*, *30*, 1–7.

Miller, J. A. O., Furness, R. W., Trinder, M., & Matthiopoulos, J. (2019). The sensitivity of seabird populations to density-dependence, environmental stochasticity and anthropogenic mortality. *Journal of Applied Ecology*, *56*(9), 2118–2130.

Niemi, G. J., & McDonald, M. E. (2004). Application of ecological indicators. *Annual Review of Ecology, Evolution, and Systematics*, *35*(1), 89–111.

O'Hanlon, N. J., Johnston, D. T., Cook, A. S. C. P., Robinson, R. A., & Humphreys, E. M. (2023). A crowded ocean: The need for demographic and movement data in seabird conservation. *Ocean and Coastal Management*, *244*, 106833.

Peschko, V., Schwemmer, H., Mercker, M., Markones, N., Borkenhagen, K., & Garthe, S. (2024). Cumulative effects of offshore wind farms on common guillemots (*Uria aalge*) in the southern North Sea—Climate versus biodiversity? *Biodiversity and Conservation*, *33*, 949–970.

Pörtner, H.-O., Scholes, R. J., Arneth, A., Barnes, D. K. A., Burrows, M. T., Diamond, S. E., Duarte, C. M., Kiessling, W., Leadley, P., Managi, S., McElwee, P., Midgley, G., Ngo, H. T., Obura, D., Pascual, U., Sankaran, M., Shin, Y. J., & Val, A. L. (2023). Overcoming the coupled climate and biodiversity crises and their societal impacts. *Science*, *380*(6642), eabl4881.

Reed, J. M., Murphy, D. D., & Brussard, P. F. (1998). Efficacy of population viability analysis. *Wildlife Society Bulletin (1973–2006)*, *26*(2), 244–251.

Ruiz, D. M., Tinker, M. T., Tershy, B. R., Zilliacus, K. M., & Croll, D. A. (2021). Using meta-population models to guide conservation action. *Global Ecology and Conservation*, *28*, e01644.

Scottish Courts and Tribunals. (2016). *Petition of the Royal Society for the Protection of Birds for judicial review*.

Scottish Courts and Tribunals. (2017). *Reclaiming motions in the petitions by the* Royal Society for the Protection of Birds against the Scottish ministers and (first) Inch Cape Offshore Ltd; (second) Neart na Gaoithe Offshore Wind Farm Ltd; and (third) Seagreen Wind Energy Ltd for judicial review.

Searle, K. R., O'Brien, S. H., Jones, E. L., Cook, A. S. C. P., Trinder, M. N., McGregor, R. M., Donovan, C., McCluskie, A., Daunt, F., & Butler, A. (2023). Resolving uncertainty: A framework for improving treatment of uncertainty in offshore wind assessments for protected marine birds. *ICES Journal of Marine Science*, fsad025. https://doi.org/10.1093/icesjms/fsad025

Secor, D. H., O'Brien, M. H. P., & Bailey, H. (2024). The flyway construct and assessment of offshore wind farm impacts on migratory marine fauna. *ICES Journal of Marine Science*, fsae138. https://doi.org/10.1093/icesjms/fsae138

Spillias, S., Kareiva, P., Ruckelshaus, M., & McDonald-Madden, E. (2020). Renewable energy targets may undermine their sustainability. *Nature Climate Change*, *10*(11), 974–976.

Tyack, P. L., Thomas, L., Costa, D. P., Hall, A. J., Harris, C. M., Harwood, J., Kraus, S. D., Miller, P. J. O., Moore, M., Photopoulou, T., Pirotta, E., Rolland, R. M., Schwacke, L. H., Simmons, S. E., & Southall, B. L. (2022). Managing the effects of multiple stressors on wildlife populations in their ecosystems: Developing a cumulative risk approach. *Proceedings of the Royal Society B: Biological Sciences*, *289*(1987), 20222058.

Van Bemmelen, R. S. A., Soudijn, F. H., Benden, D., Potiek, A., Chen, C., Hintzen, N., Wilkes, T., Van Kooten, T., & Gyimesi, A. (2021). *Individual-based model lesser black-backed gulls in The Netherlands Ecology & Landscape*. Bureau Waardenburg. www.buwa.nl

Vasilakis, D. P., Whitfield, D. P., & Kati, V. (2017). A balanced solution to the cumulative threat of industrialized wind farm development on cinereous vultures (*Aegypius monachus*) in south-eastern Europe. *PLoS One*, *12*, e0172685.

Walls, H. L. (2018). Wicked problems and a 'wicked' solution. *Globalization and Health*, *14*(1), 34.

Willsteed, E. A., Jude, S., Gill, A. B., & Birchenough, S. N. R. (2018). Obligations and aspirations: A critical evaluation of offshore wind farm cumulative impact assessments. *Renewable and Sustainable Energy Reviews*, *82*, 2332–2345.

Willsteed, E. A., New, L., Ansong, J. O., Hin, V., Searle, K., & Cook, A. S. C. P. (2023). *Advances in cumulative effects assessment and application in marine and coastal management*. Coastal Futures. 1, e18. https://doi.org/10.1017/cft.2023.6

Woodward, I. D., Thaxter, C. B., Owen, E., Bolton, M., Ward, R. M., & Cook, A. S. C. P. (2024). The value of seabird foraging ranges as a tool to investigate potential interactions with offshore wind farms. *Ocean and Coastal Management*, *254*, 107192. https://doi.org/10.1016/j.ocecoaman.2024.107192

How to cite this article: Cook, A. S. C. P., Masden, E. A., Humphreys, E. M., & Pearce-Higgins, J. W. (2025). Cumulative barriers to renewable energy development: Can we adjust our perspective and approach to benefit biodiversity? *Ecological Solutions and Evidence*, *6*, e70010. https://doi.org/10.1002/2688-8319.70010