U.S. Fish & Wildlife Service

Standard Operating Procedures for the Risk Assessment Mapping Program (RAMP)

U.S. Fish and Wildlife Service
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Part One: Introduction

Background

With the spread of invasive species and the threat of climate change, scientists and resource managers have considerable need to predict future boundaries to species ranges. Environmental tolerances, such as thermal tolerances, are important determinants of the range of a species. Despite the variety of additional factors that can influence the realized range of a species, mapping and modeling the climatic niche can be an important first approximation of potential near-future and far-future range (Pearson and Dawson 2003, Broennimann et al. 2007).

Examples abound to illustrate the utility of climate matching—that is, measuring the similarity of one set of climate conditions to another—to predict species range. Thuiller et al. (2005) predicted the ranges of nonnative plants in South Africa based on climate similarity. Bomford et al. (2009, 2010) showed significant associations between native climates and climates of the introduced ranges of amphibians, reptiles, and freshwater fishes. Indeed, Hayes and Barry (2008) showed that climate or habitat match is one of the few predictors of establishment success that holds across diverse taxa.

The Risk Assessment Mapping Program ("RAMP") is a mapping tool that uses the current geographic range of a species to predict the climate suitability of other geographic areas or future time periods. It was developed by the U.S. Fish and Wildlife Service (Service) primarily to assist with risk assessment of nonnative aquatic wildlife and plants. RAMP is user-friendly in that it requires no knowledge of statistics or coding languages to operate, and it runs on computer software that is commonly available in natural resource agency offices. RAMP provides a suite of potential target regions for climate matching focused on U.S. species management applications, although options for other target regions within North America exist.

The RAMP process was peer reviewed in 2014 to fulfill requirements established by the Office of Management and Budget for influential science produced by Federal government agencies ("Final Information Quality Bulletin for Peer Review"; OMB 2004). Three expert reviewers who were not Federal employees provided their comments, which were then summarized without attribution and addressed in the Service's Peer Review Summary (https://www.fws.gov/science/pdf/RAMPPeerReview20150831.pdf). In response to a peer review comment, we added a checklist for quality assurance and quality control (QA/QC) to Appendix B; thus, that checklist was not peer-viewed.

Purpose

The purpose of this document is to provide instruction to users of RAMP. Readers will learn how the tool works, how its output may be used, and how to operate it for themselves. Appendix A of this document provides more technical details for users who may want to further their understanding or to compare the results of this program to other methods.

How RAMP Works

RAMP identifies similarities between a selected set of global climate stations and a target set of climate stations within North America or on U.S. lands in the Pacific Ocean. For a given target region, RAMP can match current climate in the source locations to current climate (defined as the average climate between 1950 and 2000) in the target region, or predicted future climates in the target region at two time periods: 2050 (representing the average predicted climate over 2041-2060) and 2070 (representing the average predicted climate over 2061-2080). RAMP implements the climate algorithm that is currently used by Climatch (Crombie et al. 2008) and CLIMATE for Mac (Pheloung 1996) and Windows (Barry 2006). As the starting point for identifying climate matching source locations, species occurrence records are automatically downloaded from the Global Biodiversity Information Facility (GBIF; http://www.gbif.org/species) through an internet connection.

The climate stations in RAMP represent a suite of variables that characterize maximums, minimums, and changes in air temperature and precipitation on a monthly or annual basis (see Appendix A for more information). Although RAMP uses air temperatures rather than water temperatures as the temperature inputs, the tool is applicable to both terrestrial and freshwater aquatic species because of the close relationship between water temperatures and air temperatures (Stefan and Preud'homme 1993). Bomford et al. (2010) and Howeth et al. (2016) both successfully predicted freshwater fish species establishment based on air temperature. RAMP is not intended for use in assessing climate match for marine species.

RAMP Output and Applications

RAMP provides both graphical and numerical outputs to describe and quantify the degree of climate match. More explanation of these outputs and guidance on their interpretation will be provided in Part Three: Using RAMP.

As the name "Risk Assessment Mapping Program" suggests, the development of RAMP was motivated by risk assessment applications within the Service, specifically for aquatic invasive species. The Service uses RAMP to conduct climate-matching analyses that inform risk determination for the Service's Ecological Risk Screening Summary (ERSS) tool. The Service also uses RAMP to obtain a quantitative measure of climate match that serves as input to the Bayesian Network "Freshwater Fish Injurious Species Risk Assessment Model" (FISRAM). More information and standard operating procedures for both ERSS and Bayesian Network FISRAM tools are available on the Service's website:

ERSS https://www.fws.gov/fisheries/ans/species_erss.html and
Supporting Documents
https://www.fws.gov/fisheries/ans/erss_supporting_documents.html

RAMP has also been used outside of the Service for applications involving native species in the United States, particularly for prediction of future species range under different climate change scenarios (Jason Granberg, Wisconsin Department of Natural Resources, personal communication). Similarly, RAMP can be used for a species native to one region of the United States that may invade a region where it is not native.

RAMP Versions

RAMP version 2.81 was released in 2014, and was the first version used in applications. RAMP version 3.1 was released in 2018. Upgrades present in RAMP version 3.1 include:

- Addition of U.S. commonwealths and territories as target regions
- Ability to conduct a climate matching analysis for a single State or territory
- Reorganization of tool dialog boxes for improved flexibility and clarity
- Improved handling of extremely high and extremely low volumes of species occurrence data

How to Cite RAMP

Please use the following citation for RAMP version 2.81:

Sanders, S., C. Castiglione, and M. Hoff. 2014. Risk Assessment Mapping Program: RAMP. U.S. Fish and Wildlife Service.

Please use the following citation for RAMP version 3.1:

Sanders, S., C. Castiglione, and M. Hoff. 2018. Risk Assessment Mapping Program: RAMP, version 3.1. U.S. Fish and Wildlife Service.

Part Two: General Guidelines for Using RAMP

Analyst Qualifications

RAMP operates within the ArcGIS program suite (Esri, Redlands, California[1]), so it is desirable that analysts (users) have basic familiarity with ArcGIS software. This familiarity will facilitate navigation and trouble-shooting while using RAMP. ArcGIS skills that may be used in the process of conducting a RAMP climate match include:

- Opening and working within an existing project file
- Navigating the ArcToolbox
- Selecting features; adding and removing features from the current selection
- Exporting a map
- Adding and removing data layers

Analysts should have a working knowledge of population biology and of the natural history of the species to which the climate matching analysis is being applied. Additionally, analysts should be competent at conducting thorough literature searches and critically evaluating information sources. Available information on geographic range may be of varying quality. The analyst should be able to apply the data quality standards described below to discern which reported locations represent valid occurrences of a species and which reported locations are questionable.

Data Quality Standards

The quality of data informing the climate match is reflected in the quality of the climate matching analysis itself. Analysts should rely as much as possible on expert-validated species occurrence databases and peer-reviewed literature to identify geographic occurrences of the species of interest. Furthermore, unless there is a reason to do otherwise, analysts should limit the locations used for climate matching to those where a species is **established**. Established populations are those that are maintained through natural reproduction and are not reliant on the introduction of individuals from elsewhere (including escaped or released ones). By using only established locations, the analyst can ensure that medium and high matches within the target region represent places with climates where a species can not only survive briefly, but can both survive long term and reproduce.

RAMP is designed to automatically populate the map of source locations for the climate match based on data from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/), using GBIF data as a starting point for performing a match. GBIF is one of the most comprehensive databases of species occurrences worldwide, but it is not devoid of errors. GBIF occurrences need to be validated by the analyst through comparison with other reputable sources of information that report species range. Such reputable sources include expert-validated species information databases and peer-reviewed literature.

Peer-reviewed literature is a valuable source for additional species occurrences beyond GBIF. Journal articles often include a study area map that depicts species occurrences or they may report GPS coordinates of species occurrences in a table or in the text.

"Gray literature," such as non-peer-reviewed websites, newspapers, or other nonscientific literature, may also be used to identify species occurrences. Gray literature should be read

[1] Mention of commercial products does not necessarily constitute endorsement by the U.S. Government.

critically, especially in cases where a species may be hard to identify or distinguish from congeners, or if only a common name is provided. If the analyst is not confident that the species identification was correct, the source should not be used. All literature, peer-reviewed or not, should be carefully examined if the scientific name of the species has changed over time or there are other types of taxonomic uncertainty. This examination ensures that the individual or population discussed in the literature belong to the species for which the climate matching analysis is being conducted.

Administrative Record

Analysts conducting a climate matching analysis should maintain an administrative record documenting the sources of information used to produce the climate match. This set of files should include copies of all maps or coordinates used to generate the source map, such as a copy of the GBIF entry for the species and copies of any journal articles containing maps or coordinates that were used to add occurrences to the source map.

A checklist for quality assurance and quality control is included in Appendix B of this document. A completed checklist should be included in the administrative record for any climate matching analysis unless the climate matching analysis is embedded in a larger work that has its own methods of quality assurance and quality control, such as the ERSS. The checklist ensures that the analyst has conscientiously reviewed the information used in the climate matching analysis and documented all sources and decision-making involved in the analysis.

Additionally, the final administrative record should include the species folder that is created automatically while running RAMP. This folder holds all information to run a reproducible climate matching analysis with consistent source locations. The folder becomes particularly important if the analyst makes modifications to the GBIF data by adding or subtracting source locations based on other sources of information, and as the GBIF data change over time.

Part Three: Using RAMP

This part of the document is directed at the analyst as a step-by-step guide for using RAMP.

Developing an Understanding of Species Range

The first step in the process of running a climate matching analysis comes before opening the RAMP project file in ArcGIS. To produce a successful climate match, you need to be knowledgeable about the locations where the species has occurred and where it is established, whether those locations are part of the native range or part of an introduced range. You should use any resources available to you to develop your understanding of species range. At this point, range descriptions (written or graphical), rather than georeferenced occurrences, are the focus of the literature search.

Use reputable databases to identify the countries, States, provinces, or local jurisdictions in which the species is established. If the climate matching analysis is done as part of an ERSS, the analyst should follow the guidance on searching for priority databases that is found in the ERSS SOP (https://www.fws.gov/injuriouswildlife/pdf_files/ERSS-SOP-Final-Version.pdf). For other purposes, recommended databases include:

- For all taxa, worldwide – IUCN Red List[2] (http://www.iucnredlist.org/)
- For all U.S. taxa – NatureServe Explorer (http://explorer.natureserve.org/index.htm)
- For all fishes – FishBase (http://fishbase.org/search.php); Catalog of Fishes (https://www.calacademy.org/scientists/projects/catalog-of-fishes)
- For all birds – eBird (http://ebird.org/content/ebird/); Birds of North America (https://birdsna.org/Species-Account/bna/home; requires subscription); All About Birds (https://www.allaboutbirds.org/)
- For introduced or invasive taxa – Invasive Species Compendium (https://www.cabi.org/isc); GRIIS (http://www.griis.org/)
- For U.S. introduced or invasive aquatic taxa – USGS Nonindigenous Aquatic Species Database (https://nas.er.usgs.gov/default.aspx)
- For introduced or invasive estuarine invertebrates – NEMESIS (http://invasions.si.edu/nemesis/browseDB/intro.html)

Additionally, use Google Scholar (https://scholar.google.com/) or an academic search engine such as Web of Science (http://webofknowledge.com) to search for species occurrence data in the published literature. These data could come in the form of written descriptions or maps of locations where the species has been reported.

Using GBIF Data

After developing an understanding of the range of the species of interest, you should examine and evaluate the GBIF entry for that species (page 6). As stated above, this entry will provide the foundational data for the climate matching source locations.

Find the species entry using the species search tool (http://www.gbif.org/species). Note that recent taxonomic changes may not be reflected in GBIF, so try synonyms if the accepted scientific name does not yield a hit. Subspecies may have unique entries in the database. The components of a GBIF species entry include a map of all georeferenced occurrence records in

[2] The range maps provided by the IUCN Red List may have inaccuracies. When using the IUCN Red List, focus on the written description of the range rather than the map.

GBIF data sources, lists of data sources and occurrence details, and information on scientific and vernacular synonyms.

The tools in the bottom right corner of the occurrence map will allow you to modify the map appearance and explore the data in greater detail. You can change the basis of record (for example, "observation," "literature," "preserved specimen"), the style of the map, and the map projection. The "Explore Area" button leads to a table of all occurrences currently visible in the map view. Clicking on a line of the table will bring up the full record for that occurrence. To limit the size of the table, zoom in on occurrences of interest on the map before clicking "Explore Area". Pay attention to any highlighted issues in the full occurrence record. It is not necessary to check the full record of every observation in GBIF. Instead, you should use the information already gathered on species distribution to identify potential outliers—that is, occurrences that warrant further investigation when viewing the map in the species record, such as marine locations. You should then view the full occurrence record for each of those potential outliers. Compare the mapped occurrence location with any written description of the location provided within the occurrence record. For example, an occurrence described as a collection made in a forest stream but mapped to an urban center should be considered inaccurate. The geographic coordinates for such occurrences may represent the location where a specimen is held by a museum rather than the location where the specimen was collected. Make note of all GBIF occurrences that do not represent accurate locations for the species so that these points can be excluded from the climate matching source locations later. Additionally, note all GBIF occurrences that represent introduced but not established populations of the species by comparing occurrence data to information gathered on species distribution; these points will also need to be excluded from the climate matching source locations.

Collecting Supplementary Occurrence Data

Guided by the data quality standards described above, re-examine the published and gray literature you collected while developing an understanding of species range. Occurrences not from GBIF that are mapped or for which coordinates are provided can be incorporated into the climate matching source locations for RAMP. Furthermore, because the map of climate matching source locations is constructed on a 75.9-km grid, it may be possible to localize a species occurrence to a single RAMP climate matching source location from a verbal description of its location even without coordinates.

Finding additional species occurrences beyond those reported in GBIF is especially important when the mapped occurrences in GBIF do not cover the entire known range of the species. This situation is most likely to occur for species distributed in Africa or western and central Asia. Often, at least one published study can add occurrences to the collection so that no large geographic areas of the range go unrepresented.

Additional occurrence information in the form of coordinate datasets can be added to RAMP after Step 2 (page 12). As with GBIF data, these datasets should be checked for outliers and to ensure that occurrence records represent established populations. Databases from which supplementary occurrence datasets can be gathered and the data type are listed below:

- BISON (https://bison.usgs.gov/#home): Data can be downloaded as a '.csv', KML, or shapefile from the main page. The shapefile is the easiest to import to RAMP but one of the other files may be smaller in size if download size is a consideration.
- eBird (https://ebird.org/home): Data can be downloaded as a '.txt' file after submitting a request for access (https://ebird.org/data/download). A free account is required. There

will be a large amount of irrelevant data in the downloaded file in addition to coordinate data.

- EDDMapS (https://www.eddmaps.org/distribution/): Data can be downloaded as a '.csv' or KML file from the distribution maps. Some data filtering may need to occur before running the climate match if there are negative occurrence records in the data set.
- FishBase (http://fishbase.org/search.php): Data can be downloaded as a KML from the 'Point Map' page of a species entry, available in the Tools section.
- USGS Nonindigenous Aquatic Species Database (https://nas.er.usgs.gov/default.aspx): Data can be downloaded as a '.csv' file from the point map.
- VertNet (http://vertnet.org/): Data can be downloaded as a '.txt' file from the map page.
- Literature-based locations: If location coordinates are given in peer-reviewed literature, they can be entered in a spreadsheet and saved as a '.csv' or '.xls' file. This is a good option for those who do not feel comfortable adding points from literature manually (explained further below).

You can also download datasets from the Invasive Species Compendium (https://www.cabi.org/isc) but these data only give a point in the center of the country or political unit where the species is present and not the locations of actual observations. This type of data is not appropriate to use as a source for a climate match.

Conducting a Current Climate Match

Software Requirements

Running RAMP requires an internet connection and a licensed copy of ArcGIS software. RAMP version 3.1 was developed for ArcMap version 10.5. It has been tested for back-compatibility to ArcMap versions 10.3 and 10.4. These versions do not automatically install all necessary Python libraries; once these libraries ('numpy' and 'panda') are installed, RAMP 3.1 will run successfully in ArcMap 10.3 and 10.4.

The files necessary to run RAMP consist of the ArcMap project file ('.mxd'), a "data" folder, a "Scripts" folder, and a "Species" folder. All four components should be saved to the same location on your computer or network.

General Process

The RAMP toolbox[3] includes three tools that must be run in three sequential steps:

1. **Create Species Profile (New GBIF)**
2. **Get Species Pre-Selection**
3. **Perform Match**

The first tool is used to create a folder for storage of all of the files created by RAMP pertaining to the species. The first tool also downloads any GBIF data associated with the species name. The second tool is used to populate the map of climate matching source locations with species occurrences. The third tool is used to run the climate matching analysis and produce maps and other outputs. This last tool allows you to select the appropriate target region for the match as well as the appropriate climate scenario. The following sections of this Standard Operating Procedures (SOP) will step you through the use of these tools using the example of the fishhook

[3] The RAMP toolbox may need to be added to ArcToolbox manually the first time the RAMP project file is opened. It is available in the "Scripts" folder. Instructions for adding toolboxes to your version of ArcMap can be found online. You may need to restart ArcMap after adding the toolbox.

waterflea (*Cercopagis pengoi*), an aquatic crustacean native to western Asia (Benson et al. 2017). Depending on the speed of your internet connection, each tool may take up to 15 minutes to run, but with most high-speed internet connections, each tool will run in less than 3 minutes.

Step 1 - Create Species Profile

To run the first tool, type the scientific name of the species into the dialogue box (Fig. 1). To avoid errors, ensure that the scientific name you use is the same as the name used by GBIF and that there are no extra spaces before, within, or after the name. After this step is complete, a folder labeled with the species name (for example, "Cercopagis_pengoi") will have been created inside RAMP's Species folder.

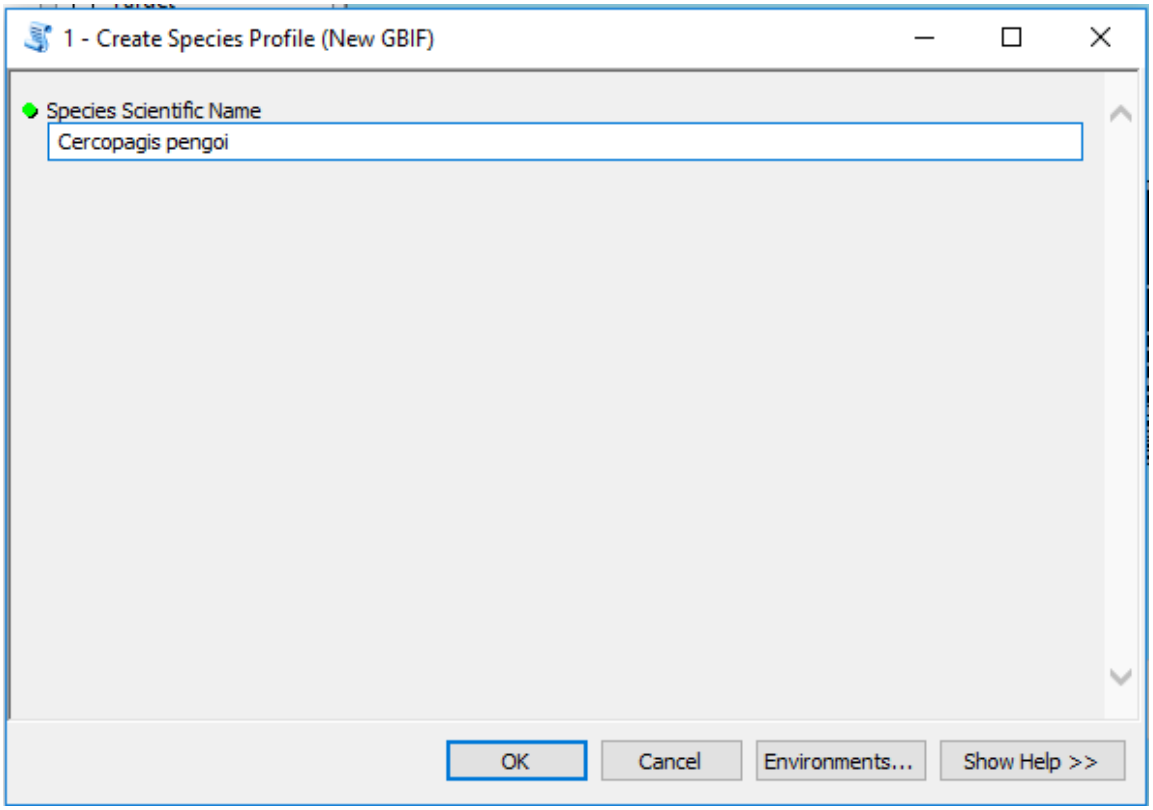

Figure 1. Dialogue box for the first tool in the RAMP process.

Errors may occur on this step if there are no georeferenced GBIF occurrence records for the species of interest, or if there are more than 200,000 georeferenced GBIF occurrence records. The error message will identify the type of error. If there were too many occurrence records, the error message will provide instructions for downloading GBIF data manually. Regardless, check the Species folder to see if a folder has been created. If so, you can still continue through the RAMP process.

Step 2 - Get Species Pre-Selection

There are three options to run the second tool (Fig. 2):

- Option 1: To use the data downloaded automatically from GBIF as the basis for selecting climate matching source locations, type the species name into the "Species Name" dialogue box. Again, ensure that the scientific name you use is the same as the name used by GBIF and that there are no extra spaces before, within, or after the name.
- Option 2: To use other sources of species occurrence data, click next to "Use Existing Data" instead of typing in the species name. Here, "existing data" refers to an ArcGIS feature class already saved on your computer. Click on the folder icon to navigate to the location where the file is saved and select it. Note that the selected file must be an ArcGIS feature class; follow the instructions in subsequent sections of this SOP to use data from other file types.
- Option 3: To use a set of climate matching source locations that you have used previously to run a RAMP climate match, type the species name into the "Species Name" dialogue box. Then, click next to "Use Previous Selection" to expand the option and then check the box. This option loads the climate matching source locations that were saved within the species folder including any modifications made in the previous run. Without checking this box, the GBIF data will be loaded without any modifications made previously.

Skip running this tool entirely if: the "Create Species Profile" tool failed earlier because of too many or too few GBIF records, you have reason not to use the GBIF records, or the only occurrence records available are not importable by the "Use Existing Data" option.

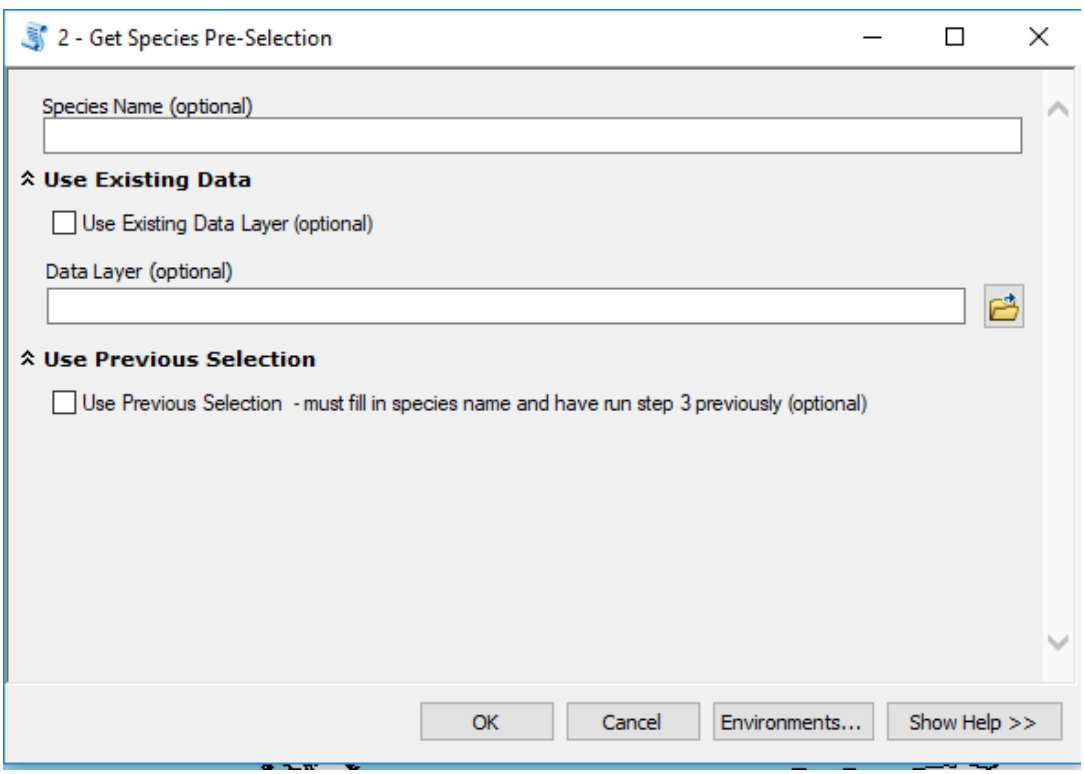

Figure 2. Dialogue box for the second tool in the RAMP process.

After running the tool, the map window will refresh with a mix of red (selected) and gray (unselected) climate stations (Fig. 3). The selected points are those within a 100-km radius[4] of a species occurrence location, as identified in the input data from GBIF or other imported data file.

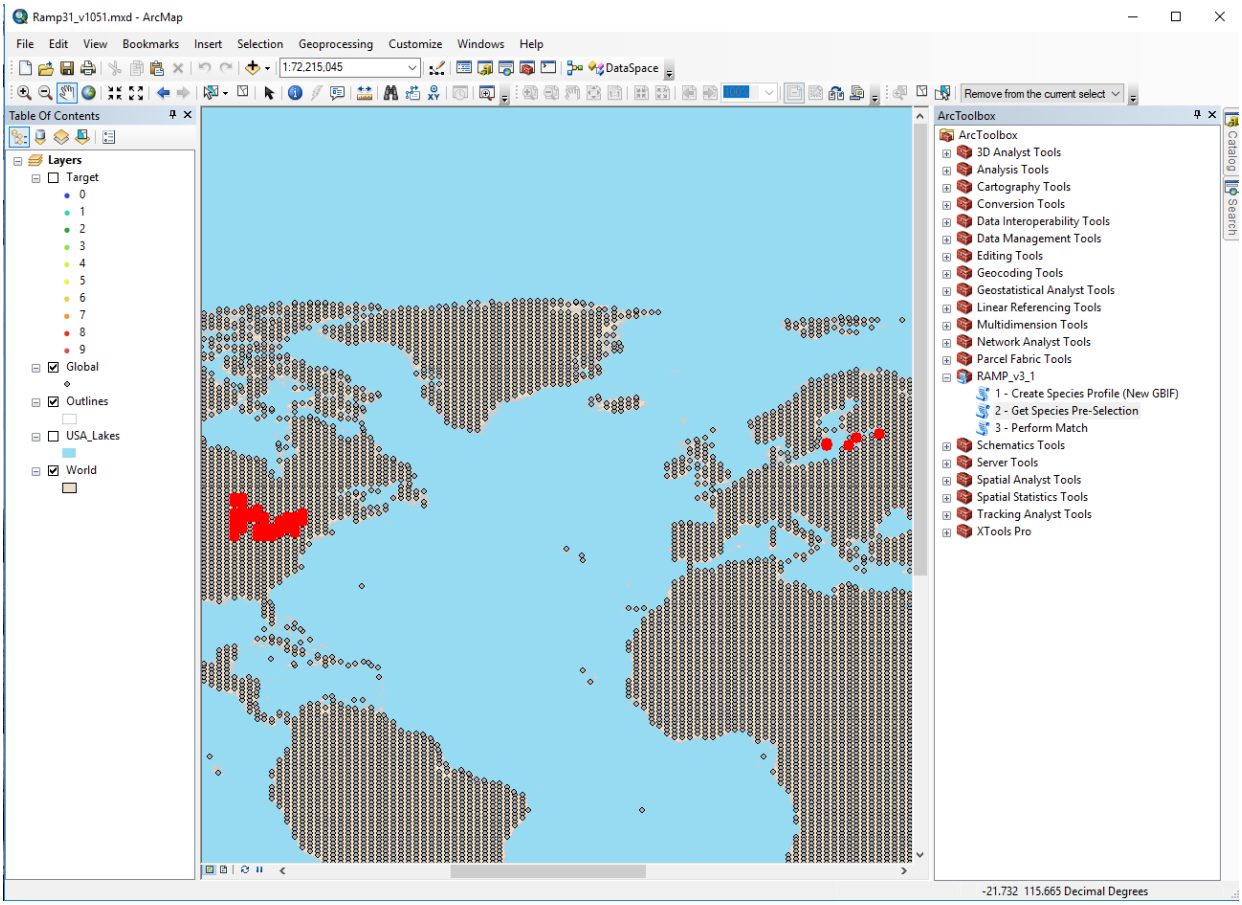

Figure 3. Selected (red) and non-selected (gray) source locations for *Cercopagis pengoi* based solely on georeferenced occurrences reported in GBIF Secretariat (2017).

Adding or Subtracting Individual Source Locations Manually

You will often need to modify the selected climate matching source locations from those generated automatically from uploaded data. Climate matching source locations may need to be eliminated or added manually if species occurrences were reported incorrectly in the species occurrence source data, if the species occurrence source data included occurrences that do not represent established populations, or if additional species locations were found in a print journal article or report.

To modify climate matching source locations manually, use the RAMP Selection toolbar (Fig. 4). The dropdown menu allows you to choose whether you want to add or remove points. Click on the selection icon to the left of the dropdown menu to activate the tool. From there, you can double-click on individual points to select or de-select them, depending on the choice selected in the dropdown menu. Alternatively, you can draw a polygon around a group of points

[4] The 100-km selection radius is the default, but you can choose a different distance by downloading the GBIF data manually and following the steps described in "Adding Supplementary Datasets" with a different selection distance specified.

to select or de-select all of the points within the polygon at once. Double-click when placing the last vertex of the polygon.

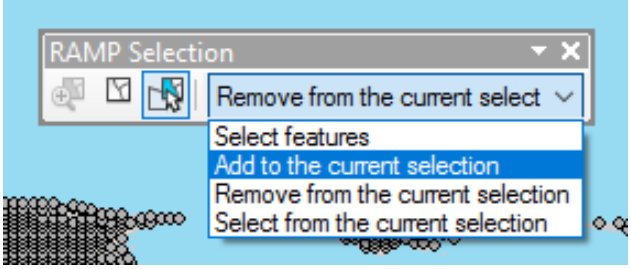

Figure 4. RAMP Selection toolbar showing drop-down menu where you can choose the type of selection to make with the selection tool.

Adding Supplementary Datasets

If you want to upload occurrence datasets from outside databases or were unable to run the "Get Species Preselection" tool, you will need to add supplementary datasets as "XY data". Datasets from other sources may be in a few different formats: '.csv', '.txt', '.xls', '.xlsx', KML ('.kml', '.kmz'), or Shapefile ('.shp' and associated '.shx' and '.dbf'). Instructions for adding these data to the map are available online: http://desktop.arcgis.com/en/arcmap/10.5/map/working-with-layers/adding-x-y-coordinate-data-as-a-layer.htm.

Once the data are added to the project, use the 'Select by Location' tool in the ArcMap Selection menu (not the RAMP Selection toolbar) to select source points based on the non-GBIF data (Fig. 5). Use the following settings:

- Selection method: add to the currently selected features in
- Target layer(s): Global
- Source layer: (the name of the layer or displayed points of the dataset)
- Spatial selection method for target layer feature(s): are within a distance of the source layer feature
- Selection distance: 100 Kilometers

Repeat the process if there is more than one supplementary dataset. After selecting the additional source points they can be edited using the manual method described above ("Adding or Subtracting Individual Source Locations Manually"). Once editing is complete, remove the supplementary dataset itself from the project. If the dataset is still displayed on the map when the final tool is run, those points will also display on the output maps. After modifying the source map as needed, proceed to the final tool in the RAMP toolbox. The climate matching analysis will now be performed on the selected source points as visible on the screen (Fig. 6), rather than the selection from GBIF alone.

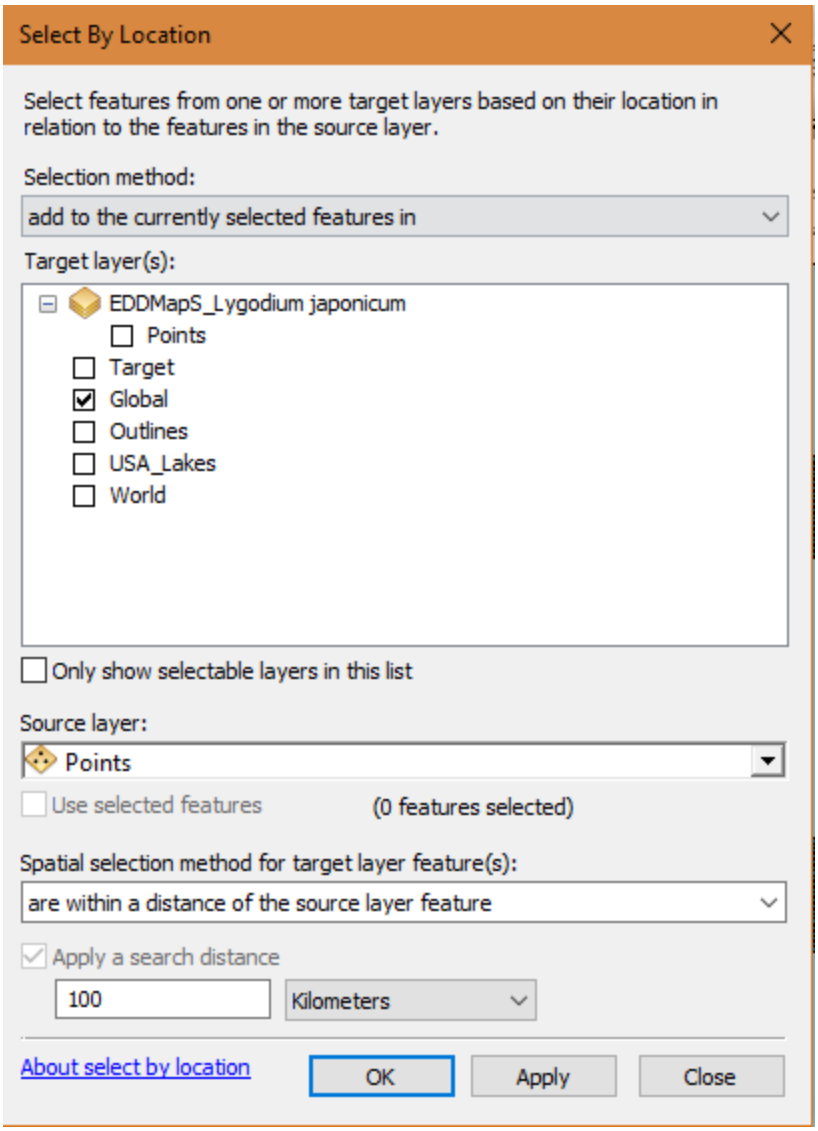

Figure 5. ArcMap Select By Location tool showing settings for selecting additional source points based on non-GBIF supplementary datasets.

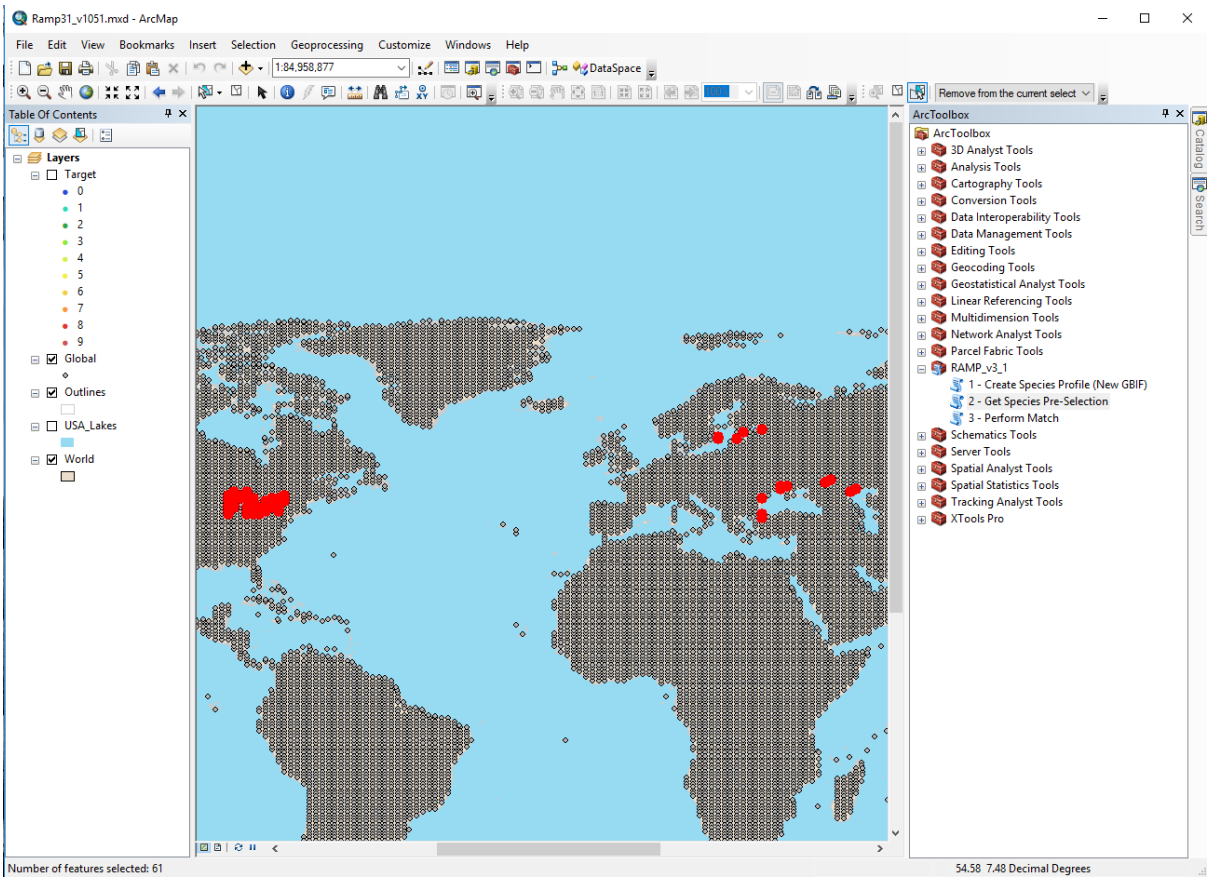

Figure 6. Selected (red) and non-selected (gray) climate matching source locations for *Cercopagis pengoi* based on georeferenced occurrences reported in GBIF Secretariat (2017), supplemented by information from Cristescu et al. (2001; for Romania, Russia, and Ukraine), Güher (2004; for Russia and Turkey), and Benson et al. (2017; for the United States).

Step 3 - Perform Match

The final tool in the RAMP toolbox runs the climate matching analysis now that the climate matching source locations have been set. To run this tool, you will need to specify the target region for the match as well as the climate scenario (Fig. 7). As with the other tools in the RAMP toolbox, you will need to enter the species scientific name as the name used by GBIF and ensure that there are no extra spaces before, within, or after the name to avoid errors.

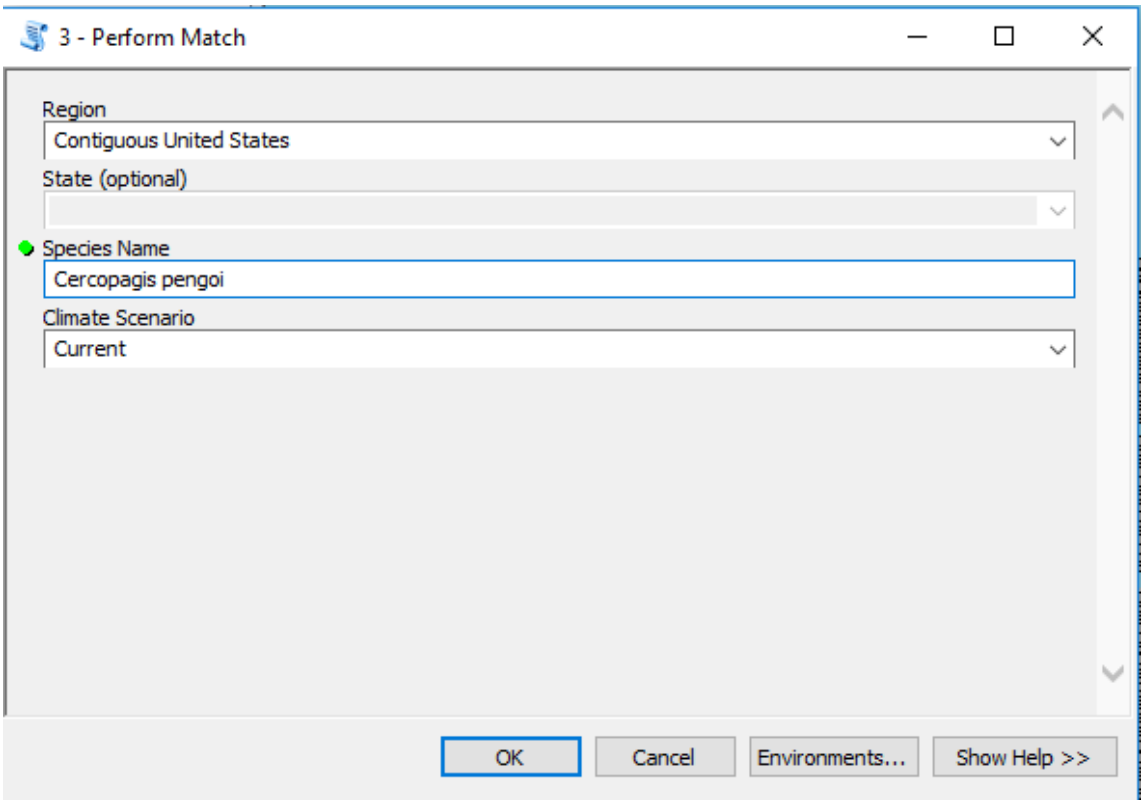

Figure 7. Dialogue box for the third tool in the RAMP process.

The target region for a match must be selected from a fixed set of options (Fig. 8). The default option is the "Contiguous United States", meaning all U.S. States except Alaska and Hawaii. Three countries can be run individually: United States, Canada, and Mexico. Larger geographic areas that can serve as targets include North America, Central America, and the Caribbean. For more localized matching, you can select target regions of "Great Lakes Basin" or "Individual State". With the "Individual State or Territory" option, a second drop-down menu will become available that enables selection of an individual State, commonwealth, or territory of interest by standardized postal abbreviation (Fig. 9). Once complete, the "Canadian Province" option will work in the same way as the "Individual State or Territory" option, but it is not currently operational.

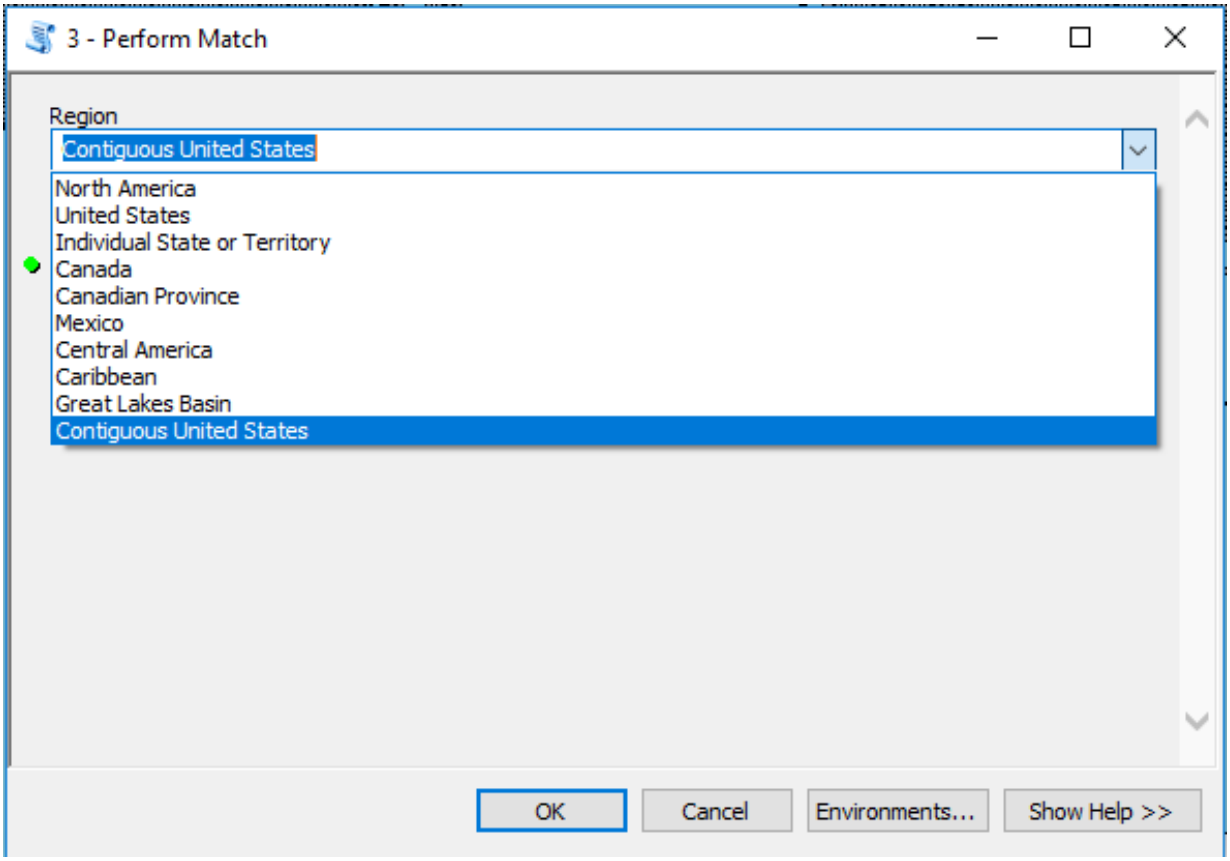

Figure 8. Menu of potential target regions for climate matching in RAMP, available in the dialogue box for the "Perform Match" tool.

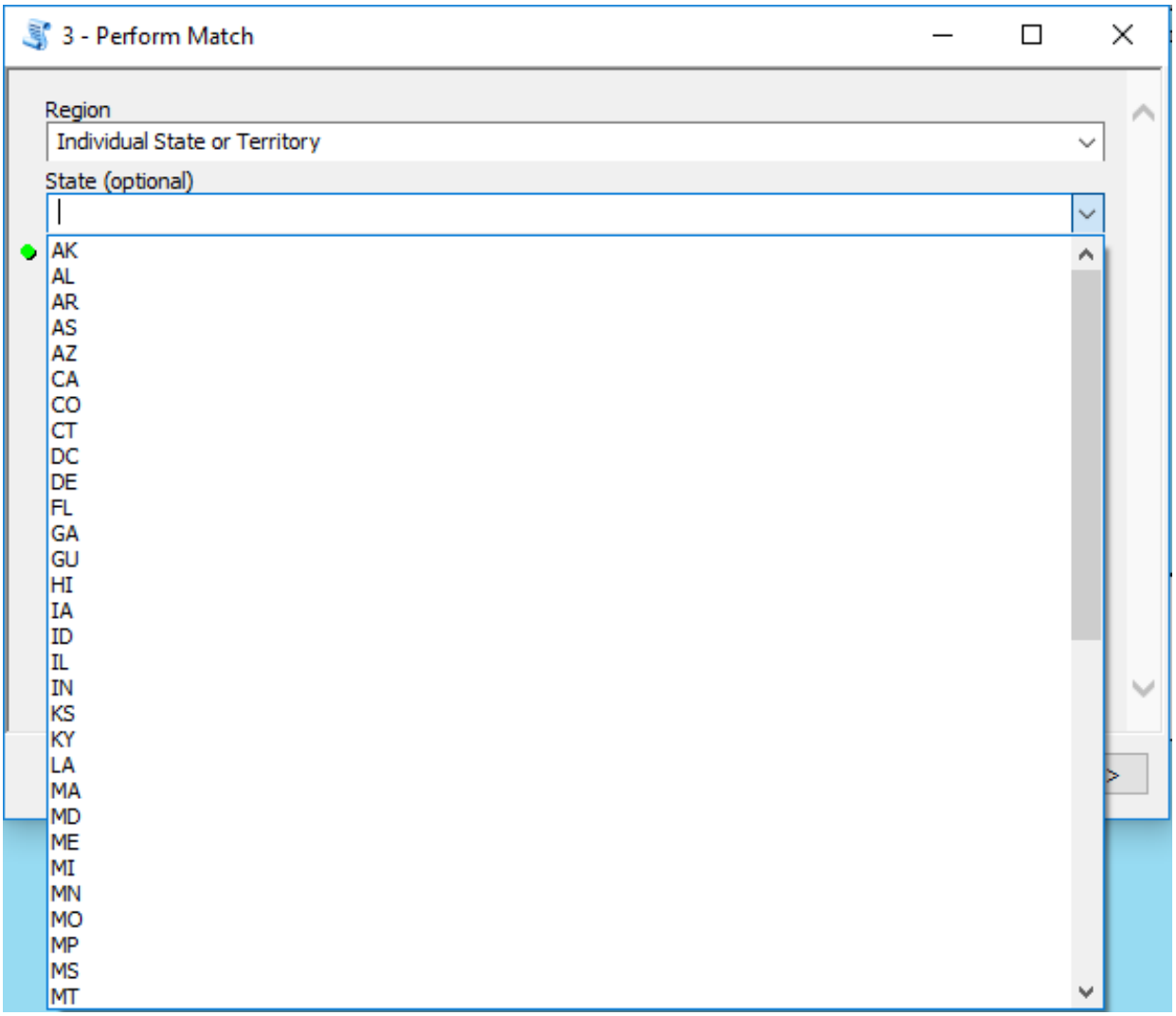

Figure 9. Sample of the menu of potential target regions for climate matching in RAMP after selecting the "Individual State" option in the dialogue box for the "Perform Match" tool.

The final specification required before the climate matching analysis can be run is to select the climate time period and scenario for matching (Fig. 10). You can calculate match to the current climate (1950-2000) in the target region or to climate in the target region as predicted for two future points in time: 2050 (representing the average predicted conditions over 2041-2060) and 2070 (representing the average predicted conditions over 2061-2080). Because the future is uncertain, if selecting a future period, you will also have to select a climate change scenario, each represented by a representative concentration pathway (RCP). The available RCPs in RAMP cover a range of scenarios, including RCP2.6 (the least extreme change), RCP4.5, and RCP8.5 (the most extreme change). More detail on these scenarios can be found in Appendix A. A general recommendation for climate matching to future climates is to calculate matches for all scenarios and both time periods to view the range of possible outcomes.

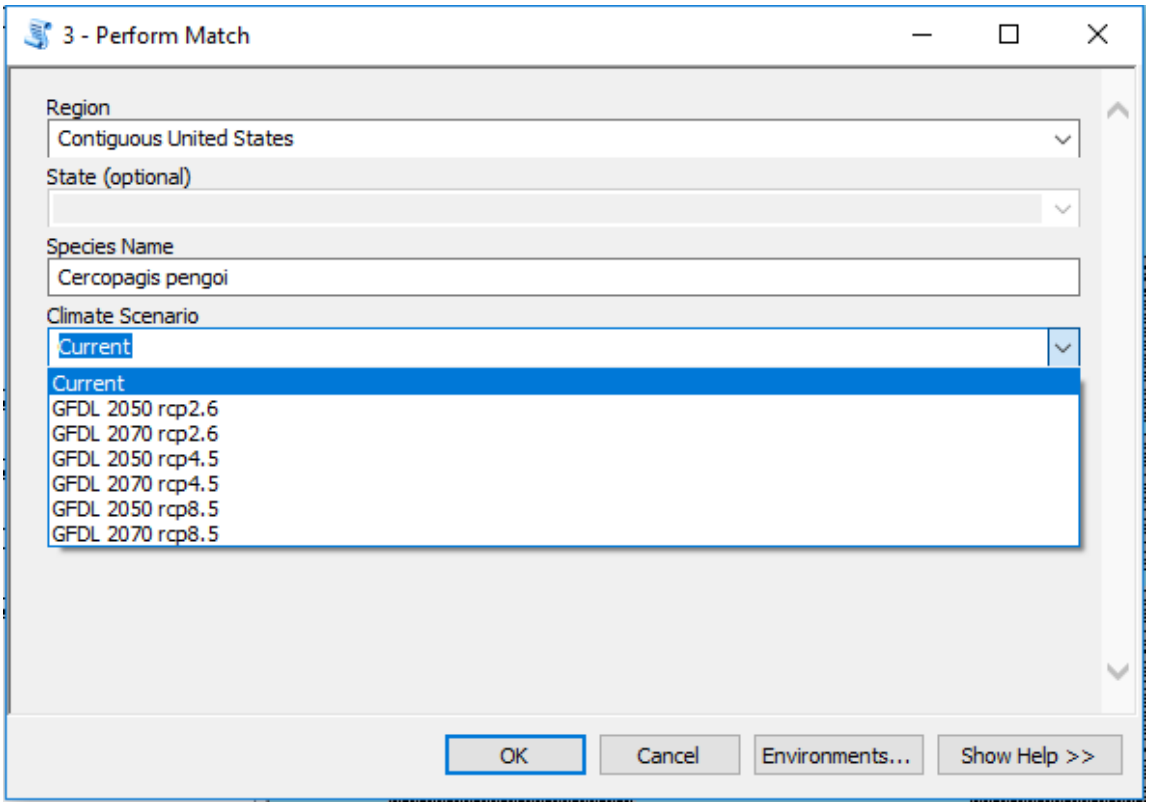

Figure 10. Menu of potential climate scenarios for climate matching in RAMP, available in the dialogue box for the "Perform Match" tool. The abbreviation "GFDL" signifies the chosen global climate model (Appendix A) for future climate matching.

After selecting the appropriate options in the "Perform Match" tool's dialogue box and clicking "OK", the climate matching analysis will run. The image shown on the screen will change a few times throughout the process. The final image will show the climate matching results; they are also saved automatically to the species folder. Interpretation of these results is discussed below, but for now you have three options: (1) close out of RAMP (do not save changes to the map file so that it will reset when you open it again); (2) run another match for the same species but with a new target region, climate scenario, or time by returning to the second tool in the process; or (3) run a match for a new species by returning to the first tool in the process.

Batch Data Processing (Advanced)

In RAMP, it is possible to run each tool for multiple species or match parameters at the same time. To access the batch processing option, right-click on the name of the tool within ArcToolbox. We do not recommend using batch processing in Step 2, because you will need to review the selected source locations for each species individually. The best use of batch processing in Step 3 is running matches for a single species with multiple target locations, climate scenarios, or time periods. When multiple species are included in the same batch, RAMP may not associate source locations with the appropriate species.

Interpreting Results

RAMP provides the results of a climate matching analysis in both visual and numerical formats, along with several files containing additional information for mapping and results (Table 1).

Table 1. Files produced as a result of running a climate matching analysis in RAMP. Example file names are provided for the species *Cercopagis pengoi*.

File Name	*Description*
Cercopagis_pengoi.gdb	Species geodatabase containing original points (Points feature class) and climate stations (*{species name}*_Stations feature class) used to perform the match, as well as symbology for the layers
Cercopagis pengoi GBIF Locations.csv	Spreadsheet of coordinates for GBIF occurrence data
Cercopagis_pengoi_Contiguous_United_States_Current_Frequency.cpg	Text file that identifies the character encoding used
Cercopagis_pengoi_Contiguous_United_States_Current_Frequency.dbf	Table of score counts for match to Contiguous United States and current climate
Cercopagis_pengoi_Contiguous_United_States_Current_results.jpg	Image of climate matching results for the United States with current climate
Cercopagis_pengoi_Global_Selected.jpg	Image of map of selected source points
GBIF Cercopagis pengoi.url	Internet shortcut to GBIF.org species profile

Maps

By running the third tool in the RAMP process, two JPEG image files are produced. One of these files shows the source map created in Step 2, along with any changes you made to the source locations (Fig. 11). You can include this image in any report about the climate match as evidence of the selected source locations. Be aware that, if the climate matching source locations are located close together, the source map image produced automatically by RAMP may have too small of an area for the locations to be identifiable. In such situations, you can export a map (File menu) with the desired area after making all necessary modifications to the climate matching source locations and before performing the match. The export should be done in the data view rather than the layout view of the map.

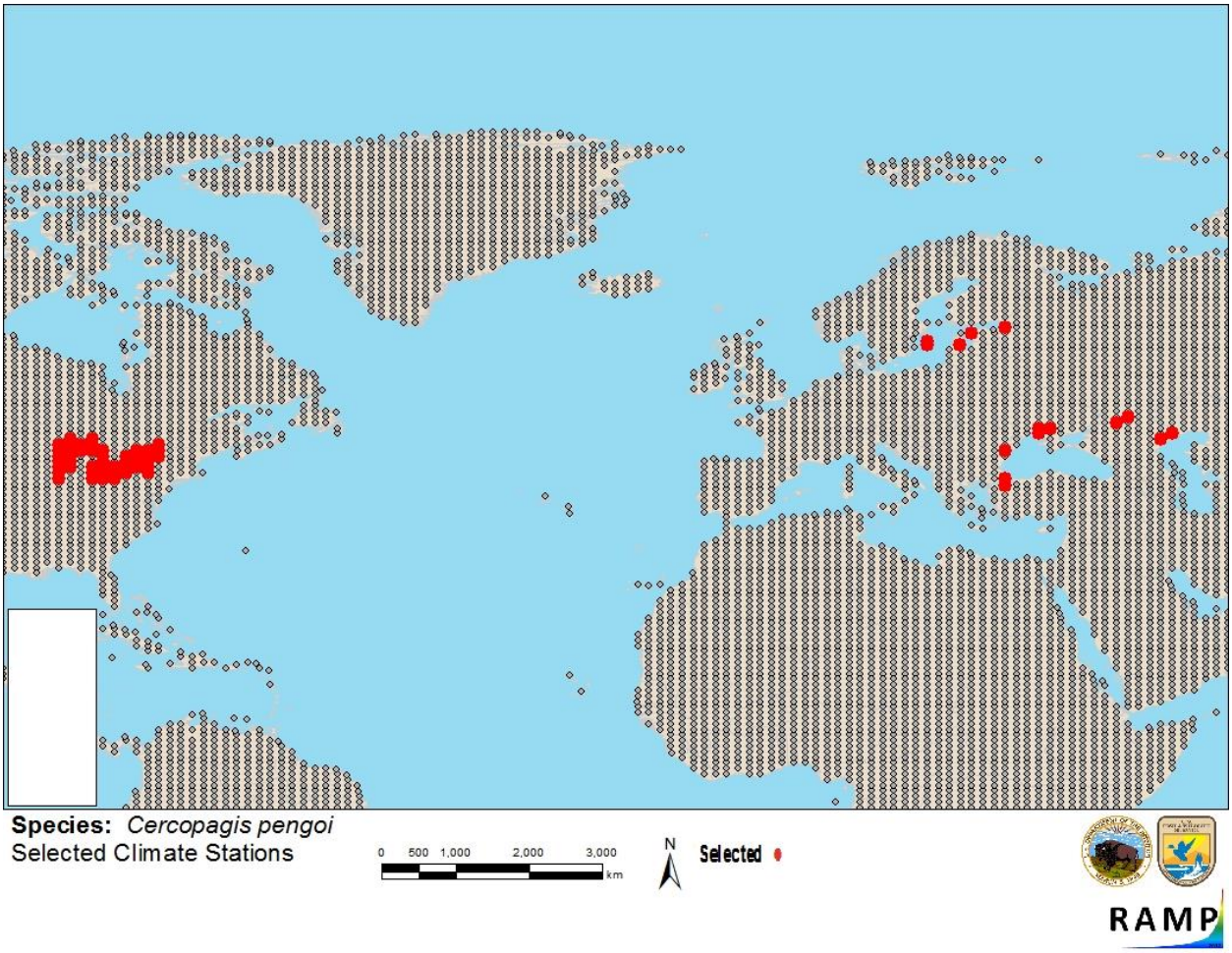

Figure 11. RAMP-produced image of selected climate matching source locations (red) and non-source locations (gray) for *Cercopagis pengoi*.

The second JPEG file shows a map of the target region, with the region shaded according to the degree of match between the source locations and the target locations (Figs. 12, 13). Blue or dark green represents low match, red represents high match, and gradations from yellow-green to orange represent medium match. Note that the resolution of the target region map (15-km grid) is higher than the resolution of the source location map (approx. 75-km grid). The colors on the map also correspond to numerical scores from 0 (lowest match) to 10 (highest match). The lower left side of the map shows a table of the number of target locations with each score. The distribution of scores is used in calculating the Climate6 score (page 24).

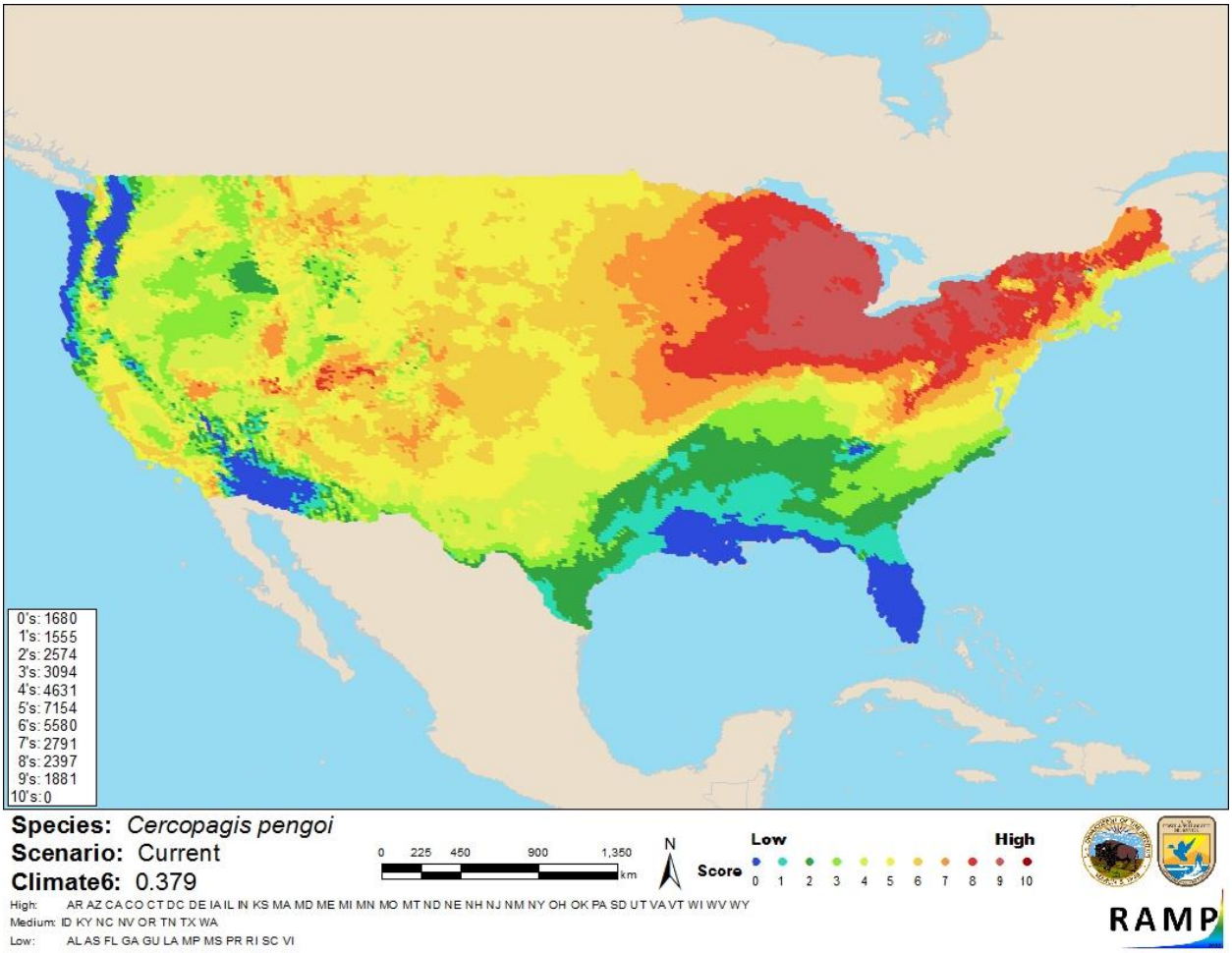

Figure 12. RAMP-produced image of the climate matching results for *Cercopagis pengoi* under the current climate scenario with a target region of the contiguous United States.

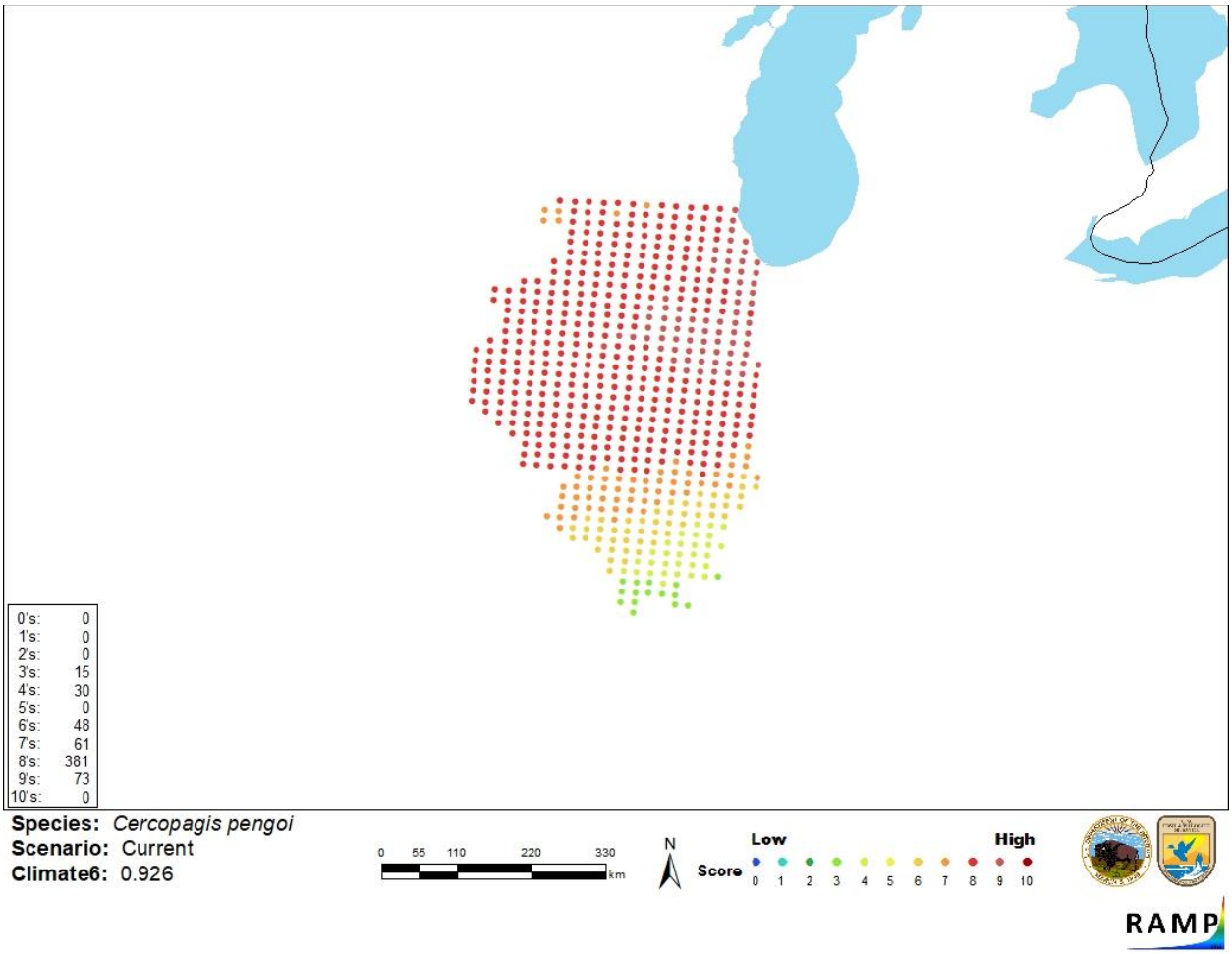

Figure 13. RAMP-produced image of the climate matching results for *Cercopagis pengoi* under the current climate scenario with a target region of the State of Illinois.

When reporting the results of the climate matching analysis, it is useful to describe what areas of the target region show what levels of climate match. Patterns can often be identified, such as a different degree of match along coastlines as compared to inland areas, or a different degree of match along mountain ranges as compared to lower-elevation areas (although RAMP will not directly account for and incorporate elevation in the model). These narrative interpretations can help those who are not familiar with climate matching analysis and RAMP to make sense of the results, as well as increase the accessibility of the results to visually impaired individuals.

Note that, unlike the image shown in the ArcGIS window after a climate matching analysis is completed, the map files produced by RAMP include information in the legend on the species and climate scenario specified for the match. **For this reason, it is important to use the RAMP output JPEG files rather than screenshots or other forms of manual export of the match results, with the exception noted above for source maps with limited extent.**

Climate6 Score

The Climate6 score is found in the legend of the climate match map. This score is calculated as the proportion of climate match scores that are 6 or above, so a Climate6 score

greater than 0 indicates that at least one location is on the high end of a medium climate match. However, note that rounding could produce a Climate6 score of 0 even if there are some higher matches.

Climate6 scores are classified as "high," "medium," or "low" according to the following table:

Climate 6: Proportion of (Number of Climate Scores 6-10) / (Total Number of Climate Scores)	*Climate Match Category*
$0.000 \leq X \leq 0.005$	Low
$0.005 < X < 0.103$	Medium
≥ 0.103	High

The climate match categories of low, medium, and high are a general indicator of where a species can establish. By using only established locations to determine the climate matching source locations, the analyst can ensure that medium and high matches within the target region represent places with climates where a species cannot only survive briefly, but is likely to survive long term, reproduce, and become established. A low category of climate match means that it is unlikely that the species could survive, and very unlikely to reproduce and establish a population. The cut points for classification of Climate6 scores are based on an analysis of Climate6 scores for 255 species established in 10 countries (Bomford 2008). The cut point of 0.005 corresponds to the 5th percentile for Climate6 scores and the cut point of 0.103 corresponds to the 20th percentile for Climate6 scores in that analysis (U.S. Fish and Wildlife Service 2016).

When the selected target region is "Contiguous United States", categories of match are provided for individual States at the bottom of the legend (Fig. 12). These categories are obtained from the Climate6 scores for each State. Numerical scores by State are not available unless the selected target region is the individual State itself rather than the contiguous United States as a whole (Fig. 13).

When reporting the results of a climate matching analysis, Climate6 score can be used as a quantitative indicator of climate match. Reporting both the score itself and its categorization can be useful. There can be a lot of variation in scores within a category (for example, 0.104 is a very different degree of match from 0.994, although both would be considered high match), but the categorization provides general guidance on how to interpret the numerical value.

Uncertainty

Acknowledgment and consideration of uncertainty in the source locations and in the results of the match are an important part of climate match interpretation. Source location uncertainty could occur when species range is not well defined, species establishment is unclear, or species misidentification is possible. You should use clues from the databases and other literature reporting source locations to decide if any of these situations exist. Uncertainty in the climate match itself can occur as propagated uncertainty from the source locations. Climate match uncertainty can also occur in cases of restricted range, particularly on islands. If only one or two source locations are available for a species, then the climate matching algorithm does not have many data informing the range of acceptable climate variable values. In some cases, particularly on islands, species distribution may be restricted by geographical barriers to range expansion more than by climate tolerance. Additionally, the climate matching analysis may not capture microclimates (small areas where the climate is significantly different from the

surrounding areas). For example, thermal springs, where the water is significantly warmer than the air, occur in many U.S. States, particularly in the West. Tropical fish may survive and establish populations in thermal springs even though they cannot establish in waters that are at ambient temperature for the region. Because the climate matching analysis uses air temperature as a surrogate for water temperature, those microclimates will not be reflected in the climate matching results. Therefore, populations may establish in areas that have been categorized as a low climate match. For all species, it is important to remember that realized distribution is determined by more than just climate tolerance, including the existence of predators, diseases, pathways and barriers to movement, and other local factors.

When reporting the results of the climate matching analysis, you should make particular note of any uncertainty in the source locations. If no source location uncertainty exists but the species range only maps to a single source location, the uncertainty in the match resulting from limited source data should be highlighted. In both cases, you should include a statement that the climate match presented is an approximation of the true climate match because of the sources of uncertainty identified.

Part Four: References

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Appendix A: RAMP Data Sources and Construction

Data Sources

Current Climate

Current climate data were obtained from WorldClim version 1.4 datasets (Hijmans et al. 2005), available through WorldClim (http://worldclim.org/). The WorldClim data layers were generated through interpolation of average monthly climate data primarily from weather stations in the Global Historical Climate Network Dataset (GHCN; Peterson and Vose 1997), with additional databases used to fill in gaps where GHCN stations were greater than 5 km apart (Hijmans et al. 2005). Existing climate data for the period 1950-2000 were interpolated to create continuous climate surfaces representing current climate (Hijmans et al. 2005). Climate surfaces were produced for precipitation, mean temperature, minimum temperature, and maximum temperature.

The WorldClim data layers selected for RAMP use a 2.5 arc-minute resolution grid (also referred to as "5 km" resolution). Sixteen bioclimatic variables derived from the WorldClim temperature and precipitation data layers are used by RAMP to calculate climate similarity (Table A1). These 16 variables are the same set used by Bomford (2008) to test the performance of the climate algorithm used by RAMP.

Table A1. Sixteen derived bioclimatic variables used by RAMP to evaluate climate similarity. Quarters are periods of three months.

WorldClim Code	*RAMP Code*	*Description*
BIO1	AVT	Annual mean temperature
BIO5	WMM	Maximum temperature of warmest month
BIO6	CDM	Minimum temperature of coldest month
BIO7	SPT	Temperature annual range (BIO5-BIO6 or WMM-CDM)
BIO8	TWQ	Mean temperature of wettest quarter
BIO9	TDQ	Mean temperature of driest quarter
BIO10	WMQ	Mean temperature of warmest quarter
BIO11	CDQ	Mean temperature of coldest quarter
BIO12	AVRF	Annual precipitation
BIO13	WTM	Precipitation of wettest month
BIO14	DYM	Precipitation of driest month
BIO15	COEF	Precipitation seasonality (coefficient of variation)
BIO16	WTQ	Precipitation of wettest quarter
BIO17	DYQ	Precipitation of driest quarter
BIO18	RHQ	Precipitation of warmest quarter
BIO19	RCQ	Precipitation of coldest quarter

Future Climate

Future climate data were also obtained from WorldClim version 1.4 datasets (Hijmans et al. 2005), available through WorldClim (http://worldclim.org/). The future climate data were downscaled and calibrated from global climate model (GCM) output used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC5; IPCC 2013). The calibration process used WorldClim 1.4 current climate surfaces (Hijmans et al. 2005) as the baseline current climate. Two periods were considered: 2050 (representing the average predicted climate for 2041-2060) and 2070 (representing the average predicted climate for 2061-2080). WorldClim provides data layers for four representative concentration pathways (RCPs) and 19 GCMs. As with current climate data, climate surfaces were produced for precipitation, mean temperature, minimum temperature, and maximum temperature.

For future climate matching in RAMP, the resolution and climate variables used were the same as for current climate. RAMP uses the Geophysical Fluid Dynamics Laboratory's coupled model (GFDL-CM3; Donner et al. 2011; Griffies et al. 2011) as the GCM for future climate predictions. For future climate scenarios, RAMP uses three Representative Concentration Pathways: RCP2.6, RCP4.5, and RCP8.5. The RCPs represent a set of scenarios of greenhouse gas and air pollutant concentrations, emissions, and land use that determine a trajectory of radiative forcing. Radiative forcing is the difference between the amount of energy absorbed by the Earth and the amount of energy radiated by the Earth. The numbers after the RCP abbreviation represent the level of radiative forcing in W/m^2. Thus, each RCP represents a different trajectory up to the year 2100, with RCP2.6 representing the lowest and earliest peak in radiative forcing followed by decline, and RCP 8.5 representing no peak or continually rising radiative forcing (Van Vuuren et al. 2011). Climate data layers for the fourth defined RCP (RCP6; Van Vuuren et al. 2011) were not available with the chosen GCM through WorldClim.

Climate Station Construction

To balance increased climate match resolution with increased match calculation time, we created grids of pseudo climate stations. The global, or source, layer consists of a grid of points spaced 75.9 km apart on all land areas across the globe except for Antarctica. Each of these points can be considered a climate station and represents the current climate for its location. In contrast, the target layer consists of a grid of points spaced 15 km apart across each of North America, Hawaii, and U.S. commonwealths and territories. Where the spatial extent of an area was limited and did not overlay the 15-km grid, target stations were created using a random point generator with a minimum distance of 15-km spacing. This allowed small islands, such as Guam and America Samoa, to be included as target regions for climate matching analysis. Target stations were linked to both current climate data and climate data for potential future conditions.

Climate model outputs were applied to points for both the Global and target layers in the same fashion. ArcMap (Esri, Redlands, California) was used to extract raster cell values from WorldClim version 1.4 climate rasters to the global and North America points to create the pseudo climate stations. Bilinear interpolation was also used to limit any raster anomalies. The resulting layer's field names were corrected and values were converted to non-integer, real world, values.

Table A2. Characteristics of two layers of pseudo climate stations constructed for climate matching analysis with RAMP.

Layer name	*Number of stations*	*Distance apart*	*Coordinate system*	*Projection*
Global	17,314	75.9 km	GCS WGS 1984	Equidistant Cylindrical (World)
Target	96,838	15 km	GCS WGS 1984	Equidistant Cylindrical (World)

Matching Calculation

In RAMP, the climate match score for a target location *j* is calculated using the Euclidian algorithm also applied in Climatch (Crombie et al. 2008):

$$score_j = floor\left\{\left[1 - \min_{i \in sites}\left(\sqrt{\frac{1}{k}\sum_k \frac{(y_{ik} - y_{jk})^2}{\sigma_k^2}}\right)\right] * 10\right\}$$

where *k* is the number of climate variables (16), *i* indexes global source locations, *j* indexes target locations, y_{ik} is the *k*-th climate variable for the *i*-th source location, y_{jk} is the *k*-th climate variable for the *j*-th target location, and σ_k^2 is the variance of all global points for the *k*-th climate variable. The minimum function selects the source location with the closest match to the *j*-th target as the location on which to base the overall score for that target. Possible scores range from 0 to 10.

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Appendix B: Quality Assurance and Quality Control Checklist for RAMP Climate Matching Analysis

Note: If the climate matching analysis is being completed as part of an ERSS, the QA/QC Checklist within the ERSS SOP (https://www.fws.gov/injuriouswildlife/pdf_files/ERSS-SOP-Final-Version.pdf) is a valid substitute for this QA/QC Checklist.

Data Sources

Which data sources were used to generate the distribution?

Was each data source reviewed for outliers and anomalies? ___ Y ___ N

Was each data source saved for the administrative record? ___ Y ___ N

Climate Matching

Were climate matching source locations edited as needed to remove outliers and anomalies? ___ Y ___ N

If any outliers or anomalies were removed, is there documentation of why they qualified for removal? ___ Y ___ N

If not documented elsewhere, explain here:

If any climate matching source locations were added manually, is there documentation of the data source of those locations? ___ Y ___ N

If not documented elsewhere, explain here:

Is there documentation acknowledging any parts of the distribution that were not represented among the climate matching source locations used in the analysis? ___ Y ___ N

If not documented elsewhere, explain here:

Was the species folder generated by RAMP saved for the administrative record? ___ Y ___ N