Module 1: Seaweed Farming Benefits and Tradeoffs Mapping

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This model evaluates a favorability score for seaweed farming based on four categories: climate mitigation, water quality improvement, conflict avoidance, and future temperature suitability. Categories are scored based on the minimum and maximum conditions found within each spatial unit of evaluation. The model 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 and five additional files with all units merged. Users may choose which weighting scheme best aligns with their priorities or consider all five.

All input conditions 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 (Table 2). 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.

Each unit of the study area raster must have its own integer code that functions as a unique ID number. This number will be appended to the names of intermediate and output files. All cells that share an ID number will be evaluated as a single unit, even if they are spatially discontinuous. (The sample input data already has ID numbers assigned.) Output files will be saved in an 'Outputs' folder.

The model will generate several intermediate files that may be of interest (Figure 2), including rasters with the scores of input categories: *GHG_score_unit[#]*, *water_quality_improvement_unit[#]*, *constraint_avoid_score_unit[#]*, and *sst_score_unit[#]*, where "#" represents the integer code of each unit. These are stored in the 'Intermediate' folder. Examining these rasters can help determine which input factors are contributing to the overall favorability scores.

This model may take a long time to run, especially if the Study Area input raster has many units. The five output files for each unit may be further combined into five composite files representing all units together. The outputs for each weighting scheme 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. Model maps do not display uncertainty associated with favorability for seaweed farming. Users are recommended to view maps as a visual guide with caution or to run the model multiple times using different 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.

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

Requirements:

- R software Version 3.3.0 or later
- Within R, the following packages are required:
  - “raster”
  - “sf”
  - “viridis”

Notes:

- Working Directory must include 3 folders named “Inputs”, ”Intermediate”, ”Output”
- Input rasters must be *.tif* format

Outputs:

- Rasters highlighting favorable areas for seaweed farming based on weighting scenario of input variables

Table 2. Description of inputs and outputs for the Seaweed Farming Evaluation model.

Parameter	Explanation
Study Area Raster (study_area)	Raster with study area boundaries. Each unit of the study area must have its own integer assigned.
Harvest Raster (harvest)	Estimated harvest (dry weight, Mg km^{-2}) of seaweed farming.
Net GHG Offset Raster (GHG_reduction)	Estimated net greenhouse gas offset or sequestration ($MgCO_2e$ km^{-2}) by seaweed farming.
Basin Distance Raster (basin_dist)	Estimated distance (km) of seaweed farming from ocean depositional basins.
Aragonite Saturation State Raster (aragonite_sat)	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 (nutrients)	Estimated amount of excess nutrients or frequency of eutrophication events.
Migratory Species Raster (migratory_spp)	Species richness of migratory fish, birds, and marine mammals.
Shipping Intensity Raster (shipping)	Relative volume of shipping traffic based on ship track density.
Commercial Fishing Raster (fishing_commercial)	Reported annual catch for industrial fishing, standardized as a proportion of regional primary productivity.
Percent Coral Reef Raster (pct_coral_reef)	Percentage of cell area with tropical and subtropical coral reefs.
Distance to Wind Farms Raster (wind_farm_dist)	Estimated distance (km) from cell center to offshore wind farms.
SST Projections Raster (SST_dist)	Average projected sea surface temperature (°C). User chooses SST projection.
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 regeneration 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.

Workflow:

1. **Setting up R**
   - Install and load the required packages using *install.packages("raster")*, *install.packages("sf")*, and *install.packages("viridis")* then *library(raster)*, *library(sf)* and *library(viridis)*.
2. **Setting the Working Environment**
   - Set your working directory to where your data is stored with *setwd("Your/Directory/Path")*.
3. **Data Preparation**
   - Input data, including all environmental factor rasters and study area, should be placed in an 'Inputs' folder within the Working Directory
   - Ensure 2 other separate folders are set up named 'Intermediate' and 'Outputs'. If folders do not exist, then the code will create them for you.
   - Load the input rasters for each environmental factor using *raster("Inputs/Raster.tif")*.
   - Ensure file is *.tif* format.
   - Set the wind multiplier using *wind_multiplier = X* ($0 \leq X \leq 1$).
   - Specify the pathways for 'Intermediate' and 'Outputs' folders using *output_path="/Outputs"* and *intermediate_path="/Intermediate"*
4. **Alignment Check of Rasters**
   - Check the extent and resolution of all input rasters. If they do not match, errors may occur in the results.

- If all rasters do not match the extent and resolution of *study_area* then proceed with alignment function to align all rasters to *study_area* extent and resolution.
- Check that all rasters aligned properly and extent / resolutions match *study_area*. Code will print "*is aligned"* for rasters which match and "*is NOT aligned*" for each raster to check alignment.

5. **Run Weighted Average Calculation Model**
   - Identify numeric codes for each study area and set desired study area using *i=eval_units[X]*.
   - Code will then clip and subset all rasters to where study area == i.
   - All clipped rasters will be scaled according to details in manuscript table S1.
   - Scores of input categories will be calculated and saved into the Intermediate folder for *GHG_reduction_score*, *water_quality_improvement_score*, *constraints_score*, *SST_score*.
   - Find the weighted averages and calculate output score for each scenario. Scores are saved in the '*Outputs'* folder.
6. **Final Output Generation**
   - Gather all output rasters into a composite with all the units.
   - Merge and save all rasters based on category score to create composite maps. Final rasters will be saved into '*Outputs'* folder.
7. **Final Plots**
   - Use diagnostic plots to visualize the favorability scores across the study area based on each scenario emphasizing '*Climate Benefits*', '*Water Quality Improvement'*, *'Conflict Avoidance', 'Temperature Suitability', 'All Factors Equally Weighted'*.