

Coastal Vulnerability Tutorial

Version 1.0

Background: Coastal environments are becoming squeezed by intensifying pressures from land and sea. Increasing human population growth and activities and worsening climate conditions are modifying coastal environments directly and indirectly. In tandem, these pressures can affect coastal vulnerability. Thus, it is important for coastal communities to understand how their exposure to these risks can alter how they respond in the present to protect the future. Moreover, with increased knowledge communities can collaborate on how to protect coastal people and assets. For instance, communities could use data to inform protection and restoration efforts of natural habitats to decrease risk to flooding.

Purpose: In this tutorial, participants will learn how to combine open-source software with freely available data, such as the Allen Coral Atlas's benthic coral/algae and seagrass and after August 2020, a bathymetry layer with 2m resolution, to perform a coastal vulnerability analysis for Pohnpei, Federated States of Micronesia. (This example was chosen based on the availability of data.)

Objectives: (1) Explore the Allen Coral Atlas data, (2) Become familiarized with different global datasets, (3) Learn and interact with a coast vulnerability model, (4) Use the model to inform environmental protection decisions

Technical requirements: Computer, Internet, GIS software (e.g., [QGIS](#), ArcGIS), [InVEST](#)

Target audience: Advanced GIS user

Expected time for completion: 1.5 - 2 hours

Advisable considerations:

- Create a project folder and subfolders for data, outputs, and documentation
- Make sure there are no spaces in file names or path names
 - *****Recommendation:** Use "_" in place of a space
- Do not have any "/" in names including the attribute tables
- That the area of interest shapefile is in a projected coordinate system
 - *****Note:** Coordinate system should have meters as the unit
 - *****Recommendation:** Use a UTM Zone or Mollweide (world)
- Helps if all the data components are in the same coordinate system and datums
- InVEST Coastal Vulnerability model generates the wave exposure, wind exposure, and surge protection data
- If more information is desired or an error occurs, review technical documentation on [InVEST](#) and the [Coastal Vulnerability model](#)
 - Natural Capital has an [active community](#) for InVEST users. If an error is encountered, the community is a good place to see if anyone else encountered the issue and a solution was provided. If no post relates to the issue, post the issue following this [guidance](#).

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The InVEST Coastal Vulnerability integrates the following inputs in relation to exposure risk:

- Area of interest: a polygon feature that should feature the total study area
- Resolution: spacing between shore points (in meters)
- Landmass: polygon feature of all physical land across the region of interest
- [WaveWatchIII](#): point features of wave and wind dynamics to represent storm conditions
- Maximum fetch distance: distance shore points are exposed to oceanic dynamics
- Bathymetry: raster of water depths required for wave height and period calculations
- Elevation average radius: radius around shore point to compute the average elevation
- Continental shelf contour: polyline feature of the continental margin
- Habitats table: table linking the habitat with ranking and protection distance in meters
- Geomorphology (optional): polyline with shoreline type (alluvial plain, cliff, rocky, seawall, etc.)
- Geomorphology fill value (optional): factor between 1 and 5
- Human population (optional): raster on human population count
- Population search distance (optional): distance from a shore point to calculate human density
- Sea Level Rise (optional): point data with values on sea level rise metric (e.g., 2 mm / year, +12 mm)
- Sea level rise fieldname (optional): descriptor of the metric (e.g., rate, net change)

Table 4.1

Example Ranking System					
Rank	1 (very low)	2 (low)	3 (moderate)	4 (high)	5 (very high)
Geomorphology	Rocky, high cliffs; fjord, fiard; seawalls	Medium cliff, indented coast, bulkheads and small seawalls	Low cliff, glacial drift; alluvial plain; revetments, rip-rap walls	Cobble beach; estuary; lagoon; bluff	Barrier beach; sand beach; mud flat; delta
Relief	81 to 100 Percentile	61 to 80 Percentile	41 to 60 Percentile	21 to 40 Percentile	0 to 20 Percentile
Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass; kelp	No habitat
Sea Level Change	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Wave Exposure	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Surge Potential	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile

Table 4.1: List of Bio-Geophysical Variables and Ranking System for Coastal Exposure.

Process

Phase 1: Data preparation

- 1.) Download and install [InVEST](#)
- 2.) Download landmass file
 - a.) Navigate to the [Data](#) page
 - ****Alternative:* Could download [global data](#) from the GADM
 - b.) Select "Micronesia"
 - c.) Select the Shapefile
 - d.) Unzip the data

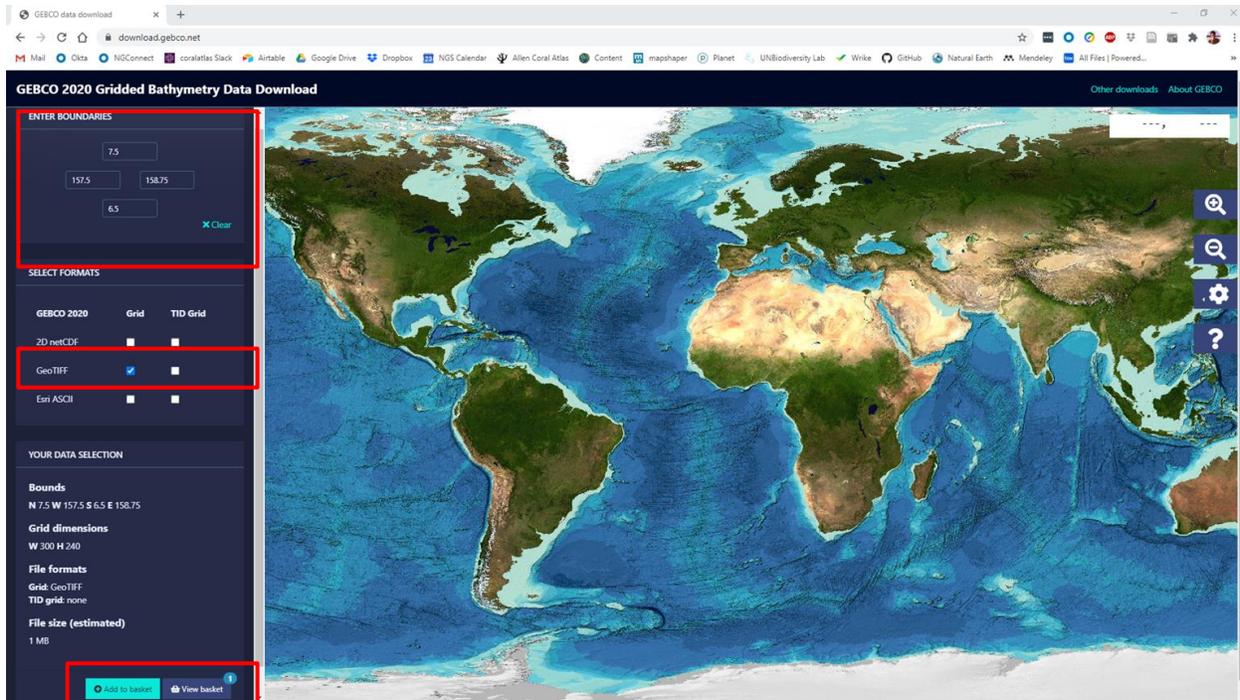
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- *****Note:** Two layers will be provided in the zipped folder. The level 0 (..._0) are the national boundaries, while the level 1 (..._1) are the states within the federation
 - e.) Change projection to UTM 57N WGS84
 - ArcGIS = [Project tool](#), QGIS = [Save data in another coordinate system](#)
 - *****Note:** A projected coordinate system in a northern hemisphere UTM zone
 - *****Note:** Can also find through the EPSG code (32657)
 - f.) Move to the gis_data folder
- 3.) Until the Atlas bathymetry data are available (August 2020), obtain the Western Micronesia bathymetry data from [GEBCO](#)
- a.) Type in the following data:
 - Top = 7.5
 - Bottom = 6.5
 - Left = 157.5
 - Right = 158.75
 - b.) *****Alternative:**
 - Windows: hold down control and left click mouse, then drag a box to select your region on the map.
 - Mac: hold command then left click mouse and drag a box to select the region of interest on the map
 - c.) Select the GeoTIFF Grid option
 - d.) Click "Add to basket"
 - e.) Click "View basket"
 - f.) Click "Download your data"
 - g.) Unzip data
 - h.) Project into UTM 57N WGS84
 - ArcGIS = [Project tool](#), QGIS = [Save data in another coordinate system](#)
 - i.) Move to the GIS folder, and rename (e.g., pohn_bath)

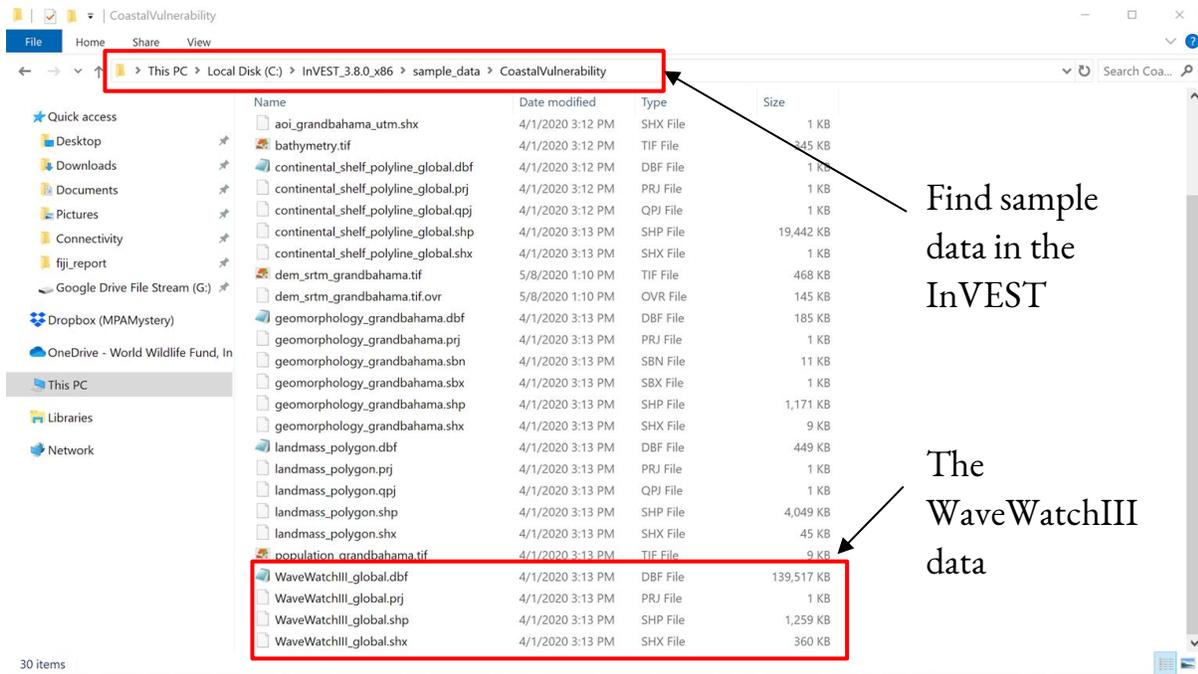
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- 4.) Download the relief data (commonly known as digital elevation model [DEM]) from the [USGS](#)
 - a.) Project into UTM 57N WGS84
 - ArcGIS = [Project tool](#), QGIS = [Save data in another coordinate system](#)
 - b.) Move to the GIS folder, and rename (e.g., pohnpei_dem)
- 5.) Download the [IFREMER - COMARGE continental margin](#) data
 - a.) Unzip the folder
 - b.) Project into UTM 57N WGS84
 - ArcGIS = [Project tool](#), QGIS = [Save data in another coordinate system](#)
 - c.) Convert to polyline (e.g., ArcGIS = [Polygon to line](#)", QGIS = [Polygons to lines](#))
 - d.) Save data to GIS folder
- 6.) Copy the WaveWatch III data from InVEST folder for the coastal vulnerability data to GIS folder
 - a.) Locate the data directory: \InVEST_3.8.0_x86\sample_data\CoastalVulnerability
 - b.) Layer name = WaveWatchIII_global
 - c.) ***Note: The coastal vulnerability folder contains global data for continental shelf and landmass

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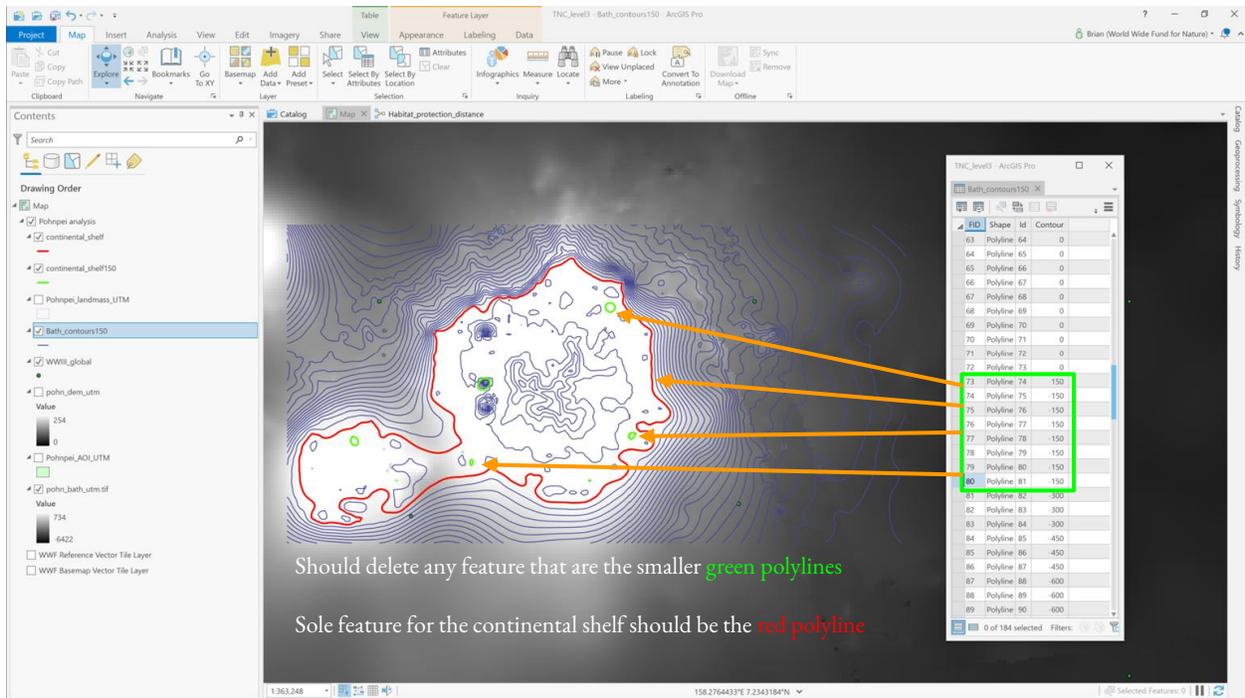


7.) Create the continental shelf polyline data

- a.) Create contour polylines every 150m using the "contour" tool ([ArcGIS](#), [QGIS](#)) with the bathymetry data (GEBCO data) as the input raster and interval as 150 (meters)
- b.) Query out and generate new layer with features at 150m of depth (Contour = -150)
- c.) Delete all the smaller polylines
 - *****Note:** the polyline feature you should see goes around the entire island of Pohnpei and extends southwest around the atoll
- d.) Save the layer as your "continental_shelf.shp" in the GIS data folder
 - *****Note:** remember to have the data in UTM 57N WGS84

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- 8.) Create the benthic habitat layers
 - a.) Open the Pohnpei AOI (area of interest) data from the geodatabase (Pohnpei_data.gdb) from the supplement materials
 - *****Note:** If using QGIS, switch the source type from "File" to "Database" when opening the files
 - b.) Export it as a new shapefile to the GIS folder
 - c.) Open the Western Micronesia benthic data (ACA_WM_benthic) from the geodatabase
 - d.) Clip the Western Micronesia benthic data from the Allen Coral Atlas data to the area of interest (pohnpei_AOI_UTM)
 - e.) Save this new layer to the GIS folder
 - f.) Generate a definition query where the benthic class field equals Coral/algae
 - g.) Export new data to the "Pohnpei_habitats" folder in the GIS folder
 - *****Note:** Example file name could be "FSM_CoralAlgae_Atlas"
 - *****Note:** data should also be in UTM 57N WGS84
 - h.) Open attribute table and change the benthic_cl from "Coral/algae" to Coral or CoralAlgae
 - *****Note:** This is required as the InVEST software will have an error reading the data with the "/" and similar issues with a space or a "-"
 - *****Note:** While "Coral" is easier, remember that the data do not differentiate between the two, so reporting should be done as Coral and Algae
 - i.) Repeat steps 9f and 9g to get the seagrass data as their own layer

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9.) Create Habitat table

- a.) Open "natural_habitat-table.csv" from the "Pohnpei_Habitats" folder
- b.) Reference the [Appendix B](#) for rank
 - *****Note:** Rank will always be between the values of 1 and 5
- c.) Add field names: id, path, rank, protection distance
 - id = CoralAlgae, Seagrass
 - *****Note:** Or Coral if that was used from step 8h
 - path = the pathname of where the data are located
 - *****Note:** Will need to add the file name for each benthic class (e.g., FSM_Coral_Atlas_UTM.shp and FSM_Seagrass_Atlas_UTM.shp)
 - *****Note:** When adding the pathname, for the spatial data, select the ".shp" files
 - rank
 - CoralAlgae = 2
 - Seagrass = 4
 - protection distance (m)
 - CoralAlgae = 1400
 - Seagrass = 550
 - *****Note:** These are distance beyond which the habitat will provide no protection to the coastline
 - *****Note:** Protection distances should make sense (e.g., coral reef protection distance is greater than seagrass protection distance)
- d.) Save file

Example Habitat Table

id	path	rank	protection distance (m)
kelp	kelp.shp	4	1500
eelgrass	eelgrass.shp	4	500
high dune	HighDunes.shp	2	300
low dune	LowDunes.shp	3	300

Check-in:

- You should now have the following data in your GIS folder and its subfolders:
 - Pohnpei landmass from the GADM
 - WaveWatchIII data from InVEST

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- Pohnpei relief from the USGS DEM
- Continental shelf contour derived from the IFREMER-COMARGE margin
- Coral and algae extent from the Allen Coral Atlas benthic coverage
- Seagrass extent from the Allen Coral Atlas benthic coverage
- Predefined area of interest from the geodatabase
- Complete habitat protection table

Phase 2: Running the model

10.) Open InVEST Coastal Vulnerability model

11.) Define the workspace as the "invest_workspace" folder

- a.) *****Note:** Can create new folders for unique runs

12.) Add model area of interest file

- a.) *****Reminder:** choose the .shp file

13.) Define the model resolution

- a.) Enter 1000

- *****Note:** Creates a point every 1000 meters on the landmass in the area of interest

14.) Add the Pohnpei landmass data

15.) Add WaveWatch III data

- a.) *****Note:** WaveWatchIII will cause issues if the global dataset is put into a UTM zone

16.) Define maximum fetch distance

- a.) Enter 12000

17.) Add bathymetry file

- a.) *****Note:** This will be a .tif file

18.) Add relief data

- a.) *****Reminder:** This is your DEM file
b.) *****Note:** This will also be a .tif file

19.) Define the elevation averaging radius

- a.) Enter 5000

20.) Add continental shelf contour data

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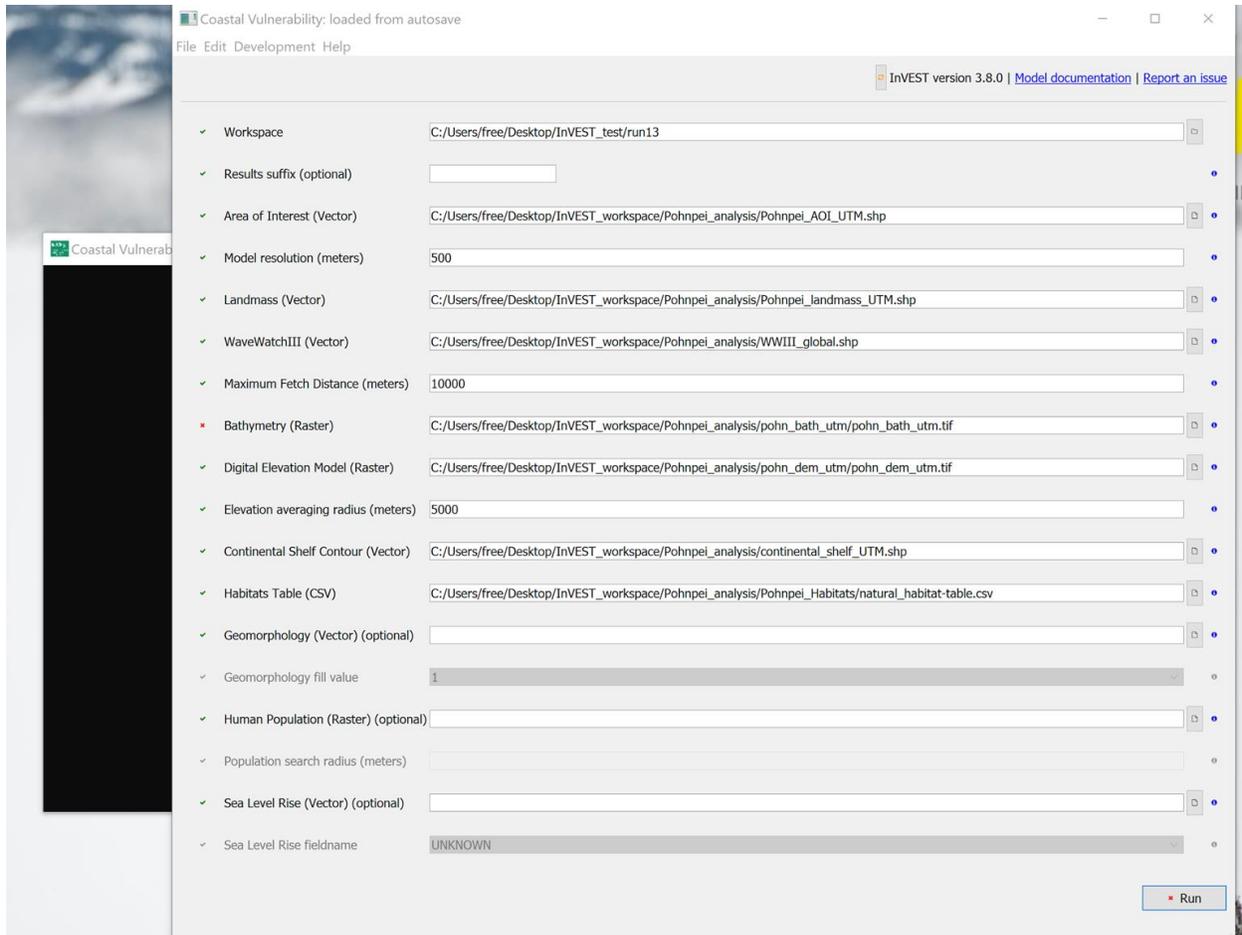
21.) Add the habitats table

a.) ****Reminder:* This will be the .csv file

22.) Run the model

23.) Add the results (.gpkg) to a GIS software to visualize the results

a.) ****Note:* the coastal_exposure.csv file in the workspace folder contains the exposure risk rankings for all the shore points as well



Model modifications:

This tutorial outlined the essential data components for the coastal vulnerability model. As previously mentioned, additional data can be added to the model which will adjust the exposure index.

- *Modification 1.* Once Atlas Sentinel-2 bathymetry data are available post-August 2020, substitute those data for the GEBCO bathymetric data. The Atlas Sentinel-2 data cover the same extent as the benthic data and have a 2-meter resolution, while GEBCO data are at 30 meters.

- *Modification 2.* Geomorphological data can be added to the model. While geomorphology data are typically not readily available, they can be generated using a combination of methods. For example, the Planet Imagery available for download from the Allen Coral Atlas website could identify coarse geomorphological structures in conjunction with the DEM data. Google Street View photos can refine the geomorphological classifications along the coastline (see [Appendix A](#)). Harder and steeper geomorphologies are less prone to erosion and inundation than softer and level sediments, such as beaches and deltas.
- *Modification 3.* InVEST can incorporate human population data and generate human density near the coastline. [Global data](#) are available through SEDAC.
- *Modification 4.* Climate change and sea level rise will impact coastal exposure risk and inundation. By adding point vector data on rate or net change, the model will join the data with the shore points and integrate the values on the exposure risk, as outlined in [Table 4.1](#). Pohnpei is no exception from having a range of sea level rise projections. [NOAA estimates](#) that relative sea level rise is 1.88 mm / year, while [CSIRO notes](#) satellites have measured the change at 10 mm / year since 1993. To compare these sea level rise scenarios and the impacts on exposure risk, sea level rise values (1.88mm, 5 mm, 10mm) can be substituted in each iteration. Building on those iterations, projected sea level rise can be run at future time steps. For example, InVEST iterations could have the following:
 - 2020 with 1.88 mm / year (run 1)
 - 2020 with 10 mm / year (run 2)
 - 2030 with 1.88 / year (run 3)
 - 2050 with 1.88 mm / year (run 4)
 - 2050 with 10 mm / year (run 5)
 - 2070 with 1.88 mm / year (run 6)
 - 2050 with 10 mm / year (run 7)
 - 2070 with 10 mm / year (run 8)
 - 2100 with 10 mm / year (run 9)
 - 2300 with 10 mm / year (run 10)

Appendix A: Available data sources

- Benthic: [Allen Coral Atlas](#)
- Mangrove: [Global Mangrove Watch](#)
- Landmass: [GADM](#)
- Elevation: [SRTM30](#) (need to create a free [NASA Earth Data](#) account--new users [link](#))
- Bathymetry: [GEBCO](#) or Atlas Sentinel-2 data
- Continental shelf contour: MarineRegions's [IFREMER-COMARGE](#)
- Human population: [Population Count v4 2020](#)
- Mean Sea Level: [Permanent Service for Mean Sea Level \(PSMSL\)](#), [GESLA-2](#)

Appendix B: Generic process for conducting the analysis for a different area of interest

- 1.) Create a workspace for exporting the InVEST coastal vulnerability runs
 - a.) ****Alternative:* can create a new workspace when you open and begin an analysis in InVEST
- 2.) Create an area of interest polygon
 - a.) Create new shapefile as polygon
 - b.) Name layer as "location_aoi"
 - c.) Select a projected coordinate system
 - i.) ****Suggestion:* Mollweide world (EPSG: 54009)
 - d.) Project into proper UTM Zone or Mollweide if AOI file already exists
- 3.) Download landmass file
 - a.) Can download global data from [GADM](#)
 - i.) Select level 0 data → country level
 - (1) Or go to a specific [territory](#) if analysis is limited to one
 - ii.) Select by attribute or definition query for target territory/territories
 - iii.) If only certain landmass features are required, may need to run the [Multipart to Singlepart](#) in ArcGIS, [Multipart to Singleparts](#) in QGIS to get only the features of interest for the area of interest
- 4.) Download bathymetry data
 - a.) Can download from [GEBCO](#) if no data exist at a finer resolution and more accurately for the area of interest
 - b.) Needs to go beyond the area of interest by at least the maximum fetch distance
 - c.) ****Note:* Allen Coral Atlas will provide Sentinel-2-derived bathymetry data for limited coastal areas
- 5.) Download relief data (commonly as DEM)
 - a.) If data are not reliable or available for the area of interest, download from a globally consistent dataset
 - i.) A commonly used global dataset is the [SRTM](#)
 - (1) Can freely download the data from [EarthExplorer](#)
 - (a) Create a new account at this [link](#)
 - (2) May need to download multiple tiles and then use the ["Mosaic"](#) tool to combine all the tiles into a single dataset for the area of interest
 - b.) Then use the "Extract by Mask" to get the data for your particular area
 - c.) Should extend beyond the area of interest
- 6.) Obtain continental shelf data
 - a.) Download the [IFREMER - COMARGE continental margin](#) data
 - b.) Convert to polyline using the "Polygon to line" tool
- 7.) Download the Atlas habitat data
 - a.) Export each target habitat type as a new layer
 - i.) This can be more easily done using Model Builder

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- (1) Add "Iterate Feature Selection" and have it group field by Benthic Class. Then "Copy Features" with the export files have names FSM_%VALUE%_Atlas
 - (a) %Value% will be replaced with the particular benthic class of interest (e.g., coral / algae, rock, rubble, seagrass, etc.)
- (2) Have new layers exported to a folder specifically for ecological habits
 - b.) Change the values of "Coral/Algae" to either "Coral" or "CoralAlgae"
 - i.) ***Note: InVEST will generate an error if the "/" remains
- 8.) For additional ecological habitat data, can integrate the 2016 [Global Mangrove Watch](#) data