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

Developed by:
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Acknowledgements

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Many thanks for Brian Gerber, Thom Witting, and David Bigger for providing feedback on SCRAM which greatly improved the final product.

For More Information

The SCRAM Tool for which this User Manual was written is available at: https://briloon.shinyapps.io/SCRAM/. 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 request and bugs can be posted post at https://github.com/Biodiversity-Research-Institute/SCRAM/issues.

Citation

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Contents

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 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 western Atlantic: Roseate Tern (*Sterna dougallii*), Red Knot (*Calidris canatus*), and Piping Plover (*Charadrius melodus*). 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 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 add data for other species and/or provide their own site-specific data for the three focal species.

The underlying statistical models in 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 wind 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 or bat 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 and blades, rotor speed, altitude of the rotor-swept zone) and site-specific estimates of passage rates of focal species through the area of interest. Information from the scientific literature is used to estimate other characteristics of target species (e.g., typical flight speed, bird size, and avoidance behavior). This type of collision risk model includes all major components that are 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. Future work on SCRAM will explore providing estimates of risk across multiple projects (cumulative risk), but as of now SCRAM can be used serially to provide individual estimates of risk which can be added together to provide a rough estimate of cumulative risk within a region across sites. Adding up risk in this way is a good starting place, but it assumes that risk is fully additive and linear, which it probably isn't.

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, typically 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 may not be an optimal study method 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). More information on the differences between SCRAM and previous implementations of Band's (2012) collision risk framework is available in Appendix I. For additional technical details of the modeling framework used in SCRAM see Band (2012), Masden (2015), and Trinder (2017). Detailed information on SCRAM data inputs is included in Appendix II.

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 translation of these data to collision risk 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 in some way, this could likewise bias resulting collision risk estimates, regardless of the degree of uncertainty incorporated into these values. A source of bias is fine-scale deviances from the input data caused by a spatial or temporal mismatch in the scale of the area of interest (e.g., project wind farm) and the underlying data. 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. Additionally, there has been limited empirical validation of collision risk estimates with real-world measurements of collisions, due in large part to the difficulty in making such measurements reliably in the offshore environment. As such, CRM estimates should always be interpreted with caution.

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 arrays. While we are using the latest regional population estimates for the target species, 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 range for tagging. We hope that updates to our understanding of the population level movements will improve our estimates of collision risk. To allow updated data to be brought into SCRAM, in the future, we intend to provide a mechanism to allow users to modify species data for the three focal species (for example, to update estimates of regional population size with new values) as well as to upload data and operate SCRAM for other species of interest. 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.

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 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 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 was further modified to run on the Shinyapps.io remote server by the team at BRI. 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 the following location: https://briloon.shinyapps.io/SCRAM/

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 and included “*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.

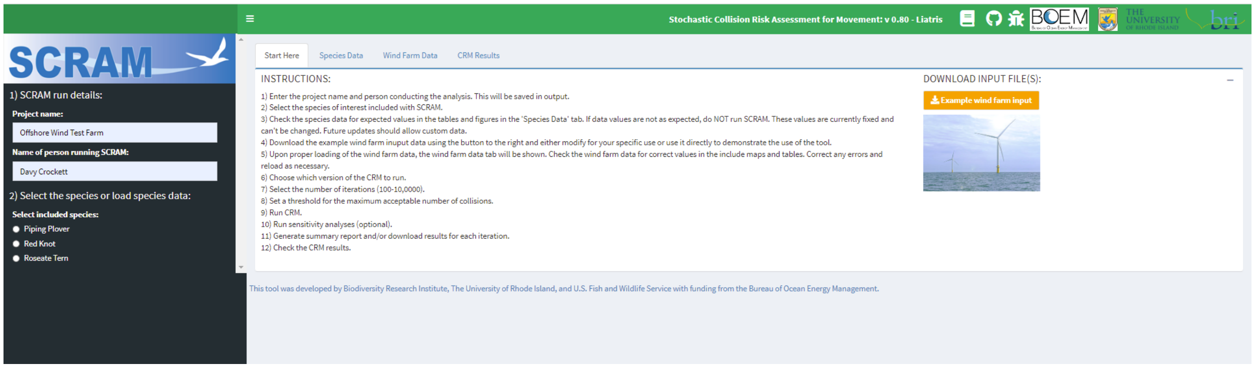
The most recent version available online is shown here along with a series of three symbols:

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 for SCRAM in GitHub.

And 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.



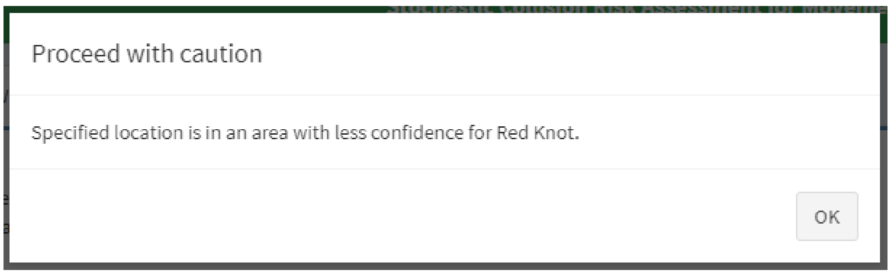
Examples of wind farm data input (Appendix II) can be downloaded from the application interface using the "Example wind farm input" buttons shown on the "Start Here" tab.

Once the data for turbine and array characteristics are compiled and formatted appropriately (see examples on interface and Appendix II), 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 which uses the flight height distribution but does not account for differences in risk along the rotor swept zone or slower/more accurate version that accounts for differences in risk by integrating the differences in risk along the turbine blades for a more accurate assessment of risk.
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.

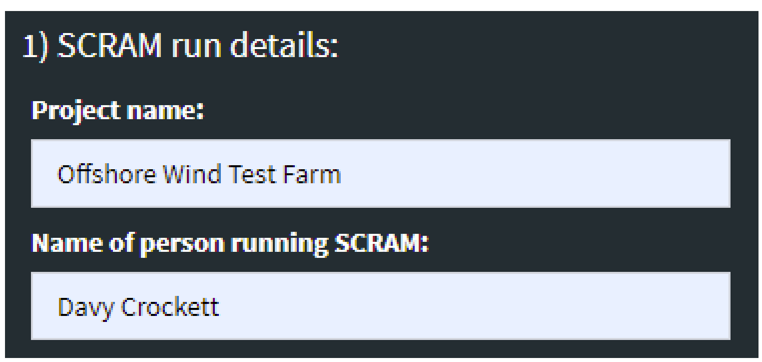
SCRAM results are not provided for locations and time periods for which the underlying species movement data are not available. For example, if the user specifies a geographic location in an area of low confidence, a warning is given, but SCRAM will still run.



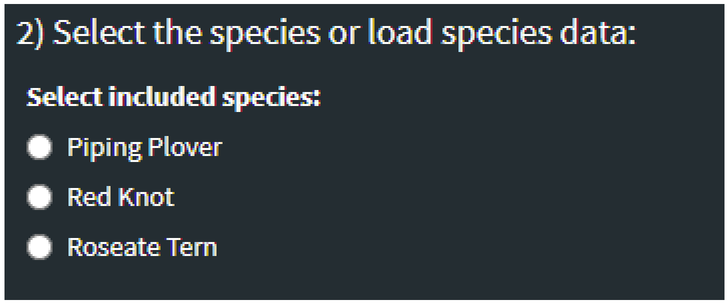
SCRAM will likewise not provide collision risk estimates for months of the year for which data are not available for a given species (e.g., winter periods for the three focal species currently included in SCRAM).

Detailed description of SCRAM usage

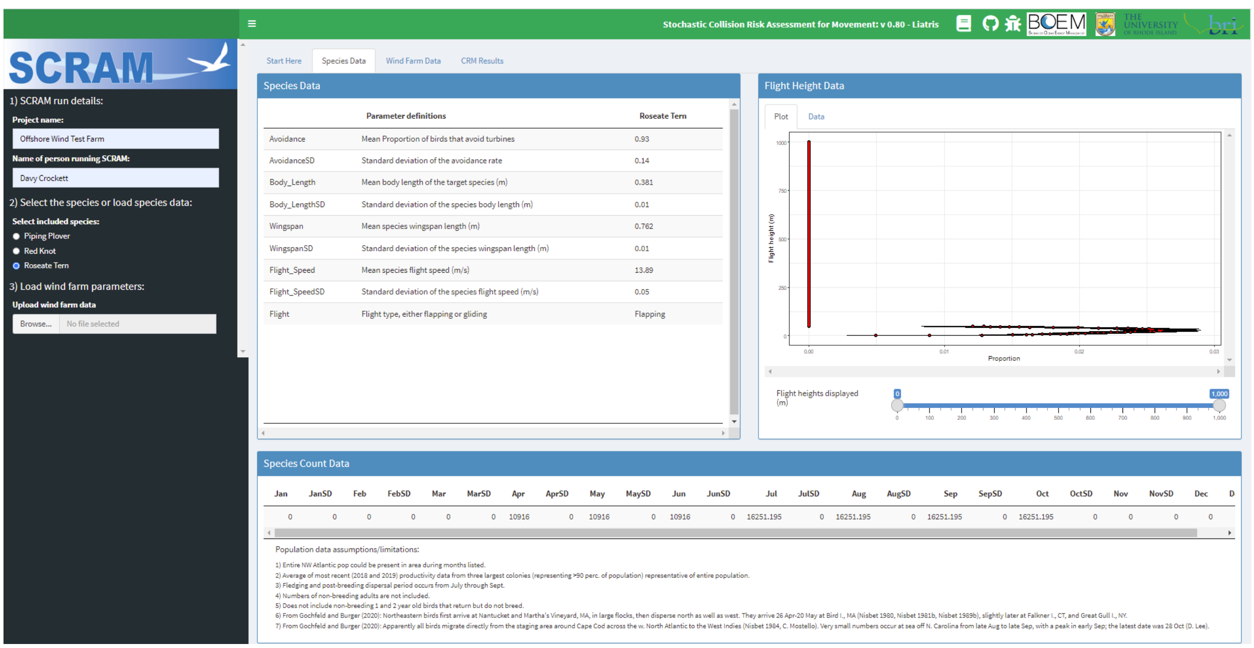
1) *Enter the project name and person conducting the analysis.* Choose whatever project name will be informative for you; this information will be saved in the output once SCRAM is run.



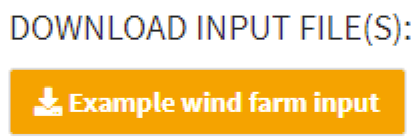
2) *Select the species of interest.* Select one of the included target species (Piping Plover, Red Knot, or Roseate Tern).



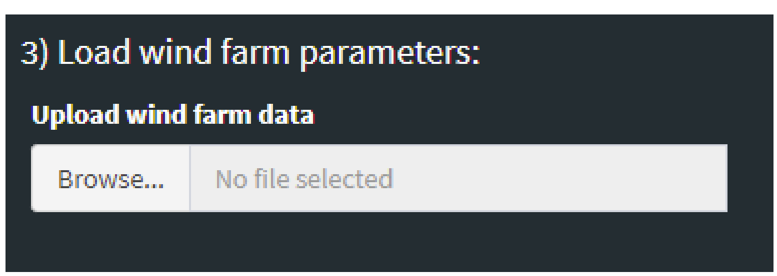
3) *Check the species data tables for correct values.* Make sure the values included in SCRAM are appropriate for these models by examining the tables and figures in the species data pane. Examine the flight height graph to see if the flight height data make sense and are appropriate for the model. The flight height graph and data table can be filtered for the range of flight heights of interest using the slider input bar. Population parameters are currently fixed in SCRAM and can't be changed, but are presented in a table for examination and outputted for reference. Do NOT run SCRAM if data is not as expected. Future updates will include the ability to add custom species data in the formats described in Appendix II.



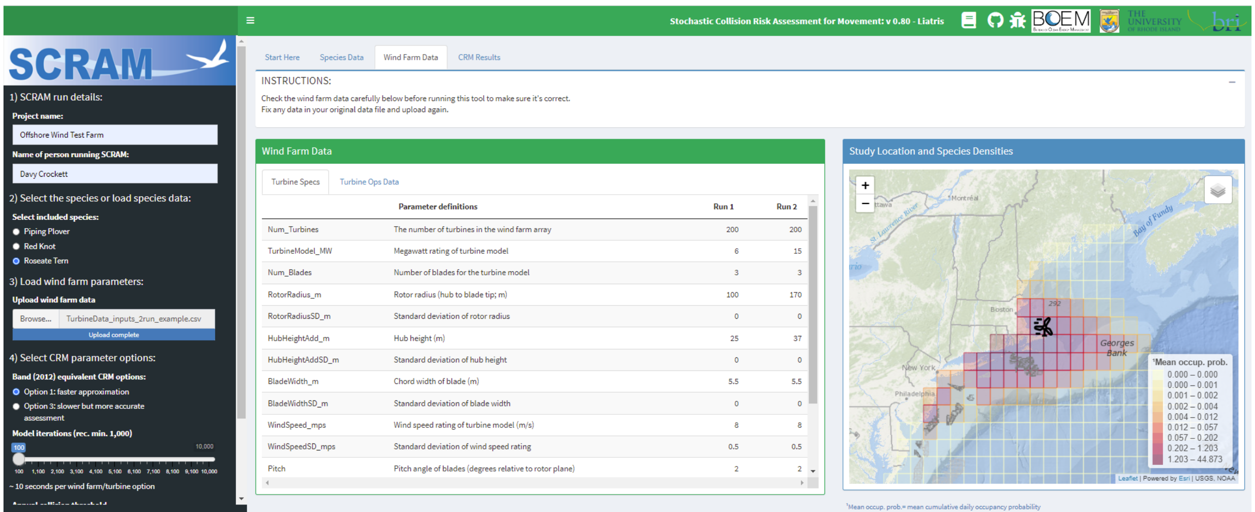
4) *Download the example wind farm input data from the "start here" tab to either use the example data directly or modify the file for your specific use.* Data for turbine and array characteristics are required to run any version of SCRAM. Turbine and array characteristics include the physical and geographic 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 II). Note that the included example file (TurbineData_inputs_2run_example.csv) shows an example of wind farm options.



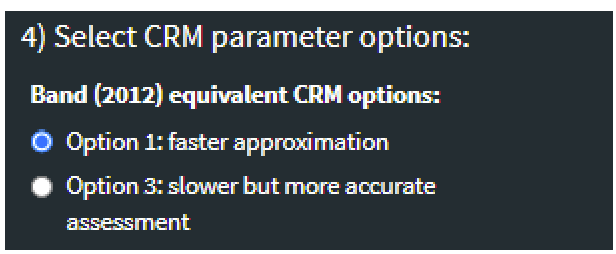
a. The application accepts these data as a single .csv file that has alternate options for arrays specified as rows. You can provide as many options as you desire by adding rows, or remove the second option row if only a single option is desired. SCRAM will run and provide outputs for each row in this 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 during the planning and consulting phases, typically specify wind turbines as a design envelope (range of engineering specs) rather than a single wind turbine specification to account for the min and maximum ranges of engineering measurements for 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) 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 II).
e. Turbine specifications, such as blade pitch and width, can 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.

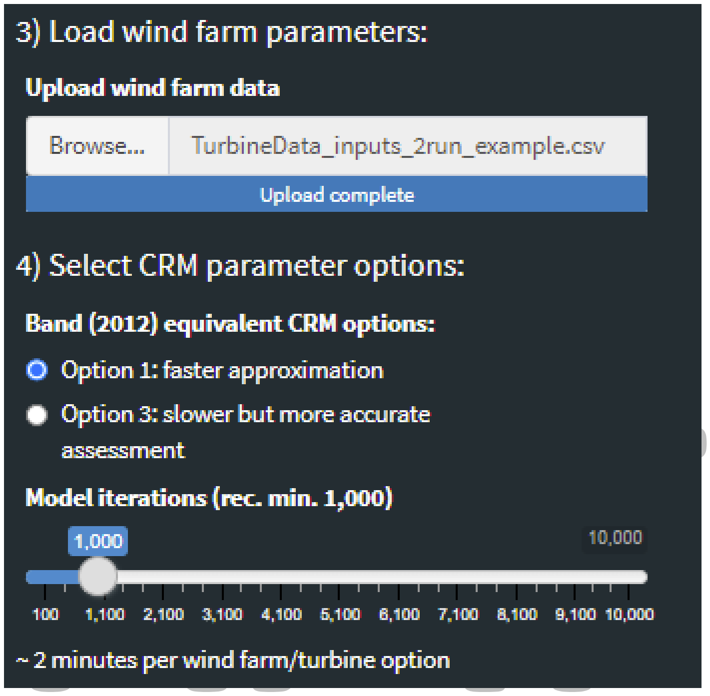


6) *Choose which version of the CRM to run (the faster/approximate version or slower/more accurate version).*

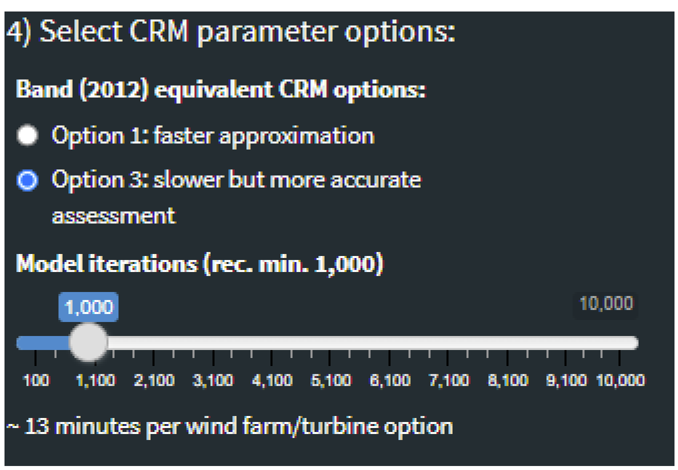


The principles that the CRM uses to simulate collision risk are simple, but there are two flavors for how these principles are executed that differ in how input data are used in the underlying calculations. Band (2012), Masden (2015), and Trinder (2017) provided several options, which we synthesized 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 but is presumed to be constant throughout the rotor swept zone and is faster to run. Using “Option 3: slower but more accurate” SCRAM allows collision risk to vary at different altitudes along the rotor blades and thus provides a more accurate accounting of collision risk (Trinder 2017) but is slower to run.

Because these options estimate collision risk using the same data input, **we recommend selecting "Option 3: slower but more accurate" whenever the user is not severely limited by computation time**. 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.

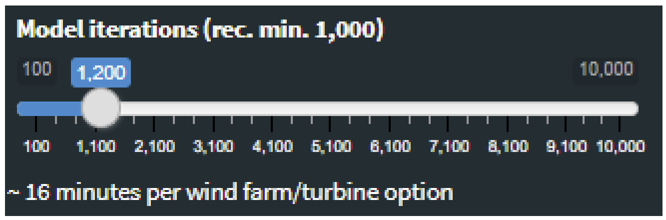


The same number of iterations per run takes ~13 minutes using option 3 when accounting for differences in risk along the blade.



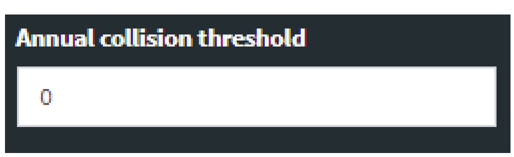
We do not recommend running both options for comparison because, in most cases, the option that estimates risk along the rotor blade (option 3) will provide the more accurate estimate. (Trinder 2017).

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 accurate 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.

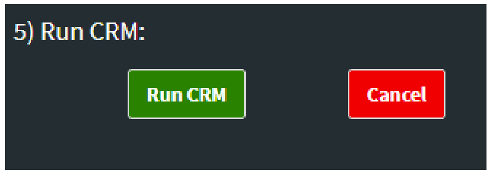


We recommend running **at least 1,000 iterations**, but SCRAM defaults to a minimum of 100. For final estimates of collision risk, and to get the best estimate from SCRAM, **10,000 iterations should be run** but note that this can take ~2 hours per turbine model/wind farm specification. The user must 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.

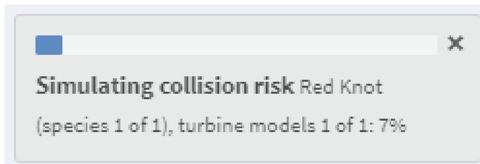
8) *Set a threshold for the maximum acceptable number of collisions in a year.* If desired, specify a threshold for the maximum acceptable number of collisions (this number can be zero). Note that changing this does not change the results except for a calculation of exceeding this probability, just the presentation of the 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.



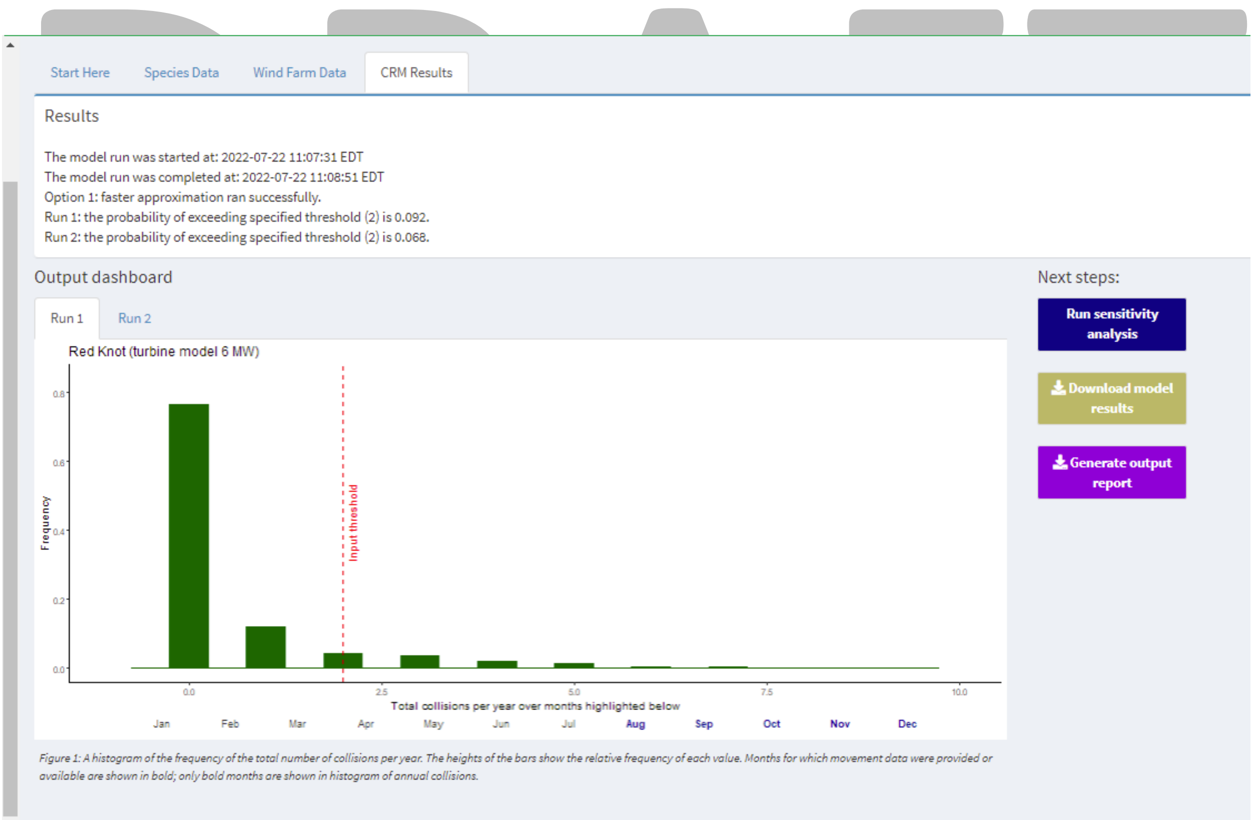
9) *Run CRM.* The button to run the CRM appears when the minimum conditions for running the model are met.



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.



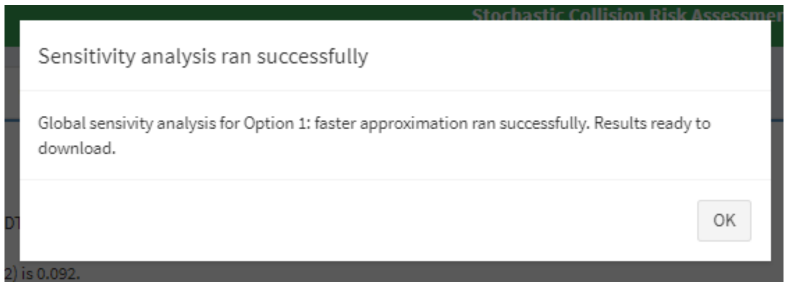
Once the model has completed, the CRM results tabs displays basic results including details of the model run times, the model that was run, probability of exceeding the threshold, and histograms (one for each wind farm option) of the number of collisions per year for each iteration. This histogram is 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. Species movement model data files zipped.
    ii. Species population data.
    iii. Model output Rdata file that can be directly loaded in R
    iv. Collision estimates for each month in each iteration as a .csv file
    v. The stochastic draws of all input parameters for each iteration as a .csv file
    vi. 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 (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, wind farm and species occurrence map, 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, a figure showing the predicted mean and 95% prediction intervals for the number of collisions per month, a figure showing the number of collisions per month for each species and

turbine model combination, and histograms comparing the difference in the number of collisions per year between models.

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 accurate 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, 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. 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 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 re-worked the data inputs to work primarily with movement data – as opposed to survey data – as 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. In developing this new input, we also made it possible to use the Band model framework with missing values, allowing assessments to be conducted for areas or time periods with incomplete data availability.

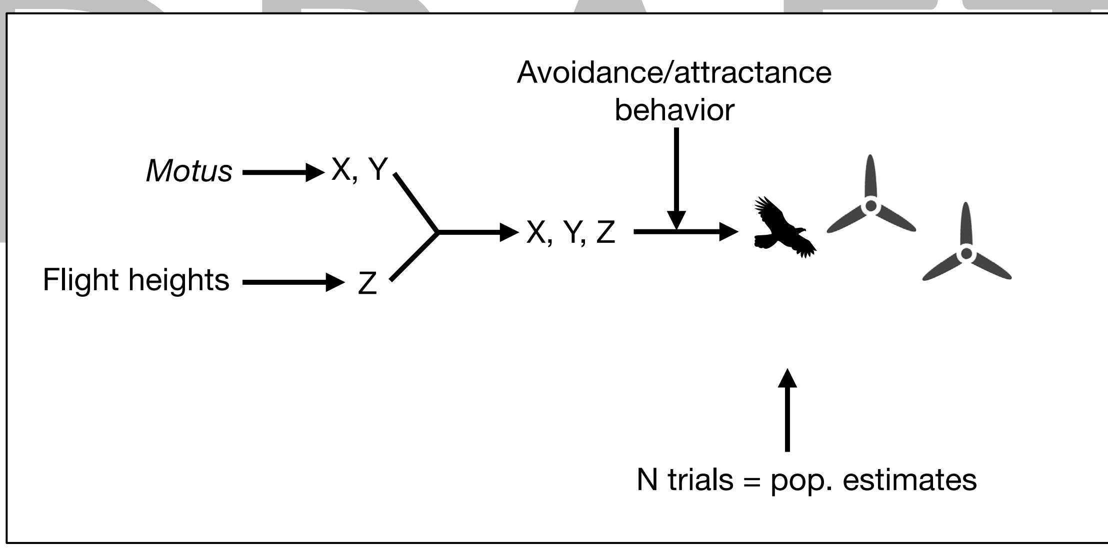


Figure A 1. Conceptual diagram of the primary model inputs for species data. Estimates of species movements from Motus data and species-specific flight height distributions determine the longitudinal (X), latitudinal (Y), and altitudinal (Z) locations of individuals over the course of a year, which in turn 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).

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.

The largest differences between our version and previous iterations relate 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 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 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's primary species input is Motus data and therefore it uses flight speed and habitat-use estimates derived from tracking data rather than bird passage rates per unit time (referred to as "flux" in Band 2012).
- SCRAM uses spatially explicit occupancy models rather than density estimates derived through surveys. To appropriately scale occupancy to the entire population an estimate of population size (and uncertainty) is used (Appendix III).
- 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 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.
- SCRAM includes additional warnings to caution the user about applying the application to areas with sparse data or low confidence.

Appendix II. Metadata for input datasets

SCRAM input datasets for turbine and array characteristics (Table A1) must match the specified input structure, including exact column names. Underlying species characteristics (Tables A2-A4), as well as movement data (Table A5), which specify the estimated probability that an individual from the target population will pass through the modeled area in each month, 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.

Table A1. Turbine and array characteristics included in input datasets. Each turbine/array characteristic, and when appropriate its associated uncertainty, is specified in a column. The table should be 54 columns wide. 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 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	Megawatt rating of turbine model
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
HubHeightAdd_m	Hub height (m)
HubHeightAddSD_m	Standard deviation of hub height
BladeWidth_m	Chord width of blade (m)
BladeWidthSD_m	Standard deviation of blade width
WindSpeed_mps	Wind speed rating of turbine model (m/s)
WindSpeedSD_mps	Standard deviation of wind speed rating
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 A2. Species characteristics included in input datasets. Each species characteristic, and when appropriate its associated uncertainty, is specified in a column. The table should be 10 columns wide. 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 A3. Flight height data example with appropriate units. 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. The table should contain 1000 rows (not including the header). The number of columns is flexible, but we recommend at least 100 to adequately represent the sampling distributions. 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 A4. 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. The table should be 25 columns wide. 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 A5. Format of underlying movement data, which 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 specifies the estimated probability that an individual from the target population will pass through the modeled area in each month. Each row is a sample from the uncertainty distributions of these estimates, is a draw from a posterior distribution. The table should be 13 columns wide. 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

Appendix III. Description and sources of target species data used in SCRAM

TODO: Before full release we will explain where the input species data are coming from or how they were derived. For example, the flight height data come from, or the regional population size estimates.

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