Module 1: Seaweed Farming Benefits and Tradeoffs Mapping

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This tool calculates a favorability score for seaweed farming based on four categories: climate mitigation, water quality improvement, conflict avoidance, and future temperature suitability. These categories are scored based on the minimum and maximum conditions found within each spatial unit of evaluation. The tool creates a weighted average of the category scores in five different ways (Table 1, Figure 1), resulting in five different output files per spatial unit, each one representing one weighting scenario. Users may choose which weighting scenario best aligns with their priorities or consider all five.

All input conditions (Table 2, S1) are scaled from 0 to 1 (with the exception of wind farm proximity), with 0 representing the least favorable conditions for seaweed farming within the spatial unit of evaluation, and 1 representing the most favorable conditions. Due to the low relative number of global wind farms, the wind farm score is treated as a bonus instead of part of the main weighted average calculation. Wind farm proximity is scaled from 0 to 0.5 instead of from 0 to 1. All input data should use the same projection. All rasters should be the same resolution.

The five output files for each unit may be further combined into five composite files representing all units together. The outputs for each weighting scenario can be compared to aid decisions about where to farm seaweed.

Limitations: This model evaluates relative favorability for seaweed farming. It does not predict the chances of success or failure for farming seaweed in any given location. The model assumes conditions are the same over an entire grid cell. Coarse input resolutions may omit some nearshore areas. Output maps do not display uncertainty associated with favorability for seaweed farming. Users are recommended to view maps as a visual guide or to run the tool multiple times for a range of input conditions. Sample data that may accompany this tool are for educational purposes only. Users are responsible for verifying the accuracy, timeliness, and relevance of all input data used in this tool.

Requirements:
- ArcGIS Version 10.2 or higher / ArcGIS Pro 3.2.2 or higher
- Spatial Analyst Extension (How to activate Spatial Analyst)

Notes:
- Before beginning, enable overwriting of results. Open the Geoprocessing menu and select “Geoprocessing Options.” Check the box for “Overwrite the outputs of geoprocessing operations” and click OK.
- All files should be loaded from and saved to a physical drive (either the regular hard drive or an external harddrive). Interacting with GIS files in common cloud storage platforms may produce slow processing times. If you are unable to store files on your machine or external drive long-term, it is recommended to download them for the duration of your work session and upload the outputs to cloud storage at the end of each session.
- A geodatabase folder must exist for processing intermediate steps. The “Default.gdb” should be already present in the “Documents/ArcGIS” folder, or the user can create one using the New File Geodatabase button  in the file browser.

- Input files must be in raster format, except for the Study Area layer, which must be in polygon format.
- This module may take a long time to run, especially if the Study Area has many units or covers a large area.
- Externally linked articles in this user guide provide additional information on how to perform basic operations in ArcMap. They are meant to provide supplemental information in case these operations are new to the user.

Outputs:

- The module produces five output rasters for each unique ID number within the Study Area. Each raster represents the favorability score for one weighting scheme for that unit.
- The module will generate several intermediate files that may be of interest (Figure S1), including rasters with the category scores for Climate benefit, Water quality improvement, Conflict avoidance, and Future temperature suitability: *climate[unit#], waterQ[unit#], constra[unit#],* and *sst[unit#]*, respectively, where *unit#* represents the integer code of each unit. These intermediates are stored in the geodatabase specified in the "Workspace" field. Examining these rasters can help determine which input factors are contributing to the overall favorability scores.

Table 1. Description and weighting of input categories. Weighting scenarios A-D put extra emphasis on a single category, while scenario E gives equal weight to all categories.

Category	Preference for:	Input variables	Weighting A	Weighting B	Weighting C	Weighting D	Weighting E (equal)
Climate Benefits	Harvest with GHG reduction or C sequestration	Production, net GHG reduction, proximity to depositional basins	40%	20%	20%	20%	25%
Water quality improvement	Improvement of water quality	Ocean acidification remediation, reduction of excess nutrients	20	40	20	20	25
Conflict avoidance	Compatibility with other marine uses	Shipping areas, fishing activity, migratory species, coral reef habitat, proximity to offshore wind farms	20	20	40	20	25
Future temperature suitability	Long-term farming opportunities	2050-2059 mean sea surface temperature	20	20	20	40	25

Table 2. Description of inputs and outputs for the module. For file names of the sample data for this module, see Table S1.

Parameter	Explanation
Workspace	File geodatabase (.gdb) where intermediate files will be saved. This must be a geodatabase and cannot be a regular folder.
Study Area Raster	Shapefile of the study area. This shapefile must have a field titled "ID no" that contains an integer ID number of the unique study area units. Each unit of the study area must have its own integer assigned (6 digits or less).
Snap Raster (Harvest Raster Recommended)	Raster to which all the outputs will be aligned. The input Harvest Raster is the recommended raster to use, but any raster may be used.
Harvest Raster	Estimated harvest (metric tons dry weight, Mg km^{-2}) of seaweed.
Net GHG Reduction Raster	Estimated net greenhouse gas offset or sequestration (Mg CO_2e km^{-2}) by seaweed farming.
Basin Distance Raster	Estimated distance (km) of seaweed farming from ocean depositional basins.
Aragonite Saturation State Raster	Aragonite saturation state (Ω) as a proxy for ocean acidification. $\Omega < 3$ indicates acidified waters that may have negative effects on calcifying organisms.

Excess Nutrients Raster	Estimated amount of excess nutrients or frequency of eutrophication events.
Migratory Species Raster	Species richness of migratory fish, birds, and marine mammals.
Shipping Intensity Raster	Relative volume of shipping traffic based on ship track density.
Commercial Fishing Raster	Reported annual catch for industrial fishing, standardized as a proportion of regional primary productivity.
Percent Coral Reef Raster	Percentage of cell area with tropical and subtropical coral reefs.
Distance to Wind Farms Raster	Estimated distance (km) from cell center to offshore wind farms.
SST Projections Raster	Average projected sea surface temperature (ºC). User chooses SST projection.
Output Folder	Folder directory where the output files will be saved.
Scenario A Output	Seaweed farming favorability score emphasizing climate benefits as the most important input category. Weights: 40% Climate benefits, 20% Water quality improvement, 20% Conflict avoidance, 20% Future temperature suitability.
Scenario B Output	Seaweed farming favorability score emphasizing water quality improvement as the most important input category. Weights: 20% Climate benefits, 40% Water quality improvement, 20% Conflict avoidance, 20% Future temperature suitability.
Scenario C Output	Seaweed farming favorability score emphasizing conflict avoidance as the most important input category. Weights: 20% Climate benefits, 20% Water quality improvement, 40% Conflict avoidance, 20% Future temperature suitability.
Scenario D Output	Seaweed farming favorability score emphasizing future temperature suitability as the most important input category. Weights: 20% Climate benefits, 20% Water quality improvement, 20% Conflict avoidance, 40% Future temperature suitability.
Scenario E Output	Seaweed farming favorability score with all input categories weighted equally.

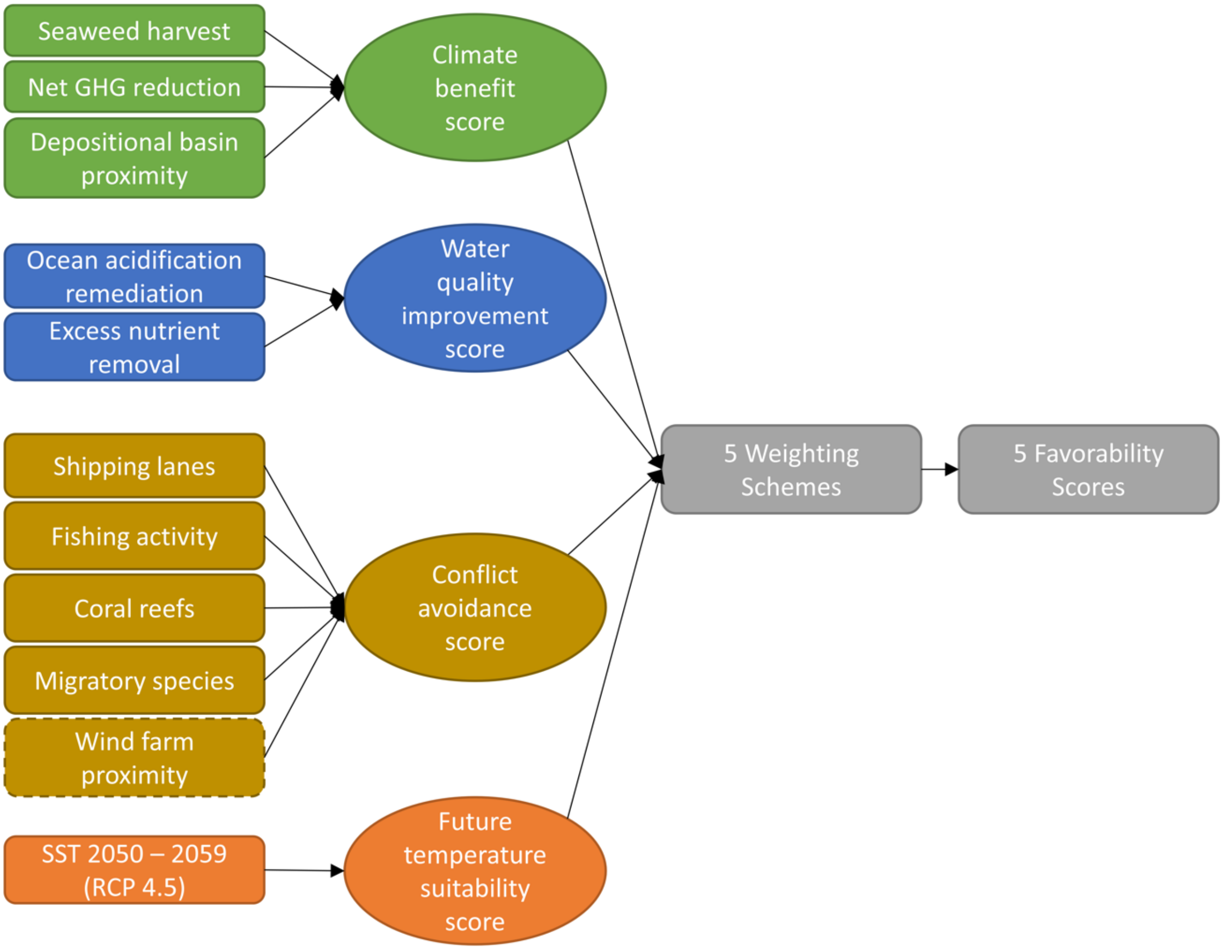
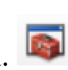
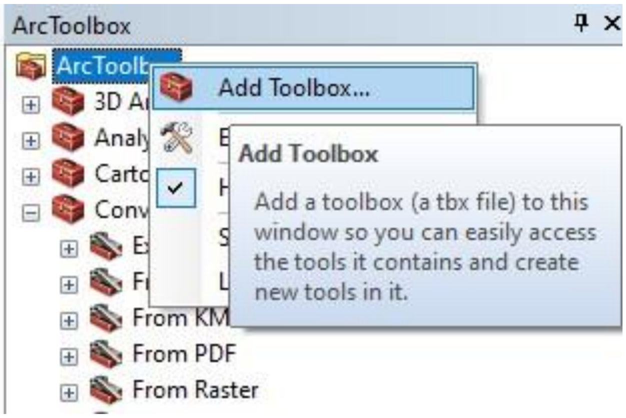


Figure 1. Schematic of how input variables are combined to calculate category scores and overall favorability scores.

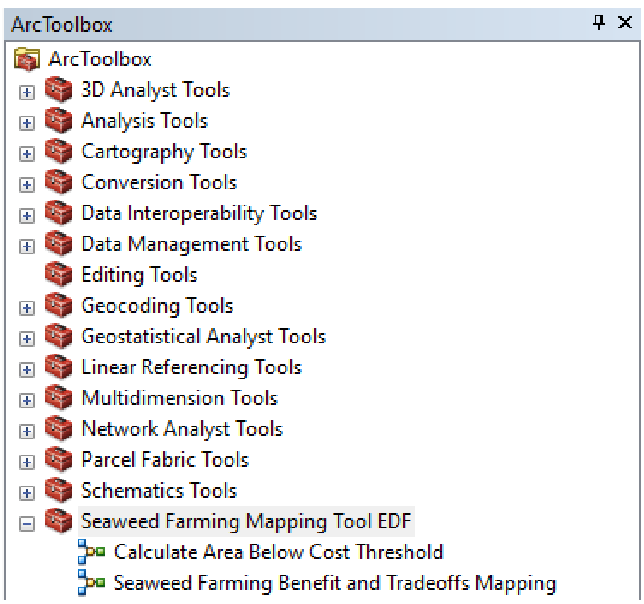
Steps:

1. **Setting up ArcMap**
   - Unzip the zip file containing the toolbox and input data and move them to the desired folder before opening ArcMap to ensure folder pathways are correctly set.

2. **Load the toolbox in ArcMap (for ArcGIS Pro, see Step 3)**
   - Open the toolbox pane in ArcMap by clicking the red toolbox button. 
   - Right-click "ArcToolbox" at the top of the pane and select "Add Toolbox."

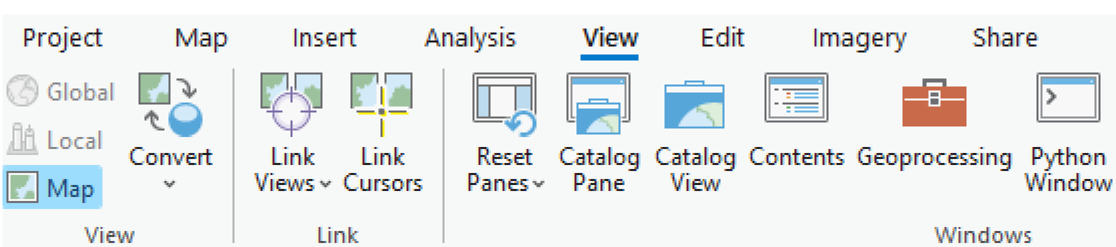


- In the window that opens, navigate to the folder where the toolbox is saved. *Single click* the appropriate .tbx file name and then click "Open." Do not double click the toolbox name.
- Find the toolbox name in the toolbox pane. Double click on the name to show individual models inside the toolbox. Toolboxes and the models within them appear in alphabetical order.
- Double click on "Seaweed Farming Benefit and Tradeoffs Mapping" to open this module.

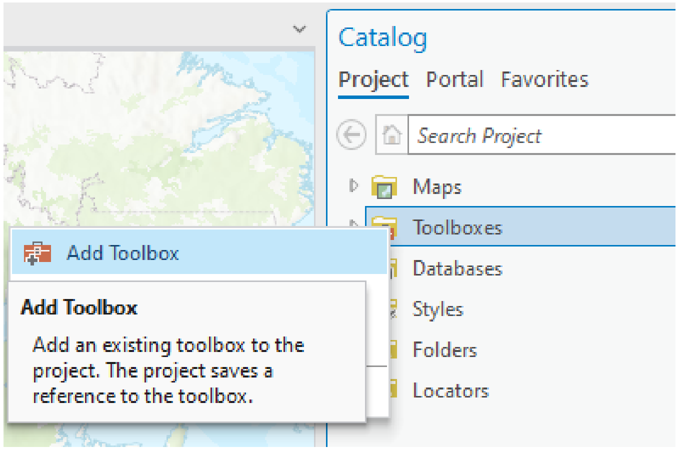


3. Loading the toolbox in ArcGIS Pro (for ArcMap, see Step 2)

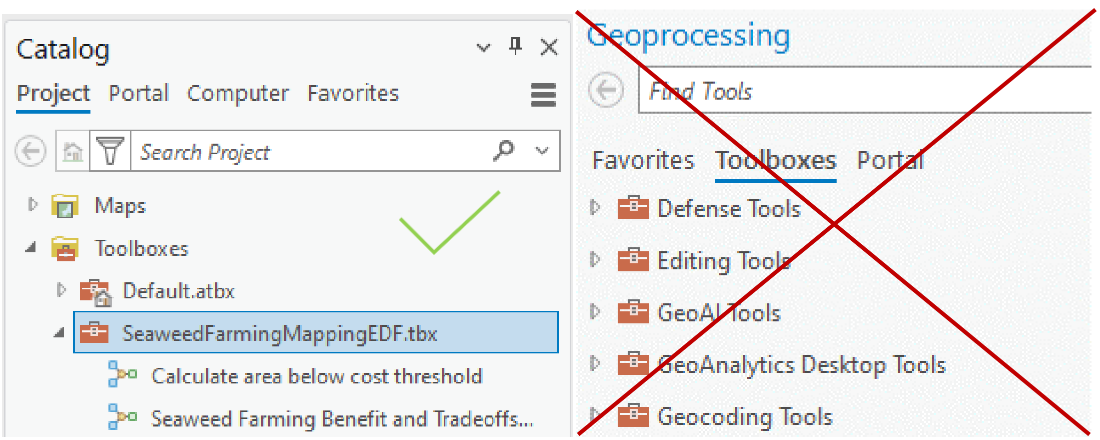
- On the Ribbon, navigate to the View tab and open the Catalog Pane.



- In the pane that opens, right click on "Toolboxes" and select "Add Toolbox."



- In the window that opens, navigate to the folder where the toolbox is saved. *Single click* the appropriate .tbx file name and then click "Open." Do not double click the toolbox name.
- Find the toolbox name in the Catalog Pane. Double click on the name to show individual models inside the toolbox. Toolboxes and the models within them appear in alphabetical order. Note that this imported toolbox will not appear in the regular list of toolboxes in the Geoprocessing Pane.



- Double click on "Seaweed Farming Benefit and Tradeoffs Mapping" to open this module.

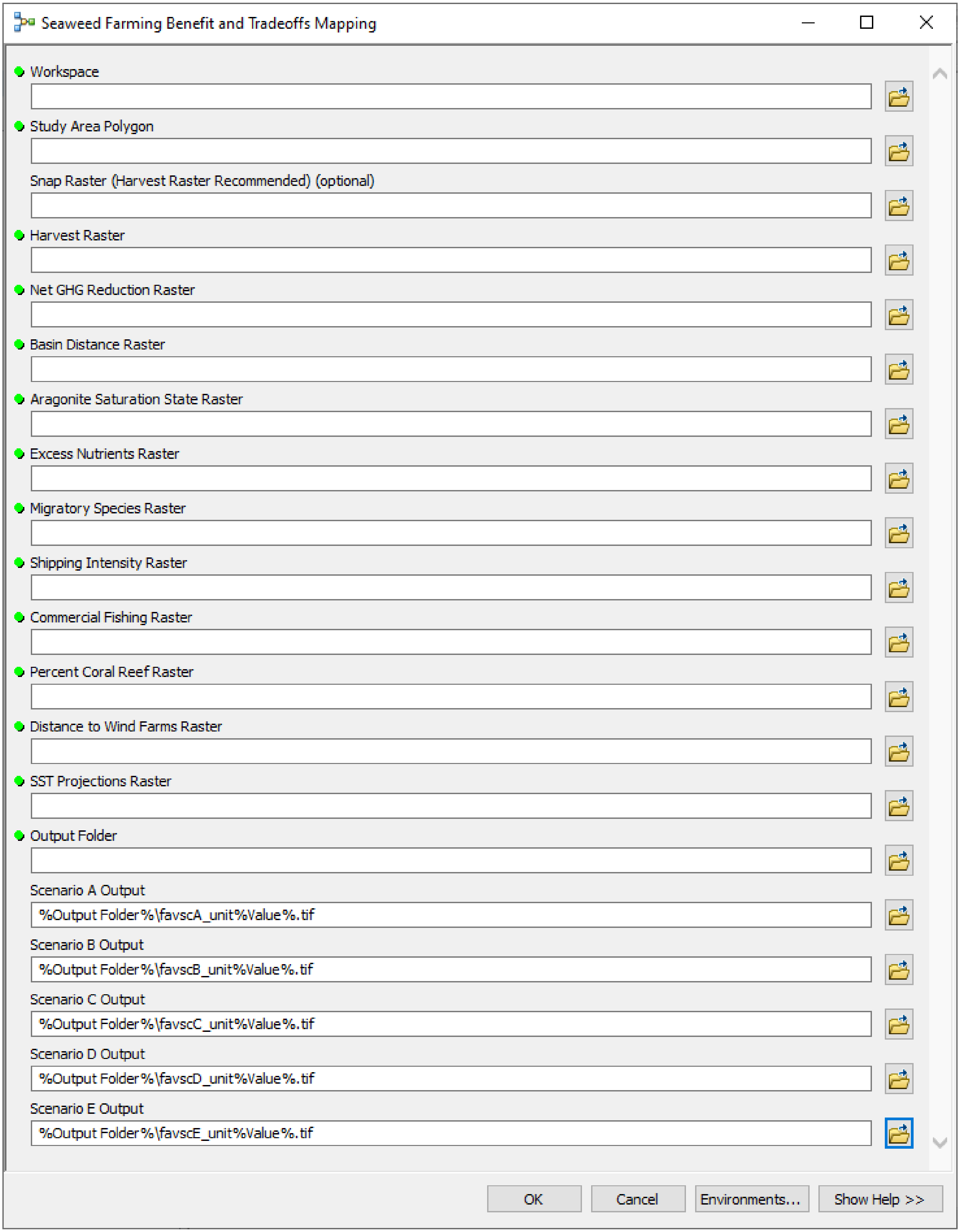
4. **Specify the workspace**

- Click the folder button  next to the "Workspace" line to open the file browser. Select the desired geodatabase for storing intermediate files. If a geodatabase does not exist, create one by clicking the New File Geodatabase button. 

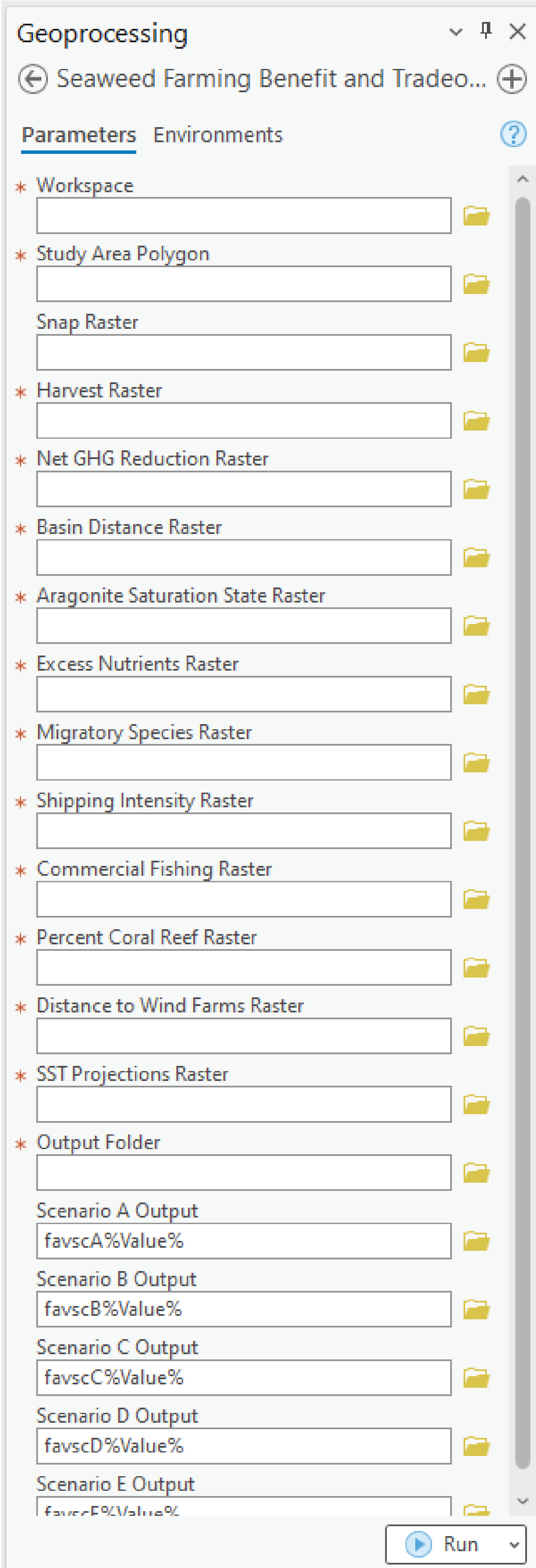
5. **Add Input Files**

- Click the folder button  to upload input files to their appropriate line, following Table 2. Alternatively, the file can be dragged and dropped into the appropriate line directly from Windows Explorer. However, this second method may be slower.
- For a list of file names corresponding to the sample data provided for this module, see Table S1.

- For the Study Area Polygon, each unit of the study area must have its own integer code stored in a field named *ID_no*, which must be a Long Integer type filed containing 6 digits or less. This number will be appended to the names of intermediate and output files. If this field does not exist in the study area polygon, add one and assign ID numbers. All features that share an ID number will be evaluated as a single unit, even if they are non-contiguous. Multiple polygons may share the same ID number. (The sample data input, *EEZ_subset_SA.shp*, already has an *ID_no* field and has all ID numbers assigned.)



Seaweed Farming Benefit and Tradeoffs Mapping
Workspace
Study Area Polygon
Snap Raster (Harvest Raster Recommended) (optional)
Harvest Raster
Net GHG Reduction Raster
Basin Distance Raster
Aragonite Saturation State Raster
Excess Nutrients Raster
Migratory Species Raster
Shipping Intensity Raster
Commercial Fishing Raster
Percent Coral Reef Raster
Distance to Wind Farms Raster
SST Projections Raster
Output Folder
Scenario A Output
%Output Folder%\favscA_unit%Value%.tif
Scenario B Output
%Output Folder%\favscB_unit%Value%.tif
Scenario C Output
%Output Folder%\favscC_unit%Value%.tif
Scenario D Output
%Output Folder%\favscD_unit%Value%.tif
Scenario E Output
%Output Folder%\favscE_unit%Value%.tif
OK
Cancel
Environments...
Show Help >>



6. **Specify location for saving outputs**

- Click the folder button next to the "Output Folder" line to open the file browser. Select the desired location for saving output files.
- Scenario Output files may be saved in any location. If saving outputs within a geodatabase, the file name must be 13 characters or less and ".tif" must be deleted from the file name, as tif files cannot be saved inside a geodatabase.
- The tool interface is pre-filled with suggested names for the five output files. The file path should include *%Output Folder%* for the files to show up in the specified output folder. The name <u>must</u> include *%Value%* when entered into the model dialogue box to append the integer code of each unit (e.g. *favscA_%Value%*). If this text is not included, the outputs for each successive study unit will overwrite the those of the previous unit.

7. **Run the tool**

Once all input rasters are loaded, click 'OK' and the model will run.

- To view the model status click on 'Geoprocessing pane' and 'Results'. Here you can view the status of the model being run with what stage the model is currently processing.
- A spinning globe icon or progress bill appear at the bottom right of the window to indicate the model is being processed. There may be a lag between when the model completes and when outputs appear on the display.
- Because many output files are generated, pausing the display during processing may help the processing finish faster. To pause or unpause the display, click the Pause button at the bottom corner of the map pane.

8. **View the outputs**

- Unpause the display (if applicable).
- If the outputs do not appear, click the Add Data button, navigate to the output folder, and select the output files to load into the map. Click "Add".

- The default symbology will be a black and white gradient. Double click on the gradient swatch in the Table of Contents pane to select a new color scheme if desired.
- Pan and zoom around the map to see where the highest and lowest scoring areas for each study unit are for the different weighting scenarios. Examine which scenarios scored the highest and lowest in each study unit or specific locations of interest.

Supplemental Information

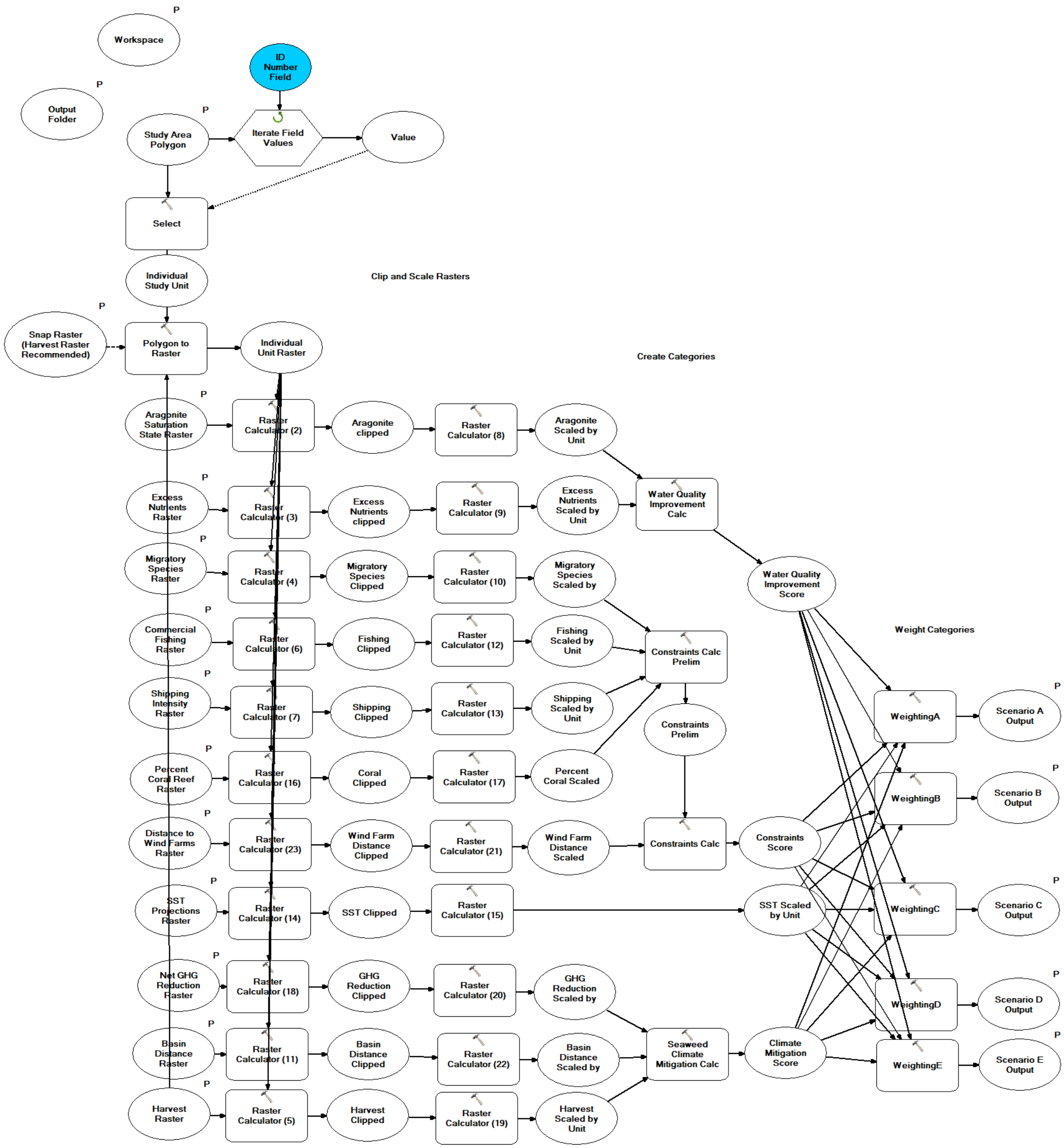


Figure S1. Detailed diagram of ArcMap geoprocessing steps for the Seaweed Farming Benefits and Tradeoffs Mapping module. “P” indicates “model parameter” where the user designates an input or output. The four category scores are saved in the specified workspace while the final outputs are saved in the specified output folder.

Sample data

Table S1. File names and references for sample data provided for this tool. These data are provided "as-is" with no warranty regarding their suitability for use in any given location.

Parameter	Input Files	Sample Data Source
Study Area Polygon	EEZ_subset_SA.shp	G-MACMODS (DeAngelo et al. 2023, Arzeno-Soltero et al. 2023)
Snap Raster	harvest_sample.tif	G-MACMODS (DeAngelo et al. 2023, Arzeno-Soltero et al. 2023)
Harvest Raster	harvest_sample.tif	G-MACMODS (DeAngelo et al. 2023, Arzeno-Soltero et al. 2023)
Net GHG Reduction Raster	GHG_reduction_sample.tif	G-MACMODS (DeAngelo et al. 2023, Arzeno-Soltero et al. 2023)
Basin Distance Raster	basin_distance_sample.tif	(Harris et al. 2014)
Aragonite Saturation State Raster	aragonite_sat_sample.tif	NOAA (Jiang et al. 2015)
Excess Nutrients Raster	nutrients_sample.tif	GEO Blue Planet (Smail et al. 2020)
Migratory Species Raster	migratory_spp_sample.tif	Migratory Connectivity in the Ocean (Dunn et al. 2019)
Shipping Intensity Raster	shipping_sample.tif	Ocean Health Index (Halpern et al. 2008, 2015)
Commercial Fishing Raster	fishing_sample.tif	Ocean Health Index (Halpern et al. 2008, 2015)
Percent Coral Reef Raster	pct_coral_reef_sample.tif	UN Environmental Programme World Conservation Monitoring Centre (UNEP-WCMC et al. 2021)
Distance to Wind Farms Raster	wind_farm_dist_km_sample.tif	(Global Energy Monitor 2023, Zhang et al. 2021)
SST Projections Raster	SST_2050s_sample.tif	(Combal and Fischer 2016)

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