U.S. Fish & Wildlife Service

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

U.S. Fish and Wildlife Service
Version 3, February 2024

Table of Contents

Abbreviations

ERSS = Ecological Risk Screening Summary

FISRAM = Freshwater Fish Injurious Species Risk Assessment Model

GBIF = Global Biodiversity Information Facility

GCM = global climate model

RAMP = Risk Assessment Mapping Program

QA/QC = quality assurance/quality control

Service = U.S. Fish and Wildlife Service

SOP = Standard Operating Procedure

SSP = Shared Socioeconomic Pathway

Part 1. Introduction

A. 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 effectiveness of climate matching—that is, measuring the similarity of one set of climate conditions to another—for predicting 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 climatic associations between the native and 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 nonnative species establishment success that is valid 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. 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-reviewed.

B. Purpose

The purpose of this Standard Operating Procedure (SOP) 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 RAMP to other methods of climate match and distribution modeling.

C. 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 (defined as the average climate between 1979 and 2013) in the source locations to current climate in the target region or predicted future climate in the target region over multiple future time periods, climate change scenarios, and global climate models. RAMP implements the climate algorithm that is currently used by Climatch (Crombie et al. 2008; ABARES 2020) 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) 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.

D. RAMP Output and Applications

RAMP provides both graphical and numerical outputs to quantify and visually display the degree of climate match. More explanation of these outputs and guidance on their interpretation will be provided in part 3.

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 Service's Freshwater Fish Injurious Species Risk Assessment Model (FISRAM). More information and standard operating procedures for both ERSS and FISRAM tools are available on the Service's website.

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 (J. Granberg, Wisconsin Department of Natural Resources, personal communication, 2019). Similarly, RAMP can be used for a species native to one region of the United States that may be introduced to a region where it is not native.

E. Citing RAMP

When referencing RAMP or its outputs in publications or other products, please use the following citations.

For these **Standard Operating Procedures**:

U.S. Fish and Wildlife Service. 2024. Standard operating procedures for the Risk Assessment Mapping Program (RAMP). Version 3. *Add link and access date if accessed online.*

For **RAMP version 5.0**:

Sanders S, Castiglione C, Hoff M. 2023. Risk Assessment Mapping Program: RAMP, version 5.0. U.S. Fish and Wildlife Service.

For **RAMP version 4.0**:

Sanders S, Castiglione C, Hoff M. 2021. Risk Assessment Mapping Program: RAMP, version 4.0. U.S. Fish and Wildlife Service.

For **RAMP version 3.1**:

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

For **RAMP version 2.81**:

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

E. RAMP Version History

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 U.S. Territories as target regions
- Ability to conduct a climate matching analysis for a single State, Commonwealth, 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

RAMP version 4.0 was released in 2021. Upgrades present in RAMP version 4.0 include:

- Use of ArcGIS Pro as base software instead of ArcMap (see software requirements in part 2A)
- Revision of underlying code for improved performance and reduced dependency on secondary libraries
- Implementation of a Python toolbox for the RAMP tools
- Climate data updated to better reflect current conditions, including incorporation of 13 years of more recent observations
- Incorporation of updated future climate scenarios (Shared Socioeconomic Pathways; SSPs) based on the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2021)
- Updated global source points to better represent island areas
- Addition of new target regions and full implementation of Canadian province target regions
- Programming-imposed cap on number of observation records downloaded from GBIF was removed; number of observations downloaded now only capped by GBIF internal controls
- New table of target scores in outputs for each run

RAMP version 5.0 was released in 2023. Upgrades present in RAMP version 5.0 include:

- Incorporation of four additional global climate models to better account for uncertainty in future climate matching
- Removal of one SSP (SSP1; IPCC 2021) due to low probability of occurrence
- New output maps showing median target point scores of the five models used for future climate matching (available for two time periods and two SSPs)
- New output maps showing the difference in target point scores between current climate match and median future climate match (available for two time periods and two SSPs)
- New output tables reporting the climate match results for each model used to calculate future climate match (available for two time periods and two SSPs)
- Revision of underlying code for improved performance and reduced dependency on secondary libraries

F. Disclaimer

Mention of commercial products does not necessarily constitute endorsement by the U.S. Federal Government.

Part 2. General Guidelines for Using RAMP

A. Software Requirements

Running RAMP requires an internet connection and a licensed copy of ArcGIS software (Esri, Redlands, California). RAMP version 5 was developed for ArcGIS Pro version 3.0. It is not backward compatible with previous versions of ArcGIS Pro.

The files necessary to run RAMP consist of the ArcGIS Pro project file ('.aprx'), the "data" folder, and the "species" folder. All three components should be saved to the same local folder or network location.

B. Analyst Qualifications

RAMP operates within the ArcGIS program suite, so it is desirable that analysts (users) have basic familiarity with ArcGIS software. This familiarity will facilitate navigation and troubleshooting 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.

C. Data Quality Standards

The quality of the climate matching analysis reflects the quality of the data inputs. 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 populations maintained through natural reproduction; they are not reliant on human-mediated introduction of individuals from elsewhere. 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 GBIF. 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 (e.g., FishBase, Birds of the World, USDA PLANTS) and peer-reviewed literature.

Peer-reviewed literature is a valuable source for additional species occurrences beyond GBIF. Journal articles may include a study area map that depicts species occurrences, or they may report spatial 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 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 if there are other types of taxonomic uncertainty. This examination ensures that the individual or population discussed in the literature belongs to the species for which the climate matching analysis is being conducted.

D. 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 species page and copies of any journal articles containing maps or coordinates that were used to add occurrences to the source map.

A QA/QC checklist 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 QA/QC, 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 3. Using RAMP

This part of the document is directed at the analyst as a step-by-step guide for using RAMP. All figures in this section were created with ArcGIS Pro v3.1.3. Newer or older versions of the software may look slightly different.

A. Developing an Understanding of Species Range

Before opening the RAMP project file in ArcGIS, you (the analyst) need to know 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. Use any resources available to you to develop your understanding of species range through written or graphical descriptions.

Specific Instructions

Use reputable databases (see part 2C) 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 priority databases found in the ERSS SOP (U.S. Fish and Wildlife Service 2023; available on the Service's website).

For other purposes, recommended resources include:

- For all taxa, worldwide – IUCN Red List (focus on written description of species range; historically, some Red List range maps have been inaccurate), Google Scholar, Web of Science (or other academic search engines)
- For all U.S. taxa – NatureServe Explorer
- For all fishes – FishBase, Catalog of Fishes
- For all birds – eBird, Birds of North America (with subscription), All About Birds
- For introduced or invasive taxa – CABI Invasive Species Compendium
- For introduced or invasive estuarine invertebrates – NEMESIS
- For U.S. introduced or invasive aquatic taxa – USGS Nonindigenous Aquatic Species Database

B. 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. As stated above, this entry will provide the foundational data for the climate matching source locations.

Specific Instructions

1) Find the species entry using the species search tool. The components of a GBIF species entry include a map of all georeferenced occurrence records in GBIF data sources, lists of data sources and occurrence details, and information on scientific and vernacular synonyms.

> Note: Recent taxonomic changes may not be reflected in GBIF, so try synonyms if the accepted scientific name does not yield a hit. Subspecies data are included on the relevant species page and may also have unique entries in the database.

2) Explore the GBIF data. Use the information already gathered on species distribution to identify **potential outliers**—that is, occurrences that warrant further investigation because they do not match your prior understanding of the species established range.

   - The tools in the bottom right corner of the occurrence map allow you to modify the map appearance. You can change the basis of record (e.g., "observation," "literature," "preserved specimen"), the style of the map, and the map projection.

3) Investigate the **full occurrence record** for each potential outlier.

   - The "Explore Area" button leads to a table of all occurrences currently visible in the map view.
     - To limit the size of the table, zoom in on occurrences of interest on the map before clicking "Explore Area".
     - Clicking on a line of the table will bring up the full record for that occurrence.
   - Pay attention to any highlighted issues in the full occurrence record (e.g., coordinate issues, incomplete information).
   - 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.
   - It is not necessary to check the full record of every observation in GBIF, only potential outliers.

4) Make note of:

   - Any GBIF occurrences that do not represent accurate locations for the species, and
   - Any GBIF occurrences that represent introduced but not established populations of the species.

C. Collecting Supplementary Occurrence Data

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. Often, at least one published study can add occurrences to the collection so that no large geographic areas of the range go unrepresented.

Specific Instructions

1) Re-examine the published and gray literature you collected while developing an understanding of species range. Are there **additional areas where the species is established** that are not represented in GBIF?

2) If yes, are there **other occurrence datasets** that fill the gaps? As with GBIF data, these datasets should be **checked for outliers** and to ensure that occurrence records represent established populations.

Table 1. Potential sources for georeferenced species occurrence data to supplement Global Biodiversity Information Facility (GBIF) data.

Database Name	Free Account Required	Available Data Formats	Notes
GBIF-US	yes	.csv, .xlsx	US partner to GBIF; may have different records than GBIF
eBird	yes	.txt	
EDDMapS	yes	.csv, .kml	may need to filter out negative (absence) observation records
FishBase	no	.kml	
USGS Nonindigenous Aquatic Species database	no	.csv	
VertNet	no	.txt	

Note: CABI Invasive Species Compendium provides aggregated occurrence data for download. These aggregated occurrences are represented by a point in the center of the country or political unit where the species is present and are not the locations of actual observations. This type of data is not appropriate to use as a source for a climate match.

3) Are there **additional locations reported within the peer-reviewed literature**, either as maps, lists of coordinates, or verbal descriptions?

- If location coordinates are given, they can be entered in a spreadsheet and saved as a '.csv' or '.xls' file.

- 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 (see Adding or Subtracting Individual Source Locations Manually, below).

D. General Process for Conducting a Climate Match

The RAMP python toolbox (RAMP_v5.pyt; figure 1) includes four tools that must be run sequentially:

1) **Create Species Profile (New GBIF):** Creates a folder for storage of all the files created by RAMP pertaining to the species. Downloads any GBIF data associated with the species name.

2) **Get Species Pre-Selection:** Selects climate matching source locations near species occurrences.

3) **Perform Match:** Runs the climate matching analysis for the appropriate target region and the appropriate climate scenario.

4) **Aggregate Scores:** Creates median target point score maps and difference maps for future climate projections.

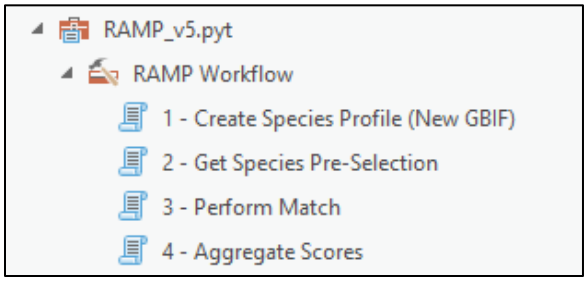

Figure 1. RAMP toolbox, containing the four tools used to run a climate matching analysis.

> Note: The RAMP Python 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 within the "data" folder. Instructions for adding toolboxes to your version of ArcGIS Pro can be found online.

The following sections of this SOP will step you through the use of these tools using the example of the fishhook 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 10 minutes.

E. Step 1 — Create Species Profile

This step needs to be performed only once, regardless of how many different climate matching iterations you run. If you already have a folder saved with the species name within the RAMP "species" folder, go directly to Step 2.

Specific Instructions

1) Open "1 — Create Species Profile (New GBIF)" from the RAMP toolbox.

2) Type the scientific name of the species into the text field in the geoprocessing pane (figure 2).

   - 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.

   - Errors may also occur if there are no georeferenced GBIF occurrence records for the species of interest, or if there are more than 100,000 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.

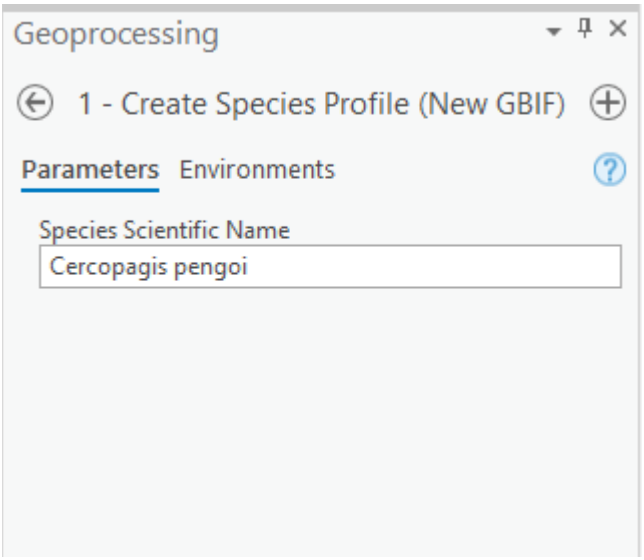

Figure 2. Top of the geoprocessing pane for the first tool in the RAMP process.

3) Click "Run."

4) Check that a folder labeled with the species name (e.g., "Cercopagis_pengoi") was created inside RAMP's "species" folder.

> Note: A species-specific folder may be created even if Step 1 produces an error message. Check for the folder; as long as it exists, you can proceed with the climate match. If no folder was created, you can create one manually.

F. Step 2 — Get Species Pre-Selection

There are several options for implementing this step, depending on whether Step 1 ran successfully and the occurrence data used.

Specific Instructions

If Step 1 ran successfully:

1) Open "2 — Get Species Pre-Selection" from the RAMP toolbox.

2) Select the species name from the "Species Name" drop-down list in the geoprocessing pane (figure 3). This list is populated using the species folders with the RAMP "species" folder.

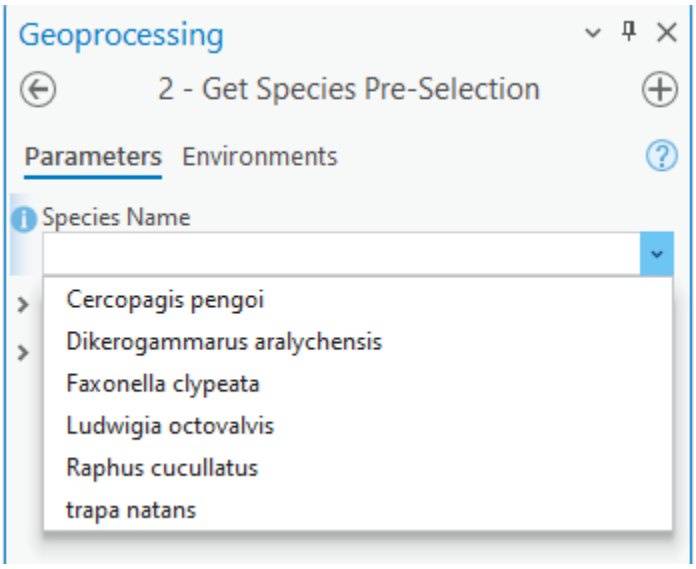

Figure 3. Top of geoprocessing pane for the second tool in the RAMP process showing the drop-down list for "Species Name".

3) If you have run a climate match for the species previously and want to recall the source locations used for that match, click the arrow next to "Use Previous Selection" and then check the box (figure 4).

   - Not checking the box means you will lose any modifications made to the selected source locations in the previous run of RAMP for this species.

4) If you want to use an ArcGIS feature class already saved on your computer in place of the auto-downloaded GBIF data, click the arrow next to "Use Existing Data" and then check the box. Click on the folder icon to navigate to the file location and select the file.

   - Refer to subsequent sections of this SOP to use data from other file types (.csv, .kml, .txt, .xlsx).

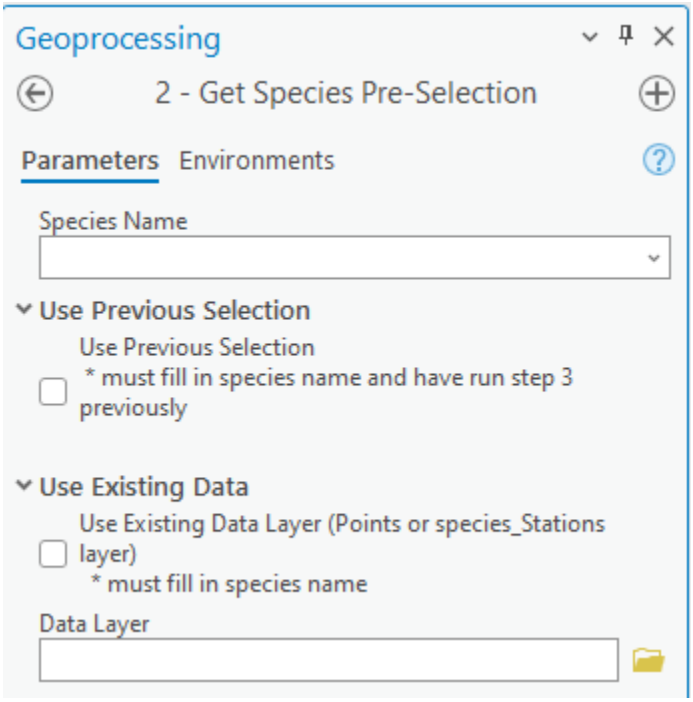

Figure 4. Top of geoprocessing pane for the second tool in the RAMP process.

5) Click "Run."

If Step 1 did not run successfully, do not run the Step 2 tool. You may also skip running the Step 2 tool if you have reason not to use the GBIF records, or if the only occurrence records available are not importable by the "Use Existing Data" option. The next sections will describe how to load other datasets.

After running the tool, the map window will refresh with a mix of red (selected) and gray (unselected) climate stations (figure 5). The selected points are those within a 100-km radius of a species occurrence location, as identified in the input data from GBIF or other imported data file.

> Note: 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.

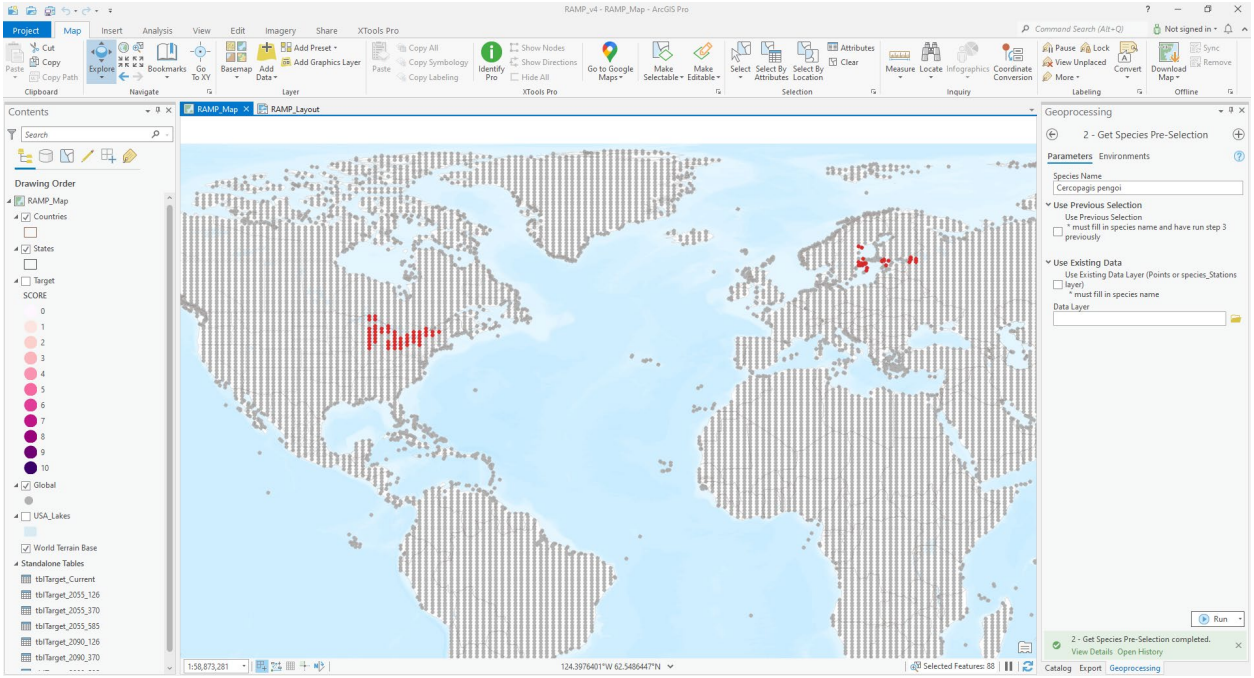

Figure 5. Selected (red) and non-selected (gray) source locations for *Cercopagis pengoi* based solely on georeferenced occurrences reported in GBIF Secretariat (2022).

G. Adding Supplementary Datasets

If you want to upload occurrence datasets from outside databases or were unable to run the Step 2 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').

> Note: If you were unable to run the Step 2 tool, you may need to manually change the map's visible layers so that the source points show up. In the Contents pane, make sure that the box next to the Global layer is checked and the box next to the Target layer is unchecked.

Specific Instructions

1) Add the supplementary dataset to the project following instructions available on the ArcGIS Pro help page for your file type.

2) Open the 'Select by Location' tool in the Selection toolbar (figure 6).

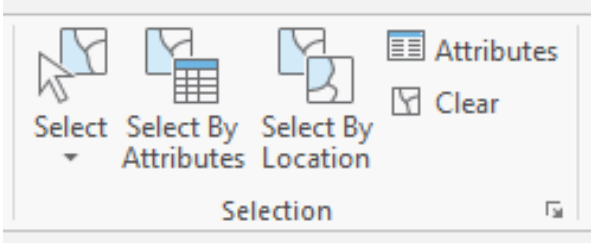

Figure 6. Selection toolbar in ArcGIS Pro.

3) When the dialog box appears, use the following settings (figure 7):

- In the "Input Features" field, select "Global."
- In the "Relationship" field, select "Within a distance."
- In the "Selecting Features" field, select the name of the supplementary data layer.
- In the "Search Distance" fields, type in "100" and select "Kilometers" as the unit.
- In the "Selection type" field, select "Add to the current selection" if there are some global source points selected already and you want to keep them selected, or "New selection" if there are no global source points selected or you want to remove the current selection.

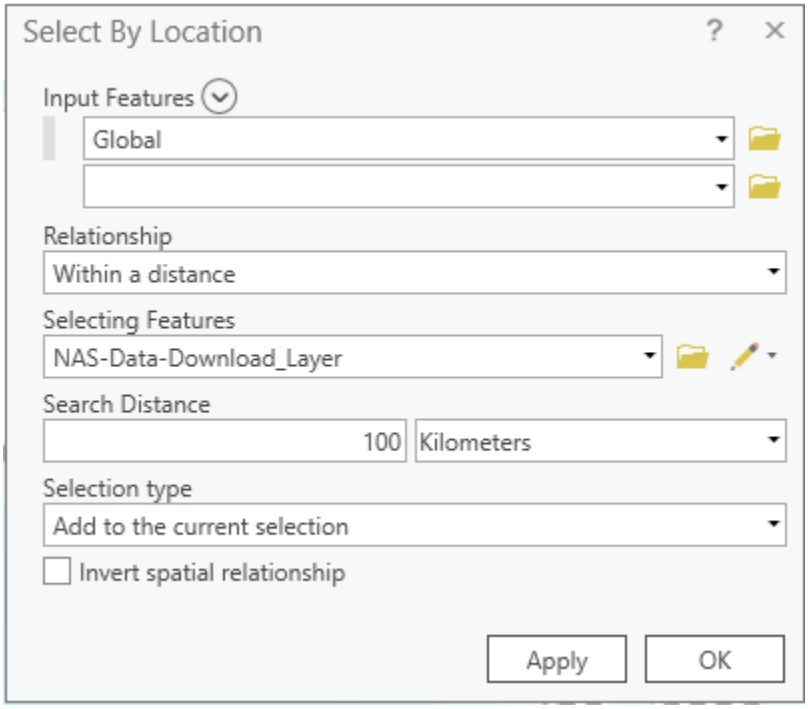

Figure 7. ArcGIS Pro Select By Location tool showing settings for selecting additional source points based on non-GBIF supplementary datasets.

4) Repeat 1-3 with any additional supplementary datasets.

H. 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.

Specific Instructions

To modify climate matching source locations manually, use the Selection tools (figure 6). The selection options menu allows you to choose whether you want to add or remove points. You can also use the keyboard shortcuts to switch quickly between modes.

1) Click on the small arrow in the lower right corner of the Selection toolbar to view the Selection Options (figure 8).

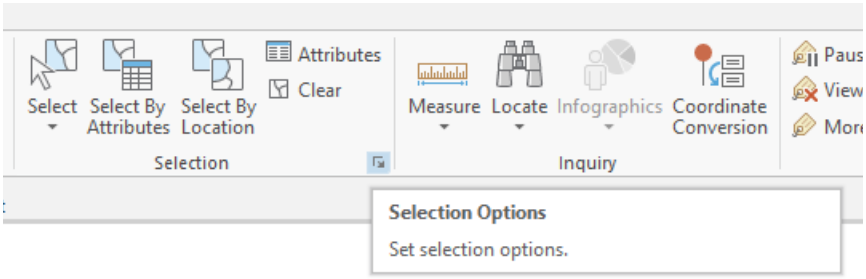

Figure 8. Accessing the Selection Options from the Selection toolbar.

2) When the dialog box appears, choose the appropriate Selection combination mode from the available options (figure 9):

- Create a new selection: if no points are selected yet
- Add to the current selection: select more points, e.g., established populations not represented in GBIF data
- Remove from the current selection: de-select points that are currently selected, e.g., points that represent introduced but not established populations

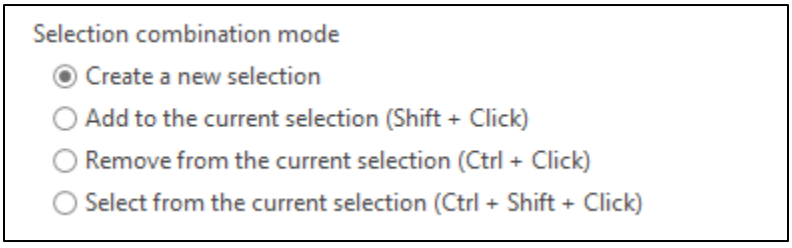

Figure 9. Selection method options.

3) Click “OK” to close the dialog box.

4) Click on the Select icon (figures 6, 8) to activate the tool. The little arrow below the icon allows you to change the shape of the selection.

5) Double-click on individual points to select or de-select them. Draw a polygon around a group of points to select or de-select all of the points within the polygon at once. Double-click when placing the last vertex of the polygon.

6) Once all editing is complete, remove any supplementary datasets from the project. If the supplementary dataset is still displayed on the map when subsequent RAMP tools are run, those points will also display on the output maps.

After modifying the source points as needed, proceed to the third tool in the RAMP toolbox. The climate matching analysis will now be performed on the selected source points (figure 10), rather than the selection from GBIF alone.

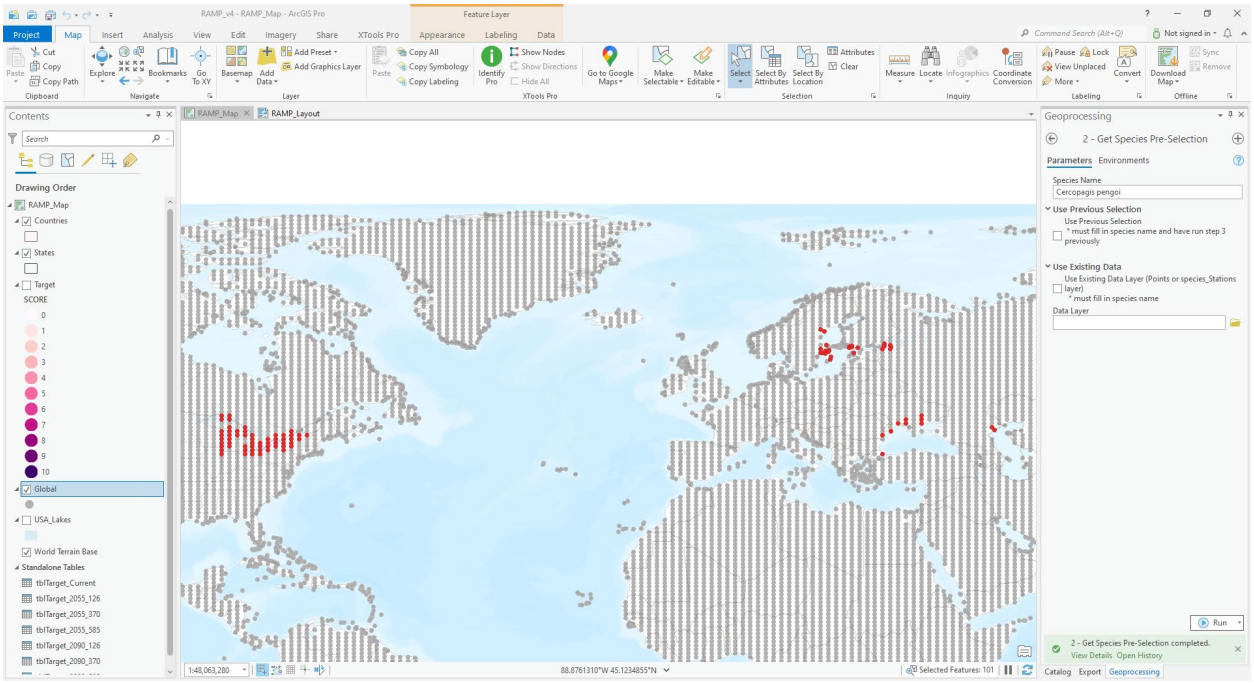

Figure 10. Selected (red) and non-selected (gray) climate matching source locations for *Cercopagis pengoi* based on georeferenced occurrences reported in GBIF Secretariat (2022), supplemented by information from Cristescu et al. (2001; for Romania, Russia, and Ukraine), Güher (2004; for Russia and Turkey), and Benson et al. (2017; for the United States).

I. Step 3 — Perform Match

The third tool in the RAMP toolbox runs the climate matching analysis now that the climate matching source locations have been set.

Climate match may be calculated for current (1979-2013) or future (2041-2070, 2071-2100) climate conditions. Because the future is uncertain, RAMP offers two climate change scenarios, each represented by a Shared Socioeconomic Pathway (SSP; IPCC 2021) and five global climate models (GCMs). The available SSPs in RAMP include SSP3 (emissions double by the end of the century) and SSP5 (emissions triple by the end of the century; IPCC 2021). More detail on the included scenarios and models can be found in appendix A. A general recommendation for climate matching to future climates is to calculate matches for both scenarios and both time steps using all GCMs (the "All Models" option described below) to view the range of possible outcomes.

Specific Instructions

1) Open "3 — Perform Match" from the RAMP toolbox (figure 11).

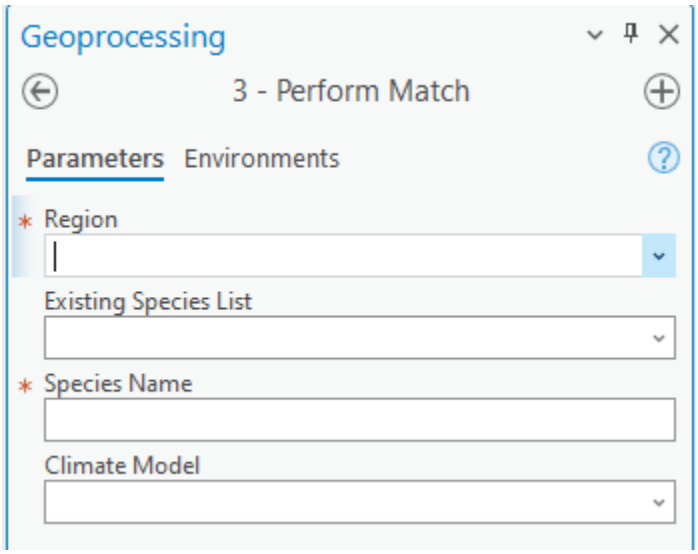

Figure 11. Top of the geoprocessing pane for the third tool in the RAMP process.

2) Select the target region for the match from the options given (figure 12).

- For ERSS applications, use "Contiguous United States", meaning all U.S. States except Alaska and Hawaii.
- Three countries can be run individually: United States (with or without territories), 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", "Individual State or Territory", or "Canadian Province". With the "Individual State or Territory" or "Canadian Province" options, a second drop-down menu will appear that enables selection of an individual State, Province, U.S. Commonwealth, or U.S. Territory of interest by standardized postal abbreviation (figure 13).

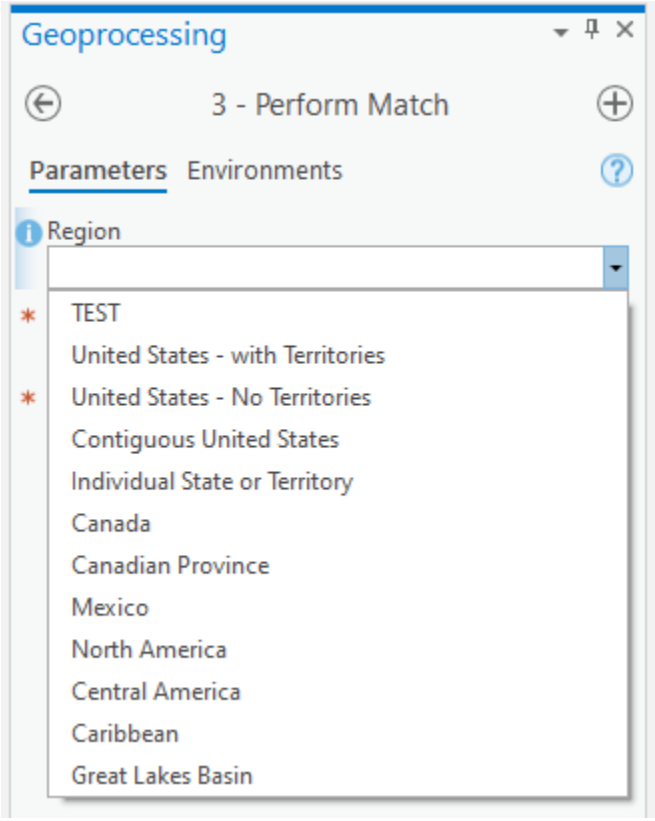

Figure 12. Menu of potential target regions for climate matching in RAMP, available in the geoprocessing pane for the "Perform Match" tool.

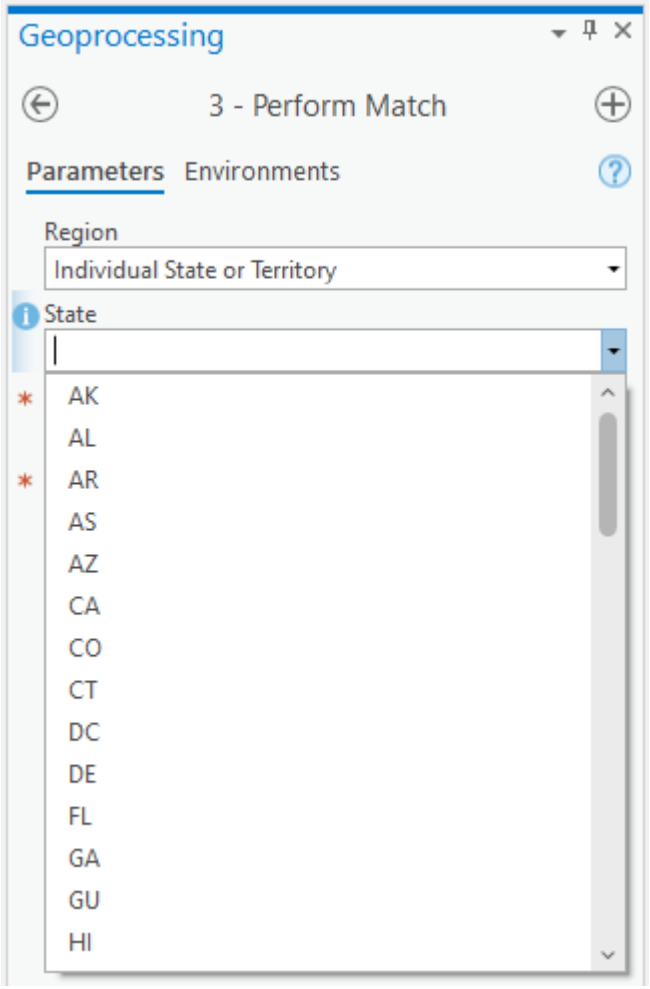

Figure 13. Sample of the menu of potential target regions for climate matching in RAMP after selecting the "Individual State or Territory" option in the "Perform Match" tool.

3) As with the other tools in the RAMP toolbox, you will need to select the species scientific name from the drop-down list in "Existing Species List". This selection will automatically populate the "Species Name" field. The drop-down list is populated from the individual species folders that currently exist in the RAMP "species" folder.

4) Select the climate model for matching (figure 14). For ERSS applications, all scenarios will be run eventually (see part 3K).

   - "All Models" will match to Current conditions as well as all future scenarios and time periods using all GCMs.
   - "Current" will match to observed climate between 1979 and 2013.
   - If an individual GCM is selected, you can then select a specific time period (2041-2070 represented as '2055' or 2071-2100 represented as '2085') and SSP for individual model matching (figure 15).

- This option may be useful if one or more individual GCMs would be more applicable to your project than others included in the suite of GCMs used by RAMP.

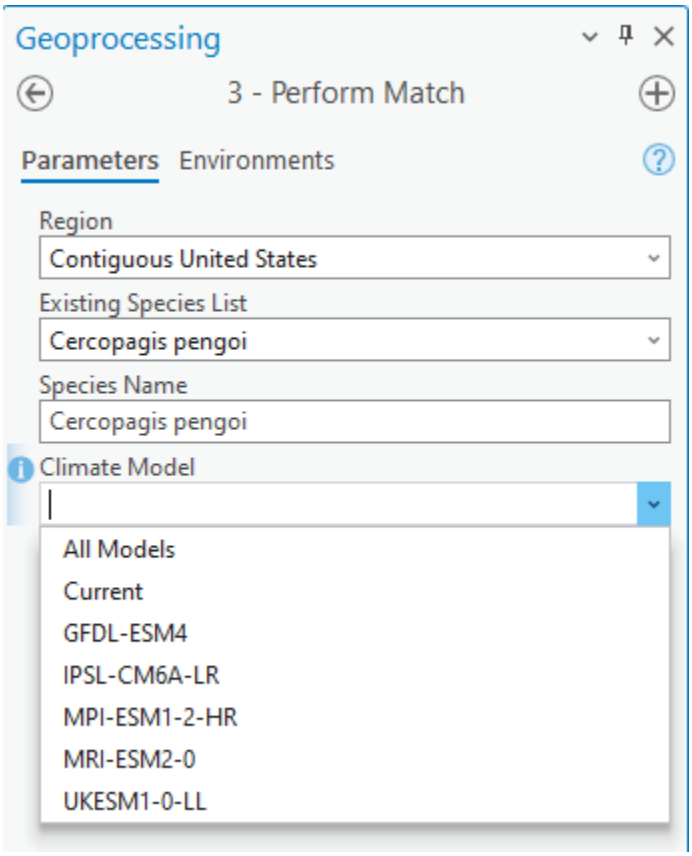

Figure 14. Menu of potential climate scenarios for climate matching in RAMP, available in the geoprocessing pane for the "Perform Match" tool. The abbreviations signify specific global climate models (appendix A) for future climate matching, which can be used to generate results under individual model/scenario combinations.

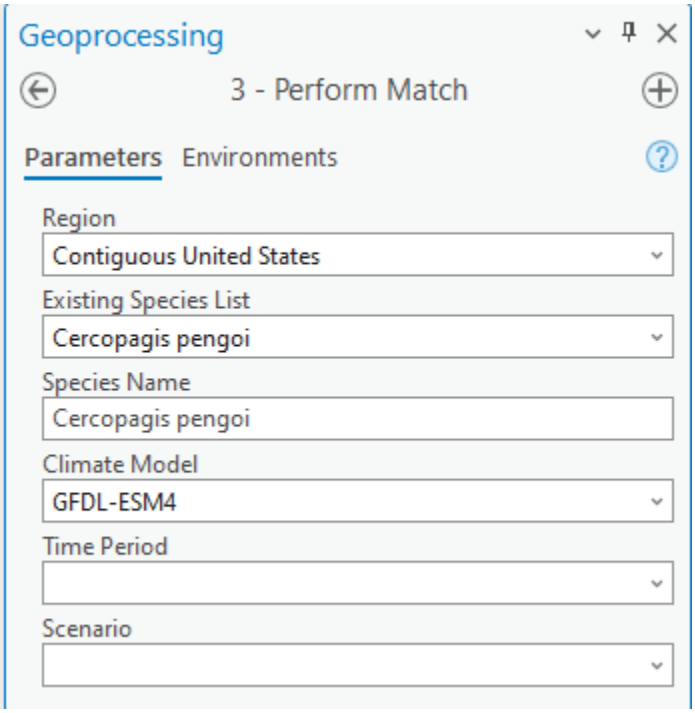

Figure 15. Sample menu selections for climate matching showing the additional fields of 'Time Period' and 'Scenario' that are available if a single GCM is selected as the 'Climate Model'.

5) Double-check that the map tab (not the layout tab) is displayed onscreen (figure 16). If not, the tool will result in an error.

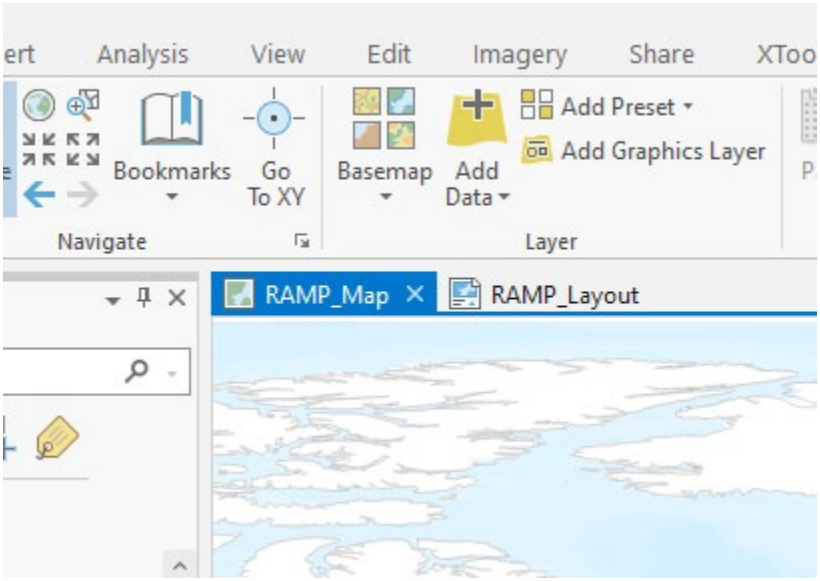

Figure 16. The map and layout tabs in ArcGIS Pro.

6) Click "Run." The image shown on the screen may change a few times while the tool runs. The final image will show the climate matching results. If running the 'All Models' option, the results shown will be the last GCM/time period/SSP combination that the program calculated.

J. Step 4 — Aggregate Scores

The fourth tool takes the climate match results for the future climate scenarios and creates two types of aggregate results maps. One type of results map shows the median target point score from the five GCMs for the time period and SSP combination. The second type of map shows the difference in target point scores between the current climate match and the median future climate matches.

> Note: If "Current" was selected under Climate Model in Step 3, there is no need to run Step 4.

Specific Instructions

1) Open "4 — Aggregate Scores" from the RAMP toolbox (figure 17).

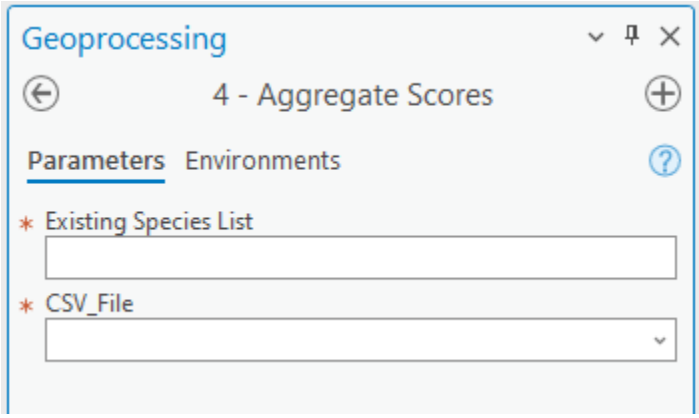

Figure 17. Geoprocessing pane showing the selection fields for the fourth tool in the RAMP process.

2) Choose the correct species name from the drop-down list in 'Existing Species List'. This list is populated from the existing species folders in RAMP's "species" folder.

3) Choose a '.csv' file from the list that is labeled with the target region, date, and run number of the data that you want to aggregate.

   - If the data are from the first run of the day for this species the file name will include the date but no run number.

   - RAMP will aggregate the data from all models associated with that target region, date, and run number. Selecting a single '.csv' file tells RAMP to look for all the data files that have the same target region, date, and run number.

4) Click "Run." After the tool runs, the output maps can be found in the species folder in the "Outputs" subfolder.

K. Running More Climate Matches

You can now return to Step 2 to run another match for the same species with different selections for "Region" or "Climate Model" in Steps 3 and 4. In Step 2, remember to check the box for "Use Previous Selection" so that the selected source locations remain the same.

Alternatively, you can return to Step 1 to run a match for a different species.

When you are done with your RAMP session, close the project. Do not save changes to the project file so it will reset when you open it again.

> Note: RAMP version 5.0 does not have capability for batch processing. Analysts interested in batch processing may prefer to use the climatchR R package (Erickson et al. 2022) which uses the same climate matching algorithm as RAMP.

Part 4. Interpreting RAMP Results

A. RAMP Output Files

RAMP provides the results of a climate matching analysis in both visual and numerical formats for each model run, including:

1) Target region results map (JPEG; figure 18)

   - Description: Image of climate matching results for the selected target region and climate scenario

   - Example file name: "Cercopagis_pengoi_ContigUS_Current_results.jpg"

2) Target scores table (CSV)

   - Description: Table with the target score of each target point in the target region

   - Example file name: "tbl_Cercopagis_pengoi_ContigUS_Current_Scores_YYYY_MM_DD.csv"

3) Frequency of target scores table (CSV)

   - Description: Table with the count of target points assigned to each target score

   - Example file name: "FreqTbl_Cercopagis_pengoi_ContigUS_Current_YYYY_MM_DD.csv"

4) State scores table (CSV)

- Description: Table with the Climate 6 score and associated Establishment Concern category (used in an ERSS, see USFWS 2024 for more detail) for each State in the contiguous United States

- Example file name: "StateScore_Cercopagis_pengoi_ContigUS_Current_YYYY_MM_DD.csv"

The name of each results file includes the target region, the climate scenario, and the date on which the climate match was run in RAMP (if multiple runs are completed on the same date, the file name will also include a run number). The current climate match files are found in the 'Current' subfolder. The files for each GCM are found in the subfolder labeled with that GCM's name. A new version of each of these files is produced every time a climate match is run for the species.

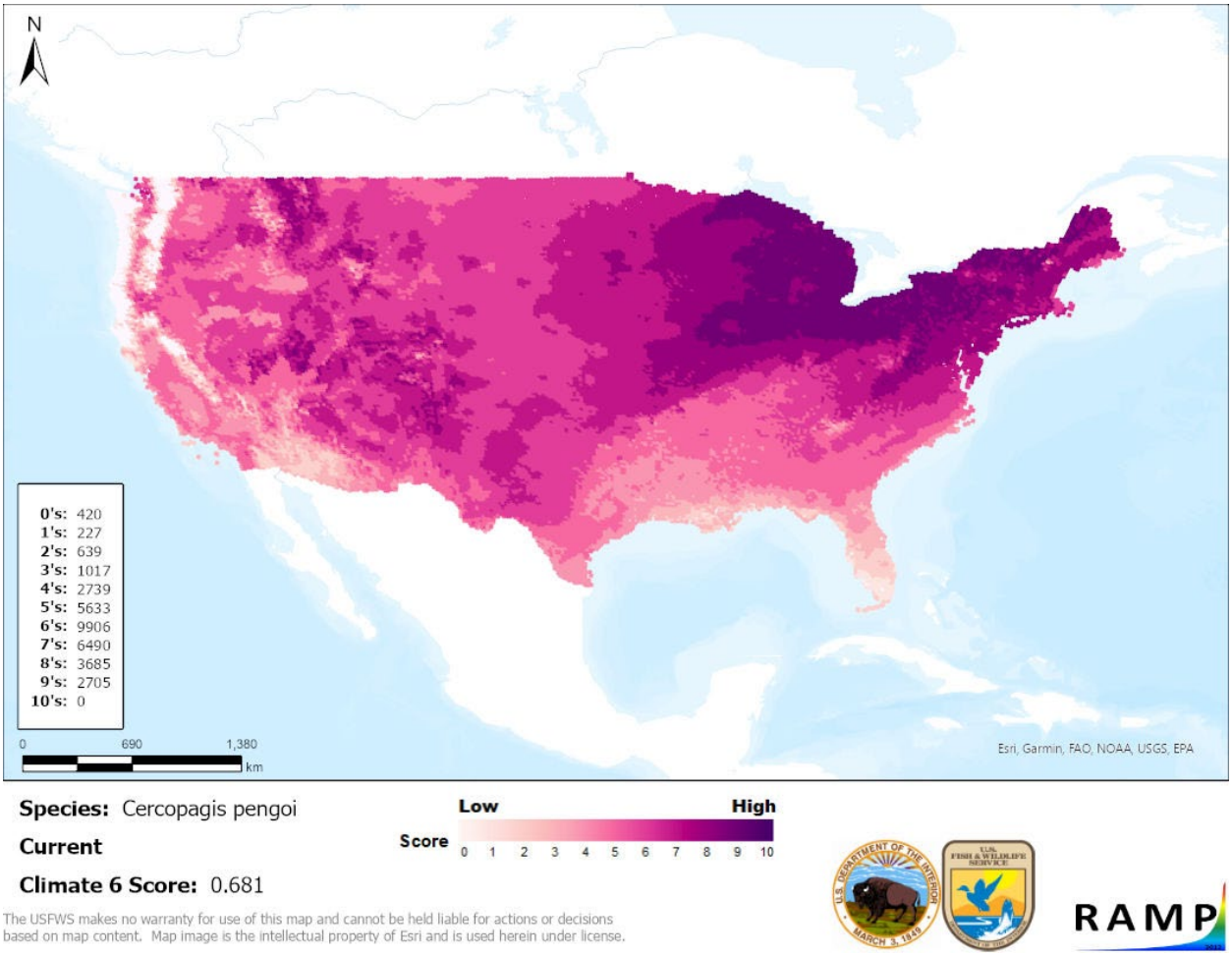

Figure 18. RAMP-produced image of the climate matching results for *Cercopagis pengoi* under the current climate scenario with a target region of the contiguous United States.

After Step 4 of the RAMP process is run, additional results files are added to the 'Outputs' subfolder. These include:

1) Target region aggregated median results map (JPEG; figure 19)

    - Description: Image of median climate matching results for a given time period and SSP, aggregated across the five available GCMs

    - Example file name: “Cercopagis_pengoi_ContigUS_TIME_SSP_Median_YYYY-MM-DD.jpg”

2) Target region aggregated difference results map (JPEG; figure 20)

    - Description: Image of difference between current climate match results and median future climate match results for a given time period and SSP, aggregated across the five available GCMs

    - Example file name: “Cercopagis_pengoi_ContigUS_TIMESTEP_SSP_Difference_YYYY-MM-DD.jpg”

3) Target scores comparison table (CSV)

    - Description: Table with the target score of each target point in the target region, including columns for the current climate match, each GCM, median future climate match, and difference between current and median future climate matches

    - Example file name: “tbl_Cercopagis_pengoi_ContigUS_TIMESTEP_SSP_Aggregate_YYYY_MM_DD.csv”

4) Climate 6 score summary table (CSV)

    - Description: Table of Climate 6 scores calculated for each GCM by time period and SSP

    - Example file name: “tbl_Cercopagis_pengoi_ContigUS_ClimateSix_YYYY-MM-DD.csv”

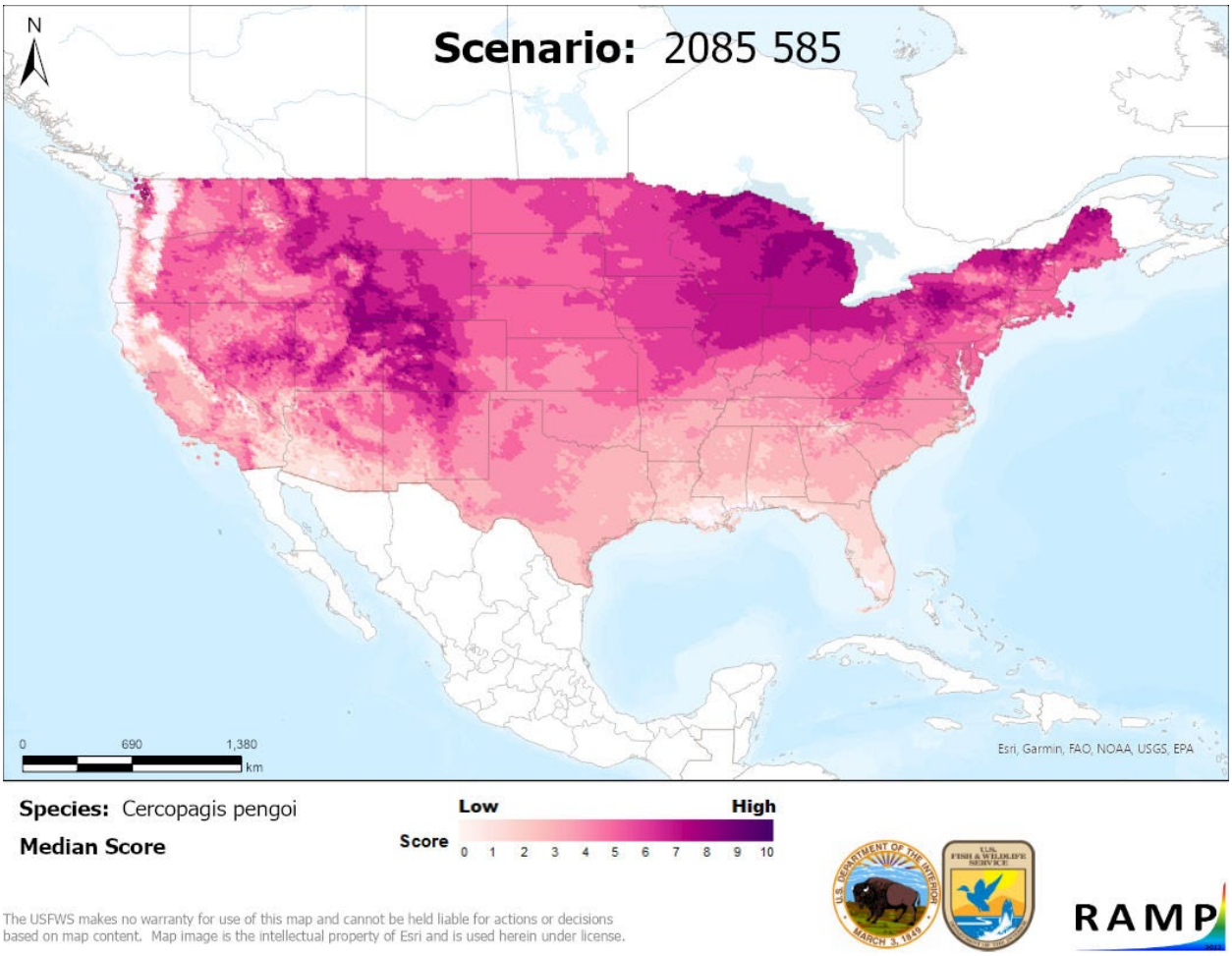

Figure 19. RAMP-produced image of the median future climate matching results for Shared Socioeconomic Pathway 5 and time period 2085, aggregated across five global climate models, for *Cercopagis pengoi* with a target region of the contiguous United States.

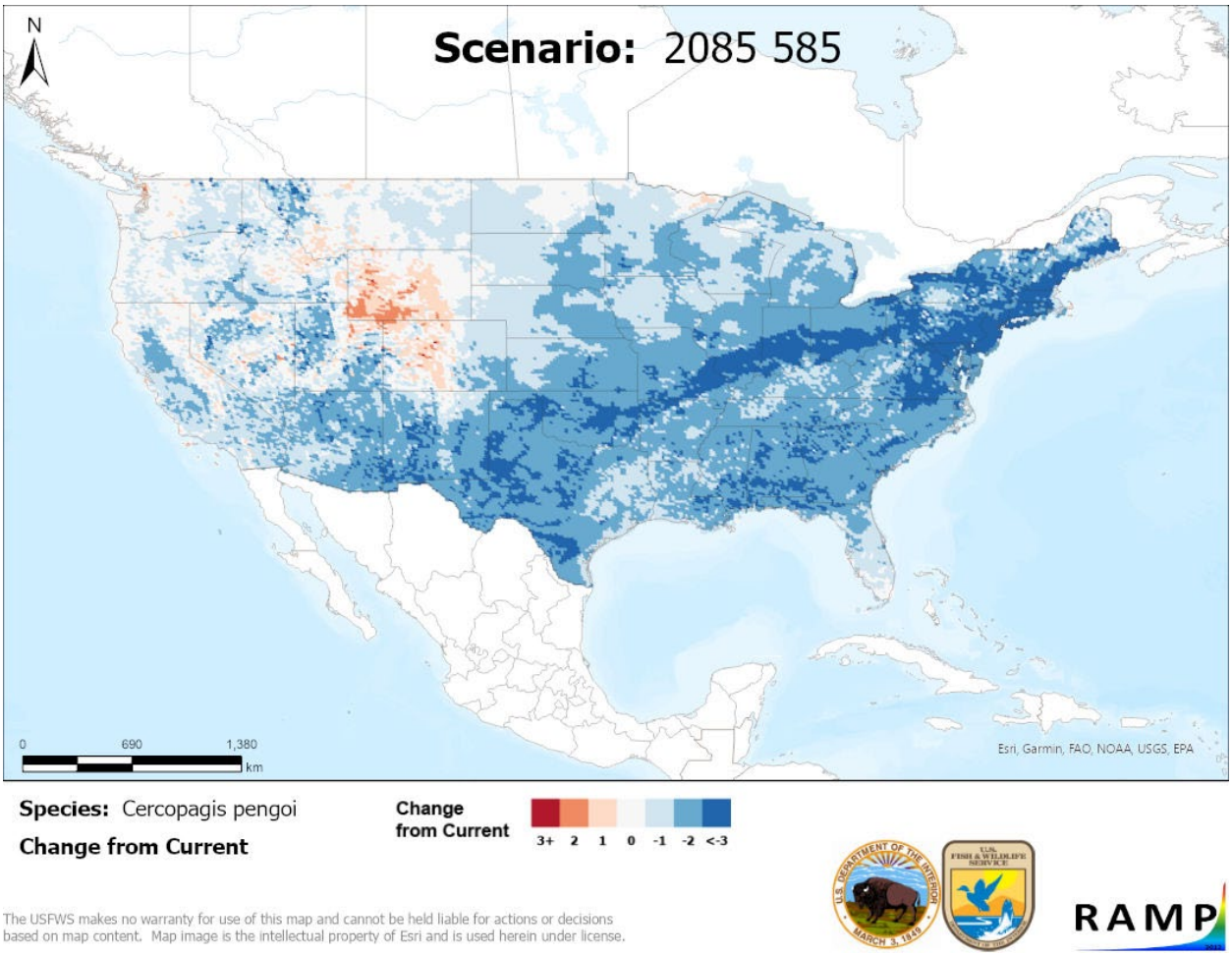

Figure 20. RAMP-produced image of the difference between current and median future climate matching results for Shared Socioeconomic Pathway 5 and time period 2085, aggregated across five global climate models, for *Cercopagis pengoi* with a target region of the contiguous United States.

Other files created as part of the RAMP process provide documentation of the climate match and ensure reproducibility:

1) Source point map (JPEG; figure 21)

   - Description: Image of selected source points for the climate match
   - Example file name: "Cercopagis_pengoi_Global_Selected.jpg"

2) Species geodatabase (file geodatabase [GDB])

   - Description: Geodatabase containing original GBIF points (Points feature class) and selected climate stations (*species name* Stations feature class) used to perform the match, as well as symbology for the layers
   - Example file name: Cercopagis_pengoi.gdb

3) GBIF occurrence data table (CSV)

- Description: Table of coordinates for each occurrence downloaded from GBIF
- Example file name: Cercopagis_pengoi_GBIF_Locations_YYYY_MM_DD.csv

Unlike the results files, there is only one copy each of the source point map and species geodatabase. Every time the climate match is run, these files are modified or overwritten so that they reflect the most recent climate match run.

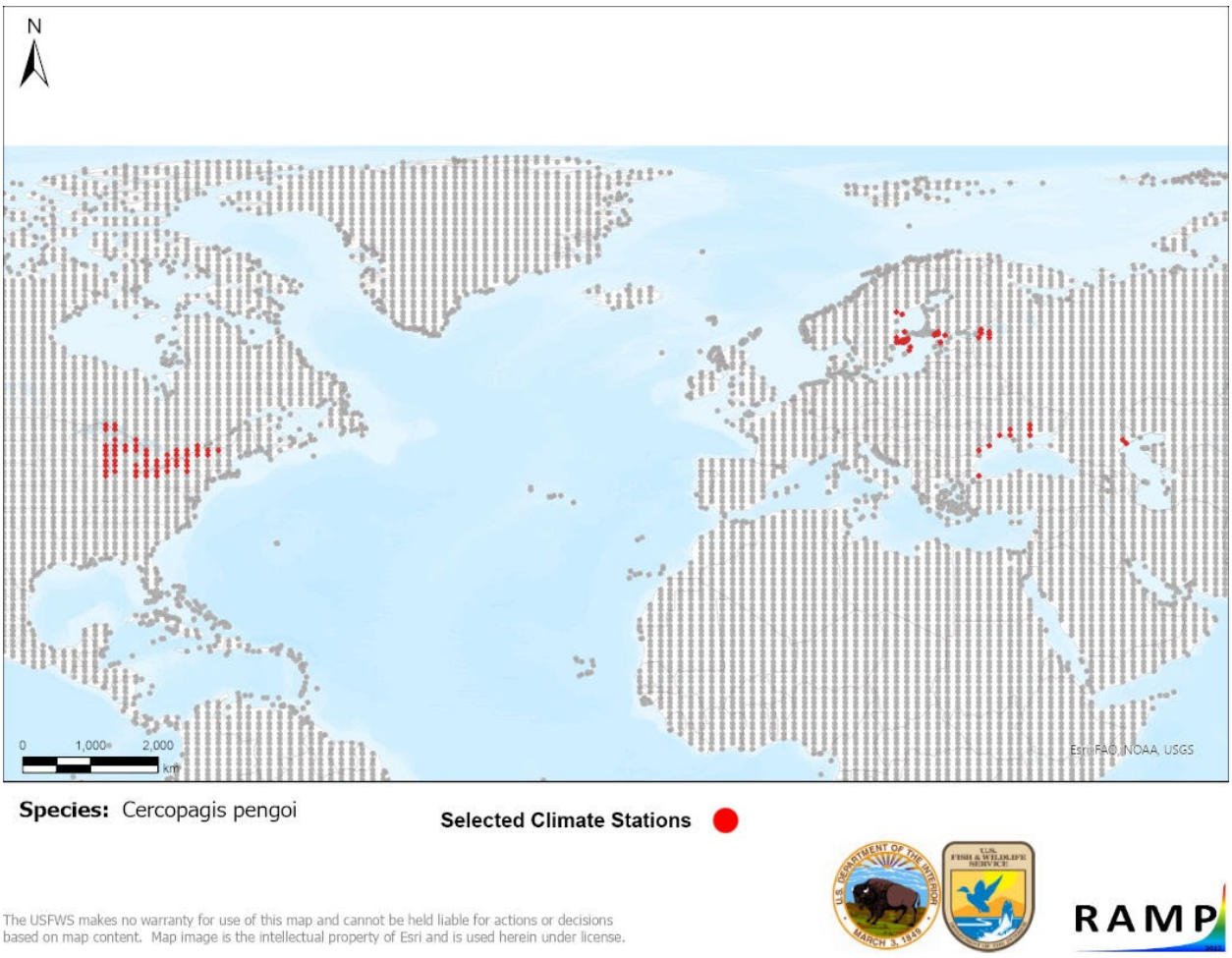

Figure 21. RAMP-produced image of selected climate matching source locations (red) and non-source locations (gray) for *Cercopagis pengoi*.

B. Source Map Considerations

Providing the source map is a simple way to report selected source locations when presenting the results of a RAMP climate matching analysis.

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 (Share tab in ArcGIS Pro) with the desired scale after making all necessary modifications to the climate matching source locations and before performing the match. The export should be done with the map tab active rather than the layout tab (figure 16).

C. Interpreting the Results Map

The results map shows the target region as a grid of points colored according to the degree of match between the source locations and each target location (figures 18, 21). For large target regions, the grid of points will appear as a single shaded surface (figure 19). The grid becomes visible with smaller target regions (figure 22). 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). On the map, light pink represents low match, dark purple represents high match, and gradations of medium pink represent medium match.

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. This is the same “frequency of target scores” table also provided in CSV format. It is used in calculating the Climate 6 score (see part 4D).

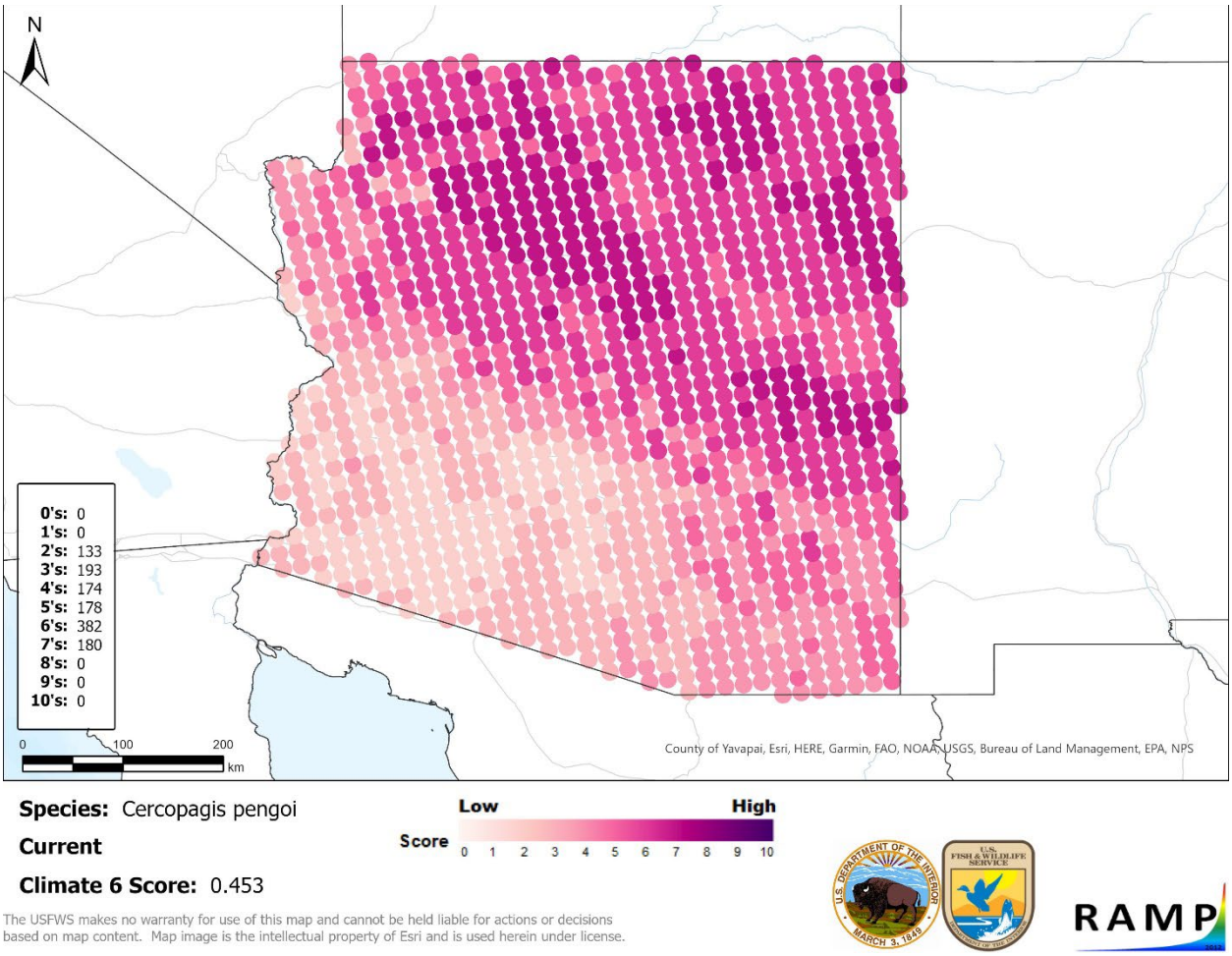

Figure 22. RAMP-produced image of the climate matching results for *Cercopagis pengoi* under the current climate scenario with a target region of the State of Arizona.

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: **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** (see "Source Map Considerations"). Unlike the image shown in the ArcGIS Pro map tab 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. Manual exports and screenshots may contain inaccurate labeling or text.

D. Understanding and Interpreting the Climate 6 Score

The Climate 6 score is a summary statistic used to estimate the overall match between the target region and source locations. The Climate 6 score for a particular species, target region, and climate scenario is stated in the legend of the climate match map. It can be calculated from the "frequency of target scores" table as the proportion of target scores greater than or equal to 6. Therefore, a Climate 6 score greater than 0 indicates that at least one target location is a good climate match. However, rounding could produce a Climate 6 score of 0 even if there are a few higher match target points.

Climate 6 scores can be used as an indicator of the probability that the species will establish within the target region. Establishment concern is warranted for species with a Climate 6 score greater than or equal to 0.002, and doubtful for species with a Climate 6 score less than 0.002. The selected threshold of 0.002 maximizes the probability that species that will not actually establish are correctly classified as doubtful to establish. This is why it is important to use only locations where the species is established as source locations for the climate match. The threshold is based on an analysis of the establishment success of 356 nonnative aquatic species introduced to the contiguous United States (see appendix I of the ERSS SOP [USFWS 2024] for further information).

When reporting the results of a climate matching analysis, reporting both the Climate 6 score itself and its categorization can be useful. There is a wide range of Climate 6 scores that indicate establishment concern, but the categorization provides general guidance on how to interpret the numerical value.

E. 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. Use clues from the databases and other literature reporting source locations to decide if any of these situations exist (see sections 3A and 3B).

Climate matching with uncertain inputs leads to uncertain outputs. However, even with high certainty in the accuracy and completeness of the source locations, there will still be some uncertainty in the climate match results as a predictor of species establishment. Although climate match is a good predictor of establishment in general (Hayes and Barry 2008), the actual distribution of a species may be influenced by pathways and barriers to movement, resource availability, presence of predators and competitors, diseases, and other factors. For example, island species may be restricted by geographic barriers to range expansion more than by climate tolerance. If only one or two source locations are available for a species, then the climate matching algorithm does not have much data informing the range of acceptable climate variable values.

Additionally, the climate data on which RAMP is based are themselves estimated and may not capture local 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 suitable microclimates will not be reflected in the climate matching results. Therefore, populations may be able to establish in areas that seem to have a low climate match.

Part 5. Literature Cited

[ABARES] Australian Bureau of Agricultural and Resource Economics and Sciences. 2020. Climatch. Version 2.0. Available: https://climatch.cp1.agriculture.gov.au/ (August 2022).

Barry S. 2006. CLIMATE (PC version). Canberra, Australia Bureau of Rural Sciences.

Benson A, Maynard E, Raikow D, Larson J, Makled TH, Fusaro A. 2017. *Cercopagis pengoi*. Gainesville, Florida: U.S. Geological Survey, Nonindigenous Aquatic Species Database. Available: https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=163 (September 2017).

Bomford M, Barry SC, Lawrence E. 2010. Predicting establishment success for introduced freshwater fishes: a role for climate matching. Biological Invasions 12:2559–2571.

Bomford M, Kraus F, Barry SC, Lawrence E. 2009. Predicting establishment success for alien reptiles and amphibians: a role for climate matching. Biological Invasions 11:713–724.

Broennimann O, Treier UA, Müller-Schärer H, Thuiller W, Peterson AT, Guisan A. 2007. Evidence of climatic niche shift during biological invasion. Ecology Letters 10:701–709.

Cristescu MEA, Hebert PDN, Witt JDS, MacIsaac HJ, Grigorovich IA. 2001. An invasion history for *Cercopagis pengoi* based on mitochondrial gene sequences. Limnology and Oceanography 46(2):224–229.

Crombie J, Brown L, Lizzio J, Hood G. 2008. Climatch user manual. Canberra, Australia: Australian Government Bureau of Rural Sciences.

Erickson RA, Engelstad PS, Jarnevich CS, Sofaer HR, Daniel WM. 2022. Climate matching with the climatchR R package. Environmental Modelling & Software 157:105510.

GBIF Secretariat. 2022. GBIF backbone taxonomy: *Cercopagis pengoi* (Ostroumov, 1891). Copenhagen: Global Biodiversity Information Facility. Available: https://doi.org/10.15468/dl.8r2pgx (July 2022).

Güher H. 2004. A study on morphological characters, spatial and seasonal densities, and co-existence of two predatory Cladocera, *Cercopagis pengoi* (Ostroumov, 1891) and *Cornigerius meaticus* (Pengo, 1879) in Lake Terkos, Turkey. Crustaceana 77(6):669–681.

Hayes KR, Barry SC. 2008. Are there any consistent predictors of invasion success? Biological Invasions 10:483–506.

Howeth JG, Gantz CA, Angermeier PL, Frimpong EA, Hoff MH, Keller RP, Mandrak NE, Marchetti MP, Olden JD, Romagosa CM, Lodge DM. 2016. Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes. Diversity and distributions 22:148–160.

IPCC. 2021. Summary for policymakers. Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report for the Intergovernmental Panel on climate change. Cambridge: Cambridge University Press.

[OMB] U.S. Office of Management and Budget. 2004. Final information quality bulletin for peer review. Federal Register 70:10(16 December 2004):2664–2677.

Pearson RG, Dawson TP. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology & Biogeography 12:361–371.

Pheloung PC. 1996. CLIMATE: a system to predict the distribution of an organism based on climate preferences. Perth, Australia: Agriculture Western Australia.

Stefan HG, Preud'homme EB. 1993. Stream temperature estimation from air temperature. Water Resources Bulletin 29:27–45.

Thuiller W, Richardson DM, Pyšek P, Midgley GF, Hughes GO, Rouget M. 2005. Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology 11:2234–2250.

[USFWS] U.S. Fish and Wildlife Service. 2024. Standard operating procedures: how to prepare an "Ecological Risk Screening Summary". Version 3.

Appendix A. RAMP Data Sources and Construction

A. Data Sources

Current Climate

Current climate data were obtained from CHELSA version 2.1 datasets (Karger et al. 2017, 2018), available through CHELSA. The CHELSA data layers were generated through correction of the European Center for Medium-Range Weather forecast climatic reanalysis interim (ERA-Interim; Dee et al. 2011) with data from the Global Historical Climate Network Dataset (GHCN; Peterson and Vose 1997) and the Global Precipitation Climatology Center (GPCC; Schneider et al. 2013; Karger et al. 2017). Existing climate data for the period 1979-2013 were modeled and interpolated to create continuous climate surfaces representing current climate (Karger et al. 2017, 2018). Climate surfaces were produced for precipitation, mean temperature, minimum temperature, and maximum temperature.

The CHELSA data layers selected for RAMP use a 30 arc-second resolution grid (also referred to as "1 km" resolution). Sixteen bioclimatic variables derived from the CHELSA 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.

CHELSA Code/RAMP Code	Description
BIO1	Mean annual air temperature
BIO5	Mean daily maximum air temperature of warmest month
BIO6	Mean daily minimum air temperature of coldest month
BIO7	Temperature annual range (BIO5-BIO6)
BIO8	Mean daily mean air temperature of wettest quarter
BIO9	Mean daily mean air temperature of driest quarter
BIO10	Mean daily mean air temperature of warmest quarter
BIO11	Mean daily mean air temperature of coldest quarter
BIO12	Annual precipitation amount
BIO13	Precipitation amount of wettest month
BIO14	Precipitation amount of driest month
BIO15	Precipitation seasonality (coefficient of variation)
BIO16	Mean monthly precipitation amount of wettest quarter
BIO17	Mean monthly precipitation amount of driest quarter
BIO18	Mean monthly precipitation amount of warmest quarter
BIO19	Mean monthly precipitation amount of coldest quarter

Future Climate

Future climate data were also obtained from CHELSA version 2.1 datasets (Karger et al. 2017, 2018, 2020), available through CHELSA. The future climate data were downscaled and calibrated from global climate model (GCM) outputs used in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC6; IPCC 2021). The calibration process used CHELSA 2.1 current climate surfaces (Karger et al. 2017, 2018, 2020) as the baseline current climate. Two time periods were considered: 2055 (representing the average predicted climate for 2041-2070) and 2085 (representing the average predicted climate for 2071-2100). CHELSA provides data layers for three Shared Socioeconomic Pathways (SSPs) and 5 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 all five GCMs available in the CHELSA data: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0 (Karger et al. 2017). For future climate scenarios, RAMP uses two SSPs: SSP3 and SSP5. The SSPs represent a set of scenarios describing different global development patterns and associated actions for mitigating climate change. They span a range of possible futures with SSP3 based on countries focusing on domestic energy and food security more than global action leading to uneven climate impacts, and SSP5 based on uncontrolled growth and development with the most extreme climate change.

B. 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 approximately 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. Points in grid squares that fell into the ocean were moved to islands within that grid square to represent those islands in the climate matching. 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 both the global and target layer points in the same fashion. ArcGIS Pro (Esri, Redlands, California) was used to extract raster cell values from CHELSA version 2.1 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	19,852	75.9 km	GCS WGS 1984	Equidistant Cylindrical (World)
Target	97,163	15 km	GCS WGS 1984	Equidistant Cylindrical (World)

C. Matching Calculation

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

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

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 target point scores range from 0 to 10.

D. Literature Cited

Bomford M. 2008. Risk assessment models for establishment of exotic vertebrates in Australia and New Zealand. Canberra, Australia: Invasive Animals Cooperative Research Centre.

Crombie J, Brown L, Lizzio J, Hood G. 2008. Climatch user manual. Canberra, Australia: Australian Government Bureau of Rural Sciences.

Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, Andrae U, Balmaseda MA, Balsamo G, Bauer P, Bechtold P, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Delsol C, Dragani R, Fuentes M, Greer AJ, Haimberger L, Healy SB, Hersbach H, Hólm EV, Isaksen L, Kållberg P, Köhler M, Matricardi M, McNally AP, Monge-Sanz BM, Morcrette J-J, Park B-K, Peubey C, de Rosnay P, Tavolato C, Thépaut J-N, Vitart F. 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society 137(656):553–597.

IPCC. 2021. Summary for policymakers. Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report for the Intergovernmental Panel on climate change. Cambridge: Cambridge University Press.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder P, Kessler M. 2017. Climatologies at high resolution for the Earth land surface areas. Scientific Data 4:170122.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP, Kessler M. 2018. Data from: Climatologies at high resolution for the earth's land surface areas. EnviDat. Available: https://doi.org/10.16904/envidat.228.v2.1.

Karger DN, Schmatz D, Detttling D, Zimmermann NE. 2020. High resolution monthly precipitation and temperature timeseries for the period 2006-2100. Scientific Data 7:248.

Schneider U, Becker A, Finger P, Meyer-Christoffer A, Ziese M, Rudolf B. 2013. GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. Theoretical and Applied Climatology 115:15–40.

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

Use this checklist to determine if the RAMP climate matching analysis is complete, follows the SOP, and meets data standards.

> Note: If the climate matching analysis is being completed as part of an ERSS, the review checklists within the ERSS SOP are a preferred substitute for this checklist.

Subject Species Scientific Name:
Subject Species Common Name:

Name of Reviewer:
Date Reviewed:

Data Sources	
Which data sources were used to generate the distribution?	
Was each data source reviewed for outliers and anomalies?	☐ Yes ☐ No
Was each data source saved for the administrative record?	☐ Yes ☐ No
Comments:	

Climate Matching
Were climate matching source locations edited as needed to remove outliers and anomalies? ☐ Yes ☐ No
If any outliers or anomalies were removed, is there documentation of why they qualified for removal? ☐ Yes ☐ No ☐ N/A 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? ☐ Yes ☐ No ☐ N/A 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? ☐ Yes ☐ No ☐ N/A If not documented elsewhere, explain here:
Was the species folder generated by RAMP saved for the administrative record? ☐ Yes ☐ No
Comments: