CARBON STORAGE: UTILIZING CARBON-BASED MODELING FOR MANGROVE RESTORATION EFFORTS

MARISMAS NACIONALES, MEXICO

by

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In conjunction with

Ecologist Without Borders, Sustainable Fisheries Foundation and Pronatura Noroestes

Keywords: Sustainability, mangrove, Mexico, InVEST, Blue Carbon, sequestration, carbon credit, carbon pool, management scenario, emissions, time-step, land use, raster

Recommended Course of Action

Our recommended course of action for our sponsors, Ecology Without Borders (EcoWB), Sustainable Fisheries Foundation (SFF), Pronatura Noroestes and Others, is to consider further using the Blue Carbon model in the current management scenario of mangrove restoration as well as future management scenarios. The successful run of the Blue Carbon model by InVEST for the purpose of this study, has produced data that is congruent with the sponsor's primary objectives, as stated by EcoWB.

The primary objectives for the restoration of the mangrove forests, as defined by EcoWB is to 1) determine the extent of degradation of the mangrove forests in Marismas, Mexico; 2) generate and sell carbon credits on the voluntary carbon market in order to pay local residents, cooperatives, te*jidos*, etc. to participate in restoration and conservation activities and, 3) expand restoration efforts to other mangrove systems in Mexico and elsewhere.

The InVEST Blue Carbon model, by Natural Capital Project (NatCap), has supported these objectives by producing 1) output maps of both emissions and sequestration of the mangroves in Marismas, and thus demonstrating degradation levels over time; 2) output maps of carbon storage pools in the study area, over time and, 3) an economic valuation for carbon credits (USD/metric tonne/hectare).

Based on the success of using this model to meet the sponsor's primary objectives, the GIS students further recommend:

- Continue to use the Blue Carbon model, as well as other carbon sequestration models by InVEST, as comparisons, to further determine biophysical and economic valuations of mangrove forests in Mexico and elsewhere
- Consider using InVEST and other types of models for different types of management scenarios, such as coastal preservation, sea level rise, aquaculture, water quality, etc.
- Investigate other types of natural environments in which carbon pools can be found both in Mexico and elsewhere, such as deserts, marshes, forests, etc.
- Investigate further the key elements in the SES table
- Investigation of resiliency and/or thresholds of mangrove ecosystems

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Introduction

Mangroves are a group of trees and shrubs that live in the coastal intertidal zone. Warne (2007) defines mangroves as the “forests of the tide.” They support a wealth of life, from starfish to people, and are important to the health of the planet. They occupy a zone of desiccating heat, mud, and salt levels that would kill an ordinary plant within hours. Yet forest mangroves are among the most productive and biologically complex ecosystems on Earth.

Many mangrove forests can be recognized by their dense tangle of prop roots that make the trees appear to be standing on stilts above the water. This tangle of roots allows the trees to handle the daily rise and fall of tides, which means that most mangroves get flooded at least twice per day. The roots also slow the movement of tidal waters, causing sediments to settle out of the water and build up the muddy bottom.

Mangroves reside in tropical to sub-tropical environments across the globe in Asia, the Americas, Africa, and Australia (see Fig. 1).. Mangrove forests occupy about 15.2 million hectares of tropical coast worldwide (Spalding *et al.* 2010).

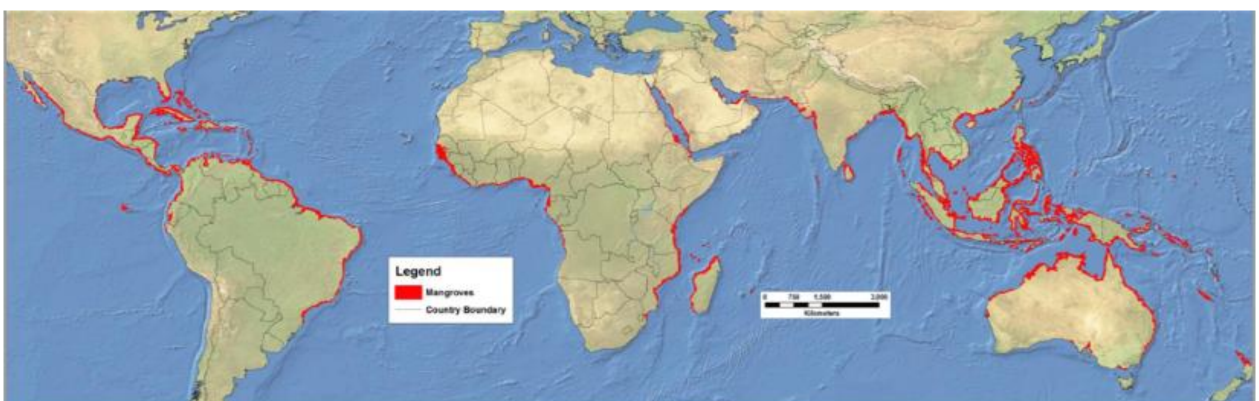


Figure 1. Global mangrove forests distribution – 2000 (Giri et al., 2011). Map redrawn by UNEP/DEWA.

The mangrove ecosystem has immense ecological value and provides income from the collection of the mollusks, crustaceans, and fish that live there. Mangroves are harvested for fuelwood, charcoal, timber, and wood chips. Services include the role of mangroves as nurseries for economically important fisheries, especially for shrimp. Mangroves also provide habitats for a large number of molluscs, crustaceans, birds, insects, monkeys, and reptiles as well as a nectar source for bats and honeybees. Other mangrove services include the filtering and trapping of pollutants and the stabilization of coastal land by trapping sediment and protection against storm damage. Mangrove forests are the supermarkets, lumberyards, fuel depots, and pharmacies of the coastal poor. Also, mangroves provide recreational, tourism, educational, and research opportunities. The ecosystem services they provide and their support for coastal livelihoods worldwide are worth at least US $1.6 billion a year (UNEP, 2013).

Despite their strategic importance, mangroves are under threat worldwide. They are sacrificed for salt pans, aquaculture ponds, housing developments, roads, port facilities, hotels, golf courses, and farms. They perish from other impacts as well such as, oil spills, chemical pollution, sediment overload, and disruption of their sensitive water and salinity balance. The greatest threats to mangrove survival comes from shrimp farming as well as rising sea levels.

In recent years, mangroves have become recognized as carbon-storage assets that radically alter the way these forests are valued. Carbon trading is a reality and forest-rich, carbon-absorbing countries are able to sell emissions credits to more industrialized, carbon-emitting countries. Carbon credits are a form of Climate Change mitigation. A carbon credit - or carbon offset - is a financial tool that represents a tonne of CO_2 (carbon dioxide) or CO_2e (carbon dioxide equivalent gases) removed or reduced from the atmosphere from an emission reduction project, which can be used, by governments, industry or private individuals to offset damaging carbon emissions that they are generating. Carbon credits can be achieved through activities such as afforestation and reforestation and can be measured by which existing emissions are removed from the atmosphere and/or carbon credits are created through reducing future emissions. Carbon credits originated through these emission reduction activities can be created under a variety of voluntary and compliance market mechanisms, schemes and standards. Some of these tools have been established so countries can comply with their mandatory Kyoto targets and others provide avenues for voluntary offsetting purposes. The Voluntary Carbon Offset Market functions outside of the compliance market and enables companies and individuals to purchase carbon credits on a voluntary basis to satisfy personal or Corporate Social Responsibility (CSR) objectives (Carbon Planet, 2015).

Collaborative Effort

Located in the Pacific Northwest of Mexico, Marismas nacionales is a complex and large region that is composed by Mangroves, lagoons, swamps and ravines. With and extension of 113,000 hectares of mangrove and estuaries which makes about 20% of the total mangrove forest in Mexico. (WHSRN 2015)

Marismas Nacionales is located at the south border of Sinaloa State with a large section of the forest in the Nayarit State (see Figure 2). It has a large variety of bird species, 446, from which 38 species are shorebirds. Marismas Nacionales is also home to different activities like shrimp farming, agriculture, fisheries cattle ranching and of course tourism. The area has developed since the first time data was collected, 1973. Since then several dams have been constructed as well as roads and shrimp ponds, causing degradation of the mangroves.

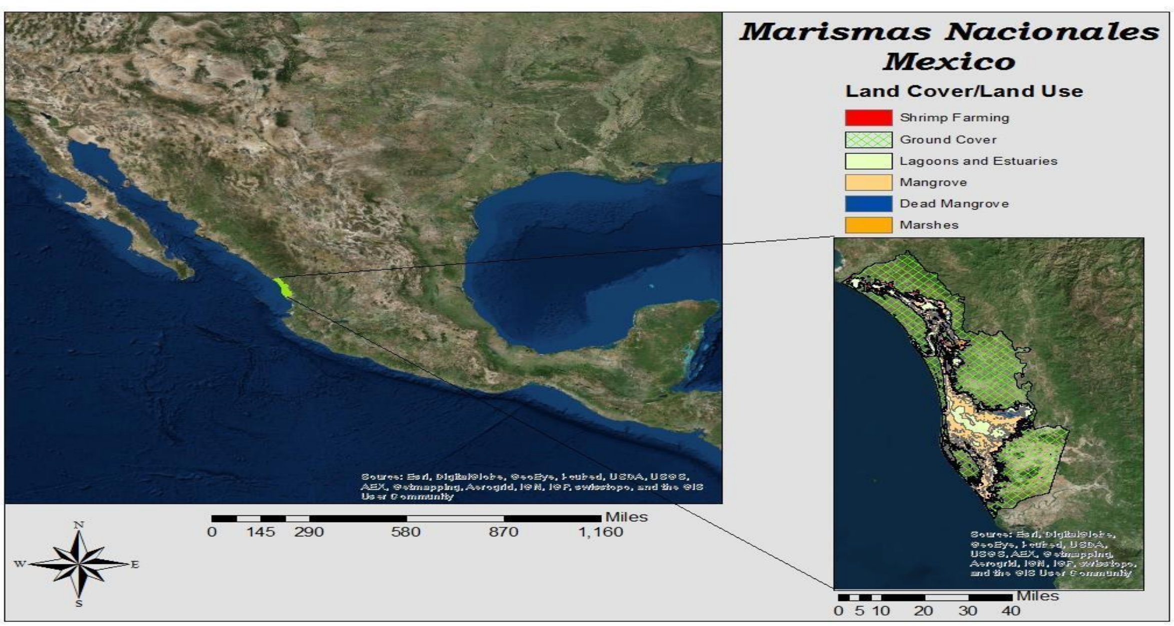


Figure 2. Map location of Marismas Nacionales in Mexico.

Because of these changes the Mexican organization Pronatura, has focus their efforts in restoring the mangrove through the collection of data to show the locations of degradation. Pronatura aims to provide viable economic alternatives to those people struggling to make a living from imperiled environments. (Pronatura 2015)

Ecologists Without Borders (EcoWB) and Sustainable Fisheries Foundation (SFF) have teamed up with a Mexican non-governmental organization, Pronatura Noroestes, to restore mangroves in the Marismas Nacionales, the largest intact mangrove forest on the Pacific Coast of Mexico. Their objectives, according to EcoWB, include "an approach to restore the conditions and physical processes mangroves require for growth and survival, and to protect these areas from future disturbances that would cause the release of greenhouse gases and contribute to global warming." EcoWB/SFF plan to use remote sensing techniques and GIS tools to assess the condition(s) and extent of the mangroves within a 50,000 to 100,000-acre area of the Marismas. After establishing the existing condition of the mangrove forests, these agencies can begin to collaborate in narrowing down the factors responsible for their decline and focus on their approach for restoring them to health. The ultimate goal of the project, as defined by EcoWB/SFF, is "to restore approximately 600 hectares (ha) of mangroves using clean technology – solar and kinetic (tidal or wave-induced) – within the next five years. [Our] key objectives are to help local communities develop and implement sustainable forestry and fisheries management plans, and to generate and sell carbon credits on the *voluntary* carbon market in order to pay local residents, cooperatives, tejidos, etc. to participate in restoration and conservation activities." EcoWB and SFF anticipate, that if this approach is successful, they would be able to expand restoration efforts to other mangrove systems in Mexico and elsewhere.

Scope of Work for GIS Graduate Students

One of the primary objectives listed for the mangrove restoration project, per EcoWB's description, is "to generate and sell carbon credits on the Voluntary carbon market."

The sponsors, EcoWB, SFF and Pronatura Noroestes, have approached University of Washington's GIS graduate students, Anssel Lopez and Kimberly Nepsa, to assist in this mangrove restoration effort.

The GIS students submitted a project proposal to the sponsors, which focuses on mangrove conservation by using the INVEST Blue Carbon Model by Natural Capital Project (NatCap) to determine net present value of carbon sequestration of the mangroves in Marismas Nacionales, Mexico. According to NatCap, "the InVEST Blue Carbon model incorporates information about changes in the storage and sequestration capacity of the marine vegetation with economic factors into a single model which can estimate the value of carbon sequestration/emission from land/seascape change."

The students' approach for using the InVEST Blue Carbon Model, is a series of output data that will help to quantify the value of carbon storage and sequestration. The model focuses on changes in atmospheric carbon dioxide and other greenhouse gases as a result of changes caused by human activities that can affect marine ecosystems which store and sequester carbon (NatCap, 2014). The anticipated outcome from using this model is to produce and present output maps that show differences, over time, in 1) rates of sequestration; 2) storage pools/sinks and 3) net present value of sequestration (sequestration multiplied by the market value of carbon) in Marismas Nacionales, Mexico. These outputs can help the sponsors determine where both gain and loss of carbon pools have occurred in the study area as well as give them a 'bird's eye view' of the value of both emissions and sequestration in the area, over time. The sponsors state in their original proposal that carbon credits are a goal in their restoration efforts. In addition to a biophysical valuation of the mangroves in Marismas, the output(s) of the model also consider an economic valuation, giving the user a marginal net present value of total sequestration. This valuation produces a number, USD per metric tonne of carbon, which can be used to determine the distribution of carbon credits.

This approach is a sustainable one because by integrating the use of this InVEST model into the restoration efforts of the mangrove forests, it tracks and evaluates the degradation rates of the mangroves over time as well as determines where carbon pools and sequestration can be anticipated in the study area both currently and in the future - if the land use in the area stays the same. Determining where areas of degradation have occurred can direct the sponsors where to focus their restoration efforts for the mangroves, now and in the future. Determining marginal values of 1) sequestration rates, 2) carbon pools and 3) market value(s) of carbon credits helps the sponsors in their stated project goals for these mangrove forests in Mexico. The successful run of this model will allow the sponsors to consider using it in other management scenarios as well. To see an itemized list of student objectives for this project, please see Appendix 1 student objectives.

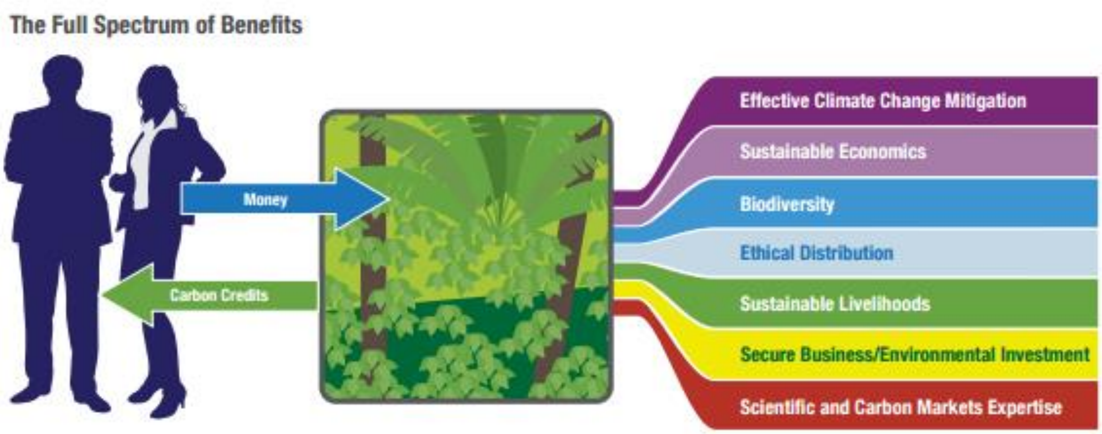


Diagram 1. Full spectrum of benefits of carbon [Carbon Planet, 2015]

Design and Methods (*English-based* Tutorial)

The InVEST Blue Carbon Model quantifies the marginal value of storage and sequestration services by comparing change in stock and accumulation of carbon between current and future scenarios. In addition to comparisons between scenarios, the InVEST Blue Carbon Model can be used to identify locations within the landscape where degradation of coastal ecosystems should be avoided in order to maintain carbon storage and sequestration services and values (NatCap 2014).

The model requires several pieces of data that are crucial for carbon sequestration projections over Time 1 to Time 2.

Data needs, per Natural Capital Project:

- **Land Use/Land Cover (LULC) Maps**: Maps of current (\ (t_ {1}\)) and future (\ (t_ {t}\)) LULC (e.g., developed dry land, shrimp aquaculture, mangrove forest, salt marsh, etc.).

- **Carbon pools and storage table by LULC type**: A table containing values of carbon storage in biomass (tons of CO_2/ha), sediments (tons of CO_2/ha) and accumulation rates (tons of CO_2/ha/yr). In order to link these values with the biomass and soil disturbance CSV tables, use the “Veg Type” column to indicate “1” for marsh, “2” for mangrove, “3” for seagrass and “0” for other LULC types.

- **Year of current LULC map**: (\(t_{1}\)), the start year of the analysis.

- **Year of one or more future LULC map**: (\(t_{t}\)), model uses this and the previous input to determine length of time (number of years; (\(t_{2}\) - \(t_{1}\)) of the analysis and multiplies this value by the user-specified accumulation rates (tons of CO_2/ha/yr). If the user is only interested in the standing stock of carbon at (\(t_{1}\), then this input is optional. Valuation, however, is not possible without estimates for at least (\(t_{2}\) (future LULC map).

- **Transition matrix**: A table is produced by the pre-processor tool and indicates either disturbance or accumulation of carbon based on pre-programmed logic for LULC transitions from (\(t_{1}\) to (\(t_{2}\). These defaults produced by the pre-processor can be overridden by the user.

- **Biomass disturbance**: A default table indicating the percent of biomass carbon disturbance by level of impact and vegetation type. Defaults are based on based on a global literature review.

- **Soil disturbance**: A default table indicating the rate of soil carbon disturbance by level of impact and vegetation type. Defaults are based on a global literature review.

- **Carbon half-lives**: A default table containing vegetation/disturbance-specific carbon decay rates based on a global literature review.

Also, to use the preprocessor tool, before running the model, the user needs to obtain a matrix table that would allow the user to determine the type of disturbances in the land cover.

Per NatCap, Blue carbon Documentation:

- **Workspace**: The directory to hold output and intermediate results from the tool. After the run is completed the output will be located in this directory.

Id	**0**	**1**	**2**	**3**
0	None	Accumulation	Accumulation	Accumulation
1	Disturbance	Accumulation	Accumulation	Accumulation
2	Disturbance	Accumulation	Accumulation	Accumulation
3	Disturbance	Accumulation	Accumulation	Accumulation

- **Preprocessor Key (CSV)**: This is the default key for ranking different degrees of accumulation and decay as a result of LULC transitions. It should be left as is.

- **Labels Table (CSV)**: Using the Carbon Pools Table (carbon.csv), the pre-processor will parse the label information including LULC ID, name and vegetation type.

- **LULC Maps (Rasters)**: Provide all the available LULC maps during the analysis time period. These maps must be in raster format (ESRI Grid or GeoTIFF).

Based on data required, Pronatura and EcoWB provided us with data that could be modified or manipulated to run the model successfully.

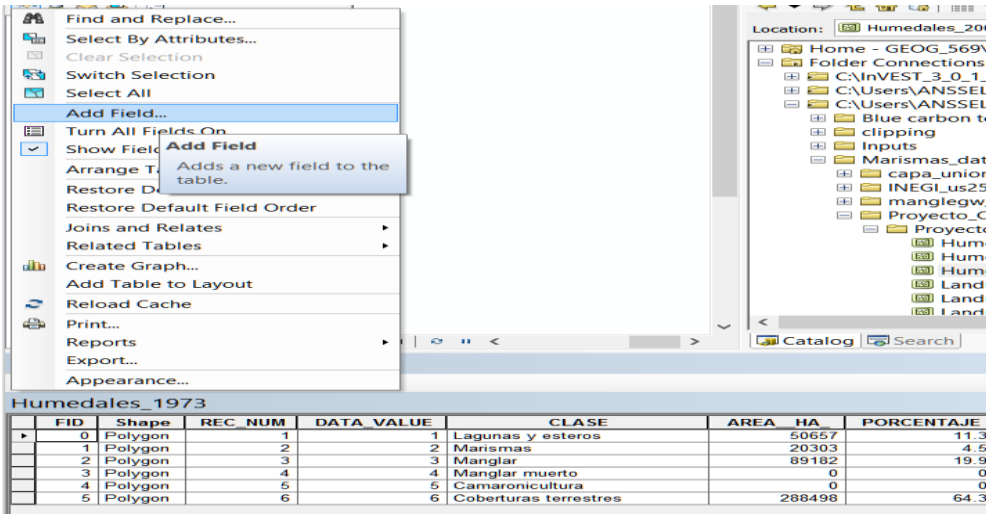
Data collected from Pronatura and EcoWB:

- Land use and Land cover (LULC) shape files, for both Nayarit and Marismas Nacionales, which encompasses Sinaloa and Nayarit States, for years 1973, 1990 and 2000.
- Mangrove location along Mexico’s coast line.
- Land used and land cover for the entire country of Mexico.

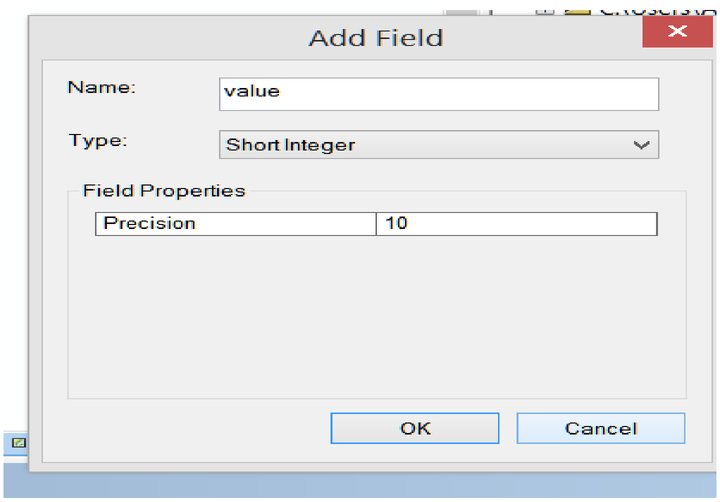
It was decided to concentrate our effort in using the data from 1973, 1990 and 2000 that covered both Sinaloa and Nayarit, Marismas Nacionales. It was decided to use these files because the data layers had more classes needed for running the model. Since the data was in shapefile format, conversions from shapefile to raster file needed to be performed. This was done using two different methods and software available. Below, are the ***steps*** taken to create raster data for the Blue Carbon Model using ArcMap.

1. Before converting LULC.shp files into raster there are a few modifications that need to be done. The LULC files needed to be added a “value” field. This field allows us to match the “Id” column of the “Prepocessor.csv” file that contains the fields for accumulation and disturbance based on the transition from one class to the other.

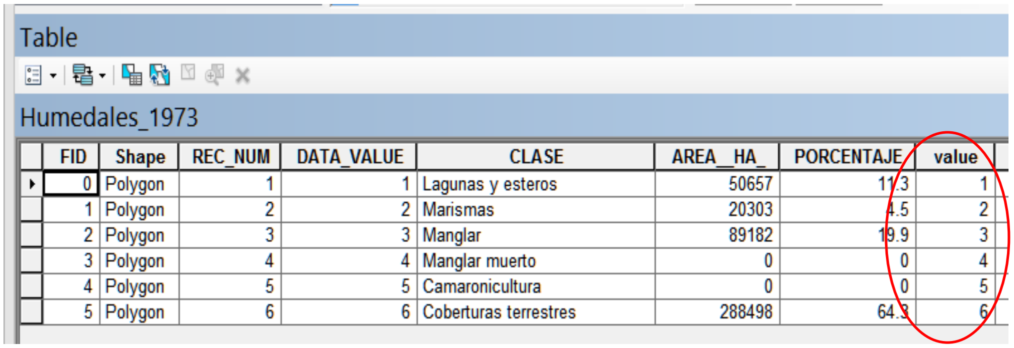
   Using ArcMap the field “value” was added by opening the table of contents. There “options” was selected in the top left corner and next “Add a field.”



In the interface, a name was given, "value" and "short integer" as type, and precision of "2". Precision values can change according to the number of classes. In this case we only had 5 classes.



These steps were repeated in all LULC .shp files.

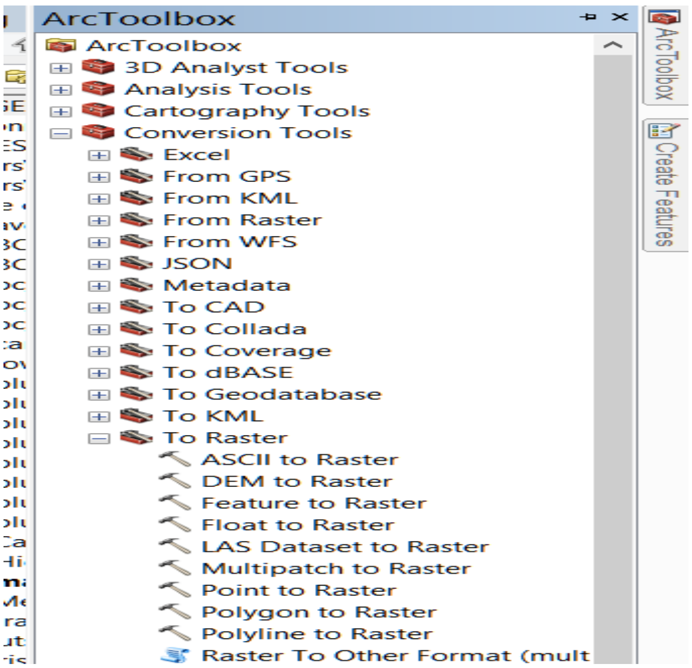


Table

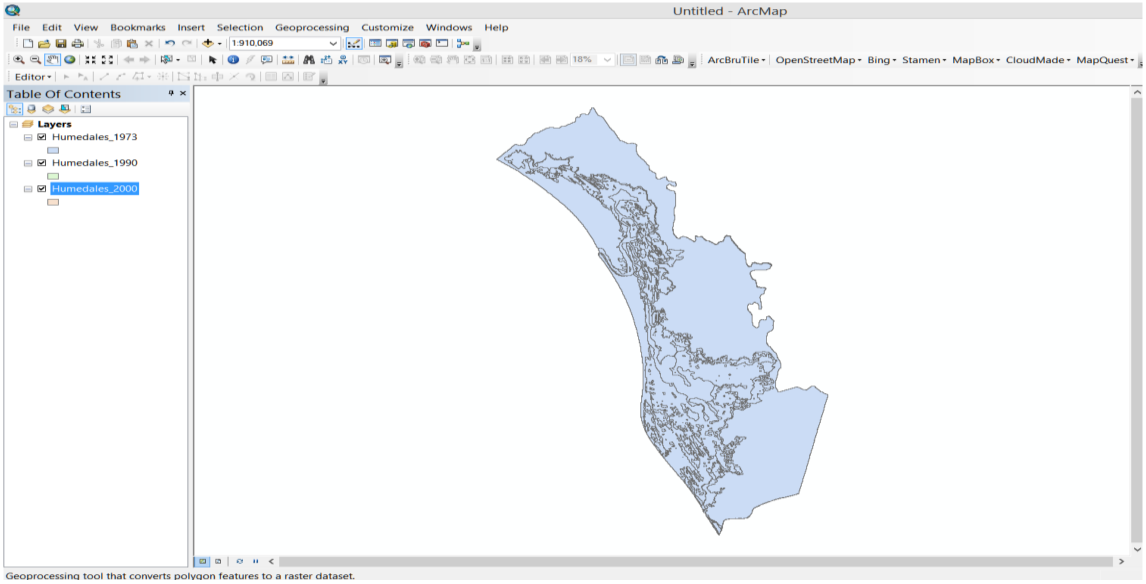
Humedales_1973

FID	Shape	REC_NUM	DATA_VALUE	CLASE	AREA__HA_	PORCENTAJE	value
0	Polygon	1	1	Lagunas y esteros	50657	11.3	1
1	Polygon	2	2	Marismas	20303	4.5	2
2	Polygon	3	3	Manglar	89182	19.9	3
3	Polygon	4	4	Manglar muerto	0	0	4
4	Polygon	5	5	Camaronicultura	0	0	5
5	Polygon	6	6	Coberturas terrestres	288498	64.3	6

2. The first method used, there was a straight conversion of shape file to raster datasets. In this method we selected the tool box named "Conversion Tools" => To Raster => polygon to Raster.



3. The files needed, LULC, were uploaded to ArcMap chronologically and were converted to raster.



The next steps are to follow the tool requirement:

Input Feature = LULC.shp desired to convert, in our case we use "Humedales_1973, Humedales_1990 and Humedales_2000"

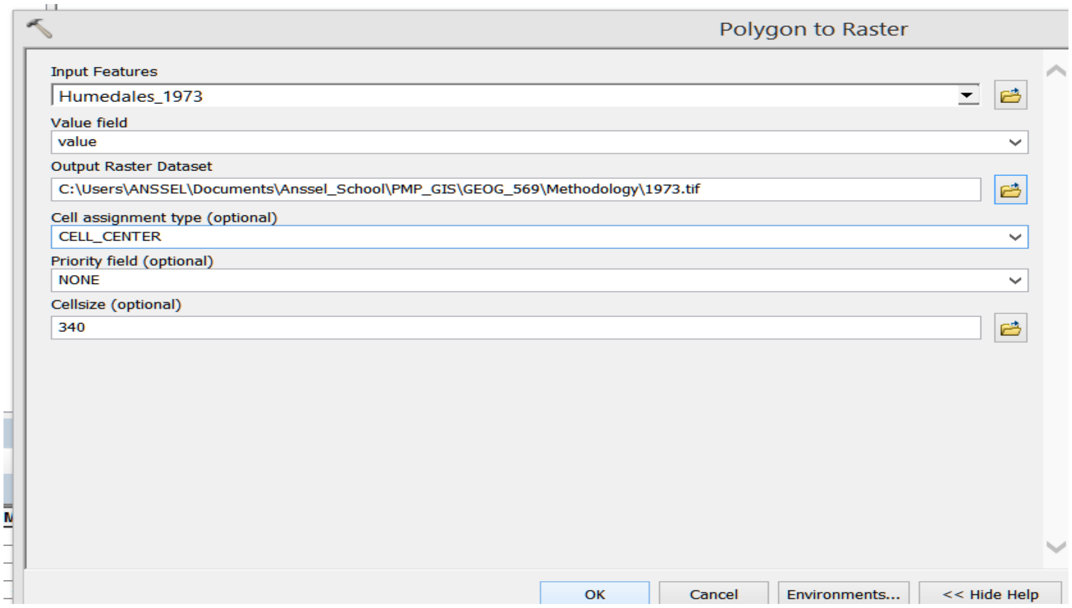
Value Field = value

Output Raster = location and named preferred follow but with the extension tiff. Ex: C:\Users\Documents\BlueCarbon\Inputs**1973.tif**

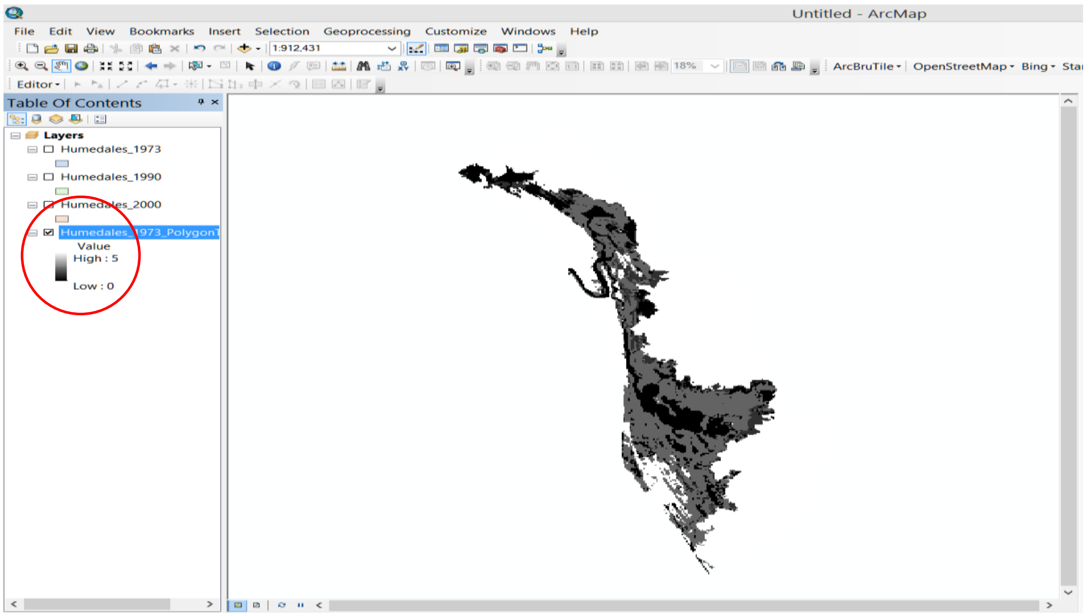
Cell Alignment = Cell Center (choose this method because if there was an overlapping of polygons, the value of the cell would be from the overlapping cell).

Priority field = NONE, this can be change if there is a field that need to be prioritized, in our case we did not have one.

Cell size = 380 (first run) 2500 (second run) this value is optional, but need to assign same value to all rasters.



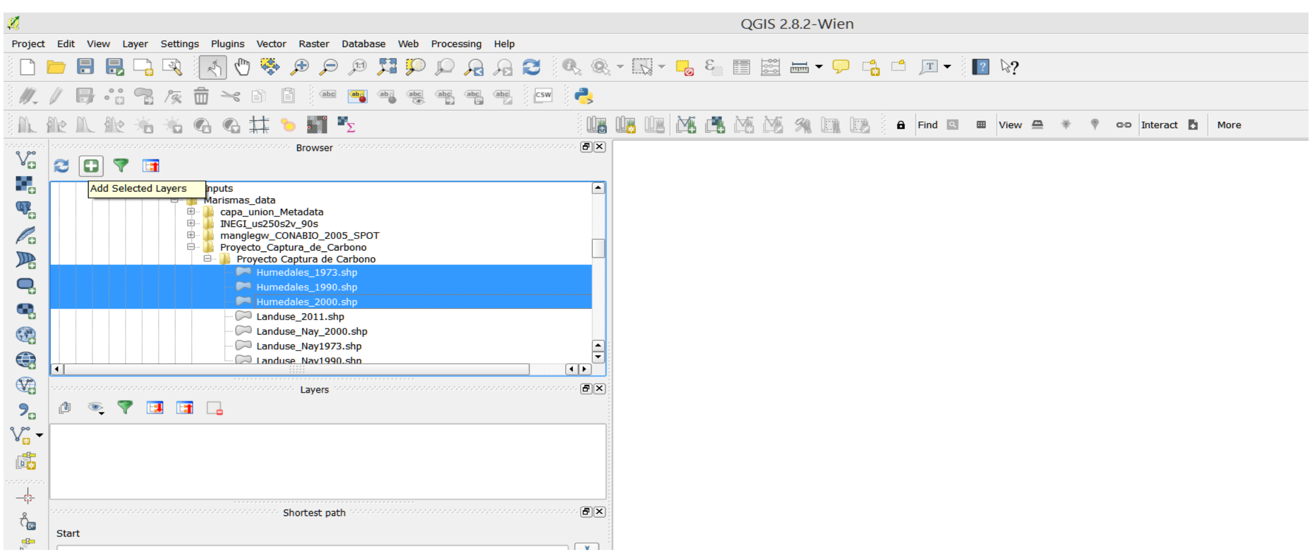
If successful, it should look like this. Note that the values are correspondent to number of classes and not the size of the area. This is important for the preprocessor tool.



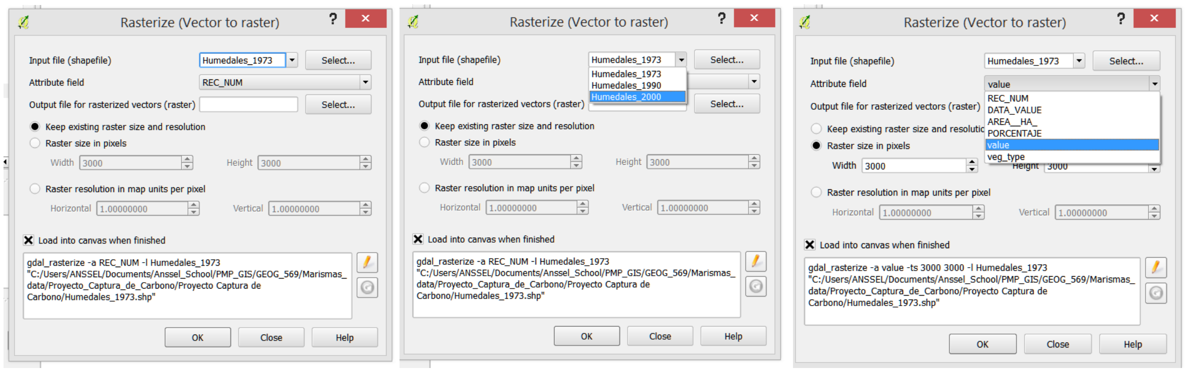
Note: Error faced during raster conversion.

QGIS was also used to create raster datasets. This was done because ArcMap presented a glitch that made rasters look like smeared paint over a canvas. Also, in case the user does not have access to ArcMap, we want to provide an alternative to be able to use the Blue Carbon Model.

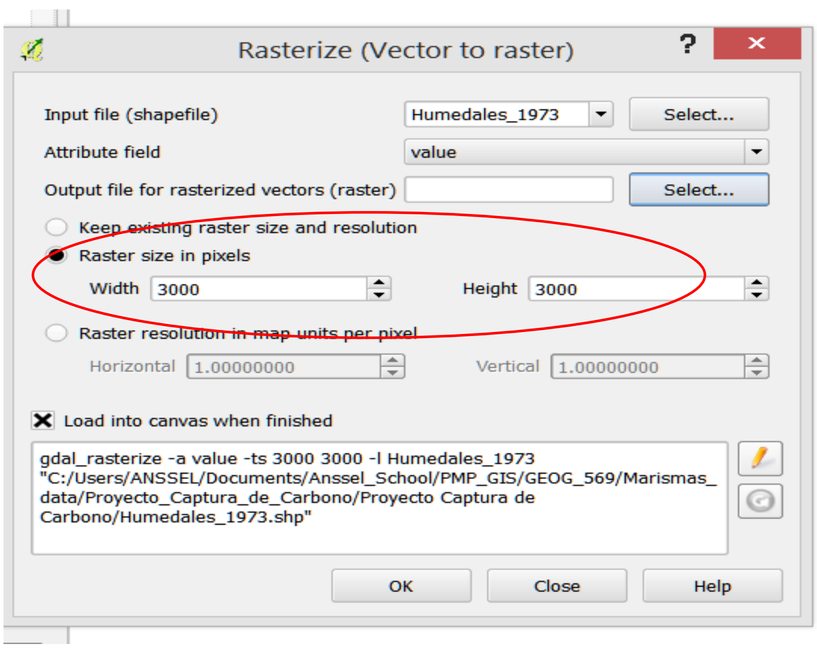
4. Open QGIS, Navigate to data location, open folder, select data, and click “add layers”.



In the top menu of the interface a menu tab named “Raster” can be seen. Click and select “Conversion” => “Rasterize” in the interface you can see the data added previously and you can make the selection of the layer desired.



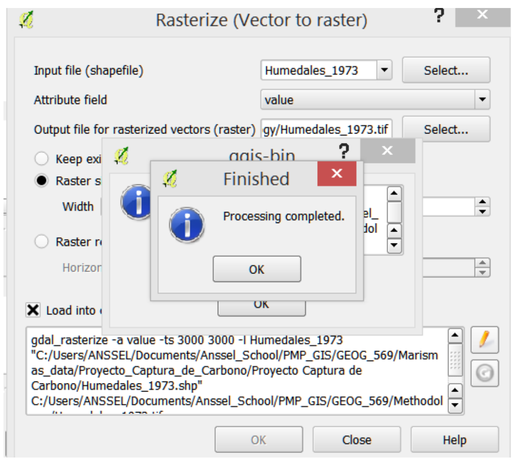
After selecting the layer, select the field “value” and click “Raster size in Pixels” leave as 3000x3000, unless you desire a smaller size. Later select the output Raster location.

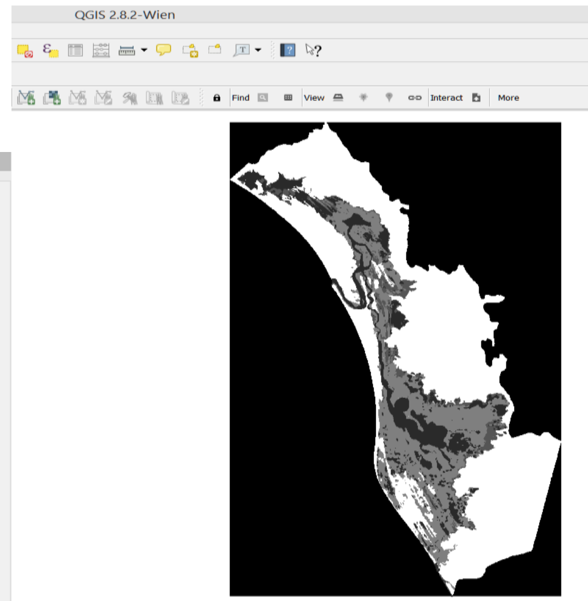


Here just click “Select” and navigate to your workspace.

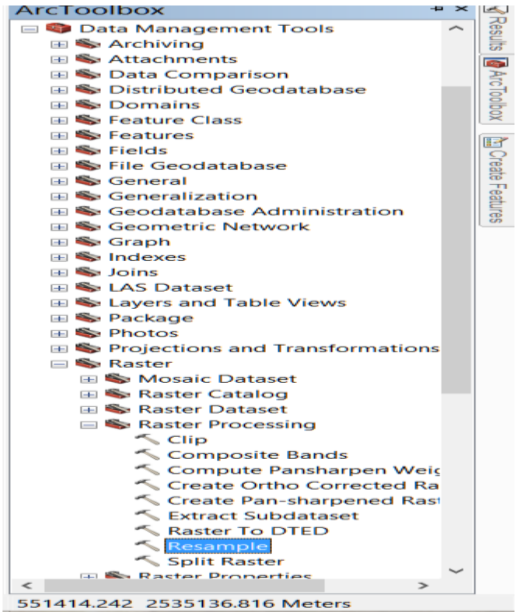
Note: Click “Ok” only one time or you will create 2 raster datasets with the same name and the program can freeze.

When done, click “Ok” in the next two windows and, without closing the interface change the layer, the output name and click “Ok” again. Repeat this for the last layer, when done you should have something like this:

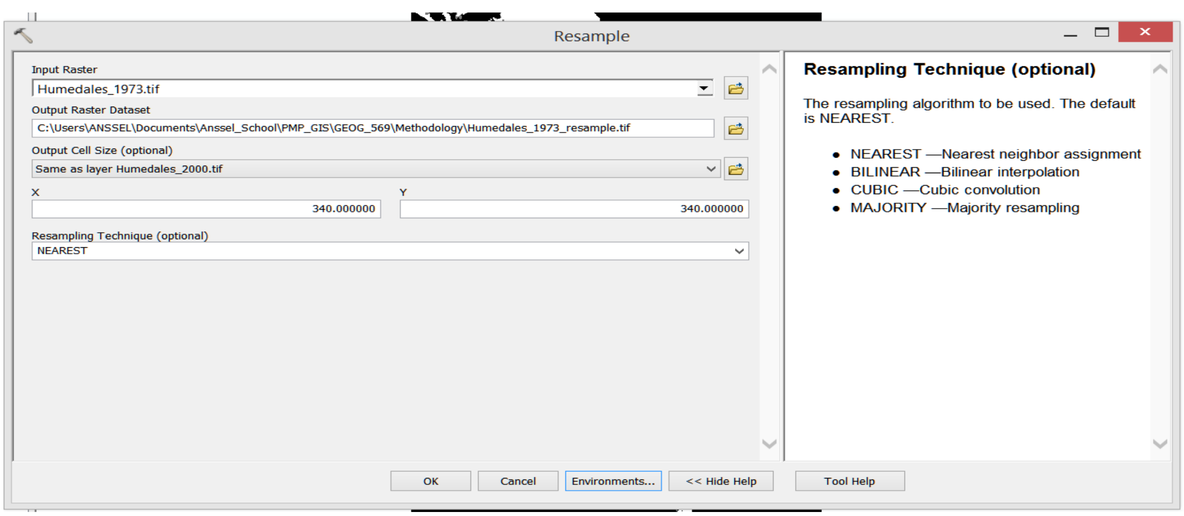




5. The next step is to modify the data to avoid errors in the Blue Carbon Model. The first thing is to resample rasters in order to have the same cell size. In ArcMap, open the tool box “Data Management” and navigate to “Raster” click it and select “Raster Processing”.



In the interface, select your layer of interest, in our case Humedales_1973.tif. This raster has different cell size, while the others have a cell size of 340 for XY, Humedales_1973 has a cell size of 28.08 and 48.80304.



Input Raster = Humedales_1973.tif

Output Raster = Humedales_1973_resample.tif, in prefered location.

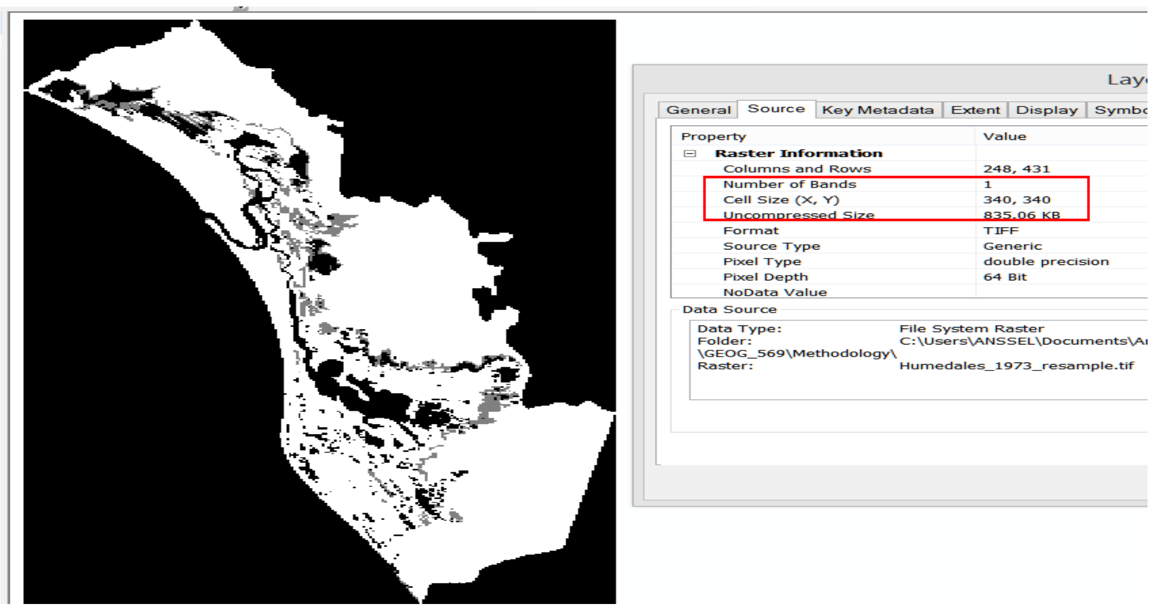
Output Cell Size (optional) = selecte the layer that has the desired cell size, in our case Humedales_2000.tif.

X = value from Humedales_2000.tif (340.000) Y = Value from Humedales_2000.tif (340.000).

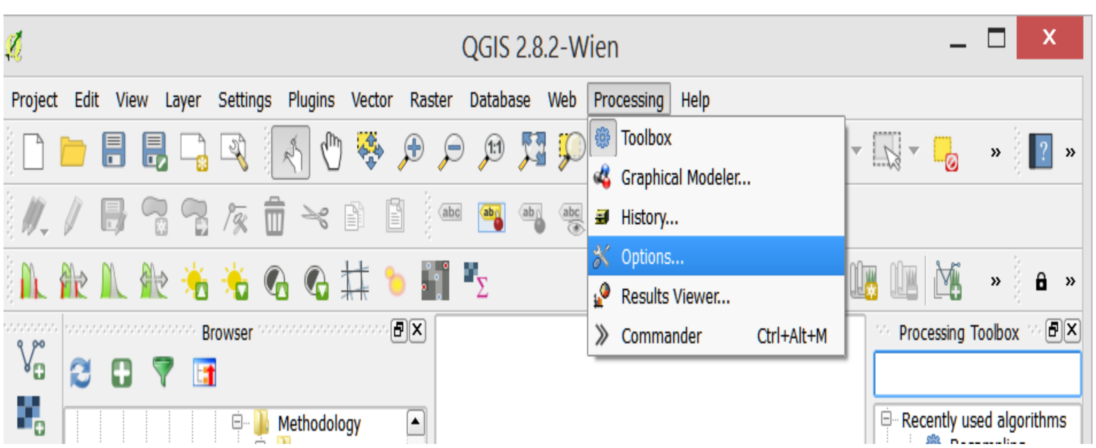
Resampling Technique (optional) = NEAREST **

**This method was used because it will not change the value of the cell. This is used for land use classification.

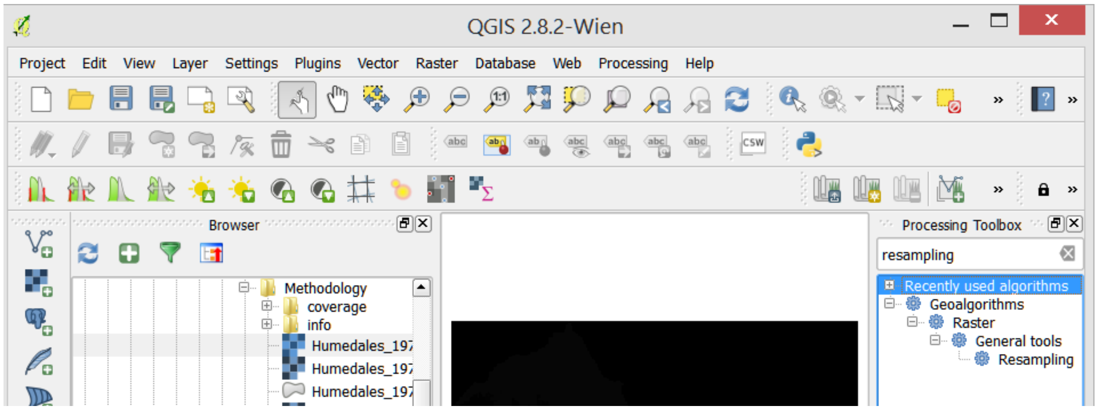
Click “OK” check that resampling was successful.



6. The same method can be done using QGIS. In the top menu bar look for the tab named “Processing” and select “Options”. This will open an interface window where you can select resampling method.



7. In the processing toolbox search area type “resampling” this will select the tool and then double click to open it.



8. In the Resampling tool window, under the Parameters tab, select the following

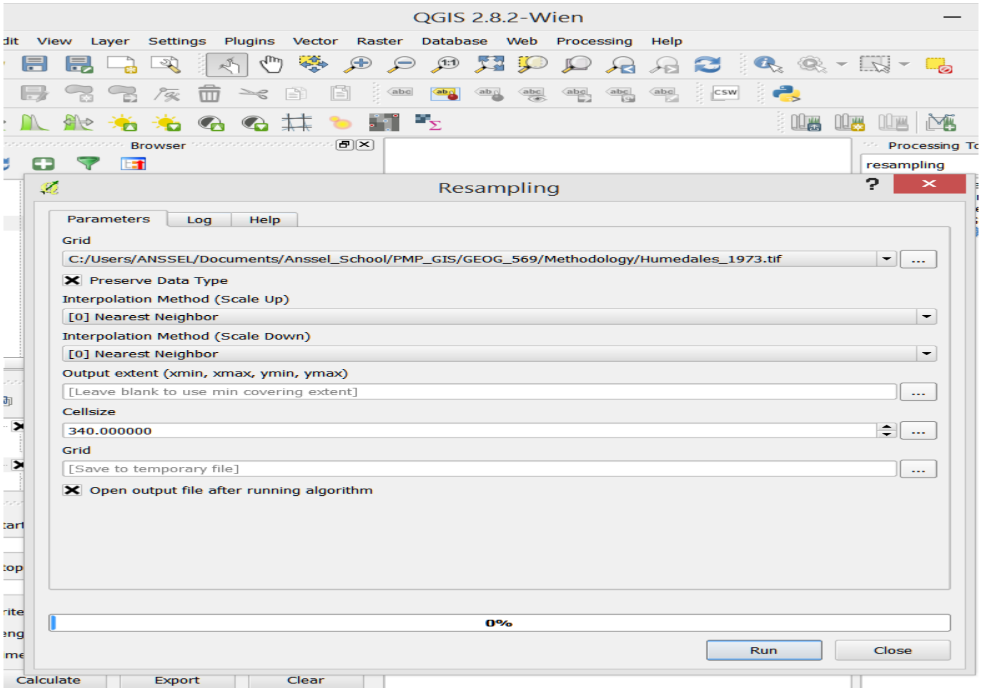
Grid = Humedales_1973 or raster.tif (click the three dots and navigate to your folder and select the layer to be resampled).

Interpolation Method (Scale Up) = Nearest Neighbor. This way the value of the cell does not change, only the size.

Interpolation Method (Scale Down) = Nearest Neighbor.

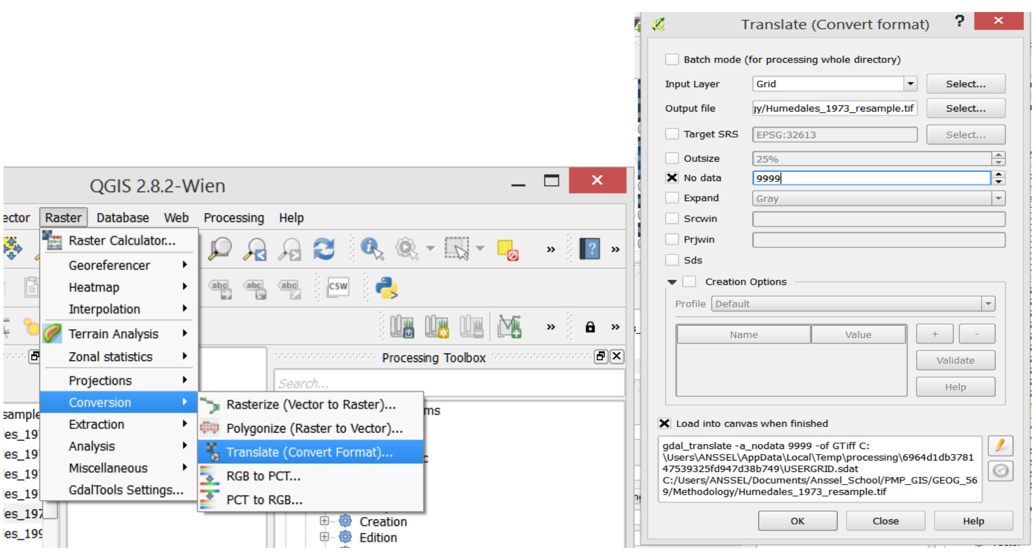
Cell size = 340 or its possible to select a layer as target match up.

Click Run.

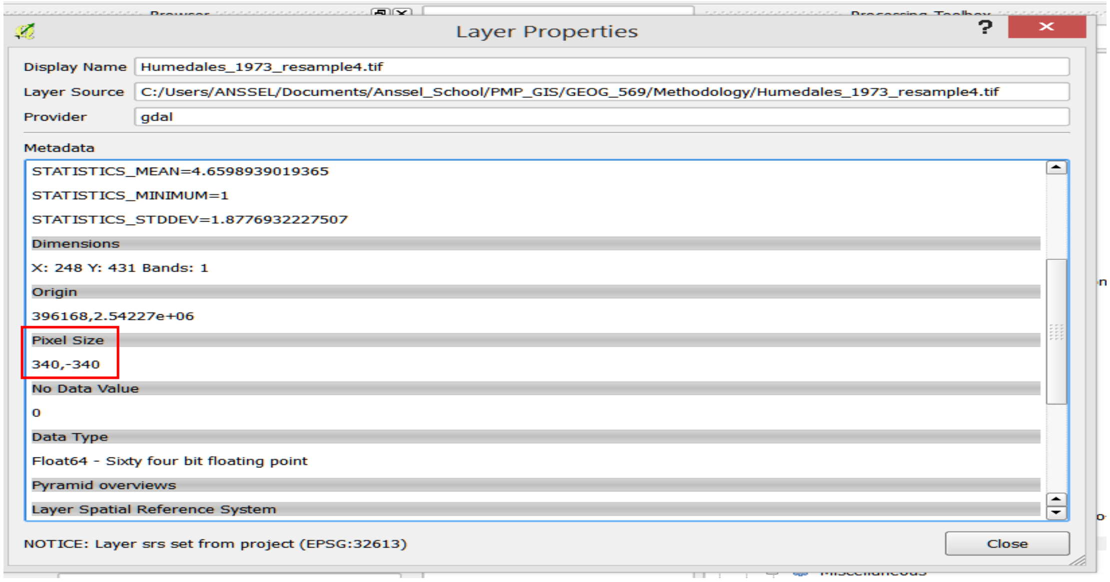


The output is named Grid, the extension is .sdat. Because this is not useable in the Blue Carbon Model, it's necessary to do a final step.

9. In the Raster Menu, select "Conversion" => "Translate". In this interface select your Grid file. Select an out folder and name and check "No data" and assign a value. In this case we used 9999, and click OK.



If successful, your layer would have been changed to the desired extension and also would be ready to use.



10. Repeat for resampling steps for each layer that will be used in the model, this way the model will have the same type of data with the same cell size and values.

Preparation of Model Inputs for .csv files:

Blue Carbon Pre-Processor Model

The Preprocessor has as objective to create a transition matrix that indicates either accumulation or disturbances as a result of different LULC transitions (e.g. salt marsh to developed dry land) (NatCap 2014).

To prepare the inputs that are needed for the preprocessor we need to start by modifying the input called Carbon.csv that comes with the original sample data of the model. Because the data received was in Spanish we had to translate and match the column “Name” with a new column created, named “Clases”. Also, it is important to check the Veg Type column to make sure that the values have been assigned correctly. The next two screen shots illustrate the changes from the original input and the new input that fit our needs.

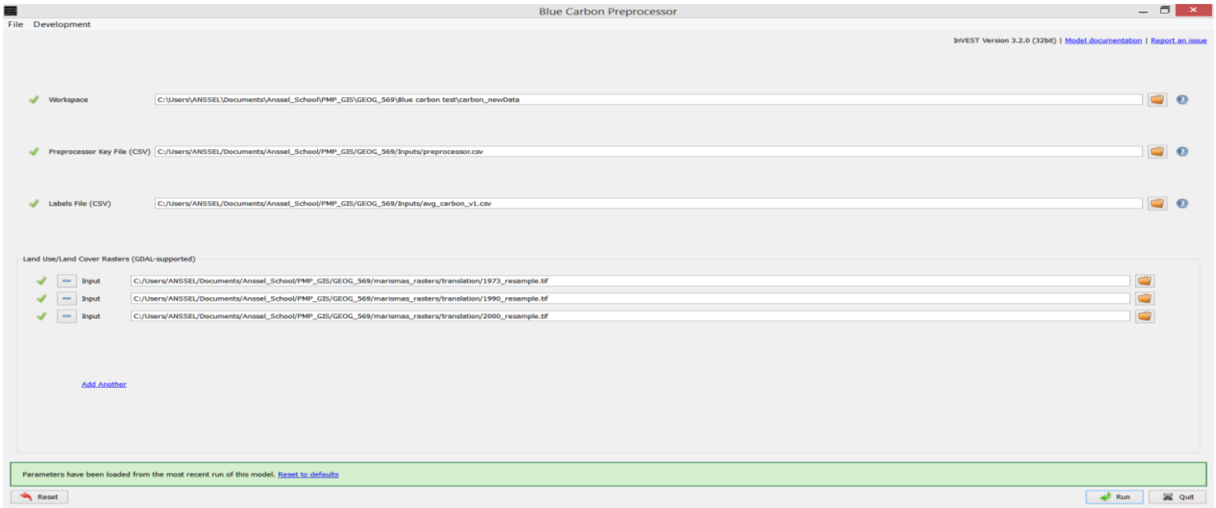
Id	Name	Veg Type	Above (MtCO2e / ha)	Below (MtCO2e / ha)	Soil (MtCO2e / ha-m)	Soil Depth (m)	Litter (MtCO2e / ha)	Bio_accum_rate (MtCO2e / ha-yr)	Soil_accum_rate (MtCO2e / ha-yr)
0	Unnamed	0	0	0	0	1	0	0	0
1	Developed	0	0	0	0	1	0	0	0
2	Undevelop	0	0	0	0	1	0	0	0
3	Nontidal S	0	20	10	244	1	0	0	0
4	Cypress Sw	0	42	24	244	1	0	0	0
5	Inland Fres	1	20	10	269	1	0	0.5	10.21
6	Tidal Fresh	1	20	10	269	1	0	0.5	10.21
7	Transition	1	20	10	100	1	0	0.5	10.21
8	Regularly F	1	20	10	222	1	0	0.5	10.21
9	Mangrove	2	35	29	313	1	0	2	5.35
10	Estuarine E	0	0	0	10	1	0	0	0
11	Tidal Flat	0	0	0	55	1	0	0	0
12	Ocean Bea	0	0	0	10	1	0	0	0
13	Unnamed	0	0	0	0	1	0	0	0
14	Rocky Inte	0	0	0	0	1	0	0	0
15	Inland Ope	0	0	0	0	1	0	0	0
16	Riverine Ti	0	0	0	0	1	0	0	0
17	Estuarine \	0	0	0	0	1	0	0	0
18	Unnamed	0	0	0	0	1	0	0	0
19	Open Ocea	0	0	0	0	1	0	0	0
20	Irregularly	1	20	10	115	1	0	0.5	10.21
21	Unnamed	0	0	0	0	1	0	0	0
22	Inland Sho	0	0	0	10	1	0	0	0
23	Tidal Swan	0	20	10	244	1	0	0	0

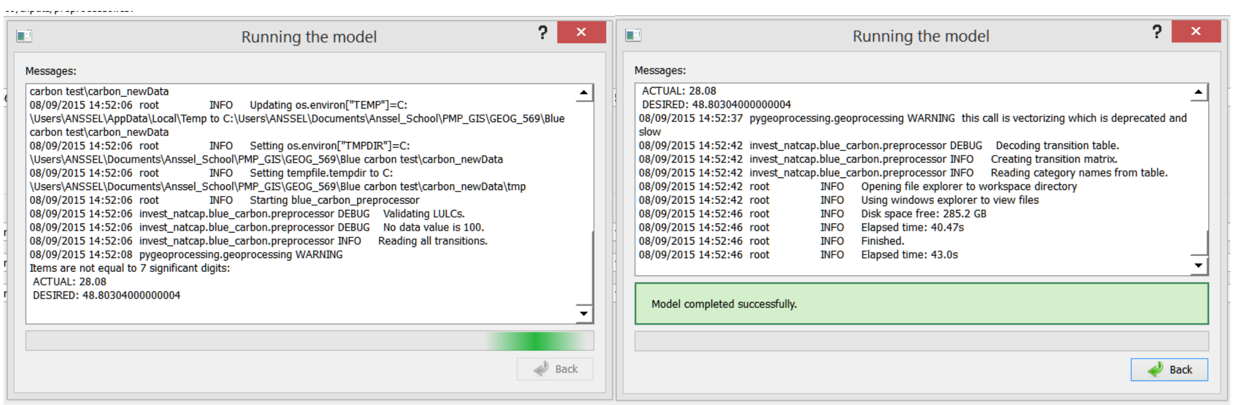
Changes in red. It is very important to add an "unname" field to help with the preprocessor**.**

Id	DATA_VAL	Name	Clases	Veg Type	Above (MtCO2e / ha)	Below (MtCO2e / ha)	Soil (MtCO2e / ha-m)	Soil Depth (m)	Litter (MtCO2e / ha)	Bio_accum_rate (MtCO2e / ha-yr)	Soil_accum_rate (MtCO2e / ha-yr)
0	0	unnamed	unnamed	0	0	0	0	0	0	0	0
1	1	Lagunas y	Lagunas y	0	0	0	0	1	0	0	0
2	2	Marismas	Marismas	1	20	10	176	1	0	0.5	10.21
3	3	Manglar	Manglar	2	35	29	313	1	0	2	5.35
4	4	Manglar m	Manglar m	0	20	10	244	1	0	0	0
5	5	Camaronic	Camaronic	0	0	0	0	1	0	0	0
6	6	Coberturas	Coberturas	0	0	0	0	1	0	0	0

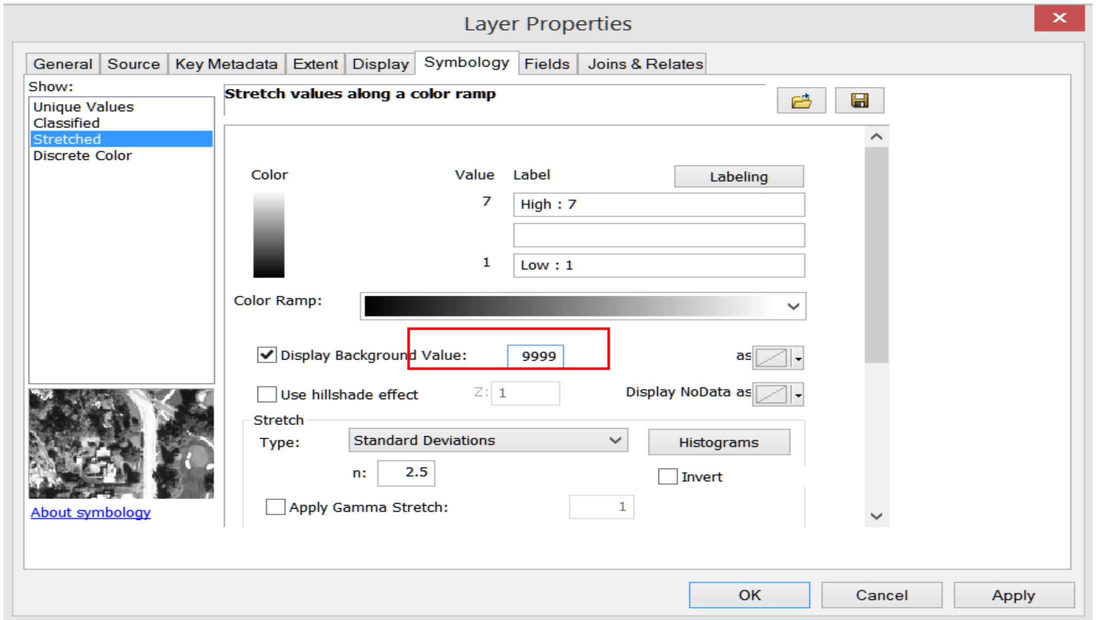
After making the changes needed save your new table and make sure has the extension .csv.

11. After making these changes the inputs are ready to be used on the preprocessor to get the Transition Matrix. After selecting inputs and workspace, click run.

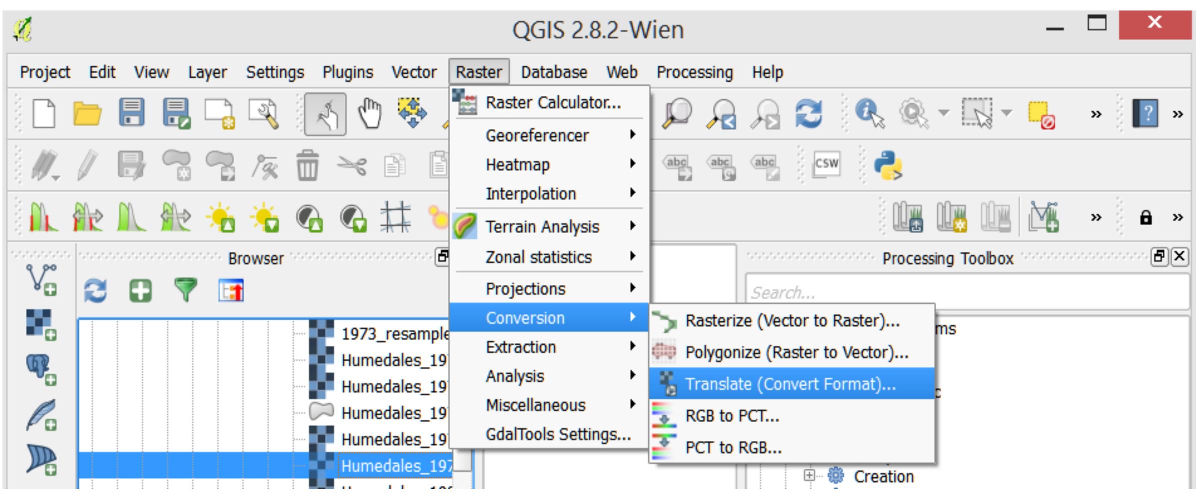




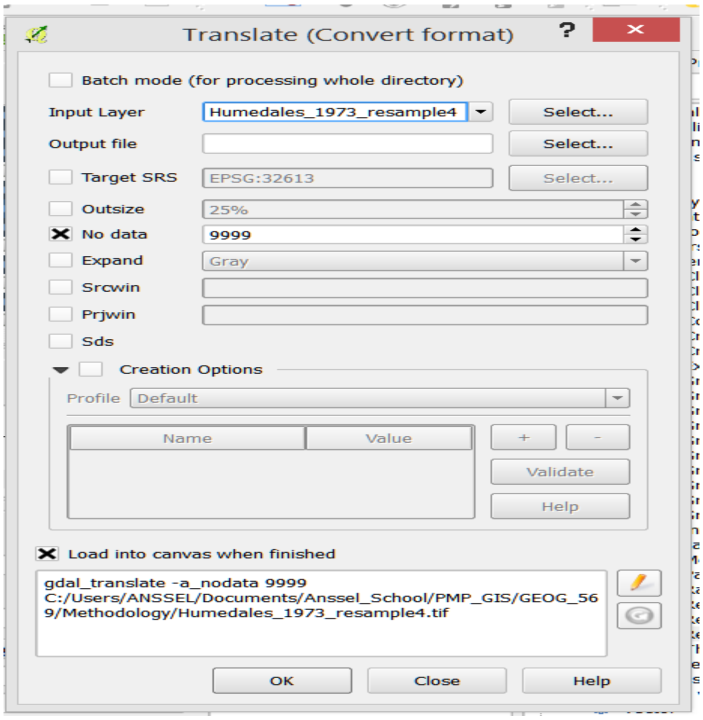
Note: If you see an error saying "No Data" it means that the no data value in the raster needs to be changed. In ArcMap it is as simple as going to the properties => Symbology Tab and check "Display Background Value " button and assign a value. It's recommended by NatCap to use 250, but any value would work as well. Click apply.



12. In QGIS it is needed to "translate" the rasters. Click the menu Raster, select "Conversions" and then "Translate".



13. In the interface select your raster and check "No Data". Assign a value and click Ok only one time. Now the data has been translated. Do not forget to give a name and select the workspace to save the file.



Blue Carbon Calculator Model – Data Inputs

14. The next step is to make changes in your transition matrix. Navigate to your space and open the file transition.csv.

Id	Name	0	1	2	3	4	5	6
0	unnamed	NONE	NONE	Accumulation	Accumulation	None	NONE	NONE
1	Lagunas y	NONE	NONE	Accumulation	Accumulation	NONE	NONE	NONE
2	Marismas	Disturbance	Disturbance	Accumulation	Accumulation	Disturbance	Disturbance	Disturbance
3	Manglar	Disturbance	Disturbance	Accumulation	Accumulation	Disturbance	Disturbance	Disturbance
4	Manglar m	None	NONE	Accumulation	Accumulation	NONE	NONE	NONE
5	Camaronic	None	NONE	Accumulation	Accumulation	NONE	NONE	NONE
6	Cobertura:	NONE	NONE	Accumulation	Accumulation	NONE	NONE	NONE
	Replace all instances of "Disturbance"							
	in the above matrix with either:							
	Low Disturbance							
	Medium Disturbance							
	High Disturbance							

15. Here you need to make sure that all data produced is consistent and that there is no difference among outputs. For example, here we can see that the table has simple problems like, some cells will say “none” or “None”, and others will say “NONE”. If these are left as is, an error will show when running the model that says “NONE”. This error refers to the labels for each cell that do not match and

need to be corrected. The model is sensitive to consistency for each cell and between tables.

	A	B	C	D
1	Id	Name	0	
2	0	unnamed	NONE	NONE
3	1	Lagunas y	NONE	NONE
4	2	Marismas	Disturbance	Disturban
5	3	Manglar	Disturbance	Disturban
6	4	Manglar m	None	NONE
7	5	Camaroni	None	NONE
8	6	Cobertura	NONE	NONE
9				

	A	B	C	D	
1	Id	Name	0	1	
2	0	unnamed	NONE	NONE	Accum
3	1	Lagunas y	NONE	NONE	Accum
4	2	Marismas	Disturbance	Disturbance	Accum
5	3	Manglar	Disturbance	Disturbance	Accum
6	4	Manglar m	NONE	NONE	Accum
7	5	Camaronic	NONE	NONE	Accum
8	6	Cobertura	NONE	NE	Accum
9					

16. After correcting these issues, the user needs to determine the type of disturbances that our LULC data has, or has suffered over time, and add to each "Disturbance" cell the adjective, Low, Medium or High, as is written. If not, the model will return with another error "Disturbance" which will indicate that we need to correct these cells.

17. To select the type of disturbances, the type of change and the type of disturbance needed to be determined. For example, in the matrix table, the column named "2" refers to mangrove and column "3" refers to dead mangrove. When column "2" and class "3", dead mangrove, cross paths the preprocessor generates a Disturbance cell. We decided that this type of transition is High because it represents a significant change, which will have a high impact in carbon sequestration. The transition table was modified based on this criteria.

	A	B	C	D	E	F	G	H	I
1	Id	Name	0	1	2	3	4	5	6
2	0	unnamed	NONE	NONE	Accumulation	Accumulation	None	NONE	NONE
3	~~1~~	~~Lagunas y esteros~~	~~NONE~~	~~NONE~~	~~Accumulation~~	~~Accumulation~~	~~NONE~~	~~NONE~~	~~NONE~~
4	2	Marismas	Low Disturbance	Low Disturbance	Accumulation	Accumulation	Medium Disturbance	High Disturbance	High Disturbance
5	3	Manglar	Low Disturbance	Low Disturbance	Accumulation	Accumulation	High Disturbance	High Disturbance	High Disturbance
6	4	Manglar muerto	NONE	NONE	Accumulation	Accumulation	NONE	NONE	NONE
7	5	Camaronicultura	NONE	NONE	Accumulation	Accumulation	NONE	NONE	NONE
8	6	Coberturas terrestres	NONE	NONE	Accumulation	Accumulation	NONE	NONE	NONE

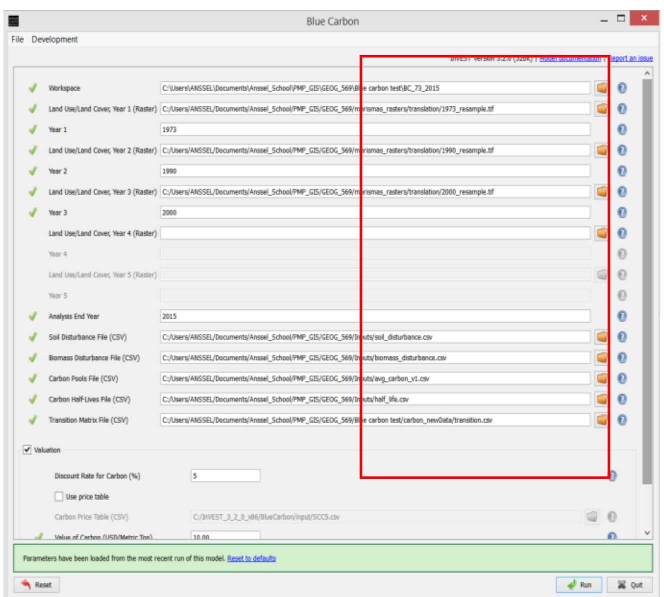
18. Save the changes and **KEEP** the same .csv format.

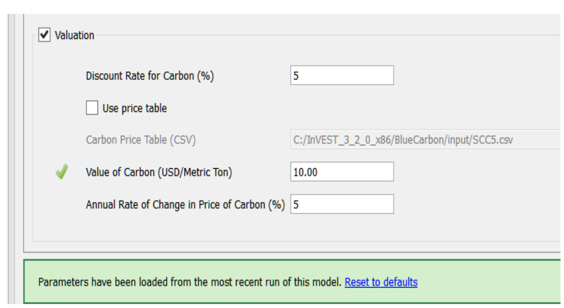
19. Look in the input folder named “Half_Life.csv.” If data exists for that specific area of study make the changes necessary, if not, use default values. We could not find Half_life values for Marismas Nacionales so we used defaults.

veg type	veg name	soil (years)	biomass (years)
0	other	None	None
1	marsh	7.5	0.5
2	mangrove	7.5	15
3	seagrass	1	0.2737

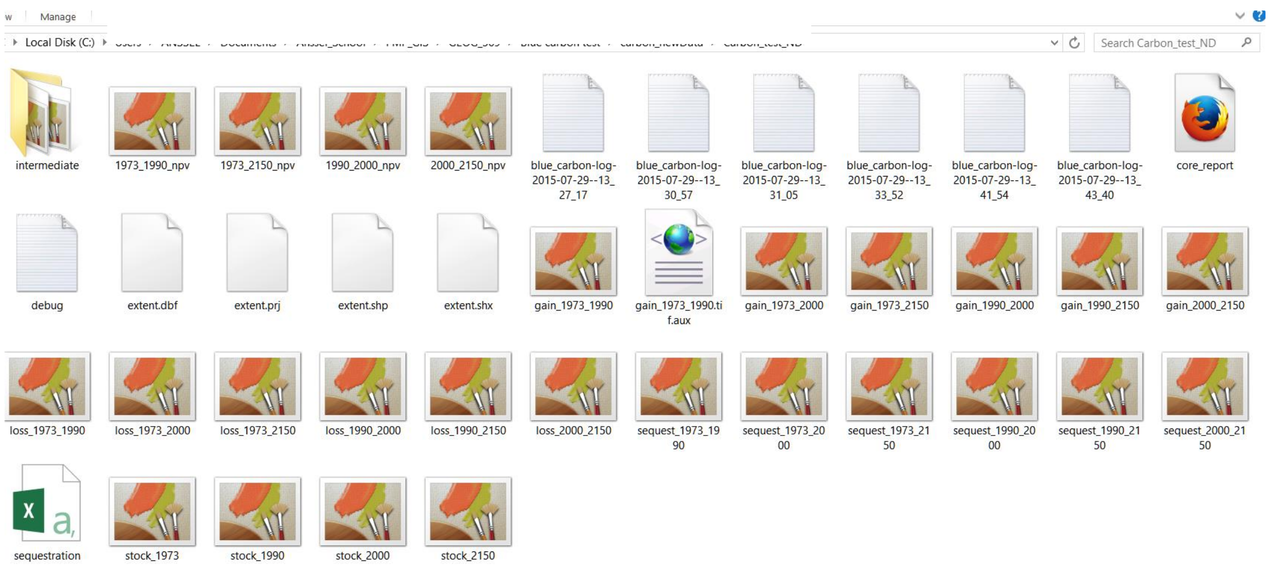
20. The carbon Price table can be modified if desired but in this study we focus on value of Carbon on dollars per metric tonne over hectare.

21. For running the model we need to select the workspace, the resampled rasters and modified input tables. Then select the Social Economic Value or the Economic Value (price in USD).





22. Click Run, the model will take a while to process all the data. After the model is done in your workspace you can see all the outputs and a folder called Intermediate. For information on this folder and the output rasters, please refer to the Blue Carbon documentation at http://data.naturalcapitalproject.org/invest-releases/documentation/current_release/blue_carbon.html.



Results

The Blue Carbon Model calculates the net present value of sequestration in the form of output raster maps, for the years specified in the Preprocessor portion of the model. In this case, time t1, t2 and t3. The pre-processor model produced an output of transition matrices of both accumulation and disturbances of the carbon pools in the study area. The users had to further define a value of low, medium or high for each transition between classes/environments in the carbon pool table. This reclassified transition data was then entered into the Blue Carbon calculator model to determine the total net present value of sequestration for the mangrove forests in Marismas Nacionales, Mexico.

The output raster maps produced by the Blue Carbon calculator model are 1) maps of total carbon stock at each year and gain/loss over each time period 2) maps of sequestration and emissions over each time period 3) a summary of storage and sequestration and 4) net present values of sequestration.

Total Carbon Stock Output Maps (over time)

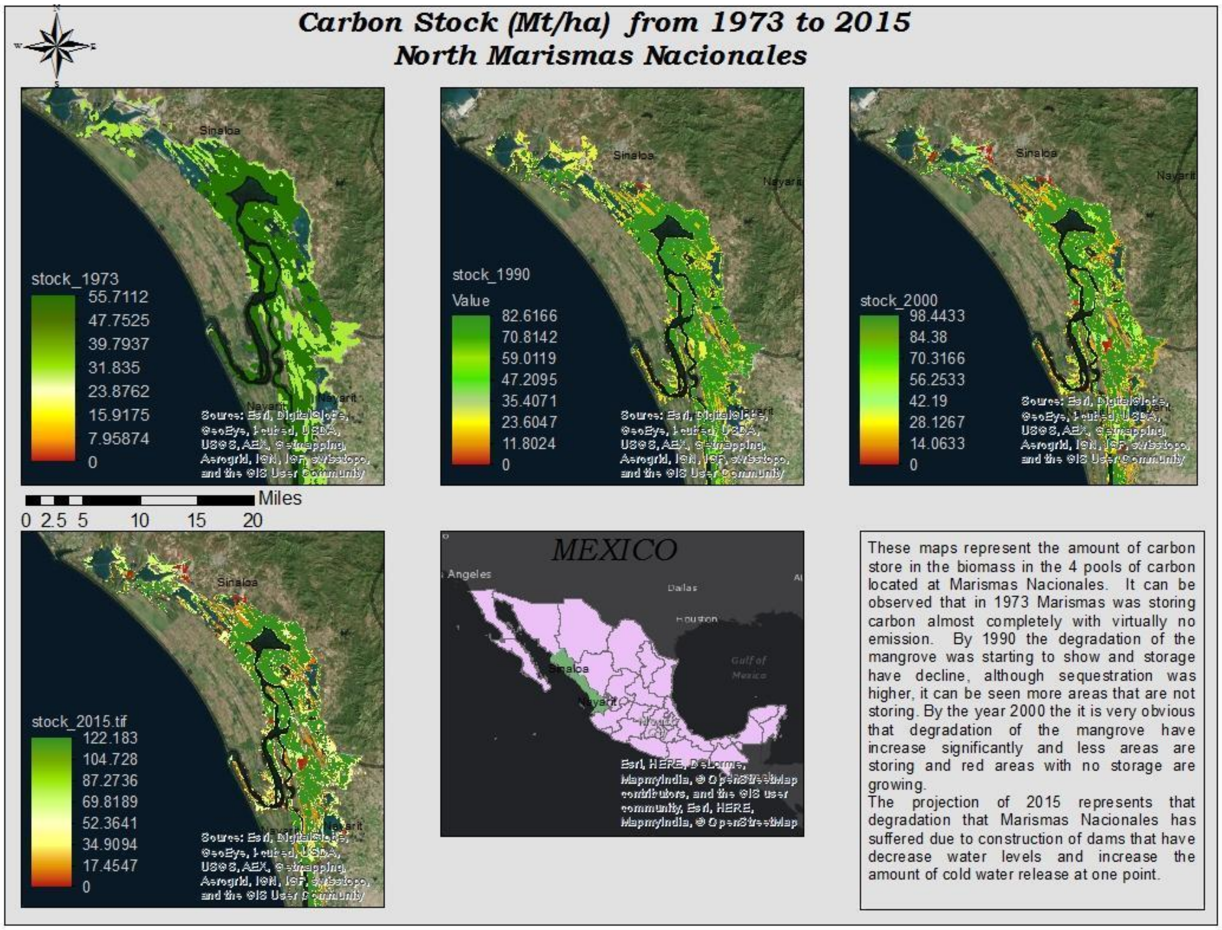


Figure 3. Map representing the carbon Stock from 1973 to 2000 and projection of carbon stock by 2015 according to the Blue Carbon Model. Location North area of Marismas Nacionales

The map above represents the changes in carbon stock from 1973 to 2000 with a projection for each year to 2015. The values of emission have changed over time as well as the carbon stock. The maps show the changes in mangrove forests, over time, and some of the areas that were once sequestrating carbon are now emitters of carbon. In 1973 the whole forest was healthy and primarily sequestrating carbon. Very few areas were low sequesters compared to the main forest. In 1990, we can see an alarming increase of emitters and bare land that was not see seventeen years before. By the year 2000 the location with zero stock, represented in red, have increased not only in size, but also in number. The model created a projection to 2015, and it shows a shocking degradation and increase of emitters that was not seen fifteen years before.

The same trend can be seen in the south part of Marismas Nacionales, although in this location, the degradation of the forest and the decrease of carbon stock throughout the forests is more obvious.

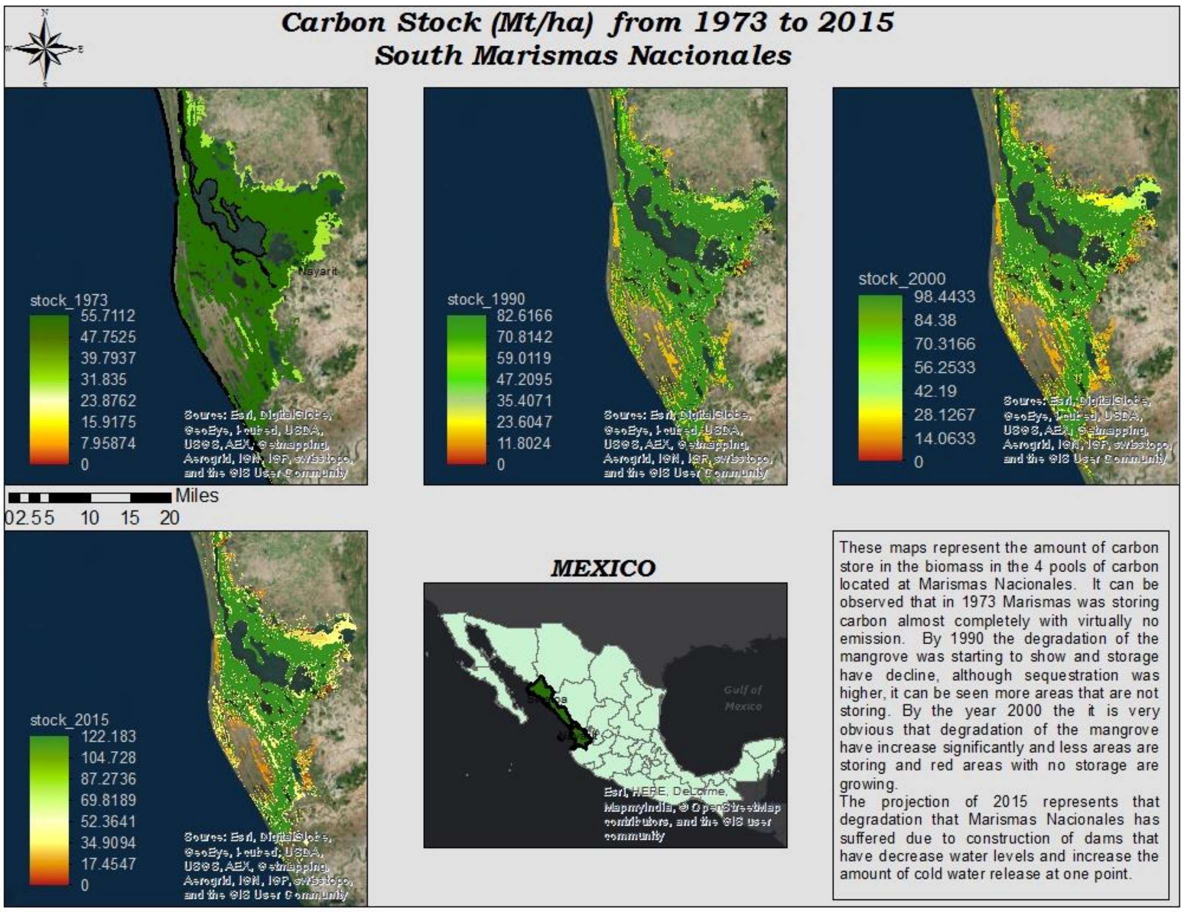


Figure 4. Map representing the carbon Stock from 1973 to 2000 and projection of carbon stock by 2015 according to the Blue Carbon Model. Location South area of Marismas Nacionales

Emissions/Sequestration Output Maps (over time)

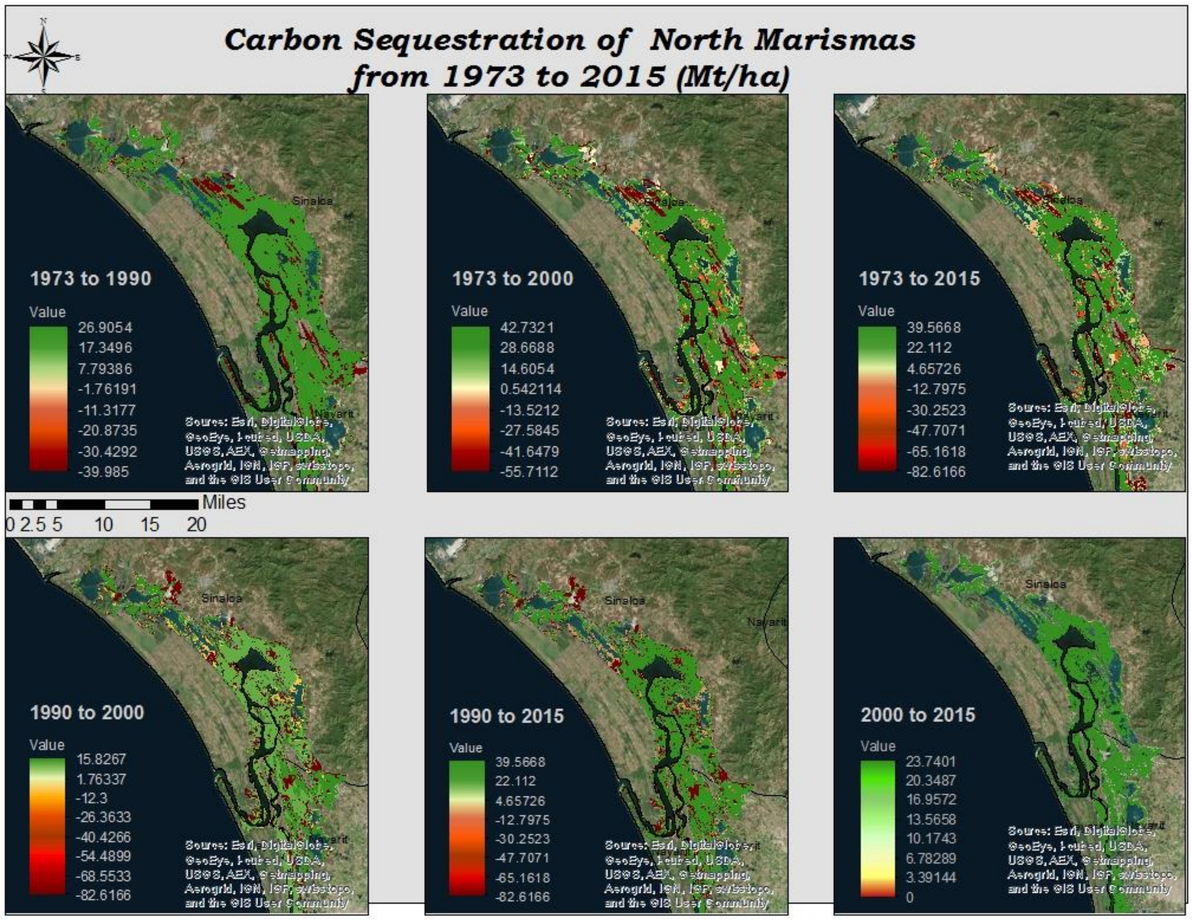


Figure 5. Map representing the carbon Sequestration from 1973 to 2000 and projection of carbon sequestration by 2015 according to the Blue Carbon Model. Location North area of Marismas Nacionales.

The map above represents the sequestration of carbon in the 4 carbon pools, aboveground biomass, belowground biomass, standing dead carbon and sediment carbon. The projections made by the model show the locations where carbon was and has been sequestered as well as the locations where the carbon has also been emitted. The green to yellow colors represent the carbon sequestration, with green being the highest sequester from all the locations and orange to red are the locations where carbon is being emitted. In 1973, areas that were considered emitters were few. In

1990, we observe the significant increase of locations with lower sequestration and also the increase of locations with higher amounts of emission. By 2000, the map shows the increase of the locations that are considered emitters. It also can be observed that by 2015 the projection is optimistic, since very few locations are considered to be emitters, but we also can see locations that have lower sequestration as well.

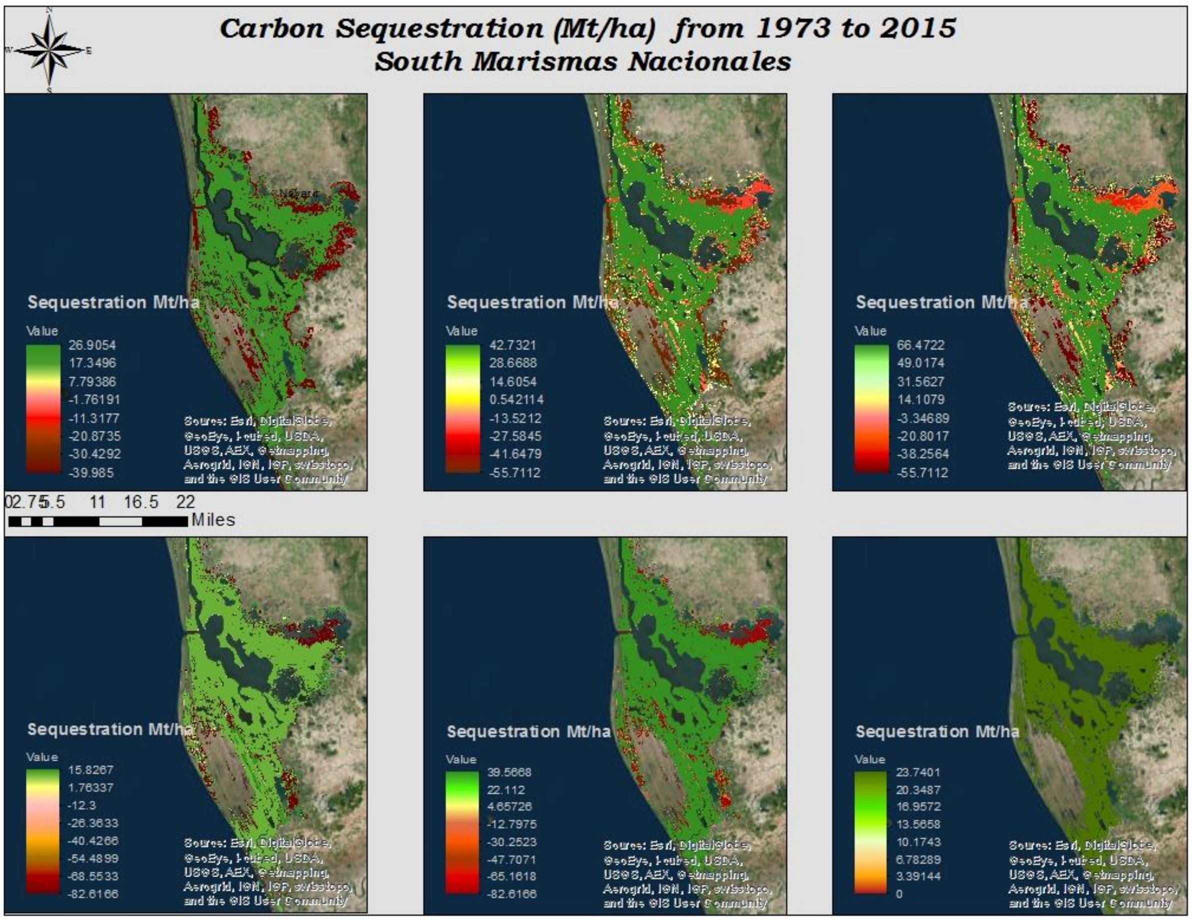


Figure 6. Map representing the carbon Sequestration from 1973 to 2000 and projection of carbon sequestration by 2015 according to the Blue Carbon Model. Location South Marismas Nacionales

The State of Nayarit, has the largest area of Marismas Nacionales, so it is expected to have more sequestration. It can be observed that during 1973 the area had emissions only outside and around the perimeter of Marismas. In 1990 to 2000 it can be seen that emissions have decreased to only 15 megagrams of CO_2e per hectare. While in 1973 to 2000 it was projected that Marismas had sequestered over 66 megagrams of CO2e per hectare. It's projected that from 2000 to 2015, Marismas will sequester 23 megagrams of Co2e per hectare. It is important to notice that the projection for 2015 from 2000 has very little to no change in regards of emission. Better said, if conservation management continues, we can see that, in the future, the area of Nayarit will be sequestering only.

Net Present Value of Sequestration Output Maps (over time)

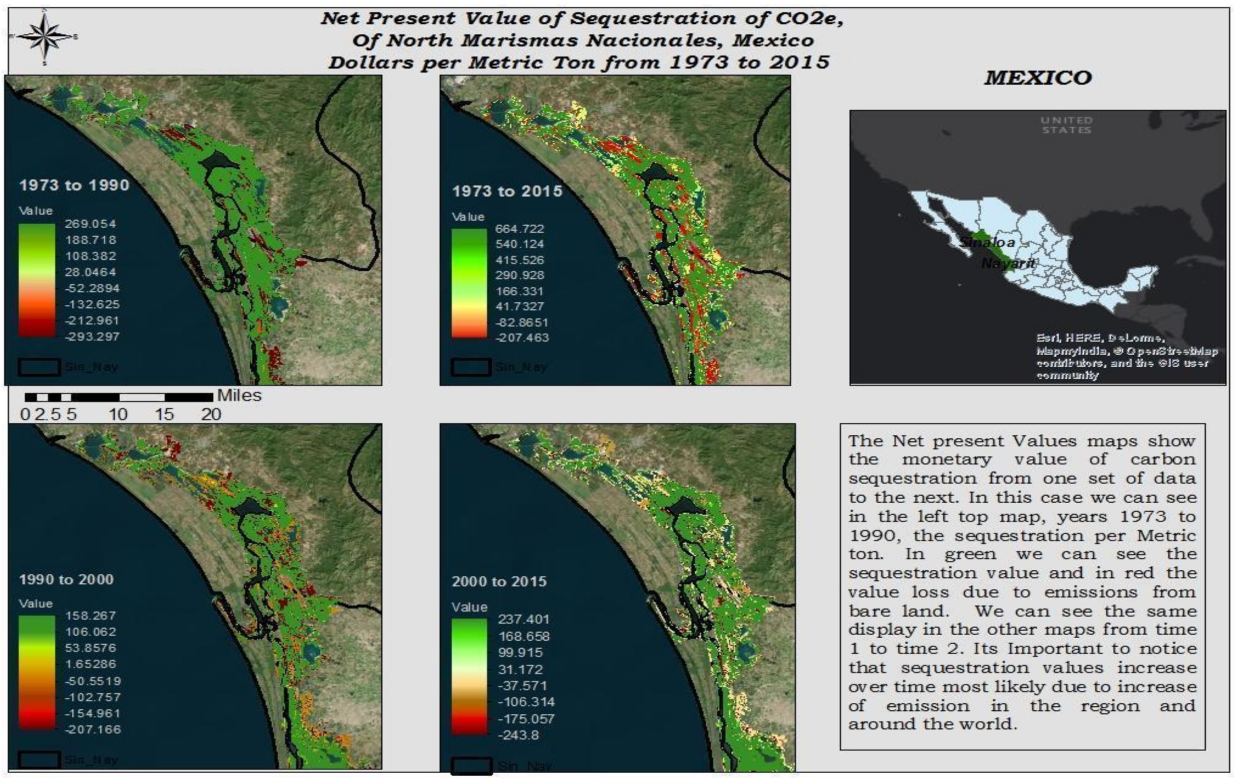


Figure 7. Map representing the carbon Net present value of Sequestration in Mt/Ha from 1973 to 2000 and projection of carbon sequestration by 2015 according to the Blue Carbon Model. Location North Marismas Nacionales.

The map of the Net Present Value (NPV), is the economic value of total sequestration in the Marismas area. It can be observed from 1973 to 1990 there was a value of a little over 269 dollars per metric ton per pixel in areas where sequestration is at its best. Compared to 1973 to 2015, the value per metric ton is 664 dollars. The most interesting part of the output map are the changes in land cover and its effects in sequestration. It is possible to see that the raster has a large variety of classes and that more areas are close to becoming emmiters while others have already made the transition.

From 1990 to 2000, the value per metric ton has decreased to 158 dollars. The radical changes in landscape where orange color represents locations where landscape has made the transition from sequester to emitter which means that Marismas is not producing money, but losing it.

From 2000 to 2015, the value per metric ton increased to 238 dollars. It's interesting to point out that the landscape has changed significantly and although the value of the pixel has increased, the number of pixels emitting Carbon now is higher with a value of -243 dollars per metric ton per pixel, meaning that the area is not as productive as it was fifteen years before or even 42 years before when data was started to be collected.

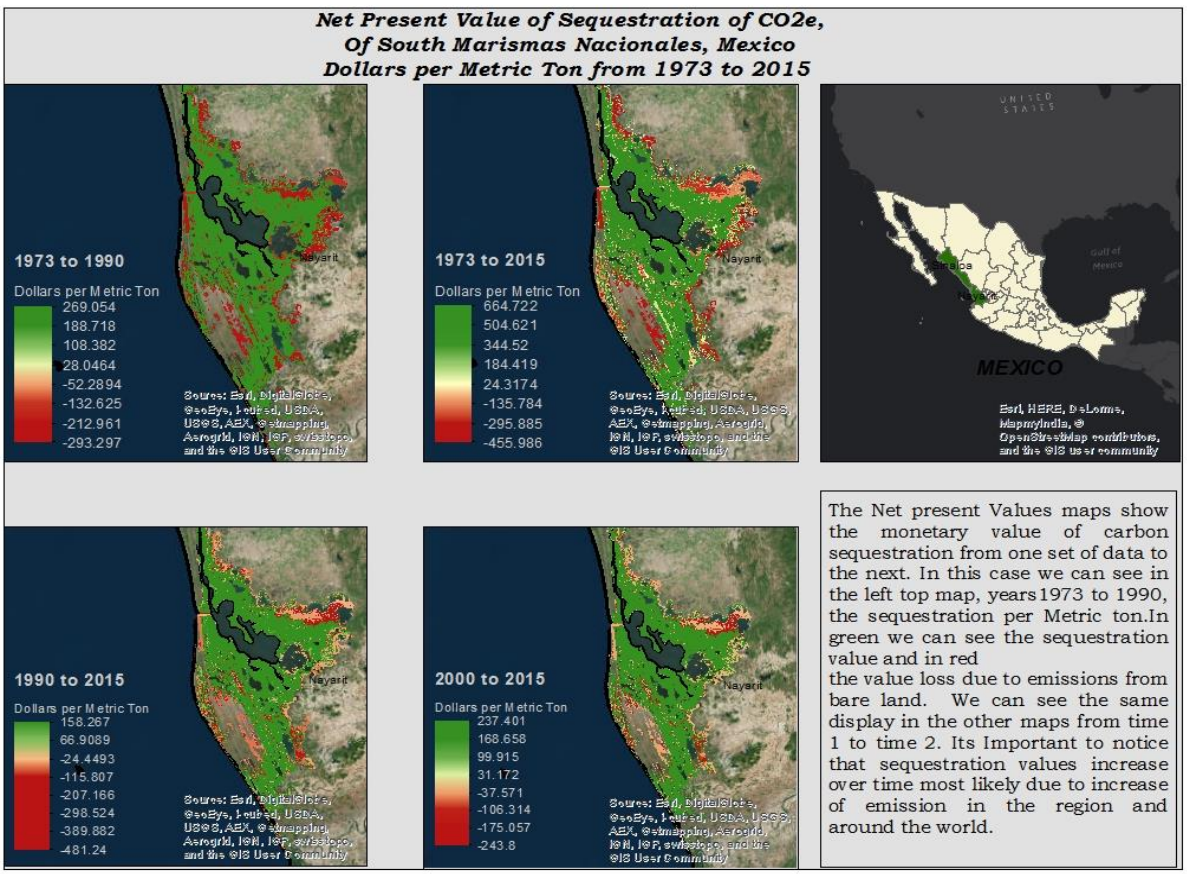


Figure 8. Map represents Net Present Value (NPV) in Mt/Ha from 1973 to 2000 and projection of NPV by 2015 according to the Blue Carbon Model. Location South Marismas Nacionales.

The map above represents the Net Present value for the south Marismas Nacionales, The value per pixel in Nayarit is not different from the northern part. Again we can see areas that produced 269 dollars per pixel in areas at its best and with a lowest of -293 dollars per pixel of emissions. It is important to note that the amount of land cover emitting CO2 are very little compared with other years. In 1990 we can see that the value of sequestration has decreased to 168 dollars, but the areas that emitting CO2 have increase dramatically. In general we can see that by 2000 the landscape have changed significantly and that emission have increased but also that in 2015 with restoration effort that emission are under control but have not change.

Output Summary table:

Output	Output file Name (Example)	Value
NPV (Net Present Value) from year 1 to year 2	1973_1990_NPV.tif	Dollars per Metric Tonne per pixel
gain (Carbon stock gain overtime) year 1 to year 2	gain_1973_1990.tif	Megagrams per pixel
loss (Emission in landscape) year 1 to year 2	Loss_1973_1990.tif	Megagrams per pixel
sequestration (gain - loss) year 1	sequestration_1973.tif	Megagrams per pixel
stock (Total carbon storage in 4 pool) year 1	stock_1973.tif	Megagrams per pixel.
sequestration	sequestration.csv	Dollars per pixel.

Table 1 Output summary table of Blue carbon model.

Discussion

To begin to understand the mangrove ecosystem and the challenges and/or threats it currently faces, it was important to first construct a social-ecological systems table that defines key elements in the system for the biophysical, economic and social domains of this particular mangrove ecosystem. (See Figure 9).

Key Elements and Relationships for Mangrove System
Marismas Nacionales, Mexico

FOCAL SCALE	BIOPHYSICAL Domain	SOCIAL Domain	ECONOMIC Domain
BELOW focal scale	▪ Fluctuating temperatures ▪ Fish communities ▪ pH Balance(s) ▪ Salinity ▪ Water quality (toxicity) ▪ Sediment flux ▪ Tidal Flow	▪ Pollution in water caused by surrounding human populations - Oil spills - Trash - Human waste - Excessive Pesticides	▪ Dam operations (opening/closing of doors) ▪ Reliance on fishing industry (employment)
AT (local) focal scale	▪ Overall Mangrove health ▪ Erosion control ▪ Wildlife ecology & habitats ▪ **Carbon pools & sinks** ▪ Marsh disturbances	▪ Tourism ▪ Recreational fishing ▪ Population health in surrounding communities ▪ **Livelihood - Carbon Credits**	▪ Tourism ▪ Fishing Industry ▪ **Sequestration - Carbon Credits** ▪ Limited Harvest ▪ Existing and proposed dams in adjacent inlets ▪ Timber cutting
ABOVE focal scale	▪ Bird Sanctuary/habitat ▪ Oxygen emissions of a [healthy] Mangrove System ▪ **Carbon pools & sinks**	▪ Erosion control and safety for surrounding communities	▪ Industry health and maintenance ▪ **Carbon sequestration and future credits**

Figure 9 – Simplified SES table, showing key relationships between elements.

Defining these relationships and how they are connected within the system, solutions can begin to form in restoring the mangrove forests back to health as well as provide a better understanding on how long-term sustainability might be achieved.

A re-occurring key element in this ecosystem are carbon pools/stocks. This element touches upon all three domains within the ecosystem and thus, deserves closer inspection. The partners for this project agreed and contacted us to help analyze the carbon stock, over time, in Marismas Nacionales, Mexico. The InVEST Blue Carbon Model was chosen to provide time-stepped "snapshots" of carbon pools within the area of interest (AOI).

The output *carbon stock* maps, Figures 3 and 4, which are measured in megagrams per Co2e per pixel, show a discernible decline in the overall health of the mangroves, over time. They also display where the carbon pools and sinks have occurred in the AOI between data years. It can be observed that in 1973 the condition of the mangrove was healthy and strong. At this time no dams have been built, and water in the estuary was at an acceptable level and thus, kept warmer. It is important to notice that by 1990, seventeen years later, landscape has changed so much that there are areas that have started to go through a transition from sequestration to emission. As time continues, more changes are visible and the sequestration, although increased, also has changed to emitted CO2. Warne 2007, mentions that water temperature is a key factor in the health of the mangroves and that they are resistant to colder temperatures. Thus, this is why they grow in the tropical to sub-tropical latitudes. Water, behind the gates of the dams is normally colder since it is contained for long periods of time and sunlight does not reach all the way to the bottom. The upper depths behind the gates of the dam receive sunlight and is warmer. The discharge of this deeper, colder water from the dams might affect the conditions of mangrove health.

The output *sequestration maps*, are measured in rates of Megagrams of carbon dioxide *equivalent* gases (CO2e) and show rates of sequestration, over time. Per the InVEST team, they have specified that the model specifically measures CO2*e* gases, not just carbon dioxide (CO2). Carbon dioxide equivalent gases are [naturally] occurring greenhouse gases and can be characterized as water vapor (H2O), carbon dioxide (CO2), methane (CH4), Nitrous Oxide (N2O) and Ozone (O3). The maps show how the landscape has changed over time and how sequestration values have changed as well over time. It is important to note that when the mangrove is not sequestrating carbon, it is emitting CO2. The changes in landscape have a significant effect on emissions and sequestration. In Figures 5 and 6, the maps from 1973 to 2015 show how much sequestration is done, but also show the degree of degradation of the mangroves, over time. It is necessary to point out that sequestration over time decreased, and by 2015 the most productive area sequesters around 23 megagrams per hectare, while in 1973, it was 26 megagrams. Three megagrams might not seem like much but when we compare the locations that were emitting 42 years before - to now – 42 years before there were no emission of CO_2e, while in 2015 the location that are emitters of CO_2 are more noticeable.

The model produces a series of .npv maps which display the *total net present value (NPV) of sequestration*. Per the InVEST team, there are generally two views for NPV of sequestered carbon. Some measure just the value of emissions, over time. While others view NPV as sequestration (storage of carbon), over time. The Blue Carbon Model, as specified by the InVEST team, considers both emissions *and* sequestration. Emissions of CO_2e are represented by a negative value in the output maps. Sequestration of carbon (avoided emissions) is represented by a positive value in the output maps. Figures 7 and 8 are maps of the Northern and Southern parts of Marismas Nacionales, where we can see the estimated value of carbon sequestration of the forest. Also we notice that the value of sequestration per pixel (USD) increases over time, anthropogenic emissions of CO_2 have increased since 1973, and because of this, it is assumed that sequestration have also increased. In 2000, the map [sadly] shows the high level of degradation of the forest, which is a huge influencer in the NPV of Marismas.

Along with output maps, the model produces a *summary table of carbon storage and sequestration*, based on the input parameters set by the user. The output figures that the model produces, are: [(Sequestration) X (the market value for carbon credits) X (discount rate)] = [npv values]. What *is* the current price for carbon credits? The market price of carbon credits can be found at Carbon Planet, one of the leading carbon credit vendors. In *2007*, this company was purchasing credits wholesale for $13.21 per credit. They were reselling them to companies at $21.25 per credit. However, in Europe, a tonne of carbon is 7.92 Euros which is about $11 USD. There are six exchanges that help companies buy and sell carbon credits and they are: CTX, Climex, Sendeco2, Nord Pool, EEX, and Powernext. Investing.com displays a snapshot of “historical data” of carbon credit pricing from July, 2015, seen below (Figure 10).

Carbon Emissions Historical Data

Time Frame: Daily | 07/13/2015 - 08/12/2015

Date	Price	Open	High	Low	Vol.	Change %
Jul 24, 2015	8.02	8.10	8.11	8.00	-	-0.87%
Jul 23, 2015	8.09	7.98	8.15	7.96	-	1.51%
Jul 22, 2015	7.97	7.97	7.97	7.89	-	0.06%
Jul 21, 2015	7.97	8.00	8.04	7.93	-	-0.56%
Jul 20, 2015	8.01	7.74	8.02	7.73	-	3.22%
Jul 17, 2015	7.76	7.70	7.76	7.64	-	1.04%
Jul 16, 2015	7.68	7.78	7.78	7.67	-	-1.41%
Jul 15, 2015	7.79	7.78	7.83	7.74	-	0.52%
Jul 14, 2015	7.75	7.82	7.85	7.72	-	-0.64%
Jul 13, 2015	7.80	7.57	7.80	7.57	-	2.23%
Highest: 8.15	Lowest: 7.57	Difference: 0.57	Average: 7.88	Change %: 5.10		

Figure 10 – Latest Carbon pricing (Investing.com, 2015)

For the purpose of this study, the users chose a round market price for carbon at **$10 USD**. The table figures also show how,over time, at a discount rate of 5% the value per pixel increases.

	A	B	C	D	E	F	G	H
1	Start Year	End Year	Accumulation	Total Emissions	Sequestration	Value	Discount Factor	Cost
2	1973	1974	780049.5945	579147.2487	200902.3458	10	1	2009023
3	1974	1975	780049.5945	407353.4978	372696.0966	10.5	1.05	3726961
4	1975	1976	780049.5945	342325.0994	437724.4951	11.025	1.1025	4377245
5	1976	1977	780049.5945	305887.5842	474162.0103	11.57625	1.157625	4741620
6	1977	1978	780049.5945	278331.8886	501717.7059	12.15506	1.21550625	5017177
7	1978	1979	780049.5945	254579.8042	525469.7903	12.76282	1.276281563	5254698
8	1979	1980	780049.5945	233224.0648	546825.5297	13.40096	1.340095641	5468255
9	1980	1981	780049.5945	213787.2044	566262.3901	14.071	1.407100423	5662624
10	1981	1982	780049.5945	196035.211	584014.3835	14.77455	1.477455444	5840144
11	1982	1983	780049.5945	179804.9727	600244.6217	15.51328	1.551328216	6002446
12	1983	1984	780049.5945	164960.257	615089.3375	16.28895	1.628894627	6150893
13	1984	1985	780049.5945	151379.9007	628669.6938	17.10339	1.710339358	6286697
14	1985	1986	780049.5945	138954.1245	641095.47	17.95856	1.795856326	6410955
15	1986	1987	780049.5945	127582.9419	652466.6525	18.85649	1.885649142	6524667
16	1987	1988	780049.5945	117175.1521	662874.4424	19.79932	1.979931599	6628744
17	1988	1989	780049.5945	107647.5307	672402.0638	20.78928	2.078928179	6724021
18	1989	1990	780049.5945	98924.12108	681125.4734	21.82875	2.182874588	6811255
19	1990	1991	730470.6956	503457.0325	227013.6631	22.92018	2.292018318	2270137
20	1991	1992	730470.6956	408003.8173	322466.8783	24.06619	2.406619234	3224669
21	1992	1993	730470.6956	360725.4209	369745.2747	25.2695	2.526950195	3697453
22	1993	1994	730470.6956	327490.4022	402980.2934	26.53298	2.653297705	4029803
23	1994	1995	730470.6956	299592.4164	430878.2793	27.85963	2.78596259	4308783

sequestration

Figure 11, NPV tablet shows how the value of carbon increases over time**.**

The Blue Carbon Model, for the purpose of this study, was successful in determining carbon pools, rates of sequestration and market value for carbon credits. The outputs of the model satisfy the sponsors' original and primary objectives. However, there were many *simplifying assumptions* associated with using the Blue Carbon Model, which allows for some interpretation by the user. The simplifying assumptions encountered during this analysis – and how they were handled - are listed below:

- *Range of Data* **–** When translating class data in the tables, there is a range between 100-269 of values for the 'Soil (MtCO2e / ha-m)' column. Which value to use? The users need more specific data from sponsors.
    - *Solution:* Students decided to include approach this range three times, using a low, average and high (100, 185 and 269) value. The initial successful run of this model included the "low" soil value. However, SFF was able to provide detailed class data and the "range" was then moot. All final outputs reflect the specific value for this column, for all the classes.
- *Localized data* - Different species of mangroves may accumulate soil carbon at different rates. If this information is known, it is important to provide this species distinction and then the associated accumulation rates in the carbon CSV input table.
- For this study, two types of mangroves were identified in the data received, mangroves and dead mangroves.
- *Categorizing table data* - With the demo or default data, if you look closely at the actual carbon accounting value there are really only 10 categories (not 23). Assumptions were made about matching the wetlands classification scheme in the focal scale data with the InVEST default data. Figure 12 was supplied to the users by Robert Aguirre, Professor of GIS, University of Washington.

Class	Class Name	Id	Name	Veg Type	Abov	Below	Soil (	Soil De	Litter (	Bio_ac	Soil_accu	SUM
1	*Mangrove*	9	Mangrove	2	35	29	313	1	0	2	5.35	***379***
2	*Cypress Swamp*	4	Cypress Swamp	0	42	24	244	1	0	0	0	***310***
3	*Fresh Marsh*	5	Inland Fresh Marsh	1	20	10	269	1	0	0.5	10.21	***300***
		6	Tidal Fresh Marsh	1	20	10	269	1	0	0.5	10.21	***300***
4	*Swamp*	3	Nontidal Swamp	0	20	10	244	1	0	0	0	***274***
		23	Tidal Swamp	0	20	10	244	1	0	0	0	***274***
5	*Regularly Flooded Marsh*	8	Regularly Flooded Marsh	1	20	10	222	1	0	0.5	10.21	***253***
6	*Irregularly flooded marsh*	20	Irregularly flooded marsh	1	20	10	115	1	0	0.5	10.21	***146***
7	*Salt Marsh*	7	Transitional Salt Marsh	1	20	10	100	1	0	0.5	10.21	***131***
8	*Tidal Flat*	11	Tidal Flat	0	0	0	55	1	0	0	0	***55***
9	*Beach*	10	Estuarine Beach	0	0	0	10	1	0	0	0	***10***
		22	Inland Shore	0	0	0	10	1	0	0	0	***10***
		12	Ocean Beach	0	0	0	10	1	0	0	0	***10***
10	*Open Water or Dry Land*	1	Developed Dry Land	0	0	0	0	1	0	0	0	***0***
		17	Estuarine Water	0	0	0	0	1	0	0	0	***0***
		15	Inland Open Water	0	0	0	0	1	0	0	0	***0***
		19	Open Ocean	0	0	0	0	1	0	0	0	***0***
		16	Riverine Tidal Open Water	0	0	0	0	1	0	0	0	***0***
		14	Rocky Intertidal	0	0	0	0	1	0	0	0	***0***
		2	Undeveloped Dry Land	0	0	0	0	1	0	0	0	***0***
		0	Unnamed	0	0	0	0	1	0	0	0	***0***
		13	Unnamed	0	0	0	0	1	0	0	0	***0***
		18	Unnamed	0	0	0	0	1	0	0	0	***0***
		21	Unnamed	0	0	0	0	1	0	0	0	***0***

- Figure 12 - Re-classified table data

- *Output Transition Tables* – The tables produced by the pre-processing model include accumulation or disturbance for each transition of environment. However, before using these output tables in the Carbon calculator model, the user needs to specify levels of transitional disturbance(s), according to InVEST (see definition below). Unless there is data that specifically identifies levels of transition disturbances in the AOI, this needs to be *assumed* by the user(s).

▪ **Transition matrix CSV: A table called "transition.csv" produced by the pre-processor that can be found in the "Output" folder of the tool's workspace. This table must be modified before it can be an input for the core blue carbon model. For all cells within the matrix containing the values "Disturbance", change to either "Low Disturbance", "Medium Disturbance", or "High Disturbance" based on the intensity of impact on carbon for that specific transition. When completed, save the edits and point to this file in the interface for this input. (NatCap, 2014)**

- *Clarification of terminology in model documentation* – There were a few times during the analysis, the users were unclear as to the units defined for the inputs/outputs or further explanation was needed for output definitions. Clarification was achieved only *after* a conversation with a member of the NatCap team. The simplifying assumption is that the material is less suited for novice users in the industry as there are assumptions users should/will know industry terminology and/or carbon based concepts.

- *Inflation Rates & Carbon Discounts* – The model asks to define annual inflation rates and annual discount for carbon. The model documentation doesn't really give any guidelines for this, so this data is user-dependent and there is room for interpretation, especially depending on which country the user is based as this data may slightly differ.

- *Model projections* - The model allows the user to include an 'end year date'. The model will calculate sequestration until the end year date that is specified. The caution to this specific function is in order to project data beyond a specific data year (shapefile), the land use/land cover data should also stay the same. If the land cover changes between the data year and the 'end year date', the projection is unreliable. So, it is an assumption that the LULC will remain the same in the future.

Business Case

A business case, attached as Appendix 4, outlines how Phase 2 of carbon-based modeling for the mangrove restoration project will address current business concerns, the benefits of the project, and recommendations and justification of the project. The business case also discusses detailed project goals, performance measures, assumptions, constraints, and alternative options.

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Appendices

Appendix 1

PROPOSAL FOR IMPLEMENTATION OF THE INVEST CARBON SEQUESTRATION MODEL

For Ecologists without Borders and Pronatura Noroeste

OVERVIEW

EcoWB and SFF have teamed up with a Mexican non-governmental organization, Pronatura Noroeste, on a project to restore mangroves in the Marismas Nacionales, the largest intact mangrove forest on the Pacific coast of Mexico. For the past several years, Pronatura has been working with local fishing-dependent communities to conserve the mangroves and associated ecological values. Mangroves are highly productive ecosystems that not only serve as important carbon sinks but also provide a myriad of other critical ecosystem services, including nursery and breeding areas for migratory waterfowl and commercially valuable fish species. (EcoWB, 2015)

Because of this, the students of the University of Washington, Kimberly Nepsa and Anssel Lopez, are pleased to submit this proposal for services to support Ecologist without Borders and its Partner Pronatura Noroeste in achieving a Carbon sequestration quantification of Mangrove restoration through the Carbon Sequestration InVest model from Natural Capital Project. Also, if possible, provide a monetary value of said analysis. We are committed to providing, EcoWB and Pronatura Noroeste with tools to recreate the analysis and to understand the results of said model.

Project Objectives

To quantify possible carbon sequestration by Mangroves in Marismas Naciones on the Pacific coast of Mexico, by utilizing the InVEST Carbon sequestration Model created by Natural Capital Project.
Needs

- Provide a Tool to quantify Carbon by Mangroves
- Assign a Monetary value to Carbon Sequestration

Project Objectives for UW students

Provide a socio-ecological systems (SES) table and/or diagram to demonstrate relationships in the mangrove ecosystem (biophysical, economic and social domains) and how they are connected. A second, smaller SES table for carbon-specific relationships may also be provided to highlight pertinent data values for the InVEST model.

Provide Carbon Sequestration analysis using ONE of two InVEST models, the Blue Carbon Model or the Carbon Model (Climate Regulation Model). If time permits, the students will attempt to perform analysis for the second carbon InVEST Model which can be used as a comparison of data input for future implementation of the project's goals.

Data collection for the data inputs needed for the InVEST model, including historical data

Provide static maps of the analysis results

Project Report with analysis details and results

Weekly updates with project partners

Provisional objectives for students, time and resource permitting:

- To complete second Carbon InVEST model for comparison purposes
- To provide partners with tutorials for one or both InVEST models
- To implement LiDAR data into the analysis, as provided
- Students have access to GRASS GIS 7.0 which may also assist in utilizing the LiDAR data

Modeling Opportunity

Goal #1: Provide static maps of the analysis results

Goal #2: Project Report with analysis details and results

Goal #3: Tutorial of InVest Model application, Data manipulation both in Spanish. If time allows it.

Solution Recommendations

Recommendation #1: Analyze Mangrove in Marismas Nacionales to quantify possible Carbon sequestration

Recommendation #2: Create static maps to represent the monetary values of carbon sequestration.

Student Proposal

EcoWB and Pronatura have a wonderful relationship and their commitment to the environment has allowed them to team up to work on this Mangrove restoration project in Mexico. However, both organizations face challenges in quantifying and adding monetary value for carbon sequestration in regards to the mangroves.

We have developed a solution to help both organizations satisfy their needs by implementing the InVEST Carbon Sequestration model. This tool can be used to analyze and quantify the possible carbon sequestered by Mangroves, but also add a monetary value to each gridcell of Marismas Nacionales in Mexico. Our solution integrates raster data manipulation to fully realize the benefits of Mangrove restoration. Most importantly, we provide expertise and knowledge to achieve these needs of Ecologist without Borders and Pronatura Noroeste.

How the Model works

The model runs on a gridded map of cells called raster format in GIS. If the HWP pool is included in the analysis, a polygon map of harvest parcels is also modeled. Each cell in the raster is assigned a land use and land cover (LULC) type such as forest, pasture, or agricultural land. Each harvest polygon is assigned harvest type referring to the harvested product, harvest frequency, and product decay rates. After running the model in raster format, results can be summarized to practical land units such as individual properties, political units, or watersheds. (NatCap, 2015)

Project Deliverables

The following table is a complete list of all project deliverables:

Deliverable	Description
InVest Model Output Static Maps	Maps showing the locations and quantification of Carbon Sequestration by Mangrove
Project Report	Result analysis of Model
Tutorial of InVest Model Used	If time allows it, an English/Spanish tutorial of how to use the model and how to manipulate data to fit model needs.

Timeline for Execution

The students have until Monday, August 17, 2015 to complete all the components of their project analysis, report and presentation materials to satisfy UW requirements for graduation. Project presentations will take place on campus in Seattle, Washington the week of August 17, 2015, more specifically Wednesday through Friday, August 19-21, 2015.

With this in mind, the students have broken down project goals/objectives into:

Description	Start Date	End Date	Duration
Project Start	June 29th		
Data Collection and compilation	June 29th	July 12th	Two weeks
Status Update 1	July 8th		
Modeling and Analysis	July 12th	August 2nd	Three weeks
Status Update 2	July 15th		
Status Update 3	July 22nd		
Status Update 4	July 29th		
Status Update 5	August 5th		
Project End and Presentations	August 19th	August 21st	Two Days
Interpretation and Implementation of analysis results into project report.	August 3rd	August 18th	Two Weeks

Expectation of Supplied Material

The following materials are to be supplied by EcoWB and Pronatura for this project. For Hewlett-Packard to meet project milestones, this material must be supplied to them on schedule. The due dates included in the following table represent our best guess deadlines based on current proposed project dates:

Materials to be supplied by EcoWB and Pronatura	Due Date*
Current land use/land cover (LULC) map (required): A GIS raster dataset, with a LULC code for each cell	July 12th
Current and previous land use/land cover (LULC) map.	July 12th
Raster data of Mangrove changes over time (Historical Data)	July 12th
If possible, GIS raster dataset with extension .adf of Marismas Nacionales	July 12th

CONCLUSION

We look forward to working with EcoWB and Pronatura and supporting your efforts to improve Carbon sequestration estimates. We are confident that we can meet the challenges ahead, and stand ready to partner with you in delivering an effective GIS support solution.

If you have questions about this proposal, feel free to contact Kimberly or Anssel at your convenience by email at knepsa@yahoo.com and anssel@myuw.net or by phone at 520-870-0123 for Kimberly and at 202-725-5401 for Anssel. We will be in touch with you next week to arrange a follow-up conversation on the proposal.

Thank you for your consideration,

Appendix 2 Economic Valuation Table

Start Year	End Year	Accumulation	Total Emissions	Sequestration	Value	Discount Factor	Cost
1973	1974	780049.6	579147.2	200902.3	10	1	2009023
1974	1975	780049.6	407353.5	372696.1	10.5	1.05	3726961
1975	1976	780049.6	342325.1	437724.5	11.025	1.1025	4377245
1976	1977	780049.6	305887.6	474162	11.57625	1.157625	4741620
1977	1978	780049.6	278331.9	501717.7	12.15506	1.215506	5017177
1978	1979	780049.6	254579.8	525469.8	12.76282	1.276282	5254698
1979	1980	780049.6	233224.1	546825.5	13.40096	1.340096	5468255
1980	1981	780049.6	213787.2	566262.4	14.071	1.4071	5662624
1981	1982	780049.6	196035.2	584014.4	14.77455	1.477455	5840144
1982	1983	780049.6	179805	600244.6	15.51328	1.551328	6002446
1983	1984	780049.6	164960.3	615089.3	16.28895	1.628895	6150893
1984	1985	780049.6	151379.9	628669.7	17.10339	1.710339	6286697
1985	1986	780049.6	138954.1	641095.5	17.95856	1.795856	6410955
1986	1987	780049.6	127582.9	652466.7	18.85649	1.885649	6524667
1987	1988	780049.6	117175.2	662874.4	19.79932	1.979932	6628744
1988	1989	780049.6	107647.5	672402.1	20.78928	2.078928	6724021
1989	1990	780049.6	98924.12	681125.5	21.82875	2.182875	6811255
1990	1991	730470.7	503457	227013.7	22.92018	2.292018	2270137
1991	1992	730470.7	408003.8	322466.9	24.06619	2.406619	3224669
1992	1993	730470.7	360725.4	369745.3	25.2695	2.52695	3697453
1993	1994	730470.7	327490.4	402980.3	26.53298	2.653298	4029803
1994	1995	730470.7	299592.4	430878.3	27.85963	2.785963	4308783
1995	1996	730470.7	274696.6	455774.1	29.25261	2.925261	4557741
1996	1997	730470.7	252074.7	478396	30.71524	3.071524	4783960
1997	1998	730470.7	231412.9	499057.8	32.251	3.2251	4990578
1998	1999	730470.7	212512.3	517958.4	33.86355	3.386355	5179584
1999	2000	730470.7	195213.5	535257.1	35.55673	3.555673	5352571
2000	2001	730470.7	179376.5	551094.2	37.33456	3.733456	5510942
2001	2002	730470.7	164874.5	565596.2	39.20129	3.920129	5655962
2002	2003	730470.7	151592.6	578878.1	41.16136	4.116136	5788781
2003	2004	730470.7	139425.8	591044.9	43.21942	4.321942	5910449
2004	2005	730470.7	128278.1	602192.6	45.38039	4.538039	6021926
2005	2006	730470.7	118062.1	612408.6	47.64941	4.764941	6124086
2006	2007	730470.7	108697.9	621772.8	50.03189	5.003189	6217728
2007	2008	730470.7	100112.6	630358.1	52.53348	5.253348	6303581

2008	2009	730470.7	92239.5	638231.2	55.16015	5.516015	6382312
2009	2010	730470.7	85017.89	645452.8	57.91816	5.791816	6454528
2010	2011	730470.7	78392.2	652078.5	60.81407	6.081407	6520785
2011	2012	730470.7	72311.69	658159	63.85477	6.385477	6581590
2012	2013	730470.7	66730.03	663740.7	67.04751	6.704751	6637407
2013	2014	730470.7	61604.89	668865.8	70.39989	7.039989	6688658
2014	2015	730470.7	56897.62	673573.1	73.91988	7.391988	6735731

Appendix 3 SES Table

Socio-Ecological System (SES) Table
Mangrove Ecoystem Restoration Efforts
Marismas Nacionales, Mexico

FOCAL SCALE	BIOPHYSICAL Domain	SOCIAL Domain	ECONOMIC Domain
BELOW focal scale (Below focal scale includes key elements that disrupt the mangroves below the surface of the water or on a molecular level)	▪ Fluctuating temperatures ▪ Fish communities ▪ pH Balance(s) ▪ Salinity ▪ Water quality (toxicity) ▪ Sediment flux ▪ Tidal Flow Many key elements are responsible for the overall health of mangrove ecosystems, across the globe. Mangroves are primarily situated in estuary-like environments. Severe fluctuations of water temperatures may have a long-term impact. pH balances in the water and their subsequent changes due to a number of possible reasons in the vicinity could have an impact on the mangroves. Toxicity caused by growing human populations in the surrounding areas could cause the pH balances to shift, thus causing a	▪ Pollution in water caused by surrounding human populations - Oil spills - Trash - Human waste - Excessive Pesticides Population growth adjacent to mangrove communities pose potential threats to the mangrove's fragile ecosystem. Pollution caused by industrial use, human waste, refuse, pesticides, etc., have the potential to travel from land to the local waterways and into the mangroves. Pollution can alter the pH balance of the water in the estuaries and eventually harm the ecosystem, long term.	▪ Dam operations (opening/closing of doors) ▪ Reliance on fishing industry (employment) Adjacent to this particular mangrove system, are dams in the watersheds/outlets that feed into the estuaries where the mangroves are located. The doors on the dams, which are located upstream from the mangroves, are opened periodically. The waters behind these doors are much deeper due to the water flow being dammed behind them. The deeper depths of water go long periods without seeing any sunshine, making their temperatures very, very cold. Mangroves are located in shallower

	negative impact to the mangroves. The salinity of the water where mangroves usually grow is important to their health. Severe salinity shifts in the water could cause stress to the mangroves. Changes in tidal flow and/or sediment fluctuations may also cause negative effects for the mangroves.		estuarine (warmer) waters. When these floodgates are opened, the severe temperature differences could have a harmful effect on the mangroves. The area has long relied on fishing as one of the primary industries for the surrounding communities. Excessive fishing and/or pollutants spilled into the waters from fishing boats have the potential to change the ecosystem in which the mangroves are located. Excessive fishing of local fish species that play an integral part of the mangrove's ecosystem and/or pollutants from the fishing can change the culture of the local fish communities, which could then change the cultures of other species who rely on those fish.
AT focal scale (The local focal scale is the existing mangrove ecosystem and the relationships that exist between key elements)	▪ Overall Mangrove health ▪ Erosion control ▪ Wildlife ecology & habitats ▪ Carbon pools & sinks ▪ Marsh disturbances Overall health of mangrove systems is important for many reasons. Mangroves help sustain many other types of wildlife. They help with erosion control and they provide carbon sinks and pools. Any type of marsh disturbance can alter/change the fragility of this type of ecosystem.	▪ Tourism ▪ Recreational fishing ▪ Population health in surrounding communities The mangrove ecosystem helps to provide continuing sustenance-and is vital-to the surrounding human populations. In addition to the importance of the mangrove system that humans use for sustenance, ie, animals, fishing, birds, carbon, etc, mangroves also provide opportunities for recreation for the surrounding communities as well. Tourism through the mangroves and	▪ Tourism ▪ Fishing Industry ▪ Carbon credits ▪ Limited Harvest ▪ Existing and proposed dams in adjacent inlets ▪ Timber cutting Besides the opportunities for recreation, humans benefit economically from a healthy mangrove ecosystem. Tourism businesses, fisheries, harvesting, timber transport, dam construction, are all peripheral economic benefits of mangrove systems. Also, the carbon pools and sinks that mangroves produce can be sequestrated into carbon credits for local businesses.

		recreational fishing are both ways humans enjoy mangrove systems.	
ABOVE focal scale (Above focal scale includes key elements that may have a peripheral impact on the mangrove system)	▪ Bird Sanctuary/habitat ▪ Oxygen emissions of a [healthy] Mangrove System ▪ Carbon pools & sinks Mangroves provide sanctuary and habitats for several kinds of species. Fish communities swim through their underwater roots. Other organisms are dependent on the fish species present in the mangroves. Birds build nests in their leaves, etc. More mangroves also mean more Oxygen emissions. Additionally, more mangroves mean more carbon pools.	▪ Erosion control and safety for surrounding communities Mangrove systems help with erosion control, thus assisting in the safety of surrounding populations. They also provide sustenance for surrounding communities and encourage wildlife species to thrive.	▪ Industry health and maintenance ▪ Carbon sequestration and future credits Mangroves, and the carbon sinks and pools they naturally produce, can help support local industry through carbon sequestration and distributing carbon credits. This helps mitigate global climate change and gives incentive for local businesses to become "carbon neutral."

Appendix 4 Business Case

PHASE 2 BUSINESS PLAN

THE USE OF CARBON-BASED MODELING FOR MANGROVE RESTORATION EFFORTS IN MARISMAS NACIONALES, SINALOA AND NAYARIT, MEXICO

ECOLOGISTS WITHOUT BORDERS, SUSTAINABLE FISHERIES FOUNDATION & PRONATURA NOROETES
UNITED STATES & MEXICO

AUGUST 21, 2015

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1. EXECUTIVE SUMMARY

This business case outlines how Phase 2 of carbon-based modeling for the mangrove restoration project will address current business concerns, the benefits of the project, and recommendations and justification of the project. The business case also discusses detailed project goals, performance measures, assumptions, constraints, and alternative options.

1.1. Issue

Three non-governmental organizations (NGOs), Ecologists Without Borders (EcoWB), Sustainable Fisheries Foundation (SFF) and Pronatura Noroestes, have teamed up to reverse the ongoing degradation and loss of mangroves in the Marismas. Their approach is to restore the conditions and physical processes mangroves require for growth and survival, and to protect these areas from future disturbances that would cause the release of greenhouse gases and contribute to global warming.

Mangroves are highly productive ecosystems that serve as important carbon sinks, with this in mind we have developed a study that would help EcoWB and other partners to quantify the potential amounts of Carbon that can be sequestered in Marismas Nacionales, Mexico. To be able to produce a net quantification, physical and economical, we would do an analysis of biomass storage through the use of the Blue Carbon Model, developed by The Natural Capital project.

1.2. Anticipated Outcomes

The three NGOs have approached UW Master Candidates to help facilitate a modeling approach to quantify carbon sequestration in the area of interest (AOI). The InVEST Blue Carbon Model, by Natural Capital Project (NatCap) was chosen to accomplish this type of analysis in ‘Phase 1’ by: 1) evaluating carbon pools in the area; 2) determine net present value of carbon sequestration and 3) produce carbon credit output data.
The quantification of carbon in Marismas nacionales Mexico, will allow the partners to identify areas that need prioritizing for restoration, and it will also provide a guideline for potential value of carbon storage which can be promoted as carbon credits on the Voluntary carbon market. This possible income will help to continue restoration efforts.

Phase 1 of the project was to modify data to fit the Blue Carbon model input requirements and to properly run and produce storage and economical outputs for carbon sequestration, as well as provide a comprehensive interpretation of that output. Also, Phase 1 provides sponsors with an instructional tutorial of how the model runs.

In Phase 2, the users will be able to understand how the model works and what modification(s) are needed before inputs for this model can be used. Also, new data could be used to produce more accurate and detailed results for the project, especially if data gaps are too wide. The users could also experiment using LiDAR data to quantify carbon storage and compare outputs and determine a realistic approach for the use of carbon credits. Finally, the user would be able to explore other InVEST model toolkits to help accomplish similar tasks or aggregate to the analysis as well as different types of project goals for the sponsors.

1.3. Recommendation

The primary objectives for the restoration of the mangrove forests, as defined by EcoWB, is to: 1) determine the extent of degradation of the mangrove forests in Marismas; 2) generate and sell carbon credits on the voluntary carbon market in order to pay local residents, cooperatives, tejidos, etc. to participate in restoration and conservation activities and 3) be able to expand restoration efforts to other mangrove systems in Mexico and elsewhere.

The InVEST blue carbon model, by Natural Capital Project (NatCap), will support these objectives by producing: 1) output maps of both emissions and sequestration of the mangroves in Marismas, and thus demonstrating degradation levels, over time; 2) output maps of carbon storage pools in the study area, over time and 3) an economic valuation for carbon credits (USD/metric tonne/hectare).

To meet the goals of this project, we would further recommend:

- Continue understanding the Blue Carbon model, as well as other carbon sequestration models by InVEST, to determine biophysical and economic valuations of mangrove forests in Mexico and elsewhere;
- Continue to use InVEST and other types of modeling toolkits, for different types of management scenarios, such as coastal preservation, sea level rise, aquaculture, water quality, etc.
- Investigate other types of natural environments in which carbon pools can be found both in Mexico and elsewhere, such as forests, deserts and marshes; and

1.4. Justification

In 1997 the Kyoto Protocol was created by the United Nations, with the objective of control to reduce greenhouse gas emissions from developed countries. Since then, the protocol has allowed these “emitters” to buy emission credits, from countries or entities that have credits that are not used. The article 17 of the Kyoto’s protocol, allow countries that have emission units to spare to sell them to those that are not meeting carbon reduction targets. This is known as the Carbon Market and has become a commodity to carbon reduction.

To avoid countries selling their entire emission unit stock, the Kyoto's protocol states that each seller must have a reserve which cannot be sold so emission can still be reduced. (Nations 2014)

Quantifying carbon storage and sequestration would allow EcoWB and Pronatura to estimate their carbon credits, which can be put up for sale in the Carbon Market. Understanding the extent of sequestration and storage of Marismas Nacionales also would allow Pronatura to create an emission unit reserve that would comply with the Kyoto's protocol and would also still be beneficial for the community as well as provide the necessary means to continue restoration efforts in the area. (Nations 2014) The model provides the necessary information to create an economic value of sequestration and storage, without this information carbon credits cannot be put in the carbon market and the possibility of gain means that for restoration to be achieved and also cannot prioritize degraded areas.

A modeling approach helps to support the sponsor's primary objectives for improving the livelihoods of local communities, near the mangrove forests. By quantifying the carbon stocks, carbon credits can be issued on the Voluntary market. Producing a visual friendly estimation of the declining health of the mangrove forests and other carbon-based pool sources, over time, it is easier to see how and where to focus on its restoration.

2. Business Case Analysis Team

The following individuals comprise the business case analysis team. They are responsible for the analysis and creation of Phase 2 of the Carbon-based Mangrove Restoration business case.

Role	Description	Name/Title
Executive Sponsor (EcoWB, SFF; Pronatura)	Provide executive support for the project	Cleve Steward, Eric Knudsen & Phil Howell; Miguel Vargas, Co-managing partners of project
Technology Support Geographic Analysis Support	Provides all technology support for the project	Anssel Lopez & Kimberly Nepsa, GIS Analysts
Process Improvement	Advises team on process improvement techniques	Giovanni Cordero, Aimee Cervantes Escobar, Ana Elena Soto Fernandez, Process Team Lead

Role	Description	Name/Title
Project Manager	Manages the business case and project team	Cleve Steward, Project Manager
Software Support (Experts)	Provides all software support for the project	Anssel Lopez & Kimberly Nepsa, Software Group Leads

3. PROBLEM DEFINITION

3.1. Problem Statement

Statement by EcoWB:
"The ultimate goal of the project is to restore approximately 600 ha of mangroves using clean technology – solar and kinetic (tidal or wave-induced) – within the next five years. Other key objectives are to help local communities develop and implement sustainable forestry and fisheries management plans, and to generate and sell carbon credits on the voluntary carbon market in order to pay local residents, cooperatives, ejidos, etc. to participate in restoration and conservation activities. If this approach is successful, we will be able to expand our restoration efforts to other mangrove systems in Mexico and elsewhere. A detailed prospectus describing project tasks, resources, roles, and other details is available from the project sponsors.

To be successful, the Marismas project must target areas that have the greatest potential for re-establishing the conditions necessary for mangrove regeneration. A critical need at the moment is a compilation, analysis, and mapping of basic information on the project area related to land use, vegetation, hydrology, geomorphology, soils, archaeology, and infrastructure (e.g., roads, bridges, canals). This information will be used to evaluate and characterize the current status and trend and potential threats to important resources, to define the geographic area that will be targeted for remote sensing and field plot inventory efforts, to visually display measured and modeled (e.g., LiDAR-derived) attributes of the mangrove ecosystem, and to identify opportunities and approaches for restoring mangroves across the landscape."

EcoWB and Pronatura have been trying to identify, the changes suffered over time, to the forests of Marismas Nacionales. They possess historical data, from 1973 to 1990 and want to use it to identify locations for restoration.

They presented a need for analyzing this data and, if possible, to quantify carbon storage and sequestration. We, candidates of Master in GIS, would serve as software and analyst experts to conduct the proposed analysis. Through the use of the Blue Carbon model by The Natural Capital Project, we will create outputs that would explain what locations need prioritization and also will provide quantification of sequestration and storage of Carbon.

3.2. Organizational Impact

Phase 2 of the Mangrove Restoration Project will impact the communities, surrounding Marismas, in several ways. The following provides a high-level explanation of how the organization, tools, processes, and roles and responsibilities will be affected as a result of the Phase 2 Project implementation:

Tools: The anticipated tools needed to implement Phase 2 of this effort are: 1) InVEST toolkit package; 2) GIS tools such as ESRI Arc Package; 3) trained personnel to use these models or training of personnel to use these model programs.

Processes: The modeling process(es) will help streamline the restoration efforts in Mexico by providing economic valuation for carbon sequestration as well as possibly narrowing down other factors in the SES table for the general decline of mangrove health. This improved efficiency will lessen the burden on project managers and help to provide an autonomous relationship, for the agencies involved, in managing other aspects of the project in Marismas.

Roles and Responsibilities: Phase 2 would be implementing a new role of GIS technicians to help navigate the modeling process and be supervised by existing project managers. All other roles and responsibilities would remain status quo.

Hardware/Software: The InVEST software and licensing for it would need to be acquired.

3.3. Technology Migration

In order to effectively migrate existing data from Phase 1 to Phase 2 of the project, an approach has been developed which will result in minimal/no disruption to day to day operations and administration.

1) Hardware/Software should be acquired by project partners.

2) All data from Phase 1 will be transferred and given to the sponsors so it can be easily transitioned into current project applications.

3) The data received from Phase 1 of the project should be used to continue restoration efforts.

4. PROJECT OVERVIEW

The Blue carbon Model uses Land Use and Land Cover data to produce raster data that contains sequestration, storage, gain and loss, and net present value of carbon in the Area of Interest.

To achieve this we have designed a set of goals that would allow us to maintain control over the time of the project.

1) Week 1 to 2 of the project would be dedicated to collection and studying of data to understand better were we need to focus to approach the model and meet the model needs.
2) Weeks 2 to 4 we will start the analysis of data, this includes the modification of data and studying the Blue carbon Model. Understanding of documentation of model will help to determine the needs and how the data need to be modified to fit the needs of the model. This includes creation of tables with carbon data that is specific to Marismas Nacionales.
3) Week 5 to 6, and after the model is running successfully, we will be able to study the outputs to better understand what data explains the objectives of the project as well as to show the location of storage of carbon in the AOI.
4) Week 6 to 8 - The final 2 weeks would to be right a comprehensive report that would explain outputs, methods and results.

4.1. Project Description

The data will need to be analyzed by studying the table of attributes, understanding the classes of vegetation type that composes Marismas Nacionales and also translating classes to English to better match the inputs when running the model.

After understanding the data, modifications can be done to the data to meet the model input needs. One important aspect would be creating a new field that would contain the ID value that would serve as main field for the next steps on the analysis.

After this, the shapefiles would be transformed to raster, either using ArcMap or QGIS. These would allow us to create a raster that would display the ids that we need to match with carbon pool inputs. When data needs are satisfied, we will run a preprocessor that would create a matrix transition table that would allow us to determine the type of disturbances that Marismas Nacionales suffer as class cross paths/transitions.

The matrix will be modified as needed and would be used to run the Blue Carbon model. The rasters created would be modified one more time in Arcmap or QGIS, as needed, to have the same size. This is crucial when running the model because to have a more accurate output, the rasters have to match in the best way possible, as if overlaying each other.

Finally, the outputs will be selected and studied to determine the best way to be used for the project's needs and data to be presented.
It's important to know that errors will be presented during the first trials of the model. These will be corrected by reading logs and model documentation to understand what the error means. There is not manual to use with this model, so it is up to the analyst to understand were the issue might be, and correct it. Also, the analyst must be familiar with python to understand better the location of the error.

For example, we ran into an error named 0.0, which at the begging was understood as value zero. The error was not related to a quantity but to the matching values of the matrix and the raster value. 0 Id is used for data that is not named or has no data. So to correct the error, it was needed to add a 0 row in the carbon pool table. But to understand this error, it was necessary to review each piece of data.

4.2. Goals and Objectives

The Phase 2 of the carbon quantification project will support EcoWB and Pronatura by providing them with a tool that will quantify carbon and that will be usable in other environments as well. The following table lists the projects goals and objectives that have been discussed with both partners.

Business Goal/Objective	Description
Accurate report	Hard and virtual copies of the results of the model.
Tutorials	Two tutorials, both English and Spanish, with detailed explanation of how the model works and how data needs are to be modified to successfully run the model will be provided.
Economic Value of Carbon Stock	The Carbon Market of the United Nations will help to determine the value per carbon credit and how this can be sold, as well as determine an appropriate reserved number of credits so as to not over sell credits.

4.3. Project Performance

The following table lists the key resources, processes, or services and their anticipated business outcomes in measuring the performance of the project.

Key Resource/Process/Service	Performance Measure
Reporting	The direct supervisor will systematically meet with project personnel so that the team doesn't get too far "off-track"
Software and System Maintenance	Analysts will supervise the maintenance of the spatial software to enable increased manager productivity
Staff Resources	Using experienced staff to perform modeling tasks will improve overall efficiency in the project analysis performance

4.4. Project Assumptions

We have listed assumptions that apply to the carbon quantification project. As the project will be taken on by both partners, if any other assumptions are made as the project develops, it will also be added.

- Personnel is knowledgeable in ArcGIS, Arcmap and have experience working with ESRI platforms base software.
- Funding is available for training
- Licenses for ArcMap are available for at least one machine.
- Internet is available for at least one machine to download QGIS and InVEST models
- Data is available for each location that this model will be used for

4.5. Project Constraints

The following constraints apply to the Blue Carbon Project. As project planning begins and more constraints are identified, they will be added accordingly.

- Knowledgeable personnel are located at only one location.
- Data is not available or in the correct format for running the model
- Accuracy of the data collected for properly representing the outputs
- Literature on Marismas Nacionales that contains specific information about carbon, carbon pools and half-life.

4.6. Major Project Milestones

The following are the major project milestones identified at this time, for Phase 1. As the project planning moves forward, into Phase 2, and the schedule is developed, the milestones and their target completion dates will be modified, adjusted, and finalized as necessary to establish the baseline schedule.

Description	Start Date	End Date	Duration
Project Start	June 29th		
Data Collection and compilation	June 29th	July 12th	Two weeks
Status Update 1	July 8th		
Modeling and Analysis	July 12th	August 2nd	Three weeks
Status Update 2	July 15th		
Status Update 3	July 22nd		
Status Update 4	July 29th		
Status Update 5	August 5th		
Project End and Presentations	August 19th	August 21st	Two Days
Interpretation and Implementation of analysis results into project report.	August 3rd	August 18th	Two Weeks

5. Strategic Alignment

The Blue Carbon Project is in direct support of several of EcoWB and Pronatura's Strategic Plans. By directly supporting these strategic plans, this project will improve their business and help move the organizations forward to the next level of maturity.

Plan	Goals/Objectives	Relationship to Project
2015 EcoWB and Pronatura greenhouse gases reduction plan	Reverse the ongoing degradation and loss of mangroves	This project provides an overlook of the degradation of mangroves in Marismas Nacionales by displaying how, over time, the sequestration and Emission have changed and what locations have changed from sequester to emitter of CO_2
2015 EcoWB and Pronatura greenhouse gases reduction information plan	Utilize the Blue Carbon Model from The Natural Capital Project to quantify carbon sequestration	The model will allow both partners to gain general knowledge on CO_2 sequestration, and would also provide a potential economic value for sequestration that can be used as a base point for selling carbon credits, according to the Kyoto's Protocol article 17.
2014 EcoWB and Pronatura Strategic Plan for Human Capital	Engage communities in Mangrove restoration and improve livelihood	This project would allow EcoWB and Pronatura to improve the livelihood of communities that are dependent on mangroves. Restoring mangroves would increase habitat conditions which will drive industry in the area, specially fishing.

6. Cost Benefit Analysis

The following table captures the cost and savings actions associated with the Blue Carbon Project, descriptions of these actions, and the costs or savings associated with them through the first year. At the bottom of the chart is the net savings for the first phase of the project.

Action	Action Type	Description	First year costs (- indicates anticipated savings)
Purchase ESRI licenses	Cost	Initial investment, if licenses are not own	$100.00 ea
Software installation and training Phase 1	Cost	Cost for IT group to install new software and for the training group to train all employees	$2100.00

Action	Action Type	Description	First year costs (- indicates anticipated savings)
Acquired QGIS	Savings	Open source GIS base software that can be an alternative to ESRI license	$100.00 for each license
Free Tutorial for QGIS	Savings	There is a wide range of online tutorials that explain very easily how to use software, which also is user friendly. QGIS is very reliable and there is enough documentation online to solve any issues.	$0.00
No annual fees	Savings	If QGIS is installed and learned there is no annual fees and update downloads are free for users.	$100.00 for each license.
Map Mangrove Occurrence Within Analysis Area	Savings	The blue carbon Model allow the partners to create data without having to create their on tool to map mangrove	$5,000.00
Technology Transfer	Savings	The tool does not need extreme modification or transformation and most of the data can be used by doing a small transfer.	$8,000.00
Net First Year Savings			**$15,300.00**

Based on the cost benefit analysis above we see that by authorizing the Blue Carbon Project, EcoWB and Pronatura have already saved approximately $15, 300.00. Also, for Phase 2, training for personnel will not be needed to decipher the model and create tutorials for each location.

7. Alternatives Analysis

The following alternative options have been considered to address the carbon quantification problem. These alternatives were not selected for a number of reasons which are also explained below.

No Project (Status Quo)	Reasons For Not Selecting Alternative
Carbon Model: Climate Regulation	• Time constrains • Data was suitable for historical analysis • Model does not provide historic analysis • Data need was not available
Alternative Option	**Reasons For Not Selecting Alternative**
LiDAR Analysis	• Data was not collected on time • Data need to be reclassify to be used • Flights were not conducted to collect data
Alternative Option	**Reasons For Not Selecting Alternative**
Development of tool	• Time constraints • Availability of software with same capabilities • Constrained to paid software

8. APPROVALS

The signatures of the people below indicate an understanding in the purpose and content of this document by those signing it. By signing this document you indicate that you approve of the proposed project outlined in this business case and that the next steps may be taken to create a formal project in accordance with the details outlined herein.

Approver Name	Title	Signature	Date
Cleve Steward	President and CEO EcoWB		
Eric Knudsen	Founder of Sustainable Fisheries Foundation		
Geovanni Cordero	General Director, Pronatura		

Appendix 5 Prototype Influence Diagram

Prototype *Influence* Diagram for mangrove system (for the purpose of 'coupled-natural human systems')

BELOW focal scale:
Fluctuating temps ← Dam operations → Dying mangroves
Water quality ← Pollution in water → Dam operations → Dying mangroves
pH Blanaces → Dam operations
Salinity levels → Dam operations
Sediment flux → Dam operations
Carbon emissions (due to dying mangroves) → Dam operations
Fish Communities ← Pollution in water → Reliance on fishing industry
Carbon Emissions → Dying mangroves → Depleting fish communities

AT focal scale:
Erosion Control ← carbon sequestration → Healthy mangroves
Healthy mangroves → Wildlife ecology & habitats → Population health
Population health → Livelihoods → Healthy Industry
Healthy industry → Tourism → Fishing industry
Tourism → Recreational Fishing → Livelihood
Carbon pools/sinks → Sequestration → Carbon credits → Livelihood → Healthy populations
Marsh disturbances → Carbon emissions → limited harvest → Existing and proposed dams in vicinity →
Timber cutting → Dying mangroves

ABOVE focal scale:
O2 emissions of healthy mangrove → Population Sustainability
Carbon pools/sinks → Population Sustainability
Healthy wildlife habitats → Population Sustainability
Erosion control/safety → Population Sustainability
Carbon sequestration → carbon credits → Population Sustainability