User documentation for the Stochastic Collision Risk Assessment for Movement (SCRAM)

Developed by:

Biodiversity Research Institute

The University of Rhode Island

U. S. Fish and Wildlife Service

With funding from:

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For More Information

This user manual is for SCRAM tool version 1.0.3 (Cathartic Adela), available at https://briloon.shinyapps.io/SCRAM/. Updates to the tool and user manual will be posted at https://briloon.shinyapps.io/SCRAM/ and at the SCRAM project webpage at briwildlife.org/SCRAM. Additional information on this effort will also be made available via a report to the Bureau of Ocean Energy Management, which will be made available on the Data and Information Systems webpage at www.boem.gov/Environmental-Studies-EnvData.

For more information on the tool or provide comments, contact Andrew Gilbert at the Biodiversity Research Institute (Andrew.gilbert@briwildlife.org). The R code for SCRAM is provided at the SCRAM GitHub repository: https://github.com/Biodiversity-Research-Institute/SCRAM. Update requests and bugs can be posted at https://github.com/Biodiversity-Research-Institute/SCRAM/issues, or by contacting Andrew Gilbert at Andrew.Gilbert@briwildlife.org. Users that have species data to contribute for the three baked-in species can contact Andrew Gilbert at Andrew.Gilbert@briwildlife.org.

Citation

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Overview

This is a user guide to an online web tool that provides access to a model that simulates collision risk to birds from existing or planned offshore wind energy development in the eastern United States. The underlying model is adapted from the widely used framework developed by Band (2012), which is often referred to as a collision risk model (CRM). This CRM for the eastern U.S. (i.e., Atlantic Outer Continental Shelf) is run in the open-source computing software environment R (R Core Team 2021) using code adapted from Masden (2015) and Trinder (2017). There is also a user interface for running the CRM in a web browser, similar to the application developed by Marine Scotland (McGregor et al. 2018), with results specific to the eastern United States. Collectively, we are calling this adaptation of the CRM and user interface the Stochastic Collision Risk Assessment for Movement (SCRAM).

The model and web application have been initially implemented for three birds that are often the focus of species impact assessments in the northwestern Atlantic: Roseate Tern (*Sterna dougallii*), Red Knot (*Calidris canatus*), and Piping Plover (*Charadrius melodus*). The model predictions are bound to areas of the U.S. Atlantic where automated radio telemetry data from these three species are currently available from the Motus Wildlife Tracking System ('Motus'; www.motus.org). This user manual for SCRAM has been developed to communicate the basics of the model and to guide users in its execution via the user interface.

What is the goal of SCRAM?

CRMs generate estimates of the number of bird collisions that may occur at offshore wind farms, which can be used to inform planning, mitigation, and assessments of the impacts of increased mortality for at-risk species. SCRAM can provide decision support for both environmental assessments and research related to avian collision risk from offshore wind. SCRAM facilitates the use of CRMs by providing all necessary species inputs to generate collision risk estimates for locations on the Atlantic Outer Continental Shelf for the three target species. The model and web application have been initially implemented using Motus telemetry data (Loring et al. 2018, Loring et al. 2019) for the Roseate Tern, Red Knot, and Piping Plover. Future updates are planned to allow the user to provide their own site-specific data for the three focal species.

The underlying statistical models describing movement and flight height are aiming to capture the large-scale processes that drive variation in collision risk across the Atlantic OCS, and therefore might not fully capture fine-scale variation (i.e., at the project-level scale) in movement and/or flight height and thus collision risk; users should be cautious about applying SCRAM in anything other than a relative way. For more specialized applications, the underlying code for our adaptation of the Band, Masden, and Trinder CRM is available on GitHub for downloading and modification.

Intended audience for SCRAM

The intended audience is anyone with an interest in understanding collision risk from offshore wind energy development for decision-making, planning, policy, or environmental assessments.

This audience includes conservation practitioners, state and federal agencies, non-governmental organizations, and the offshore wind energy industry. The web application was developed for users who do not have previous experience with statistical or computational modeling.

What is a Collision Risk Model?

At its core, a Collision Risk Model (CRM) estimates the number of collisions between a given bird species and an array of wind turbines. The key pieces of information are: (1) how many individuals of a given species are in the area that will be developed, (2) how many of those animals could pass through the rotor-swept zone of the turbines, (3) the flight behavior of the animals, and (4) the probability that the animal will avoid the turbine blades through meso- or micro-avoidance. The rules of the simulation are determined by first principles of physical phenomena – e.g., blade rotation frequency is used to determine how often they would strike objects passing through them– as well as basic ecological models that estimate the likelihood of birds being in the vicinity of turbines. The simulation relies on turbine array-specific data for physical turbine characteristics (e.g., number of turbines, rotor speed, altitude of the rotor-swept zone) and site-specific estimates of passage rates of focal species through the area of interest. This latter value is calculated differently for migrants than for resident birds; residents are assumed to have a constant flux through the rotor-swept zone of the wind farm that is dictated by their flight speed and active period of flight. For migrants that are assumed to transit through an area once within a specified timeframe (such as a season), the user must estimate the width of the population's migratory corridor to help calculate the number of birds per km moving across this migratory front. The vertical density is calculated from the migratory frontal passage rate multiplied by the diameter of the rotor-swept zone (RSZ). This vertical passage or “flux” value is then scaled to the total area of the RSZ across all turbines to estimate the total number of passages in the wind farm. Information from the scientific literature is used to estimate other characteristics of target species (e.g., flight height distributions, flight speed, bird size, and avoidance behavior) to determine what proportion of birds represented in the flux estimate are actually at risk of collisions. This type of collision risk model includes all major components that are thought to be likely to influence the risk for a proposed or existing array, but it does not integrate information from other arrays in the region. It is, therefore, best suited for array-specific assessments of risk.

How does SCRAM work?

The overall framework for SCRAM has four major components: (1) the estimated number of bird passages through the project area, (2) the proportion of those birds estimated to occur within the RSZ, (3) the proportion of time the turbine is active, and (4) the collision rate with the turbine. The overall structure is similar to the Band et al. (2012) collision risk model for migrants, where we reduce the migrant passage rate by the proportion of animals in the RSZ, by the avoidance rate of the turbines and micro- and meso-scales, by the proportion of time the turbine is active, and then multiply that value by the per-animal collision rate. After we determine the best estimate for the number of expected collisions for a single turbine, collisions are scaled up to an entire wind farm. An example of how SCRAM works is presented in Appendix I.

The process for estimating number of passages (Step 1) differs from that used in the Band et al. (2012) migratory CRM. In SCRAM, we use automated radio telemetry (‘Motus’) data to estimate occupancy based on movement data, which when combined with regional population estimates provide the local migratory passage rates. First, we use daily detection data at Motus stations to parameterize a multi-state correlated random walk movement model. Through this process, we estimate the most likely daily locations for animals (along with model uncertainty) and overlay these predictions across a spatial grid. We estimate the number of individuals found in each grid cell and divide that value by the total number of individuals we were tracking that month. This allows us to estimate the proportion of the population found in each grid cell in each day. By summing that value across a month and multiplying that with the regional population size (as estimated by USFWS experts and monitoring efforts; Appendix II), we determine the expected number of animals in each cell in each month. This value is converted to birds/km passage rate by dividing total birds by the mean width of the grid cell. This value is now an estimate of cumulative daily migratory passages for that area.

Because the Motus stations, which are coastally located, detect animals during coastal stopover as well as during migratory flight, the estimated the daily number of birds in coastal grid cells (e.g., cells that overlap land) is likely an overestimate of migratory flight activity. Birds actively migrating are vastly more likely to encounter offshore turbines than birds stopping over along the coast. To address this issue, behavioral state transitions were estimated using the movement model and the ratio of transient to non-transient behavior was estimated by location. The probability of transient behavior then further reduces passage rate by that proportion and adjusts for the number of animals that are likely moving offshore. This adjustment is applied to all grid cells, though it most strongly scales estimates for coastal areas, since offshore locations have a very high proportion of transient states.

Steps 2-4 are functionally similar to the Band et al. (2012) migratory model. First, the number of passages through the wind farm is estimated by calculating the vertical density of animals along the front (frontal area divided by the RSZ diameter) and scaling to the wind farm by multiplying by the total frontal area of the wind farm, which is calculated by multiplying the number of turbines in a wind farm by the area of the RSZ (Appendix I). Second, the flight height distribution is used to estimate the proportion of those individuals expected to fly at rotor height. In the current version of SCRAM, we use flight height from Motus tracking data for our study species, but will refine our estimates in the future using GPS tracking data for the species of interest when available. Third, the “amount of time active” for turbines is estimated as a proportion of the time in a month based on the expected average wind speed at the site as it relates to cut-in and cut-out speeds of the turbine model (the operational proportion of time) which is reduced by the expected maintenance time or other turbine downtime expected. Finally, the proportion of birds expected to exhibit avoidance behaviors are accounted for, and then for the remaining individuals the collision rate is calculated as a function of flight speed, length and wingspan of the bird, and turbine parameters such as turbine rotational speed and blade width (Appendix I). Note that there are two ways of estimating collision rates in SCRAM, Option 1 and Option 3 in the Band Model, so the specifics of this process vary depending on the model option chosen. In short, collision rate can be estimated for the entire RSZ (Option 1), or it can be estimated in 5m increments to account for varying collisions throughout the RSZ (Option 3).

SCRAM does not integrate information from multiple wind energy arrays in a region of interest. Future work on SCRAM will explore providing estimates of risk across multiple projects (cumulative risk). In its current form, SCRAM can be used serially to provide individual array estimates of risk which can be added together to provide a rough estimate of cumulative risk across sites within a region. This additive framework for risk is a reasonable starting point, but assumes that risk is fully additive and linear, which is unlikely to be the case.

How does SCRAM differ from previous models?

One major difference in our adaptation of this CRM framework is in how bird passage rates are parameterized. Previous models typically used observational survey data, most often collected from vessels, to estimate passage rates and flight heights. However, observational line-transect surveys at sea are primarily intended to obtain data on marine birds (as opposed to shorebirds like Piping Plovers and Red Knots) and are not optimal methods for obtaining information on at-sea behaviors or potential for interactions with anthropogenic structures (Camphuysen et al. 2012, Ronconi et al. 2015). Thus, SCRAM parameterizes bird passage rates using data from the Motus Wildlife Tracking System, an automated radio telemetry network (Taylor et al. 2017, Loring et al. 2018, Loring et al. 2019). While these changes provide more useful information for focal species of interest, they have their own biases and change the methods for estimating passage rates from the typical Band model. In future work, we hope to incorporate GPS data into both estimation of bird passage rates and flight heights to further improve our models. For technical details of the general modeling framework used in SCRAM, see Band (2012), Masden (2015), and Trinder (2017). More information on the differences between SCRAM and previous implementations of Band's (2012) collision risk framework is available in Appendix III. Detailed information on SCRAM data inputs is included in Appendix IV.

Limitations of the current version of SCRAM

The reliability of any collision risk modeling framework is determined by 1) how it handles uncertain data, 2) how representative the data are, and 3) whether the assumptions underlying the model are appropriate. Incorporating uncertain data is relatively straightforward, as current implementations of the Band (2012) framework for collision risk modeling are stochastic – i.e., the bounds of the collision risk estimates reflect the uncertainty of the input data. However, if the input data are biased, this could likewise bias resulting collision risk estimates. Uncertainty estimates should account for bias whenever possible, but unknown or unquantifiable biases are challenging to incorporate. A source of bias could be a spatial or temporal mismatch between the scale of the area of interest (e.g., project wind farm) and the underlying data, which causes fine-scale deviances between the input data and real values for the location/time period of interest. For example, SCRAM facilitates the use of CRMs by providing all necessary inputs to generate estimates for locations in a large area of the Atlantic Outer Continental Shelf. The underlying statistical models are aiming to capture the large-scale processes that drive variation across this planning area, and therefore might not fully capture fine-scale variation. Further, Motus stations can only capture data around active receivers and are likely create estimates that are biased toward coastal areas. This degree of bias is difficult to estimate given current data and could be significant. Additionally, there has been limited empirical validation of collision risk estimates with real-world measurements of collisions (though see Skov et al. 2018 and Tjørnløv et al. 2023), due in large part to the difficulty in making such measurements reliably in the offshore environment.

SCRAM is an evolving tool that will be updated as additional data and methods become available. SCRAM's CRM currently uses static flight height distributions, as opposed to distributions that vary over space and time, which would be more realistic (Péron 2020). While we feel that treating flight heights as a non-parametric distribution, as we have done, implicitly accounts for some of this potential variation, more research is needed to determine whether unexplained variation is likely to influence collision risks (e.g., if flight heights increase substantially with increasing distance from land, for example). One particular challenge to estimating passage rates from movement data is determining the overall number of individuals that could potentially encounter offshore wind farms. While we are using the latest regional population estimates for the target species (Appendix II), there are limitations in our knowledge of how representative the available movement dataset is of broader population-wide movement patterns. Movement data are limited by the availability of offshore Motus stations to detect animals and limited in the number of animals tagged and potentially biased by the limited geographic range where tags were deployed. We hope that future updates to our understanding of population-level movements will improve our estimates of collision risk. To allow updated data to be brought into SCRAM, future tool updates will include a mechanism for users to modify species data for the three focal species (for example, to update estimates of regional population size with new values) and may also expand SCRAM to other species. The current iteration of SCRAM, however, is limited to the three focal species of interest, and the species data are "baked in" to the model.

In general, CRMs should be implemented with some amount of caution. As with all models, they are only as good as their inputs and ability to represent observed phenomena. There has been only two major tests of CRMs to determine if seabird collision rates were similar to what these models found, and these studies had small sample sizes of actual collisions (Skov et al. 2018, Tjørnløv et al. 2023). It also appears that meso- and micro-avoidance behavior within a species may vary by location and with weather conditions, including degree of air turbulence, which suggests that generalized models assuming the same species-level behavior across sites are unlikely to be accurate. In general, however, avoidance rates appeared to be quite high and we know that these models are quite sensitive to this parameter (Masden et al. 2021). Because of the lack of empirical testing of these models, particularly for our focal species of interest, we have high uncertainty that CRMs are well-tuned to realized collision risk. Therefore, we suggest thinking about using SCRAM in a comparative context as much as possible. Even if the collision risk estimate is biased due to a lack of information on avoidance behavior, if we can assume that bias is similar across space, then there is value in comparing collision estimates from multiple sites.

What software and/or hardware is required for SCRAM?

Masden (2015) adapted the Band (2012) model for the programming language of the computing software R (R Core Team 2021). Trinder (2017), McGregor et al. (2018), Christopher Field, Brian Gerber at the University of Rhode Island, and these authors have further adapted this R code for use with Motus data as well as numerous other enhancements. McGregor et al. developed online user interfaces for the 'StochLab' R package (developed from McGregor et al. 2018; https://cran.r-project.org/web/packages/stochLAB/index.html) using the R package 'shiny' (Chang et al. 2021), which allows users to run computational tasks in R on a remote server. SCRAM adapted the code from McGregor et al. and further modified it to run on the Shinyapps.io remote server. No software is needed other than an up-to-date web browser running on any PC, Mac, or Linux device.

Updates to the Tool

Users experiencing problems with the operation of the tool should contact Andrew Gilbert at Andrew.gilbert@briwildlife.org or post a bug request at the SCRAM GitHub repository (https://github.com/Biodiversity-Research-Institute/SCRAM/issues). Updates to the tool and/or this user manual will be published at https://briloon.shinyapps.io/SCRAM/ and at the SCRAM project webpage at briwildlife.org/SCRAM. Additional information will also be made available via a report to the Bureau of Ocean Energy Management, which will be made available on the Data and Information Systems webpage at www.boem.gov/Environmental-Studies-EnvData.

How to use the web application (SCRAM)

Overview

SCRAM requires two types of data: 1) “Wind farm data”, which are provided via a single spreadsheet of turbine and array characteristics, and 2) “Species data”, which are incorporated into the tool for the three target species. Currently, custom species data can **NOT** be uploaded - the “*baked in*” species data can **NOT** be changed.

The application is built as a dashboard-type layout in which input is added on the left-hand side of the screen (the sideboard) and outputs are available on the tabs to the right of the sideboard in the main body of the dashboard. Additional links and information are available in the header bar of the app:

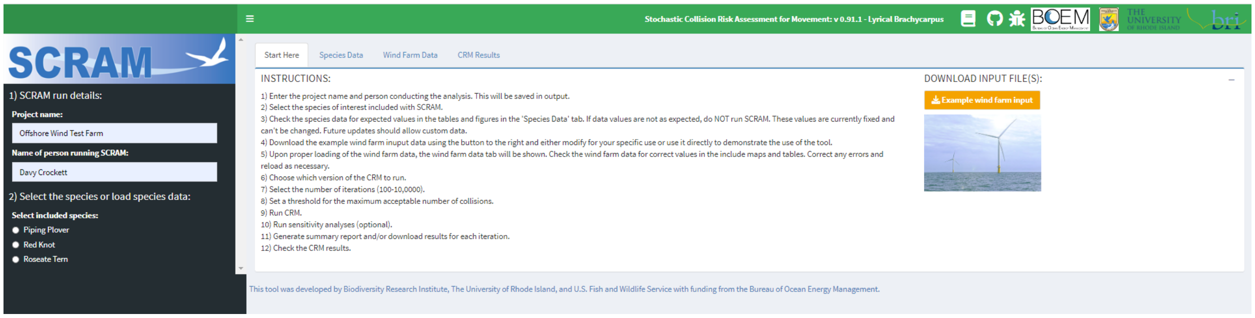
The most recent version that is available online is shown in the header along with a series of three symbols:

1)  provides a link to the user manual.
2)  provides a link to the SCRAM GitHub project.
3)  provides a link to the bug submission/improvements request for SCRAM in GitHub.

The header bar also includes links to the affiliated institutions.

There are currently four tabs in the main body of SCRAM: “Start Here”, “Species Data”, “Wind Farm Data”, and “CRM Results”:

1) Start Here – this tab includes some basic instructions for use as well as a button for example wind farm data.
2) Species Data – this tab includes tables of species data and a plot of the flight height data that are included with SCRAM for Red Knot, Roseate Tern, and Piping Plover, and the species monthly count data.
3) Wind Farm Data – A table showing the wind farm specifications and operational data for the uploaded wind farm, as well as a map of the wind farm location with the ability to look at the predicted occupancy probabilities for the target species.
4) CRM Results – This tab is where basic output is provided following a model run. Outputs are provided as a histogram of the number of collisions per year for each iteration. This tab is also where the user can perform a sensitivity analysis, download data, and download a PDF report of the SCRAM results.



Examples of wind farm data input (Appendix IV) can be downloaded from the application interface using the “Example wind farm input” buttons shown on the “Start Here” tab.

Once the data for turbine and array characteristics are compiled and formatted appropriately (see examples on interface and Appendix IV), it should take 3-5 minutes to finish setting up SCRAM to run for a target species. The run time once the data are uploaded will depend on which version of the model specification is selected. The general steps for running SCRAM are discussed below. The interface was created to lead users through data input and model run, with some inputs not available to the user until the prior input has been entered in SCRAM. The basic steps are as follows (with a more detailed description of each step included below):

1) Enter the project name and person conducting the analysis.
2) Select the species of interest.
3) Once the species is selected, the species data tab will be shown. Check that the species data and flight height data are as expected for this species. If not as intended, do NOT run SCRAM.
4) Download the example wind farm input data as compressed file from the “start here” tab using the “example wind farm input” button to the right. Decompress the file and either use the example data directly for learning or testing purposes or modify the file for your specific use.
5) Upon loading the wind farm data via a csv file, the wind farm data tab will be shown. Check the wind farm data are correct by examining the maps and tables in the wind farm data pane. Correct any errors and reload as necessary.
6) Choose which version of the CRM to run: the faster/approximate version that uses the flight height distribution but does not account for differences in risk along the rotor-swept zone, or the slower/more precise version that accounts for differences in risk by integrating the differences in risk along the turbine blades for a more robust assessment. *Note that for some species, the faster Option 1 may significantly over- or underestimate risk as compared to Option 3, depending on the distribution of flight heights throughout the RSZ.*
7) Select the number of iterations (100-10,0000).
8) Set a threshold for the maximum acceptable number of collisions. Estimates that are above the threshold number will be highlighted in model outputs.
9) Run CRM.
10) Run sensitivity analyses (optional).
11) Download model results (optional).

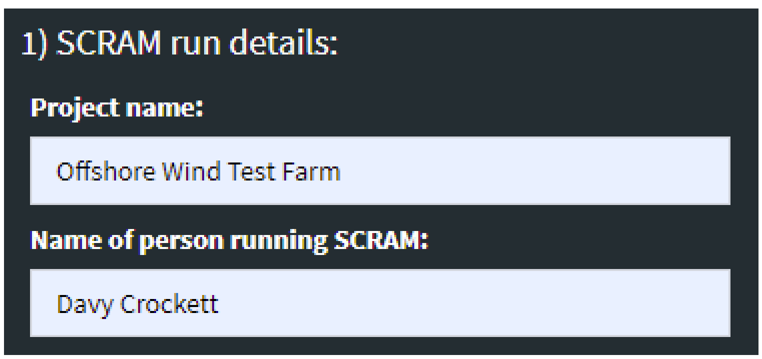
12) Generate output report (optional).
13) Check the CRM results.
14) Run SCRAM again as needed.

SCRAM results are not provided for locations for which the underlying species movement data are not available.

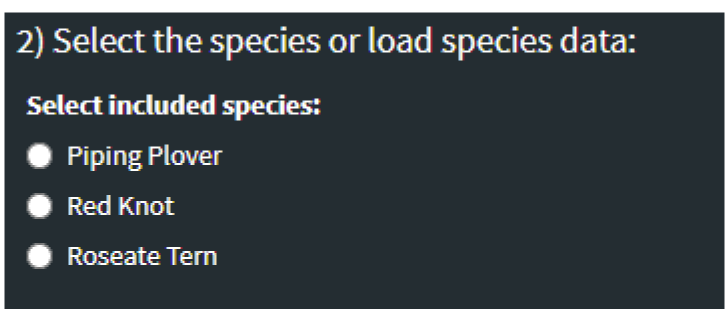
SCRAM will likewise not provide collision risk estimates for months of the year for which movement data are not available for a given species. For the three focal species currently included in SCRAM, predictions are limited to fall migration (Red Knots); incubation period through fall migration (Piping Plovers); and incubation period through post-breeding dispersal (Roseate Terns; Appendix II).

Detailed description of SCRAM usage

1) *Enter the project name and person conducting the analysis.* Choose whatever project name will be informative for you; this information will be saved in the output once SCRAM is run.

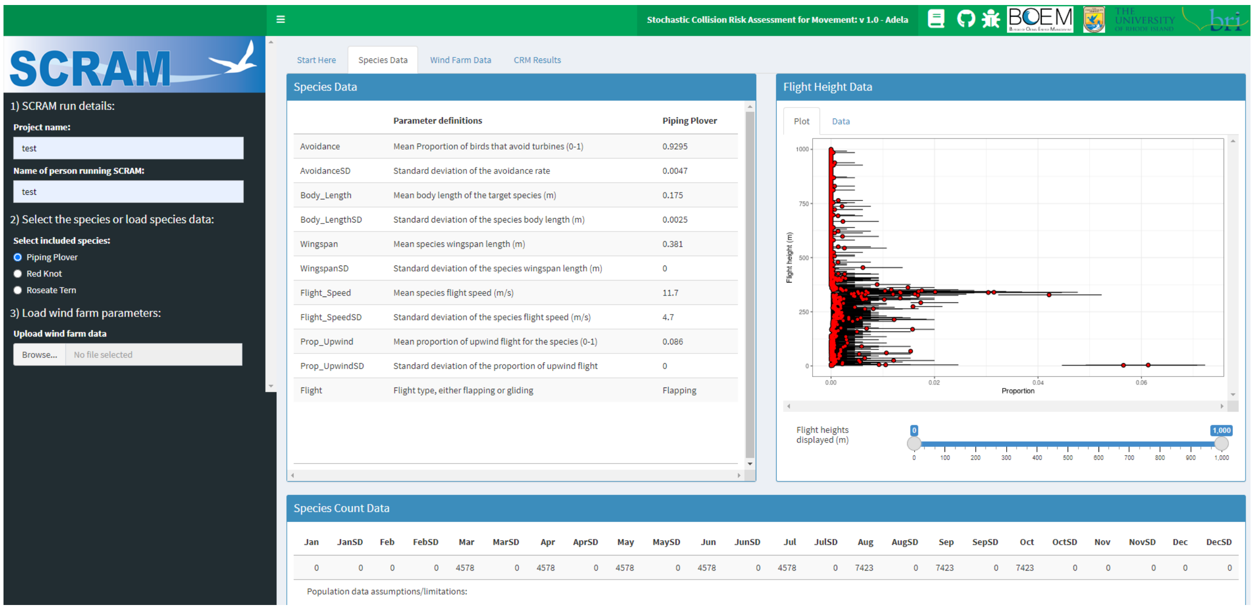


2) *Select the species of interest.* Select one of the included target species (Piping Plover, Red Knot, or Roseate Tern).

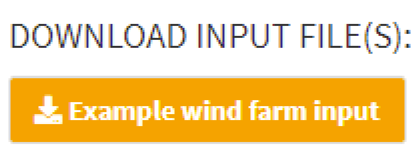


3) *Check the species data tables for correct values.* Make sure the values included in SCRAM are appropriate for these models by examining the tables and figures in the species data pane. Examine the flight height graph to see if the flight height data make sense and are appropriate for the model. The flight height graph and data table can be filtered for the

range of flight heights of interest using the slider input bar but doing so does not affect the data used in the model. This feature is for viewing purposes only. Population parameters are currently fixed in SCRAM and can't be changed but are presented in a table for examination and outputted for reference. (We describe how the current values were derived in Table A7 in Appendix II). Do NOT run SCRAM if data is not as expected. Future updates will include the ability to add custom species data.



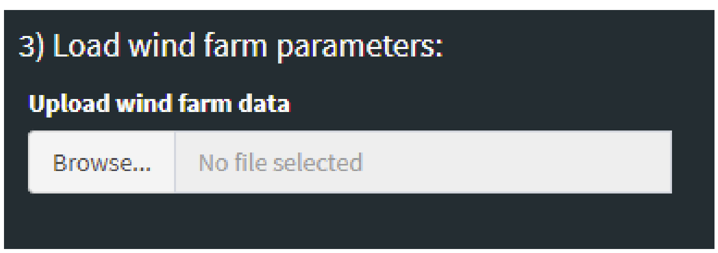
4) *Download the example wind farm input data from the "start here" tab to either use the example data directly or modify the file for your specific use.* Data for turbine and array characteristics are required to run any version of SCRAM. Turbine and array characteristics include the physical and geographic characteristics of the wind farm, including the dimensions of the turbine model, power targets, and the width and geographic coordinates of the turbine array (Table 1 in Appendix IV). Note that the included example file (TurbineData_inputs_2run_example.csv) shows an example of wind farm options and can be used to test and learn SCRAM.



a. The application accepts these data as a single .csv file that has alternate options for arrays specified as rows. You can provide as many options as you desire by adding rows or remove the second option row if only a single option is desired. SCRAM will run and provide outputs for each row in this table, assuming they have the same geographic location.
b. Specified array options can vary by parameters including power, size, and turbine model specifications among others. Due to rapidly changing wind turbine

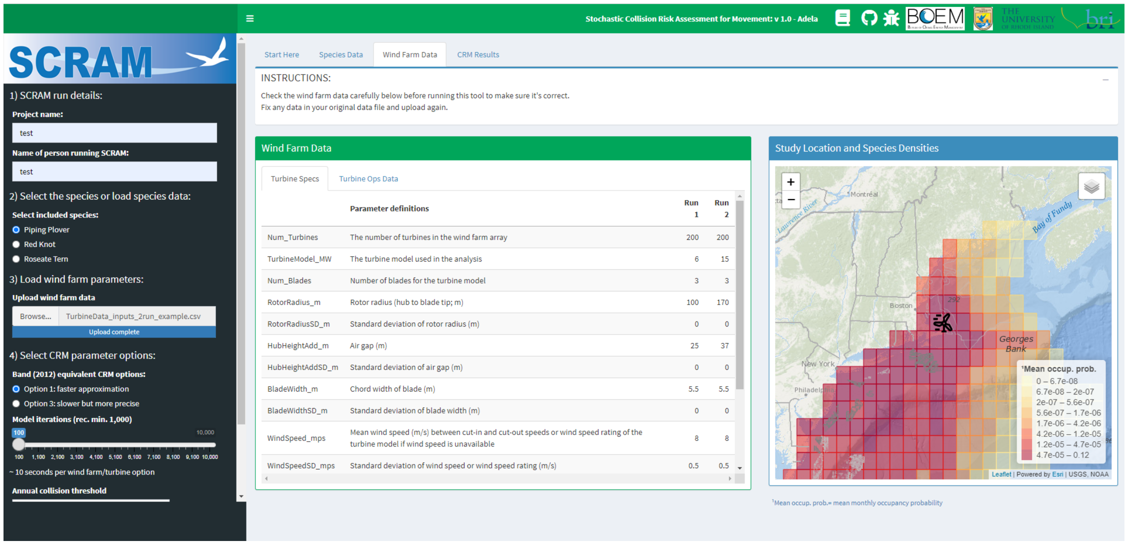
technology, offshore wind farms in the U.S. now typically specify a design envelope for wind turbines (range of engineering specs) during the planning and consulting phases, rather than selecting a single wind turbine specification, to account for the minimum and maximum ranges of engineering measurements under consideration. To account for this design envelope, SCRAM can be parameterized with the range of options given in the design envelope to generate two or more collision risk estimates during a single SCRAM run. Also, changing size of the wind turbine generator (e.g., 6 to 12MW capacity) can lead to fewer turbines being installed; providing different turbine options will allow users to evaluate the differences in collision risk across these scenarios. Note that SCRAM only allows for changes to design parameters (e.g., rotor radius, blade width) in this fashion, and not location parameters.

c. SCRAM can run using only **ONE wind farm location at a time**. If the rows for the turbine and array data include more than one set of geographic coordinates (latitude/longitude), only the coordinates from the first row will be used for model output. In order to run multiple locations for SCRAM, you must run SCRAM multiple times and change the geographic coordinates for each run.
d. The naming convention of the file itself does not matter, as long as the appropriate fields are included and correctly named (Appendix IV).
e. Turbine specifications, such as blade pitch and width, can sometimes be found at locations such as the manufacturers' web pages (e.g., models from General Electric) or the U.S. Geological Survey's Wind Turbine Database.
f. Upload the data file once you are satisfied with the values in the file.

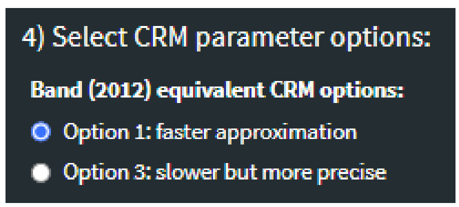


5) *Check the wind farm data tables for correct values*. Make sure the values you uploaded to SCRAM are appropriate for these models by examining the tables in the wind farm data pane. Correct any errors and reload as necessary. The map on the right of the "Wind Farm Data" tab shows the occurrence probability surface generated from the modeled Motus data for each species. The user can also turn off the modeled data layer by clicking on the

symbol at the upper right corner of the map. Default map layers turned on include the BOEM lease areas and wind energy areas, the wind farm location, and the species occurrence data.

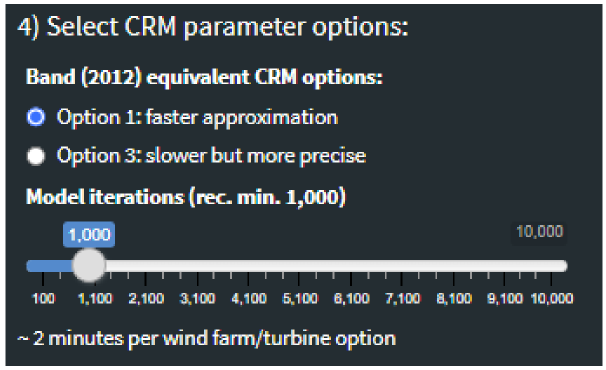


6) *Choose which version of the CRM to run (the faster/approximate version or slower/more precise version).*

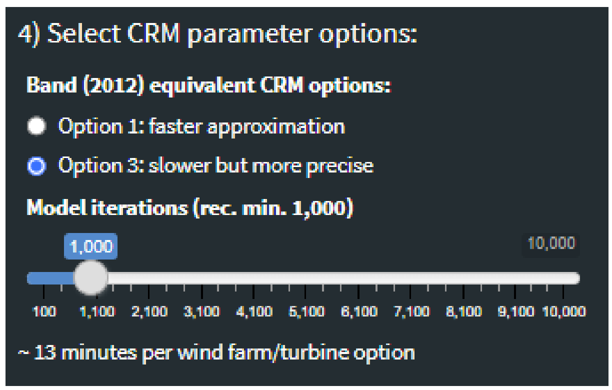


The principles that the CRM uses to simulate collision risk are simple, but there are two options for how these principles are executed that differ in how input data are used in the underlying calculations. Band (2012), Masden (2015), and Trinder (2017) provided several options, which we synthesized to provide two options – one that we have shown performs best and one that gives approximate estimates in much less time. Using “Option 1: faster approximation”, SCRAM does not model risk along the rotor; it is presumed to be constant throughout the rotor-swept zone, and as a result the model is faster to run. Using “Option 3: slower but more precise”, SCRAM allows collision risk to vary at 20 fixed length increments in altitude along the rotor blades and thus provides a more precise accounting of collision risk (Trinder 2017) but is slower to run. For some species and turbine models, Option 1 may significantly over- or underestimate risk as compared to Option 3, depending on the distribution of flight heights throughout the RSZ.

The avoidance values included in the species data assume that Option 3 is used. Thus, we recommend selecting “Option 3: slower but more precise” whenever the user is not severely limited by computation time, and **ONLY Option 3 should be used to develop final estimates of collision risk**. **Do not use Option 1 to develop final estimates.** Estimates of time are given below the iterations slider and are dependent on the options used and the number of model iterations desired (100-10,000). For example, an estimate of 2 minutes per run is given for Option 1 with 1,000 iterations.

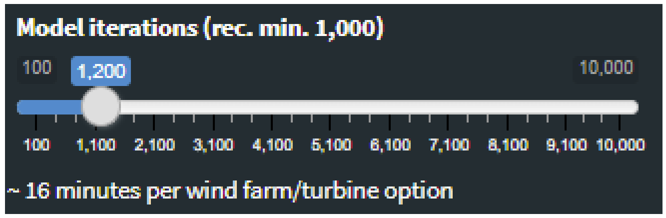


The same number of iterations per run takes ~13 minutes using Option 3 when accounting for differences in risk along the blade.



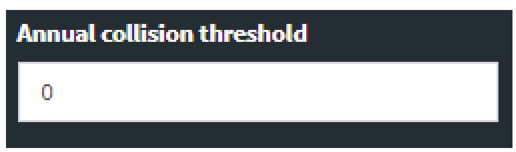
We do not recommend running both options for comparison because, in most cases, the option that estimates risk along the rotor blade (Option 3) will provide the more precise estimate (Trinder 2017), and the avoidance estimates included in the species data (Appendix II) assume this more precise option has been selected. **Option 1 is provided as a "short-cut" for exploring SCRAM but should not be used to develop final collision risk estimates.**

7) *Select the number of iterations*. Use the slider to specify how many iterations of the model will be run in order to propagate the influence of parameter uncertainty on the simulation results. A dialog box at the bottom of the application interface will give an estimated run time for the currently selected option. In this CRM framework, uncertainty – i.e., variation in the results among iterations – is a result of the variance estimates provided for the input parameters. Increasing the number of iterations will give more precise estimates for the model outputs, until the error associated with estimating outputs via stochastic simulation is arbitrarily small, which is around 10,000 iterations for this model.

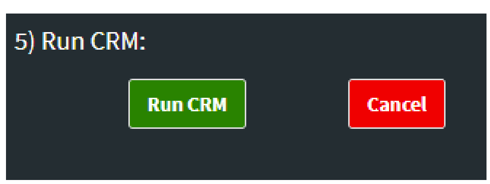


We recommend running at least 1,000 iterations, but SCRAM defaults to a minimum of 100. **For final estimates of collision risk, and to get the best estimate from SCRAM, 10,000 iterations should be run** but note that this can take ~2 hours per turbine model/wind farm specification. The user must pay attention to SCRAM when the model is running and the browser window is open, because **once it is finished, the application will time out after 30 minutes of inactivity** and will disconnect from the server, and no results will be available for export. Results are not automatically saved, so **the user must export results within 30 minutes after the model finishes**, or otherwise interact with SCRAM to make sure the application is not closed prior to downloading of data and/or report.

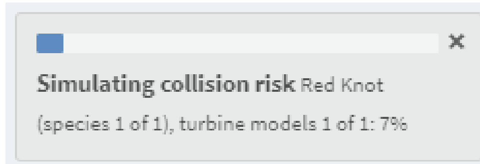
8) *Set a threshold for the maximum acceptable number of collisions in a year.* If desired, the user can specify a threshold for the maximum acceptable number of collisions (this number can be zero). Note that changing this threshold does not change the results themselves, but rather the presentation of those results. When provided, SCRAM will calculate the proportion of iterations that produce a collision estimate larger than the specified threshold. The application will show the threshold value alongside the results for reference and will include the probability of exceeding this value in a dialog box.



9) *Run CRM.* The button to run the CRM appears when the minimum conditions for running the model are met.



A status bar will update progress through the specified species and turbine models. If this button is clicked in error, clicking “Cancel” will stop the current run.

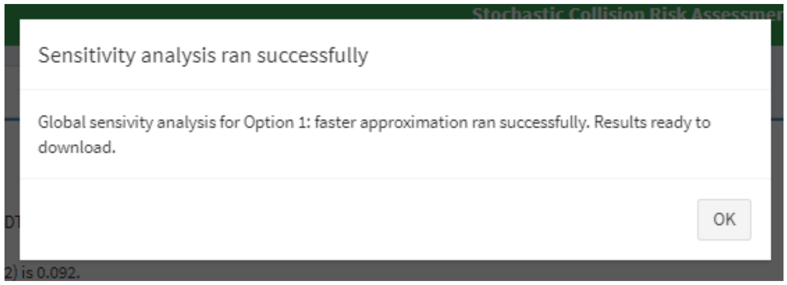


Once the model has completed, the CRM results tab displays basic results including details of the model run times, the model that was run, probability of exceeding the selected annual collision threshold, and histograms (one for each wind farm option) of the number of collisions per year for each iteration. This histogram is also provided in the output report.

10) *Run sensitivity analysis (optional)*. Once the model has been run successfully, SCRAM provides the option to run a simple sensitivity analysis that determines the relative contribution of the input parameters to the uncertainty bounds of the results. We have provided this option as a general guide for determining where (e.g., for which parameters) more precise data are likely to lead to the biggest gains in our understanding of collision risk for the species and arrays of interest. We do not recommend running sensitivity analyses

when the number of iterations is less than 1000. The results are saved to a .csv file that can be exported from the application using the “Download model runs” button.

Successful sensitivity analysis will show the following dialog box:



For the 10 most influential parameters, the analyses provide estimates of the proportion of the variation in the results that is contributed by each parameter. For example, if the value for turbine avoidance rate is 0.12, approximately 12% of the width of the final uncertainty bounds is a result of uncertainty in our understanding of avoidance behavior. The analyses provided in SCRAM are approximate (see Borcard 2002 for details on the methods) due to computational constraints, so we recommend using this option as a rough guide for understanding parameter sensitivity or potentially planning additional sensitivity analyses.

11) *Download model results (optional).* Once the model has run successfully, which will be indicated in a dialog box at the bottom of the interface, the option to download the full results will appear. When the user clicks the button, a file save dialog box will appear with the ability to browse to a location for saving as well as change the compressed file name. A compressed file will be downloaded containing the following files:
    i. The original wind farm data file that was uploaded.
    ii. Species movement model data files, zipped.
    iii. Species flight height modeled data.
    iv. Species population data.
    v. Model output Rdata file that can be directly loaded in R.
    vi. Estimated number of birds in the model cell and wind farm per day as .csv files.
    vii. Collision estimates for each month as daily and monthly estimates in each iteration as .csv files.
    viii. The stochastic draws of all input parameters for each iteration as a .csv file.
    ix. Sensitivity analysis results as a .csv file (if run).

12) *Generate output report (optional).* The user can also download a custom PDF report for the model runs by clicking the “Generate output report” button. The report provides details about the model run (including SCRAM version, run times, project, user, and probability of exceeding the user-specific collision risk threshold), model input parameters including both species and wind farm parameters, guidance on biases and interpreting wind farm and species occurrence map, a table of the estimated daily number of birds present and

collisions in the target grid cell for each month, a table of the monthly mean and 95% prediction intervals for estimated collisions and the annual mean number of collisions and range, a histogram of the number of collisions per year for each iteration, and a figure showing the predicted mean and 95% prediction intervals for the number of collisions per month. If multiple turbine models are run, results will be presented in separate figures/histograms for each model.

13) *Check the CRM results.* Check the results of the model to see that they are sensible. Tips for interpreting the results are discussed below.

14) *Run again.* The model may be run again at this point by selecting another species or varying other model run options (you can also refresh the browser if you prefer to start with a clean slate).

Tips for interpreting the results

SCRAM provides several types of visualizations to aid with interpreting results in the model output report (and in a more limited way in the "CRM Results" tab), as well as the option of downloading data as spreadsheets and an RData file of the raw model output (Step 11) to conduct further analysis and/or generate other figures and tables. All figures include uncertainty estimates, either summarized as bars or shown as variation in the model runs across stochastic iterations. In this CRM framework, uncertainty in the collision risk estimates is the result of variation in key parameters (e.g., variation in wind speed, variation in monthly operational values, wingspan and flight speed) as well as uncertainty in our estimation of these parameters (e.g., uncertainty in flight height estimates due to estimation error or uncertainty in habitat use due to variation in Motus coverage in the region). Increasing the number of iterations will give more precise estimates for the model outputs until the error associated with estimating outputs via stochastic simulation is arbitrarily small, which is around 10,000 iterations for this model. Note, however, that we do not measure the bias or uncertainty of the collision risk model itself; rather, we propagate uncertainty in model parameters through the stochastic CRM. If model parameters are biased or uncertainty estimates are inaccurate, then CRM results may be inaccurate or biased regardless of their precision.

The plot on the application interface shows the number of simulation iterations associated with the values on the x-axis, with wider distributions being a result of greater uncertainty in the number of collisions per year. We have also provided the option to summarize this uncertainty probabilistically by specifying a threshold for the acceptable number of collisions per year. This threshold can be any integer between zero and an arbitrarily large number. When provided, SCRAM will calculate the proportion of iterations that produce a collision estimate larger than the specified threshold (which can be interpreted as an estimate of the probability that the number of collisions will exceed the specified threshold value). This value is a probability, rather than a known outcome, because there is uncertainty in the input data. This probability is also dependent on model assumptions. A plain language interpretation is "X is the probability of exceeding the specified threshold, taking into account the uncertainty of the input data and assuming that the model is a reasonable description for how collisions happen in reality.”

For more detailed visualizations, including variation by month, users should download the output report. We have included tables for the input parameters so that all results are associated with the input data, as the results of CRMs can be sensitive to certain aspects of the availability and quality of the underlying data.

Appendix I. Example of how SCRAM works

The below example uses hypothetical values to illustrate how SCRAM uses input data to estimate passage rates and numbers of collisions. The grid cell of interest is selected based on the centroid of the wind farm location. Note that the below values, including grid cell size, are **not** values actually used in SCRAM and are being used here for illustrative purposes only. Additionally, SCRAM incorporates uncertainty into many of these values, which for simplicity's sake is not presented here.

Input values:

- Monthly population estimated to be present in the Atlantic study area = 4000 birds
- Cumulative daily occupancy in the month = 0.25 (this is the proportion of tagged birds detected in a selected grid cell as compared to all tagged birds in that month)
- Grid cell size = 50 km wide, 50 km long
- Proportion of habitat use by transient birds predicted by movement model in the grid cell = 0.98
- Rotor radius (R) = 0.1 km
- Number of turbines (T) = 100
- Proportion of birds flying at RSZ altitudes = 0.1 (in SCRAM this is a draw from a modeled distribution, not a single value, but we are using one value in this example for simplicity's sake)
- Proportion of time that wind farm turbines are operational = 0.95
- Avoidance rate = 0.925
- Collision rate of birds that do not exhibit avoidance behavior = 0.035

Step 1: Calculate the density of birds in the grid cell by multiplying the monthly population estimate by the cumulative daily occupancy and dividing by the size of the grid cell:

4000 * 0.25 = 1000 birds in the grid cell

Scale that value by the proportion of birds estimated to be in migratory flight (transient) as opposed to stopover (stationary)

1000 birds*0.98 = 980 birds

Step 2: Calculate the number of birds passing through the grid cell as a evenly distributed migratory front:

980 birds / 50km = 19.6 birds/km

Step 3: Calculate the density of birds across the migratory front for a single turbine RSZ:

19.6 birds/km / (2*0.1km) = 98 birds/km^2

Step 4: Scale the vertical density to the RSZ of the wind farm. This is calculated as:

Number of passages = Vertical density * number of turbines * pi * rotor radius^2

Using our input values above, this becomes:

$$98 \text{ birds/km}^2 * 100 * \text{pi} * (0.1 \text{ km})^2 = 307.9 \text{ birds}$$

Step 5: Scale the predicted number of bird passages to the proportion of birds expected to be flying within the altitude of the RSZ and the proportion of time that the wind farm is operational:

307.9 * (0.1 in RSZ) * (0.95 wind farm op) = 29.3 birds

Step 6: Add avoidance and collision probabilities to estimate number of collisions in that month, where we actually multiply by 1 minus the avoidance rate (the non-avoidance rate):

29.3 * (1- 0.925) * (0.035) = 0.077 collisions

Step 7: Repeat for all months for which we have monthly movement models.

Appendix II. Species input data used in SCRAM

Table A 1. Regional population estimates used in SCRAM for Red Knots.
Estimates of regional population size (with standard deviation values in parentheses) are presented by month. If no birds were assumed to be present in the U.S. Atlantic study region for a given month, that month was assigned a population size of zero. If there are no available data to estimate the standard deviation of a population estimate, it was assigned a value of zero. Collision risk estimates are not generated by SCRAM for months in which there are no data from the movement model (indicated in the far right column). Sources: U.S. Fish & Wildlife Service 2020, Lyons et al. 2017, W. Walsh pers. comm Jul. 2022. Regional wintering population size estimates are presented in Table A 2, below.

Month	Population Size Estimate	Justification	SCRAM estimates collision risk?
Jan	10400 (±0)	Wintering population estimate for Southeast U.S.	No
Feb	10400 (±0)	Wintering population estimate for Southeast U.S.	No
Mar	10400 (±0)	Wintering population estimate for Southeast U.S.	No
Apr	10400 (±0)	Wintering population estimate for Southeast U.S.	No
May	59200 (±0)	Combined population estimate for Southern, Northern Brazil, Southeastern U.S., & Caribbean wintering populations	No
Jun	59200 (±0)	Combined population estimate for Southern, Northern Brazil, Southeastern U.S., & Caribbean wintering populations	No
Jul	59200 (±0)	Combined population estimate for Southern, Northern Brazil, Southeastern U.S., & Caribbean wintering populations	No
Aug	59200 (±0)	Combined population estimate for Southern, Northern Brazil, Southeastern U.S., & Caribbean wintering populations	Yes
Sep	72520 (±0)	Combined population estimate for Southern, Northern Brazil, Southeastern U.S., and Caribbean wintering populations, plus 13320 hatch-year birds	Yes
Oct	54720 (±0)	Combined population estimate for Northern Brazil and Southeastern U.S. wintering populations, plus 13320 hatch-year birds	Yes
Nov	41400 (±0)	Combined population estimate for Northern Brazil and Southeastern U.S. wintering populations	Yes
Dec	10400 (±0)	Wintering population estimate for Southeast U.S.	Yes

Table A 2. Regional wintering population size estimates for Red Knots.
Sources: U.S. Fish & Wildlife Service 2020, Lyons et al. 2017, W. Walsh pers. comm Jul. 2022.

Wintering Population	Population size estimate
Southern (south of northern Brazil)	12,700
Northern Brazil	31,000
Caribbean	5,100
Southeast US	10,400
Total	**59,200**

In addition to the assumptions used to estimate Red Knot regional population sizes by month that are presented in relation to Table A 1, above, regional wintering population size estimates include the following assumptions (Sources: U.S. Fish & Wildlife Service 2020, Lyons et al. 2017, W. Walsh pers. comm Jul. 2022):

- Winter population estimates represent the total # of adults and sub-adults (in general); they do not include hatch-year (HY) birds from the previous fall.
- Southern and northern wintering birds could be present during July – Sept.
- Only northern wintering birds could be present during Oct – Nov.
- Only southeast US and Caribbean birds could be present during December. However, based on Lyons et al 2017, the December estimate only includes Southeastern U.S. birds, not Caribbean.
- Birds from the western Gulf of Mexico population are excluded from totals in the Atlantic region due to lack of information on the extent to which they use the Atlantic region.
- Issues with double counting addressed because birds may be present in different areas of Atlantic region for weeks to months.

Table A 3. Regional population estimates used in SCRAM for Piping Plovers.
Estimates of regional population size (with standard deviation values in parentheses) are presented by month. If no birds were assumed to be present in the U.S. Atlantic study region for a given month, that month was assigned a population size of zero. If there are no available data to estimate the standard deviation of a population estimate, it was assigned a value of zero. Collision risk estimates are not generated by SCRAM for months in which there are no data from the movement model (indicated in column at far right). Source: U.S. Fish & Wildlife Service 2022.

Month	Population Size Estimate	Justification	SCRAM estimates collision risk?
Jan	0 (±0)		No
Feb	0 (±0)		No
Mar	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	No
Apr	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	No
May	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	Yes
Jun	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	Yes
Jul	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	Yes
Aug	7423 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 4)	Yes
Sep	7423 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 4)	Yes
Oct	7423 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 4)	No
Nov	0 (±0)		No
Dec	0 (±0)		No

Table A 4. Atlantic Coast population data for Piping Plovers (2021 update).
Source: U.S. Fish & Wildlife Service 2022.

Parameter	Value
US pairs	2109
US adults	4218
Eastern Canada pairs	180
Eastern Canada adults	360
HY fledged per pair in US	1.22
HY fledged per pair in eastern Canada	1.51
Total HY fledged in US	2573
Total HY fledged in Canada	272
Total Adults + HY	7423

In addition to the assumptions used to estimate Piping Plover regional population sizes by month as presented in Table A 3, the values presented in Table A 4 include the following assumptions (Source: U.S. Fish & Wildlife Service 2022):

- The entire Atlantic coast population could be present in the area with model predictions (northeastern to mid-Atlantic region of Atlantic Outer Continental Shelf) during the months listed
- Occurrence in the study area through October is assumed to potentially include all birds, via birds stopping over in the mid-Atlantic (e.g., North Carolina), though the number of birds truly still present in the Atlantic study region is likely lower by this point in the year
- Estimate of HY fledges uses the 20-year (2002 - 2021) average productivity (unweighted)

Table A 5. Regional population estimates used in SCRAM for Roseate Terns.
Estimates of regional population size (with standard deviation values in parentheses) are presented by month. If no birds were assumed to be present in the U.S. Atlantic study region for a given month, that month was assigned a population size of zero. If there are no available data to estimate the standard deviation of a population estimate, it was assigned a value of zero. Collision risk estimates are not generated by SCRAM for months in which there are no data from the movement model (indicated in far right column of table). Source: Mostello 2021, Gochfeld & Burger 2020.

Month	Population Size Estimate	Justification	SCRAM estimates collision risk?
Jan	0 (±0)		No
Feb	0 (±0)		No
Mar	0 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	No
Apr	10916 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	No
May	10916 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	No
Jun	10916 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	Yes
Jul	4578 (±0)	Population estimate for U.S. and Eastern Canada (adults only)	Yes
Aug	16251 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 6)	Yes
Sep	16251 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 6)	Yes
Oct	16251 (±0)	Population estimate for U.S. and Eastern Canada (adults plus hatch-year birds; see Table A 6)	No
Nov	0 (±0)		No
Dec	0 (±0)		No

Table A 6. Northwest Atlantic population data for Roseate Terns.
Source: Mostello 2021.

Parameter	Value
Pairs	5458
Adults	10916
Average productivity (HY fledged per pair)	0.9775*
HY fledged	5335
Adults + HY	16251

*Average of 2018-2019 productivity for colonies at Bird (1.04 and 0.79 fledged/pair in 2018 and 2019, respectively), Ram (0.98 and 0.80), and Great Gull Islands (1.48 and 0.775 fledged/pair).

In addition to the assumptions used to estimate Roseate Tern regional population sizes by month as presented in Table A 5, the population size estimates include the following assumptions (Source: Mostello 2021, Gochfeld & Burger 2020):

- The entire Northwest Atlantic population could be present in the study area during the months listed
- The average of the most recent (2018 and 2019) productivity data from the three largest colonies (representing >90% of population) is representative of the entire population
- Fledging and post-breeding dispersal period occurs from July through September
- Occurrence in the study area through October is assumed to potentially include all birds, via birds stopping over in the mid-Atlantic (e.g., North Carolina), though the number of birds truly still present in the Atlantic study region is likely lower by this point in the year
- Non-breeding adults and one- and two-year-old birds that return but do not breed are not included in estimates

Table A 7. Morphometric and behavioral parameter values used in SCRAM.
PIPL – Piping Plover; ROST – Roseate Tern; REKN – Red Knot. Source documents are listed in the references below, and the reader is referred to these sources for additional detail on how values were derived. Note: values presented in this table are in the required units for inclusion in CRMs (see "Parameter Definitions"), and thus in some cases were standardized from units used in source documents. In the absence of reliable data on avoidance rates for any shorebird species at offshore wind farms, SCRAM uses the "all gull and tern species" avoidance rate as presented in Cook 2021 for all three species.

Parameter	Parameter definition	Value	Source	Derivation
Piping Plover				
Avoidance	Mean proportion of birds that avoid turbines	0.9295	Cook 2021	"all gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model (also almost the exact same value used for REKN in Gordon and Nations 2016 collision risk model)
AvoidanceSD	Standard deviation of the avoidance rate	0.0047	Cook 2021	"All gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model
Body_Length	Mean body length of the target species (m)	0.175	Elliot-Smith and Haig 2020	Midpoint of listed range of body length values
Body_LengthSD	Standard deviation of body length (m)	0.0025	Elliot-Smith and Haig 2020	Calculated from listed range of body length values
Wingspan	Mean species wingspan length (m)	0.381	Palmer 1967	
WingspanSD	Standard deviation of the species wingspan length (m)	0	N/A	No values found in the literature. Per McGregor et al. (2018), using zero SD until appropriate value can be estimated
Flight_Speed	Mean species flight speed (m/s)	11.7	Loring et al. 2020	From modeled migratory routes of Motus-tagged Piping Plovers across the mid-Atlantic Bight (n=17)
Flight_SpeedSD	Standard deviation of the species flight speed (m/s)	4.7	Loring et al. 2020	From modeled migratory routes of Motus-tagged Piping Plovers across the mid-Atlantic Bight (n=17)
Flight	Flight type, either flapping or gliding	Flapping	Hedenström 1993	Per definition provided for flapping vs. gliding
Roseate Tern				
Avoidance	Mean Proportion of birds that avoid turbines	0.9295	Cook 2021	"All gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model

Parameter	Parameter definition	Value	Source	Derivation
AvoidanceSD	Standard deviation of the avoidance rate	0.0047	Cook 2021	"All gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model
Body_Length	Mean body length of the target species (m)	0.37	Gochfeld and Burger 2020	Midpoint of listed range of body length values
Body_LengthSD	Standard deviation of body length (m)	0.02	Gochfeld and Burger 2020	Calculated from listed range of body length values
Wingspan	Mean species wingspan length (m)	0.76	Gochfeld and Burger 2020	Midpoint of listed range of wingspan values
WingspanSD	Standard deviation of the species wingspan length (m)	0.02	Gochfeld and Burger 2020	Calculated from listed range of wingspan values
Flight_Speed	Mean species flight speed (m/s)	12.77	Loring et al. 2019 (appendix)	Average speed across Mid-Atlantic U.S. Wind Energy Areas for PTT-tagged Common Terns (n=7 exposures from n=3 individuals)
Flight_SpeedSD	Standard deviation of the species flight speed (m/s)	4.8	Loring et al. 2019 (appendix)	Average speed across Mid-Atlantic U.S. Wind Energy Areas for PTT-tagged Common Terns (n=7 exposures from n=3 individuals)
Flight	Flight type, either flapping or gliding	Flapping	Hedenström 1993	Per definition provided for flapping vs. gliding
Red Knot				
Avoidance	Mean Proportion of birds that avoid turbines	0.9295	Cook 2021	"All gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model (also almost the exact same value used for REKN in Gordon and Nations 2016 collision risk model)
AvoidanceSD	Standard deviation of the avoidance rate	0.0047	Cook 2021	"All gulls and terns" avoidance rate from Table A2 - recommended value for terns using extended sCRM model
Body_Length	Mean body length of the target species (m)	0.24	Baker et al. 2020	Midpoint of listed range of body length values
Body_LengthSD	SD for body length of target species	0.005	Baker et al. 2020	Calculated from listed range of body length values
Wingspan	Mean species wingspan length (m)	0.495	Baker et al. 2020	Midpoint of listed range of wingspan values
WingspanSD	Standard deviation of the species wingspan length (m)	0.0225	Baker et al. 2020	Calculated from listed range of wingspan values

Parameter	Parameter definition	Value	Source	Derivation
Flight_Speed	Mean species flight speed (m/s)	20.1	Alerstam et al. 2007 (as calculated in Gordon and Nations 2016)	Estimate of cruising ground speed under calm conditions based on predicted relationship between body mass and wing loading
Flight_SpeedSD	Standard deviation of the species flight speed (m/s)	1.9	Alerstam et al. 2007 (as calculated in Gordon and Nations 2016)	Estimate of cruising ground speed under calm conditions based on predicted relationship between body mass and wing loading
Flight	Flight type, either flapping or gliding	Flapping	Hedenström 1993	Per definition provided for flapping vs. gliding

Appendix III. Differences between SCRAM and previous implementations of the Band model

SCRAM makes full use of recent advancements in quantifying the potential impacts of offshore wind energy development from Band (2012) and adaptions of the Band framework (Masden 2015, Trinder 2017, McGregor et al. 2018). We aimed to advance the implementation of this framework in the western Atlantic by 1) contributing updates to the primary model script and 2) developing an online interface that best addresses the specific needs of users and stakeholders in the eastern U.S. While there is significant overlap in the model description between our version and previous iterations, there are several important differences. The most consequential change to the underlying model is that we have reworked the data inputs to work primarily with movement data, as opposed to at-sea survey data. Movement data are widely available through automated telemetry, such as the Motus Wildlife Tracking System (Figure A 1), for key species of interest which may lack available density estimates to use in the prior CRM versions from which SCRAM was derived.

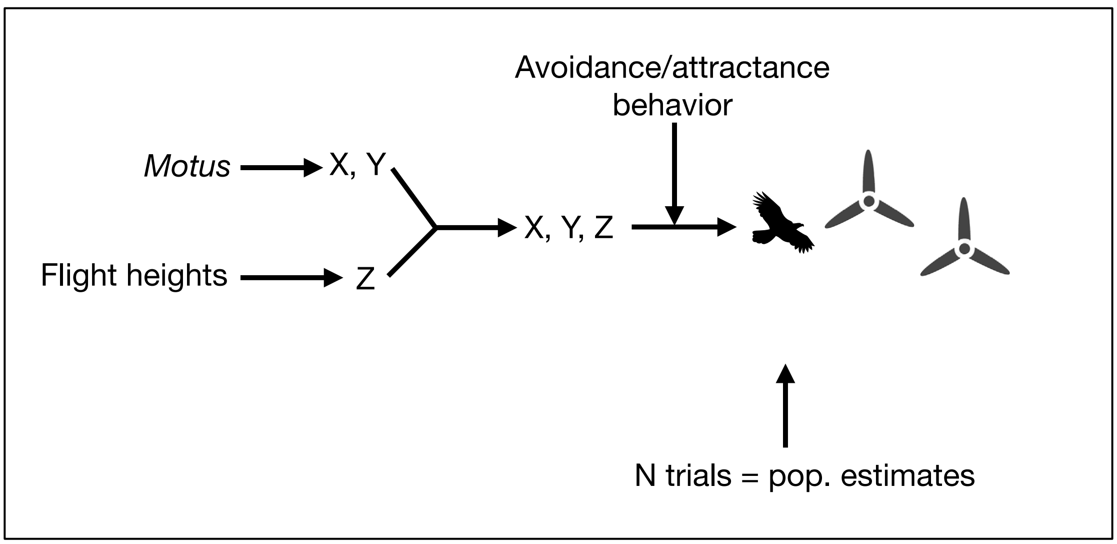


Figure A 1. Conceptual diagram of the primary model inputs for species data.
Estimates of species movements and species-specific flight height distributions from Motus data determine the daily longitudinal (X) and latitudinal (Y) position, and the summed altitudinal (Z) locations of individuals, which are combined with wind farm-specific information on turbine size/numbers to determine their risk of encountering rotor space. These estimated movements are combined with regional population estimates, corresponding to the sampling populations of the Motus projects, to estimate the total number of individuals likely to encounter rotor space for each month in which birds were tracked. Monthly collision risk is then estimated using the same assumptions as the other CRMs based on the Band framework (this component of the model is denoted by the square that contains turbines).

Rather than using density estimates developed from observational surveys, as with previous CRM iterations, in SCRAM we use daily detection data at Motus stations to parameterize a correlated random walk movement model (Baldwin et al. 2018). Through this process, we estimate the most likely daily locations for animals (along with model uncertainty) and overlay these predictions across a spatial grid. We estimate the number of individuals found in each grid cell and divide by the total number of individuals we were tracking that month. This allows us to estimate the proportion of the population found in each grid cell. By multiplying that with the regional population sizes (as estimated by USFWS experts and monitoring efforts; Appendix II), we determine the expected number of animals in each cell in each month and the width of the grid cell to convert those expected individuals to a passage rate per km. Past this point the model goes through the same process as Band (2012). An illustrative example of this process is presented in Appendix I. While the approach to population density estimation is different from CRM models that use survey data, the estimates of flux and collision risk remain substantially similar to the Band (2012) migratory collision risk model.

We have also revised several components of the primary model script, including an adjustment to how flight height distributions are integrated with risk along the rotor blade. We modified this component to treat flight heights as a statistical distribution, as opposed to point-wise sampling along the range of flight heights (see bullets below for more information). All of the changes to the underlying model code are tracked on GitHub.

In addition to the method whereby we estimate flux (above), perhaps the largest difference between our version and previous iterations relates to the delivery of the primary model script via the online interface. Our general philosophy was to make the interface as simple as possible, with most data inputs being embedded in the app or accomplished using .csv files that the user can store locally, as opposed to requiring the user to input data on the interface itself. We also designed the tool to encourage linear advancement through the model specification process. We accomplished this by 1) having a defined order of operations, and 2) providing specific, evidence-based guidance to identify the most appropriate model option while discouraging the use of more than one option at a time. We have also created more points of dialog with the user and functionality that address the inconvenience of potentially long run times with this CRM framework. SCRAM provides the take-home results on the application interface, but most of the model output is delivered via downloads of the raw results or a generated report that contains visualizations and input and output data tables. A more comprehensive list of differences between our version and previous iterations is given below.

Major differences in primary computational script

- SCRAM uses spatially explicit occupancy models derived from Motus data, rather than density estimates derived through surveys. To appropriately scale occupancy to the entire population, an estimate of population size (and uncertainty if available) is used (Appendix II).
- The primary computational script was revised to include a preamble that conducts a set of checks on the input data sources to ensure they are uploaded correctly.
- SCRAM's calculation of bird passage rates (referred to as "flux" in Band 2012) defines the migratory corridor width, required in the Band single transit model, as the width of

the grid cell. It also includes a correction for the proportion of transient vs. stationary behavioral states the model predicts for a given grid cell.

- SCRAM integrates the flight height distributions with risk along the rotor blade using cell-wise instead of point-wise probabilities. The consequence of this change is that the first probability of the flight height distribution (labeled as 1 m) corresponds to the band that is 0 – 1 m above sea level.
- SCRAM allows the user to conduct an approximated global sensitivity analysis to quantify the contribution of input data to the uncertainty bounds of the results.
- SCRAM allows for missing values (specified as NA) in the input data. This is useful, for example, when movement data are not available for every month. Missing values are automatically propagated through the model and displayed in the results accordingly.
- SCRAM calculates total operation time as wind availability*(1 – down time) to avoid the fact that negative values can theoretically happen with the original formulation (wind availability – down time).
- SCRAM estimates rotor speed using the relationship between tip speed ratio (TSR), wind speed (S), and rotor diameter (r): w = (TSR * S)/r * pi (in radians/s), which is converted to rpm.
- SCRAM fixes an error in the Riemann sum for rotor risk (used for the “extended” version of Band [2012]) that was causing a redundant loop.
- The primary computational script is run asynchronously, using the framework of making “promises” with the ‘promises’ and ‘future’ R packages (Bengtsson 2020, Cheng 2020), to allow multiple users simultaneously and allow the ability to cancel computational tasks.
- SCRAM allows the user to download inputs and outputs from every iteration of the model run.
- Tidal offset and nocturnal activity are no longer user-specified parameters.
- Inputs were simplified so that a global avoidance is used instead of option-specific rates.

Major differences in online interface

- SCRAM’s interface was built from the ground up, focusing on simplicity and encouraging a linear path through the tool.
- Only the most appropriate options in SCRAM are available to the user, depending on the input data and model specifications, to minimize the chance of running the model in a way the user did not intend.
- The majority of SCRAM’s results are given in a downloadable report rather than on the application interface.

Appendix IV. Metadata for input datasets

SCRAM input datasets for turbine and array characteristics (Table A 8) must match the specified input structure, including exact column names. Underlying species characteristics (Table A 9-Table A 11), as well as movement data (Table A 12), are "baked in" to the tool for the three focal species of Red Knot, Roseate Tern, and Piping Plover and do not need to be provided by the user. Movement data specify the estimated probability that an individual from the target population will pass through the modeled area in each month.

Table A 8. Turbine and array characteristics included in input datasets.
Each turbine/array characteristic, and when appropriate its associated uncertainty, is specified in a column. Each row gives the specifications for a turbine array of interest, so the number of rows should be equal to the number of different wind farm arrays in a single location and will dictate how many times the model will run.

Turbine parameter name	Definition
Run	The model run value – wind farm array number
Num_Turbines	The number of turbines in the wind farm array
TurbineModel_MW	The turbine model; this can be an descriptor
Num_Blades	Number of blades for the turbine model
RotorRadius_m	Rotor radius (hub to blade tip; m)
RotorRadiusSD_m	Standard deviation of rotor radius (m)
HubHeightAdd_m	The lower air gap – distance between lower blade tip and sealevel (m)
HubHeightAddSD_m	Standard deviation of the air gap (m)
BladeWidth_m	Chord width of blade (m)
BladeWidthSD_m	Standard deviation of blade width (m)
WindSpeed_mps	Mean wind speed at the wind farm (m/s) for the periods during which wind speeds are between cut-in and cut-out speeds of the turbine (i.e., turbines could be spinning); or if not available, the rated wind speed of the turbines. The speed at which turbines produce maximum power
WindSpeedSD_mps	Standard deviation of wind speed for the periods during which wind speeds are between cut-in and cut-out speeds of the turbine (m/s) or sd of the wind speed rating if it varies
Pitch	Pitch angle of blades (degrees relative to rotor plane)
PitchSD	Standard deviation of pitch angle of blades
WFWidth_km	Wind farm width (km)
Latitude	Latitude (decimal degrees)
Longitude	Longitude (decimal degrees)
Prop_Upwind	Proportion (0 - 1) of birds flying in upwind direction

MonthOp *(x12)*	Wind availability (maximum amount of time turbines can be operational/month). One column for each month, e.g., JanOp, FebOp…
MonthOpMean *(x12)*	Mean time that turbines will not be operational ("down time"), assumed to be independent of "MonthOp" – i.e., total operation = MonthOp*(1 – MonthOpMean). One column for each month, e.g., JanOpMean, FebOpMean…
MonthOpSD *(x12)*	Standard deviation of mean operational time. One column for each month, e.g., JanOpSD, FebOpSD…

Table A 9. Species characteristics included in input datasets.
Each species characteristic, and when appropriate its associated uncertainty, is specified in a column. Note: these data are currently baked into the model for the three focal species and cannot be user-specified.

Species parameters	Definitions
Species	Species name for associated data
Avoidance	Proportion of birds that avoid turbines
AvoidanceSD	Standard deviation of avoidance estimate
Body_Length	Body length of target species (m)
Body_LengthSD	Standard deviation of body length
Wingspan	Wingspan of target species (m)
WingspanSD	Standard deviation of target species
Flight_Speed	Flight speed of target species (m/sec)
Flight	Flight mode ("flapping" or "gliding")

Table A 10. Flight height data example.
This dataset specifies the estimated flight height distribution for the species of interest. The flight height distribution gives the relative probabilities of an individual flying at each height across the range of possible heights, at 1 m intervals from 1 - 1000 m. Columns are samples from the uncertainty distributions of the relative probabilities, which can be bootstrap samples or draws from a posterior distribution. Note: these data are currently baked into the model for the three focal species and cannot be user-specified.

Species	Height_m	BootId_1	BootId_2	BootId_3	BootId_4	…	BootId_100
Roseate_Tern	1	0.10	0.08	0.10	0.08		0.09
	2	0.09	0.08	0.09	0.07		0.08
	.						
	1000	0.08	0.07	0.08	0.07		0.04

Table A 11. Count data example.
This dataset specifies population sizes associated with the movement dataset for each species of interest. Columns specify the mean and standard deviation for the estimated population size, which can

vary by month. Note: these data are currently baked into the model for the three focal species and cannot be user-specified.

Species	Jan	JanSD	Feb	FebSD	Mar	MarSD	…	Dec	DecSD
Roseate_Tern	8598	912	8598	912	8598	912		8598	912

Table A 12. Format of underlying movement data.
Data are "baked in" to the tool for Piping Plover, Red Knot, and Roseate Tern and do not need to be provided by the user. This dataset integrates the summed daily (total monthly) occupancy probability that an individual would use habitat in a given grid cell for each month they are present in the area. Since each day can have an occupancy value from 0-1, the max value that can occur for any cell in any month is 31 (max. value 1 x 31 days = 31, range = 0-31 but depends on month length). Typically, values will be much less than that since distribution is spread over a large area. Each row is a sample from the uncertainty distributions of these estimates, is a draw from a posterior distribution. Note: these data are currently baked into the model for the three focal species and cannot be user-specified.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Roseate_Tern	NA	NA	NA	NA	NA	0.009	0	0.049	0	NA	NA	NA
	NA	NA	NA	NA	NA	0.104	0.37	2.1	6.6	NA	NA	NA
	.	.	.	.	.	.	.	.	.	.	.	.
	NA	NA	NA	NA	NA	0	0.21	1.2	7	NA	NA	NA

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