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SeabORD v2.0: An Individual-Based Model for estimating demographic impacts for breeding seabirds arising from offshore windfarm sub-lethal effects

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SeabORD v2.0: An Individual-Based Model for estimating demographic impacts for breeding seabirds arising from offshore wind farm sub-lethal effects

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Overview

SeabORD is an Individual-Based Model (IBM) developed to predict demographic impacts (changes to breeding success and adult survival) on four species of chick-rearing seabirds exposed to displacement and barrier effects from one or more offshore wind farms (OWFs). This report provides a summary of the updated version 2.0 of SeabORD, briefly describing the model, outlining the key developments since SeabORD v1.0, and providing links to access the open source v2.0 model code and accompanying evidence summary for its underlying parameters (Leedham et al. 2025). We also describe, and provide links to, a pre-print for an under peer-review manuscript demonstrating the application of SeabORD v2.0 to understand cumulative impacts in the context of two breeding populations in the North Sea (Pollock et al. *in review,* preprint: https://doi.org/10.32942/X2V36P).

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1. Introduction

Offshore wind farm-related displacement and barrier effects on seabirds are underpinned by a complex set of behavioural and energetics changes – ('sub-lethal effects') – which over time, may result in mortality of affected individuals and/or their dependents. The complexity of these effects means that there is currently a lack of direct empirical evidence on the demographic consequences of displacement and barrier effects on seabirds in both the breeding and non-breeding seasons. This lack of data, particularly on the mortality consequences to individuals from such impacts, has meant that the UK assessment process has looked to estimate these consequences via the use of best available ecological data and knowledge in Individual-Based Models (IBMs).

When direct empirical data are lacking, predictive mechanistic modelling is an important tool for addressing this evidence gap, and IBMs (Grimm & Railsback, 2013) have been widely used in many disciplines to model complex systems, including responses of seabirds and other species to anthropogenic activities. Various IBMs have been developed to estimate demographic consequences of displacement impacts on seabirds in both the breeding (Searle et al. 2014, Warwick -Evans et al. 2017, Searle et al. 2018) and non-breeding seasons (van Kooten et al. 2019, Layton-Matthews et al. 2023, Buckingham et al. 2026). Therefore, IBMs are a powerful tool in predicting the consequences of environmental change on animal populations and supporting evidence-based decision making for conservation planning (Stillman et al. 2015, Warwick-Evans et al. 2017).

SeabORD (v1.0; Searle et al. 2014, 2018) is an IBM developed to estimate demographic impacts (breeding success and survival) on chick-rearing birds encountering displacement and barrier effects from one or more offshore wind farms (OWFs). The IBM breaks down the biological processes involved in assessing impacts into a set of functions, parameters and assumptions, and it is possible for each of these to be evaluated for their appropriateness and support in evidence. The structure of the IBM is designed to allow for this scrutiny to be undertaken, and provides a natural process for improvements and refinements to incorporate new biological knowledge.

Here, we provide a summary of the updated version 2.0 of the IBM SeabORD, briefly describing the model, the updates delivered since v1.0, providing links to access the open source v2.0, and links to the accompanying evidence summary for its underlying parameters (Leedham et al. 2025). We also describe and provide links to a pre-print of a peer-reviewed manuscript currently in revision (March 2026) demonstrating the application of SeabORD v2.0 to understand cumulative impacts (Pollock et al., *in revision J. Appl. Ecol.,* preprint: https://doi.org/10.32942/X2V36P).

2. Model summary

2.1 Model overview

SeabORD is an IBM that simulates the individual behaviour, energetics and demography of four species of seabirds (Common guillemot *Uria aalge*, Razorbill *Alca torda*, Atlantic puffin *Fratercula arctica*, and Black-legged kittiwake *Rissa tridactyla*) during the chick-rearing period of the breeding season in the context of user-specified OWFs. The tool uses a simulation model to predict the time/energy budgets of breeding seabirds, with model outputs including mass of individual adult birds at the end of the chick-rearing period and survival of their associated offspring. Adult mass can then be translated into estimates of adult annual survival via the use of two published mass-survival relationships (Erikstad et al., 2009, Oro & Furness 2002). The model simulates foraging decisions of individual seabirds under the assumption that they are acting in accordance with optimal foraging theory. Each individual selects a suitable location for feeding during each foraging trip from the colony, based on bird density maps derived from a range of methods, and the subsequent behaviour of birds is then simulated, incorporating realistic assumptions and constraints derived from observed behaviour. Fundamentally, the model assumes that the foraging behaviour of individual seabirds is driven by prey availability, travel costs, provisioning requirements for offspring, and behaviour of conspecifics. The specific mechanisms within the model are based upon the best available evidence or expert opinion for how breeding seabirds are likely to behave in terms of time-activity budgets and specific behaviours relating to their own energy acquisition, provisioning of energy for chicks, and breeding behaviours such as attendance at nests (Leedham et al. 2025, Pollock et al. *in review,* preprint: https://doi.org/10.32942/X2V36P).

We note that in previously published descriptions of SeabORD (Searle et al, 2014, 2018, 2022), we have strived to be clear that whilst much of the model's functionality and parameterisation rests upon best available empirical evidence (published literature or data from long-term studies, in particular the Isle of May National Nature Reserve), inevitably there are aspects of the model for which expert opinion is required to define some of the underlying ecological processes. In such cases where expert opinion has been used within the model, these decisions were made in strong collaboration with the Project Steering Groups (PSGs) in the two main Scottish Government (ScotMER) funded projects in which the initial model (v1.0) was developed (Searle et al. 2014, 2018). These steering groups included ornithological experts, government advisors (Marine Directorate, NatureScot), and NGOs (RSPB). In all cases, where such decisions were based on expert judgement, the collective group sought to find a balance between best-available ecological understanding (e.g., from other, related species, or from understanding or data relating to alternative, but similar ecological processes or anthropogenic impacts) and an application of conservatism. This conservatism was designed to result in an overall model that, where lacking empirical data, applies functionality in such a way as to minimise the risk of representing processes in ways which could lead to an underestimation of the potential importance of either key ecological processes (e.g., mass loss of adults over the chick-rearing period), or of potential OWF impacts (e.g., reductions in foraging rates arising from increased competition from displaced individuals).

3. Model developments since SeabORD v1.0

SeabORD v2.0 includes important improvements to various components, primarily relating to its transparency, ease of application, flexibility of use, and processing speed. The updated version brings improved model spatial resolution and faster processing times, improved parameterisation of inter-colony competition allowing for any number of additional colonies to be included in assessments of a focal colony. Species parameters have been updated in line with new evidence (Leedham et al. 2025) and comprehensive documentation of all code, parameters and data sources is now available (https://github.com/NERC-CEH/seabORD_pkg) with associated user guidance (https://nerc-ceh.github.io/seabORD_pkg/articles/B_explanation_model.htmlhttps://nerc-ceh.github.io/seabORD_pkg/reference/index.html).

3.1 Updated parameter values and synthesis of evidence

Many of the parameters used within SeabORD v1.0 and v2.0 relate to time-activity and energetic variables governing energy acquisition and expenditure for adults and their chicks. Leedham et al. (2025) have undertaken a comprehensive review of many of these parameters for the four seabird species included in SeabORD, Common guillemot (*Uria aalge*), Razorbill (*Alca torda*), Atlantic puffin (*Fratercula arctica*), and Black-legged kittiwake (*Rissa tridactyla*). This dataset reviews key behavioural and physiological traits, including the daily time allocation to, and energetic costs of, core activities and other energetically important processes of seabirds during chick-rearing. The purpose of this dataset is to collate and standardise important energetic and demographic parameters to underpin energetic, behavioural and demographic modelling analyses for key seabird species, including those used within SeabORD v1.0 and v2.0. Data primarily correspond to measurements of seabirds breeding in the UK & British Isles. The dataset has been deposited in the NERC EDS Environmental Information Data Centre (EIDC), and is available here:

https://doi.org/10.5285/07b1105a-4a14-47e3-b491-9af59be90aff

3.2 Accessibility and transparency

SeabORD v2.0 has been reimplemented in the open-source programming language, R (2025) improving accessibility and transparency compared with SeabORD v1.0. The original SeabORD v1.0 could be executed using a free runtime version of MATLAB, but the underlying bespoke MATLAB code was not released.

The complete SeabORD v2.0 model code is openly accessible on the UKCEH GitHub repository:

https://nerc-ceh.github.io/seabORD_pkg/articles/B_explanation_model.htmlhttps://github.com/NERC-CEH/seabORD_pkg

With a user guide available: https://nerc-ceh.github.io/seabORD_pkg/index.html including full descriptions of:

- Model purpose
- Model code structure and function
- Model functions for OWF interactions
- Main functions within SeabORD including:
  - 1. Body mass increase for adult birds
  - 2. Calculate Daily Energy Requirement
  - 3. Probability of winter survival
  - 4. Puffin chick mortality from predation due to hunger
  - 5. Chick mortality as a result of other causes
  - 6. Chick mortality as a result of adults not attending the nest
  - 7. Parenting the chicks
  - 8. Calculate the time taken to forage required amount
  - 9. Calculate the foraging strategy for the timestep
- Worked examples for:

- Model inputs
- Creation of a bird distance-decay density map
- Model calibration
- Model installation instructions
- Running the model
- Interpretation of model outputs

3.3 Foraging competition arising from other colonies

One important update within SeabORD v2.0 is the way that competition from colonies other than the colony of interest (within each run) is considered. Within SeabORD v1.0 (Searle et al., 2018, 2022) the effects of competition from non-focal colonies were quantified by simulating individuals from these colonies in the same way as individuals from the colony of interest. This was computationally time consuming, and involved simulating more information about these individuals than was needed for calculating competition, so within SeabORD v2.0 the calculations of the levels of competition from other colonies have been streamlined, leading to considerable reductions in run times without substantively altering the way that levels of competition are modelled (Pollock et al. 2025, *in review,* preprint: https://doi.org/10.32942/X2V36P; and https://nerc-ceh.github.io/seabORD_pkg/articles/I_main_functions.html#calculate-the-time-taken-to-forage-required-amount).

3.4 Parameterisation of bird distance-decay density maps

One issue that has been previously identified with the use of the distance-decay method in SeabORD v1.0 to generate bird density maps is the difficulty in assigning a biological interpretation to the parameter that controls the rate of decay, making it difficult to determine a meaningful value for this parameter. In SeabORD v2.0 we have therefore used a reparametrized version of the same distance-decay model, in which the parameter that controls the rate of decay ought to be more readily interpretable, and hence can hopefully be specified in a more transparent and defensible way (https://nerc-ceh.github.io/seabORD_pkg/articles/D_DistanceDecayMap.html).

3.5 Peer-reviewed manuscript and Sensitivity Analysis

The updated SeabORD v2.0 has been fully described and applied within a manuscript, currently under revision (Pollock et al, *in revision, J. Appl. Ecol. March 2026,* preprint: https://doi.org/10.32942/X2V36P), to estimate cumulative impacts arising from a series of hypothetical OWFs in the Forth-Tay, Scotland. The manuscript examines the use of SeabORD v2.0 to predict the demographic consequences (breeding success, adult mass change and year-round survival), of multiple OWFs, termed cumulative effects, on a population of interest. It provides a full description of the model including its rationale, and processes, delivers an investigation for how predicted cumulative effects scale with increasing numbers of hypothetical OWFs on two populations of black-legged kittiwakes (*Rissa tridactyla*) and common guillemots (*Uria aalge*) at a North Sea breeding colony, and critically includes a new sensitivity analysis to assess the relative importance of different model parameters, focusing on those parameters that most lacking empirical support.

4. Summary

Here, we provide an overview of updates to the Individual-Based Model, SeabORD v2.0, designed to improve its accessibility, flexibility, functionality and transparency. The model and underlying code are freely available via a UKCEH GitHub repository[1] (https://github.com/NERC-CEH/seabORD_pkg), alongside a pre-print of an accompanying under revision peer-review manuscript (Pollock et al, *in revision, J. Appl. Ecol., March 2026,* https://doi.org/10.32942/X2V36P).

Quantifying the likely displacement mortality associated with offshore wind farms is an exceptionally challenging scientific problem, and any model that attempts to address this will necessarily have substantial caveats and limitations. The assumptions underpinning SeabORD v2.0 are explicit, allowing the reasonableness of each assumption to be evaluated. This, in particular, makes it possible for stakeholders to evaluate whether each assumption or parameter value is conservative or not, in light of available relevant evidence. By disaggregating displacement mortality down to the level of individual biological processes, many of which are observable and so can be informed by empirical data, a mechanistic model such as SeabORD provides a natural process by which new empirical evidence can be incorporated into the model, and, where this appropriate, can be used to remove conservatism from the model.

The appropriateness of SeabORD for use in offshore wind farm impact assessments should also continue to be evaluated over time. It may be that tools based on alternative IBMs, or alternative non-IBM modelling approaches, will become available that are, on balance, more appropriate for use in assessments. In light of this, we have worked within the PrePARED project to make the underpinning SeabORD v2.0 model and underpinning code as accessible as possible, because we acknowledge that this is an important aspect of transparency.

We stress that one of the main advantages of developing and using an explicitly mechanistic model, such as SeabORD, is that such approaches provide a natural mechanism for incorporating new empirical learning and biological knowledge as it becomes available. This is because the parameters and processes within the model relate relatively closely to observable quantities. Mechanistic models, such as SeabORD, also provide a natural framework for quantifying uncertainty and variability, and therefore for representing the reduction in uncertainty that arises from the incorporation of new evidence. In cases where uncertainty is likely to be important but cannot be explicitly quantified (e.g., because of a lack of relevant empirical data), mechanistic models such as SeabORD can contribute to a precautionary approach by making assumptions that are explicitly designed to be conservative – e.g., that have the potential to over-estimate, but should not under-estimate, impacts. Mechanistic models provide a natural framework for explicitly making such assumptions, and for using emerging evidence to refine these assumptions over time, thereby making them less conservative, where evidence suggests this is appropriate.

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