

Guatemala, July 2018

## Acronyms

CEM	Centro de Estudios Marinos (Honduras) (Centre for Marine Studies)
COCATRAM	Comisión Centroamericana de Transporte Marítimo (Central American Commission for Maritime Transport)
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Mexico) (National Commission for Knowledge and Use of Biodiversity)
CONANP	Comisión Nacional de Áreas Naturales Protegidas (Mexico) (National Commission for Protected Natural Areas)
CONAP	Consejo Nacional de Áreas Protegidas (Guatemala) (National Protected Area Council)
ECOSUR	El Colegio de la Frontera Sur (The College of the South Border)
EROS	Earth Resources Observation and Science Centre
FUNDAECO	Fundación para el Ecodesarrollo y la Conservación (Guatemala) (Foundation for Eco-Development and Conservation)
GIS	Geographic Information Systems
HRI	Healthy Reefs for Healthy People Initiative
ICF	Instituto de Conservación Forestal (Honduras) (Forest Conservation Institute)
INAB	Instituto Nacional de Bosques (Guatemala) (National Institute of Forests)
MAR	Mesoamerican Reef
MARN	Ministry of the Environment and Natural Resources (Guatemala)
MaxEnt	Maximum Entropy
MCA	Multicriteria Analysis
NOAA	National Centres for Environmental Information
NODC	National Oceanographic Data Centre
nRBI	Normalized Relative Biodiversity Index
PU	Planning Unit
RBI	Relative Biodiversity Index
TNC	The Nature Conservancy
USGS	U.S. Geological Survey
WLR	Wildlife Reserve

## **FINAL TECHNICAL REPORT**

### **1. Cover**

#### **1.1. Number of the Project**

REEF RESCUE-GUA-001-2017

#### **1.2. Name of the Project**

Preparing Thematic Maps and Establishing a GIS Baseline for Vulnerable Reefs in the MAR Region

#### **1.3. Beneficiary**

The target group are decision makers and governments of each MAR country, the Central American Commission on the Environment and Development (CCAD), and non-governmental organizations working to strengthen reef restoration in the four countries and the region, thus promoting sharing and dissemination of better practices and information to select the reef sites that are the most important from the economic and biodiversity standpoint.

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#### **1.6. Period covered in the report and date of presentation**

This report covers from September 20 to July 31, 2018

#### **1.7. Executive Summary**

This proposal was developed to establish a baseline for the vulnerable reefs in the Mesoamerican Reef region, by using geographic-information systems and various analysis techniques. Its aim is to establish a standardized and normalized database as a useful tool to be used in decision-making and research in the region, mainly in the four countries that constitute it: Mexico, Belize, Guatemala, and Honduras.

In addition, it is expected that by establishing a baseline and creating the thematic maps of the reefs within the MAR region, a risk analysis and an analysis of environmental (anthropogenic and natural) threats that endanger reef conservation can be undertaken. Furthermore, it is expected that through this consultancy, institutions have unified and standardized quality information that will contribute to strengthening the work that they have been performing.

The authors participated in a meeting with the Committee of the Reef Rescue Initiative at which they presented the results contained in the mid-term report; that is, the thematic maps. The

Committee provided their input on them and requested corrections, which were made according to their requirements set forth on November 16, 2017.

A total of 278 thematic maps were developed, both in English and Spanish, in the required format; achieving 100% of the deliverables. Certain layers that were to be researched for some countries could not be obtained, regardless of the efforts that were made. However, it is important to underscore the support and contributions provided by the various entities in the four countries and the members of the Committee of the Reef Rescue Initiative. Additionally, the two analyses to determine the risk and threat areas and the potential or priority conservation zones have been performed to complement the consultancy.

## **2. Objectives:**

The main objective of this project was to establish a baseline for vulnerable reefs, applying the adequate geographic-information techniques to develop the layer overlays and to edit a set of thematic maps related to coral reefs with various activities, risks and key threats in the MAR region.

### **2.1. The specific objectives of the consultancy are:**

- To gather and standardize geographic information to develop a baseline and to create thematic maps.
- To create a set of thematic maps of the reefs in the MAR region with regard to predominant risks, conservation and productive activities, and key threats in the region.
- To contribute to the analyses of the reef areas that have been most impacted by hurricanes, ship groundings, coral bleaching, and other threats in the region.
- To propose prioritization scenarios to guide coral reef rehabilitation and restoration efforts in the region.

## **3. Project Progress:**

### **3.1. Describing the results, progress and deliverables to date by programmed activity**

Following is a description of how consultancy activities have been undertaken:

#### **3.1.1. Standardizing and normalizing digital layers and databases, and creating the reference file for all files and digital layers**

This activity was performed in parallel with the activity included in item d of this section, with the aim of placing the layers in order and developing the corresponding maps. Standardized and normalized layers constitute one of the deliverables of this report in its digital format. They are located in files identified according to their theme and their GIS projects, both in English and Spanish. In order to perform this activity, approximately 90 editable layers were used. Some of them were used as base information and others were combined to obtain desired results.

### **3.1.2. Developing thematic maps and maps of various conservation activities and threats in the MAR region:**

A total 278 thematic maps were created with the templates, both in the Spanish and English languages. The .JPG files have been appended as digital attachments to the printed report delivered to MAR Fund, with their backup layers in an editable format. Maps have been created for each country, except for the bathymetry, salinity, temperature, chlorophyll, illegal shipping routes, model for the probability of grounding occurrence (due to the lack of data pertaining to this probability, the model was developed), and hurricane analyses, which have been developed for MAR region as a whole, since the context for these layers is regional.

Following is a description of the activities by objective:

#### **3.2.Objective 1: To gather and standardize geographic information to develop a baseline and to create thematic maps**

To achieve this objective, approximately 200 geo-spatial layers and various databases belonging to public, private, and academic entities in the four countries were reviewed.

Geo-spatial layers were standardized to the WGS84 coordinate system with the aim of placing all the data in a single system and performing various GIS operations and analyses.

Each one of the layers is included in the database delivered to MAR Fund and they are placed in such an order as to simplify their use, since both the base layers and the ones based on the required analyses are duly identified.

These analyses included hurricanes, groundings, threats, and analyses by quadrants, which are described below under the consultancy objectives.

#### **3.3.Objective 2: To create thematic maps and maps of various conservation activities and key threats in the MAR region**

278 thematic maps were developed with the templates approved by CTP, both in the Spanish and English languages. They were delivered to MAR Fund in a digital format, along with the first draft of the printed technical report. Maps were delivered in their corresponding .JPG format, with their backup layers in editable format and their GIS projects.

Maps have been developed for each country, except for bathymetry, salinity, temperature, illegal shipping routes and chlorophyll layers.

The grounding map was treated differently; since there were no data, a proposal was put forward to develop a model for the probability of grounding occurrence with the aim of obtaining areas where it is probable that these groundings occur and hurricane analyses, which were developed for the MAR region as a whole, because the context of these layers is regional.

To be able to develop these thematic maps, a database in which geographic information was gathered and standardized (Objective 1) was developed in order to establish a baseline. These data

were the starting point to develop the thematic maps. Objectives 1 and 2 were achieved with these activities.

The following table shows a summary of map development, which shows achievement of Objective 2.

Table 1. A Summary of the Development of the Thematic Maps Requested

<b>Summary of the Development of the Thematic Maps Requested in the ToRs</b>					
<b>Maps</b>	<b>General</b>	<b>Belize</b>	<b>Guatemala</b>	<b>Honduras</b>	<b>Mexico</b>
Spanish	47	25	20	23	21
English	47	25	20	23	21
<b>Total</b>	94	50	40	46	42
<b>Overall Total</b>	<b>278</b>				

### 3.3.1. Methodology:

Following is the name of the map, the source, the year of the source and the treatment used to develop the thematic maps according to the Terms of Reference and the agreements with the Technical Committee at the meeting in Antigua Guatemala on November 16, 2017; the video call on January 25, 2018, and the meeting with the Coordinator of the Reef Rescue Initiative on April 3 in Guatemala City.

Following are the maps developed throughout the project, in alphabetical order, according to their name in Spanish:

#### i. Fishing Areas/Áreas de pesca

This map was only developed for Belize. Its name is Fishing Areas, and it corresponds to the map previously named “Managed Access”.

The layer was obtained from Belize’s Fishery Department, 2016. Except for its digitalization, it was not provided any further treatment.

#### ii. Marine Coastal Protected Areas/Áreas protegidas costero marinas

General maps and country maps differentiated by the category to which each protected area belongs were developed and placed in alphabetical order.

- Mexico: CONANP, 2017
- Belize: Coastal Zone Management Authority and Institute, 2015
- Guatemala: CONAP, 2016
- Honduras: ICF, 2017

No data treatment was performed for these layers.

#### iii. Bathymetry/Batimetría

This map was obtained from USGS-EROS 2014 data.

The treatment for this layer was to cut the global data for the MAR region.

**iv. Coral Bleaching (AGRRA-HRI)/Blanqueamiento de corales (AGRRA-HRI)**

To develop this layer, the HRI's AGRRA Project 2016 databases were used.

Type of bleaching: Not bleached, partly pale, partly bleached, pale, and completely bleached

No data treatment was performed to develop the map.

**v. Coral Bleaching (ReefBase)/Blanqueamiento de corales (ReefBase)**

ReefBase 2013 databases were used to develop this layer.

Type of bleaching: high, medium and low bleaching, not bleached, and unknown severity of bleaching.

No data treatment was performed to develop the map.

**vi. Water quality–Pollution/Calidad de agua-contaminación**

This layer is a raster that was clipped to extract only the MAR region. It was taken from doi:10.5063/F1S180FS, 2013, from the Internet reference page: <https://knb.ecoinformatics.org/#view/doi:10.5063/F1S180FS>

**vii. Water quality–Chlorophyll/Calidad de agua-clorofila**

This layer is a raster that was clipped to extract only the MAR region. The data stem from CONABIO, 2013.

**viii. Water quality–pH/Calidad de agua-pH**

This layer is a raster interpolation aimed at extrapolating the data from global points; it was clipped to extract the MAR region. Data come from NODC-NOAA, 2013.

**ix. Water quality–salinity/Calidad de agua-salinidad**

This layer is a raster interpolation aimed at extrapolating the data from global points; it was clipped to extract the MAR region. Data come from NODC-NOAA, 2013.

**x. Water quality–Temperature/Calidad de agua-temperatura**

This layer is a raster interpolation aimed at extrapolating the data from global points; it was clipped to extract the MAR region. Data come from NODC-NOAA, 2013.

**xi. Coral Coverage/Cobertura de coral**

This layer originated from Millenium Coral Reef and AGRRA HRI data for 2013 and 2016 respectively. Except for Guatemala, the data were provided by Ana Giró from HRI, who has undertaken activities to locate the polygons in Guatemala.

This is information for 2017-2018. Using it, it was possible to refine the coral coverage areas in Guatemala a bit more.

No data treatment was performed for the layers.

**xii. Mangrove Cover and River Mouths/Cobertura de manglares y desembocadura de ríos**

The data to create this map stem from CONABIO (Mexico), Biodiversity.bz (Belize), INAB and CONAP (Guatemala), ICF (Honduras), MAR Fund 2015 (2016), 2015, 2012 (2015), 2012 (2014), 2015, respectively. Parentheses in the dates of the data indicate the year in which they were published and the date that is not in parentheses shows the year of the source.

The river layer was modified at the suggestion of the CTP with the purpose of obtaining only the river mouths of the main rivers. No data treatment was performed for the remaining layers.

**xiii. Mangrove, Beach and Seagrass Cover/Cobertura de manglares, playas y pastos marinos**

To create this map, layers were obtained from CONABIO (Mexico), Biodiversity.bz (Belize), INAB, and CONAP (Guatemala), ICF (Honduras), MAR Fund, COCATRAM, ReefBase, from 2015 (2016), 2015, 2012(2015), 2012 (2014), 2015, 2012, 2013, respectively.

No data treatment was performed for these layers.

**xiv. Ocean Currents East and Ocean Currents North/Corrientes marinas este y corrientes marinas norte**

Two maps were developed for these ocean currents, named:

- Ocean currents East: ECOWATCH-NCDDC-NOAA, 2017.
- Ocean currents North: ECOWATCH-NCDDC-NOAA, 2017.

Layers are from a raster clipped for the MAR region.

**xv. Distribution of Marine Algae/Distribución de algas marinas**

2016 Databases from the HRI's AGRRA Project were used to develop this layer.

No data treatment was performed for the layer.

**xvi. Coral Disease/Enfermedades de coral**

Data from AGRRA-HRI, 2016.

It lists the various coral diseases present in the MAR region.

No data treatment was performed for this layer.

**xvii. Hurricanes (9)/Huracanes (9)**

Two types of maps were developed:

- Hurricane Recurrence
- Hurricane Intensity



### **xviii. Hurricane Recurrence Map:**

The Hurricane Recurrence Map was developed based on NOAA 2017 data.

The treatment for these layers was the monthly addition of each hurricane occurrence; data for the MAR region was clipped.

The map shows the recurrence in each month within a period of the two established years. That is, the number of hurricanes per month for the number of years being analysed.

### **xix. Hurricane Intensity Maps:**

A table was developed for these maps in which hurricane categories are shown, in relation to wind speed. The map has a high-, medium- and low-intensity scale, because this map originates from points and lines that contain specific information on wind speeds. To translate these data into continuous data in order to have information for the whole MAR region, a GIS operation –called interpolation– must be performed.

Interpolation is obtaining new points based on a known discrete set of points. In this case, the kriging<sup>1</sup> interpolation was used.

Four maps were developed for the following periods:

- 1851-2014
- 1900-1986
- 1987-2015 (last 30 years)
- 2005-2015 (last 10 years)

### **xx. Mangroves, Beaches, Rivers and Tourist Sites/Manglares, playas, ríos y sitios turísticos**

Data from CONABIO (Mexico), Biodiversity.bz (Belize), INAB and CONAP (Guatemala), ICF (Honduras), MAR Fund, COCATRAM, and TopoSIG, from 2015 (2016), 2015, 2012(2015), 2012 (2014), 2015, 2012, 2017, respectively, were used to create this map.

The river layer was modified as per CTP's suggestion, with the aim of obtaining only the mouths of the main rivers. No data treatment was used for the other layers.

### **xxi. Surgeon Fish/Pez cirujano**

The data come from AGRRA-HRI, 2016.

No data treatment was performed for this layer.

### **xxii. Lion Fish/Pez León**

The data come from AGRRA-HRI, 2016.

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<sup>1</sup> Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Unlike other interpolation methods in the Interpolation toolset, to use the Kriging tool effectively involves an interactive investigation of the spatial behaviour of the phenomenon represented by the z-values before you select the best estimation method for generating the output surface. (<https://pro.arcgis.com/es/pro-app/tool-reference/3d-analyst/how-kriging-works.htm>).

No data treatment was performed for this layer.

**xxiii. Parrot fish/Pez loro**

The data come from the AGRRA-HRI, 2016 database.

No data treatment was performed for this layer.

**xxiv. Probability of groundings/Probabilidad de encallamientos**

This map was named “groundings”; however, there is no sufficient geo-spatial data to develop it. Therefore, a proposal was put forward to develop a model for the probability of grounding occurrence.

The model was developed using MaxEnt software. The results are included as an .html digital file that can be viewed in any search engine. It also includes the raster that was used to create the map.

**xxv. Reef Restoration Projects/Proyectos de restauración de arrecifes**

This map refers to the reef-restoration zones, based on data from the Reef Restoration Network, 2017 Biennial Meeting.

No data treatment was performed for this map.

**xxvi. Navigation Routes/Rutas de navegación**

In this case, several layers were developed, due to the dispersed and diverse information found for the MAR region, that is:

- Illegal navigation routes: obtained from Juan Pérez Ventura, 2014. [www.vaventura.com](http://www.vaventura.com)
- Navigation routes: provided by Belize’s Coastal Zone Management Authority and Institute, 2010.
- COCATRAM navigation route: This map was developed based on COCATRAM data, which specifically covers the Gulf of Honduras, 2012
- Navigation route frequency: obtained from metadata related to doi:10.5063/F1S180FS, 2013 publication identifier (<https://knb.ecoinformatics.org/#view/doi:10.5063/F1S180FS>).
- Navigation routes by type of vessel: This specific analysis comes from COCATRAM, 2012. Difference in the types of vessels that sail through the area.

**xxvii. Fish Aggregation Sites/Sitios de agregación de peces**

The data come from AGRRA-HRI, 2016.

No data treatment was performed.

**xxviii. Whale shark aggregation sites/Sitios de agregación del tiburón ballena**

Data stem from COCATRAM, 2012. COCATRAM data were used instead of countries’ diversity data, since there was no geospatial information on these living organisms. Additionally, COCATRAM staff

performed studies on diversity to develop these final reports. See the reference on the assorted studies cited in the bibliographical references.

No data treatment was performed for these layers.

**xxix. Bird nesting sites/Sitios de agregación de aves**

Data stem from COCATRAM, 2012. COCATRAM data were used instead of countries' diversity data, since there was no geospatial information on these living organisms. COCATRAM staff performed studies on diversity to develop these final reports. See the reference on the assorted studies cited in the bibliographical references.

No data treatment was performed for these layers.

**xxx. Turtle Nesting Sites/Sitios de anidación de tortugas**

Data originate from COCATRAM, 2012 and CONABIO (Mexico), Coastal Zone Management Authority and Institute (Belize), 2017, (2007).

No data treatment was performed for these layers.

**xxxi. Manatee Sighting Sites/Sitios de avistamiento de manatí**

Data originate from COCATRAM and FUNDAECO (Guatemala), CONABIO (Mexico), Coastal Zone Management Authority and Institute (Belize), 2012, 2008, 2012 respectively

No data treatment was performed for these layers.

**xxxii. Larva Collection Sites/Sitios de colecta de larvas**

Data come from the ECOSUR (Mexico) database, 2017.

No data treatment was performed for this layer.

**xxxiii. Oil Exploration Sites/Sitios de exploración petrolera**

When developing this map, it was established that only Guatemala had oil exploration sites in the MAR region. These data stem from the Ministry of Energy and Mines 2017. Mexico does not have any records of this activity in the MAR region.

No data treatment was performed for this layer.

**xxxiv. AGRRA-HRI Monitoring Sites/Sitios de monitoreo AGRRA-HRI**

This layer was created based on 2016 data from the AGRRA-HRI Project.

No data treatment was performed for this layer.

**xxxv. ReefBase Monitoring Sites/Sitios de monitoreo ReefBase**

This layer was developed based on 2017 ReefBase data.

**xxxvi.** No data treatment was performed for this layer.

**xxxvii. Tourist Sites and Type of Tourism Use/Sitios y tipo de uso turístico**

This map was created by the TopoSIG Consulting Group with 2017 data.

No data treatment was performed for this layer.

**xxxviii. Fish Replenishment Zones/Zonas de recuperación pesquera**

Data were taken from several sources: Mexico: CONANP/2015; Belize: MAR Fund and TNC/2015; Guatemala: MAR Fund 2015; Honduras: Martín Galo and Pablo Ricco/2017 (Barra Cuero y Salado Wildlife Refuge), and the Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre/2015 (PAMUCH).

No data treatment was performed for any of these layers.

**xxxix. Fishing Zones/Zonas de pesca**

The map named Fishing Zones is only available for Mexico, Guatemala, and Honduras.

Data stem from MAR Fund (Guatemala, Mexico), FUNDAECO (Guatemala), CEM (Honduras) from 2015, 2015, 2017, respectively.

No data treatment was performed for any of these layers.

**xl. Acropora**

These data originate from Rodríguez-Martínez RE, Banaszak AT, McField MD, Beltrán-Torres AU, Álvarez-Filip L. 2014. Assessment of *Acropora palmata* in the Mesoamerican Reef. PLoS ONE 9(4): e96140. doi:10.1371/journal.pone.0096140.

No data treatment was performed for this layer.

**3.4. Specific Objective 3: To contribute to the analyses of the reef areas that have been most impacted by hurricanes, ship groundings, coral bleaching, and other threats in the region:**

**3.4.1. Analysis 1:**

Because the “risk/threat” variable is essential, it is defined as the development of a surface based on mapped risk factors; that is, the socio-economic, ecological and other activities that have been identified by means of an expert review of them as generators of negative impacts on the conditions of habitats, species and/or ecological systems related to them (Schill and Raber, 2006).

11 geo-spatial layers were identified by means of consultations with experts and individuals related to management in the region.

After the analysis mentioned above, the CTP requested a second analysis of the threats described subsequently. The 11 variables defined below were included in the latter analysis.

In this case, the Water Pollution layer (effluent discharge, which is included in the second analysis described subsequently) was the only one that was not found in order to include it in the model.

After a comprehensive bibliographic review and consultation (Phillips et al, 2006; Segurado and Araujo, 2004; Naoki et al, 2006 and Rojas, 2001), the MAXENT method was selected, having identified this method as the one with the most solid and precise results for cases with small occurrence-data samples, which in this case, were represented by the threats that have already occurred in the area, such as coral disease and bleaching.

They also suggested using the Pearson correlation coefficient analysis to find highly-correlated climate data ( $r > 0,9$ ), with the aim of reducing analysis time and data redundancy (Naoki et al, 2006); however, MaxEnt makes this correlation.

#### **a) MaxEnt**

This is software to model potential species distribution using the maximum-entropy method. It is based on mechanical statistical methods to make predictions based on incomplete information. MaxEnt estimates the most uniform distribution of points of occurrence in a study area, subject to the constraint that the expected value for each environmental variable under the estimated distribution matches its empirical average (Phillips et al, 2004).

#### **b) Geographic Information Systems**

Geographic Information Systems (GIS) contribute to: (a) developing input variables to be used in modelling; (b) Identifying spatial patterns in data; (c) quantifying observed or predicted temporary changes; (d) evaluating the factors that operate across a number of scales, and (e) visualising results (Henríquez, Azocar, and Aguayo, 2006).

#### **c) Materials**

Digital layers and .shp, .jpg, .tif, .dbf files provided by government institutions and organizations throughout the consultancy have been used.

#### **d) Cartography**

An inventory of the layers that were available was performed. A detailed analysis was made of which layers were needed to perform the threat and risk analysis and which of them were not available. Following is a detailed list of the layers used for the analysis. Some layers were developed based on others.

- Water sport activities
- Groundings (model for the probability of grounding occurrence)
- Hotels (stemming from re-classification of the tourist-activities layer)
- Hurricanes
- Invasive species: Lion fish (classified according to biomass, so that 4 layers of the same one were developed to differentiate the areas according to biomass range)
- Shipping routes

- Illegal navigation routes
- Water temperature
- Navigation routes
- Diving zones

These were developed in a format that is appropriate for MaxEnt (.csv).

The main output of the models are accumulated-probability surfaces with values between 0 and 100, assigned to each cell in the study area (CV). A record omission threshold (approximately 0.2 omissions) will be applied to convert the cumulative probability values into a binomial layer representing presence/absence of the modelled variable. This output represents the potential distribution of the modelled variable.

#### **e) Summary of the Methodology**

Models for the probability of occurrence (risks and threats) to use and develop MaxEnt:

- a) Essential layers are sought to create the models (MDP) (inventory)
- b) Something that is very important and must be taken into account when preparing the data to be entered into MaxEnt is that the species data must be in .csv format and the data for independent variables in .asc format (ASCII), and must contain the same cell number and size, as well as the same extent.

A 1,000 x 1,000m resolution was selected because the climate data (temperature) had that resolution and because the rest of the data has the same one. By doing so, we do not add more uncertainty by changing resolutions.

#### **f) Environmental Cost (pressures, threats) Development, Treatment, and Analyses in the MAR region**

In order to develop this sole environmental risk and threat layers and each one of the criteria, a multi-criteria evaluation (MCE) of Boolean logic was used; that is, 1 was used to define the zones we are interested in and 0 for the zones that we are not interested in. This was done because (1) it decreases the volume of information in order to process it in GIS and (2) the zones that present considerable threats are the ones nearest the selected criteria. In some components that interested us, such as temperature, the layer is continuous, while in others, we applied categories.

#### **g) General Objective**

To establish an allocation of land uses and/or activities that is coherent with area resources that does not cause conflict and that, at the same time, minimizes existing or potential impacts, based on implementing an allocation model that considers the factors and constraint of each one of the criteria.

Questions that will be answered by means of the MCE:

- Where is the most damage caused to conservation targets?

- What zones are the least appropriate for conservation?
- Which are the zones that cause the most damage or generate the greatest environmental costs to the territory?
- Which are the zones that cause the most damage or pose the greatest environmental threat to the territory?

#### **h) Methodology**

Firstly, the criteria that have effects or impacts were established; that is, those territorial variables that have influence on the activity.

The criteria are represented by thematic layers defined for each case. Thus, the characteristics that we desired were established for the territory under study where the designed activities took place.

Thus, through the objective and the factors to locate each use, it was possible to define the criteria (variables) that have impact on the model of environmental costs or pressures for the MAR region.

After the criteria to be considered had been established, the factors were defined –in this case, impact factors–, and the restrictions or constraints for the assessed uses were defined.

Let us remember that the criteria are the evidence on which a decision is based (Eastman et al., 1993); therefore, the factors are the criteria that have been evaluated.

Variable selection was made based on our study objectives, by consulting with various experts on the topic and with managers in some protected areas, based on experience and current relation, among others.

All those variables that were thought to have any influence were inventoried; however, not all of them could be modelled (generate spatial predictions), because data were not available in the appropriate format for a GIS. Some thematic layers were developed based on existing ones (see Table 2).

Table 2. Treatment of Variables Used to Develop the Environmental Cost Model for Analysis 1

<b>ID</b>	<b>Variable</b>	<b>Treatment</b>
01	Water sport activities	Modelled
02	Groundings (model for the probability of occurrence)	Modelled
03	Hotels (stemming from re-classification of the tourist-activities layer))	Modelled
04	Hurricanes	Modelled
05	Invasive species: Lion fish (classified according to biomass, so that 4 layers of the same one were developed to differentiate the areas according to biomass range)	Modelled
06	Shipping routes	Modelled

07	Illegal navigation routes	Modelled
08	Water temperature	Modelled
09	Navigation routes	Modelled
10	Diving zones	Modelled
11	Water Pollution layer (effluent discharge)	Modelled (only for the second threat analysis that was requested)

Based on these criteria, several potential locations were established, according to different viewpoints.

The study required that some variables be studied or analysed further than others, due to their importance or their fundamentality for the study; however, all variables were provided the same treatment and attention to avoid more uncertainty in the overall data.

Based on the objective established in the model, we established a number of criteria (variables) with which to measure the impact of each one of the factors of the territory for the use or activity being proposed. Then, a layer was generated with all the factors that had been previously established.

The result is a map showing the probability of occurrence of risks and threats in the zone and indicating the areas that are more susceptible to threats in the MAR region.

The result of the map can always be improved; that is, it can be further detailed. Further analyses can be performed on the inclusion or exclusion of other variables, provided they are available.

**i) Environmental Risk:**

It represents the mean value of environmental risks to the planning units. In this case they were 1,000 x 1000m grids and it was 9.101165.

This number could be used as the cut-off point to determine a threshold for conservation targets that could be most impacted by the intensity and distances of influence of the characteristics of underlying risk factors (Schill and Raber, 2008).

If the mean value is 9.10, all the planning units exceeding it could be considered as candidates for high risk, or units that could be impacted by higher risk levels (Schill y Raber, 2008).

**3.4.2. Analysis 2: Threats including the coral-reef layer (requested by the Committee after January 25)**

Through a video-conference on January 25, 2018, the Reef Rescue Initiative Committee requested that we perform another threat analysis, incorporating the coral-reef layer. To that end, a sample was taken of 500 coral-reef location points along the whole coast within the MAR region.

The table below shows the analysis of the contribution made by each variable and the analysis of how important the permutation of said variables is for the model. The sample used by the model is 25% of the training data.



The following table contains the estimates of the relative contributions of variables to the Maxent model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable, in turn, the values of said variable in the presence of training and background data are randomly permuted.

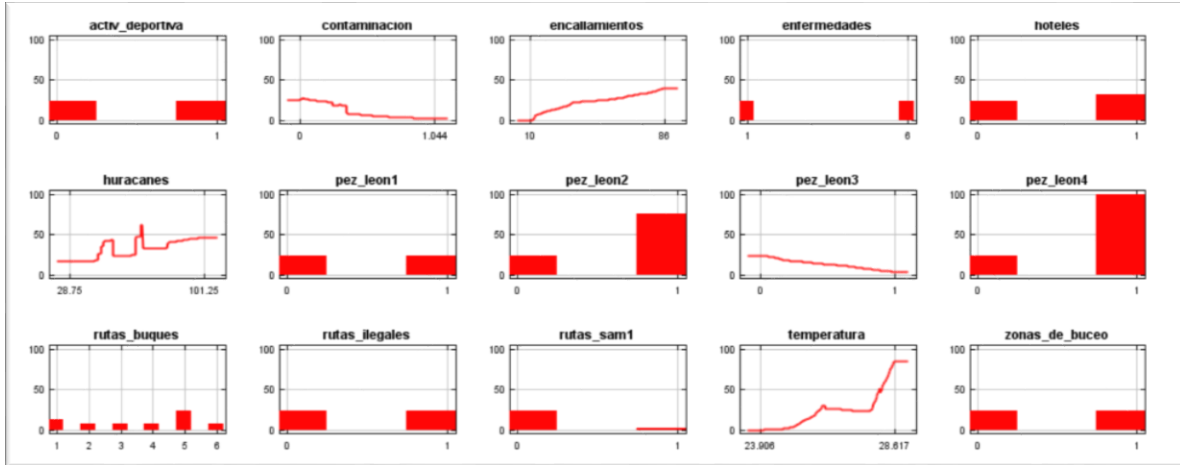
The model is reassessed with permuted data and the drop in the area under the curve (AUC) of training is shown in the table, normalized to percentages. As with the jackknife test, variable contributions must be interpreted with caution when predictor variables are correlated (see Table 3).

Table 3: Variables Used for Modelling

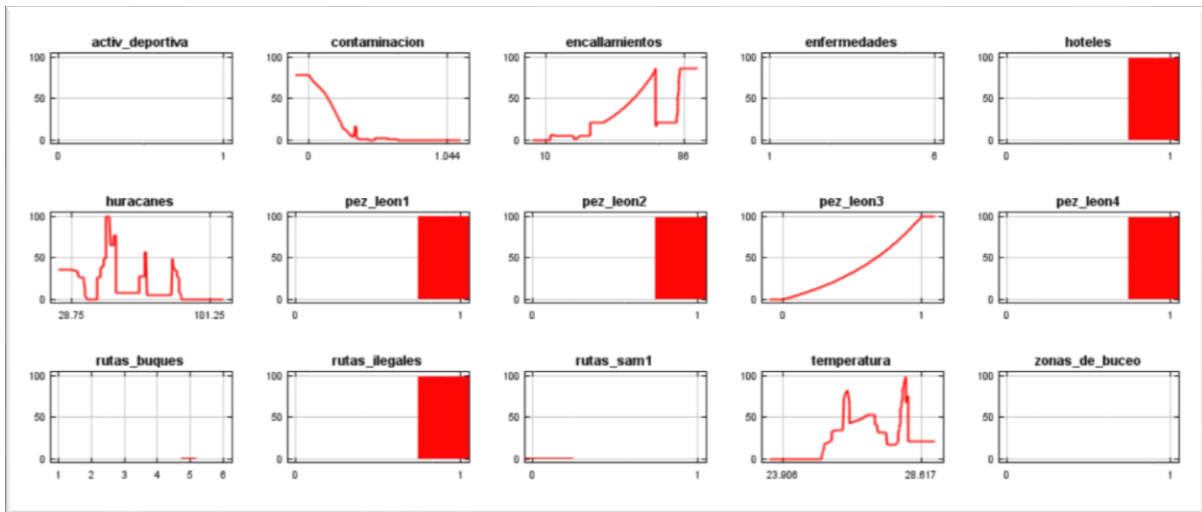
Variable	Percentage of contribution	Permutation Importance
Groundings	67.6	80.3
Pollution	15.9	6.3
Temperature	6.5	1.8
Routes_sam1	5.3	8.2
Hurricanes	3.8	2.4
Lion_fish4	0.4	0.2
Shipping_routes	0.4	0.8
Lion_fish2	0.1	0.1
Lion_fish3	0.1	0
Hotels	0	0
Illegal_routes	0	0
Diving_zones	0	0
Lion_fish1	0	0
Disease	0	0
Sport activities	0	0

In addition, model response curves are shown.

These curves show how each environmental variable affects the MaxEnt prediction. The curves show how the logistical prediction changes as each environmental variable varies, keeping all other environmental variables at their average sample value. It is important to note that the curves may be difficult to interpret if they have variables that are strongly correlated, since the model may depend on correlations in ways that are not evident in the curves. In other words, curves show the marginal effect of changing a variable exactly, whereas the model may take advantage of sets of variables that change together.



Unlike the marginal response curves shown above, each of the curves shown below represents a different model; that is, a MaxEnt model created by using only the corresponding variable. These plots reflect the suitability predicted both for the selected variable and for the dependencies induced by correlations among the selected variable and other variables. They may be easier to interpret if there are strong correlations among variables:



The following picture shows the results of the jackknife test on variable importance. The environmental variable with the highest gain when used in isolation is “groundings” (encallamiento), which is, therefore, the one with the most useful information. The environmental variable that most decreases the gain when it is omitted is “groundings” (encallamiento), which therefore appears to have the greatest amount of information that is not present in other variables.



The corresponding map is included in the digital deliverables named: Riesgos / amenazas en arrecifes de coral (Risks / Threats in Coral Reefs).

This risk layer represented in the map already contains the variable of water contamination, as suggested by the CTP.

This layer was obtained from Benjamin Halpern, Melanie Frazier, John Potapenko, Kenneth Casey, Kellee Koenig, et al. 2015. Cumulative human impacts: raw stressor data (2008 and 2013). Knowledge Network for Biocomplexity. doi:10.5063/F1S180FS.



Maxent model for Arrecifes\_de\_coral.pdf

Click on this file to see the detail of the results described above.

### 3.5. Specific Objective 4: To propose prioritization scenarios to guide coral reef rehabilitation and restoration efforts in the region.

#### a) Conservation Targets

A conservation target is a biodiversity component that is spatially measurable and definable and that is to be conserved within a network of protected natural spaces (Ardron, Possingham and Klein,

2008), which in this case, is the Mesoamerican Reef (MAR) region. It is constituted by the habitats and species intended for conservation.

In this case, the conservation targets are:

1. Seagrasses
2. Mangrove cover
3. Aggregation sites (fish)
4. Sighting sites (birds, turtles, whale-sharks)
5. Coral cover
6. Parrot fish, and
7. Surgeon fish

A constraint found for this work is the effect of the data-availability bias. It is probable that we face a problem generated by the differences in sample efforts in the territory under study, since some distributions of species may appear larger or smaller than they actually are. On the other hand, there have been greater sampling efforts for protected areas than for other areas, and they may seem to have a greater number of species than those in areas adjacent to them.

#### **b) Relative Biodiversity Index**

The Relative Biodiversity Index (RBI) of a landscape is estimated to identify the relative biological wealth, measured in terms of abundance of its characteristic biodiversity, compared with the general study area. Individual rankings can be used for each occurrence of biodiversity, as an independent evaluation of each planning unit or subset of units (for example, hexagons, squares or watersheds).

A map with Relative Biodiversity Indices (RBIs) was created with the PAT v4 tool, developed by TNC (Schill y Raber, 2008), used by means of ArcGis 10.3.1.

The Normalized Relative Biodiversity Index (nRBI) quantifies the relative weighted contribution of each planning unit compared with the total distribution of each conservation target. In other words, the nRBI of each planning unit (PU) is directly proportional to the number of conservation targets existing in the PU (in this case, hectares). The index may be summed for multiple targets, creating and aggregate nRBI. The advantage of this approach is that it can be used to identify the best remaining areas, in terms of target abundance for each target or set of targets at the planning unit scale (query domain) or the landscape scale (universe domain) (TNC, 2005).

$$nRBI= RBI/RAI$$

where:

RBI = abundance (PU) / abundance (study area)

RAI = area (PU) / area (study area–MAR)

This index computes the *relative* abundance in such a way that it may be any measurement, such as hectares or occurrences. Values for nRBI greater than 1 indicate proportionately more target abundance in a PU than is expected for the PU size. Normalized relative biodiversity index values

can be summed across multiple targets to calculate aggregate nRBI. A higher RBI summed score (> 1) implies that there is a greater representation or extent of the targets than is expected for the PU size, which may or may not justify conservation actions (TNC, 2003).

Thus, we can interpret RBI as:

= 1 target is proportional to its area

> 1 target is over-represented in the PU

< 1 target is sub-represented in the PU

The Normalized Relative Biodiversity Index (nRBI) is calculated using an area-weighted function. Values greater than 1 indicate a high level of habitat wealth compared to the overall landscape. (Schill y Raber, 2008).

As part of the RBI analysis results, two outputs are created, one in .shp format and another one in .dbf tables named: *RBI\_ALL\_TARGETS* and *RBI\_SUMMARY*.

The table named “RBI\_ALL\_TARGETS.dbf” contains six columns that describe target occurrence in each Planning Unit:

Table 4. Contents of Table “RBI\_ALL\_TARGETS.dbf”. From Schill and Raber, 2008.

<b>FIELD</b>	<b>DESCRIPTION</b>
ID	Planning Unit Identifier
RAI	Relative Area Index
TCOUNT	Total count
RBI	Non-Normalized Relative Biodiversity Index
RBN	Normalized Relative Biodiversity Index
RBI_TARGET	Name of the target

The other table, *RBI\_SUMMARY*, has 5 columns:

Table 5. Contents of Table “RBI\_SUMMARY.dbf”. From Schill y Raber, 2008.

<b>FIELD</b>	<b>DESCRIPTION</b>
RBIT1	<b>Non-normalized</b> RBI value average based on the sum of the total number of targets found in the <i>universe domain</i> (that is, the total landscape).
RBIT2	Non-normalized RBI value average based on the sum of the total number of targets found in the <i>query domain</i> (that is, the hexagon planning unit)
RBNT1	<b>Normalized</b> RBI value average based on the sum of the total number of targets found in the <i>universe domain</i> (that is, the total landscape).
RBNT2	<b>Normalized</b> RBI value average based on the sum of the total number of targets found in the <i>query domain</i> (that is, the hexagon planning unit).
UNIT_ID	<i>Planning Unit sole identifier</i>

This approach allows a more specific understanding of the potential conservation areas; it can also be used to set priority sites based on specific strategies to this or that habitat. Furthermore, this combination may be used to predict the highest return for conservation investments, to achieve long-term goals in habitats and to systematically provide sequential information to build a representative network of conservation areas (Schill and Raber, 2008).

In the case of the MAR region, a map in which the colour ramp ranges from green to red is submitted. Colours with numbers over 1 indicate a greater relative biodiversity. This datum is interpreted through the RBN column. The higher the RBN value, the higher the Normalized Relative Biodiversity Index.

The result of the map is included in the digital attachments delivered as established in the ToR. In order to interpret the results, consider Table 2, and then we can identify the RBI:

= 1 target is proportional to its area

> 1 target is over-represented in the PU

< 1 target is sub-represented in the PU

The normalized indices for all conservation targets in the MAR region; that is, the total landscape. The detailed nRBI tables for conservation targets are only available in their digital version, since they are 464,921 PUs, so they are very extensive.

**c) To propose prioritization scenarios to guide coral reef rehabilitation and restoration efforts in the region**

To achieve this objective, an initial step was taken to identify the geo-spatial zones containing higher biodiversity indices, with the aim of proposing, based on four scenarios, the priority zones for conservation and/or to guide conservation efforts.

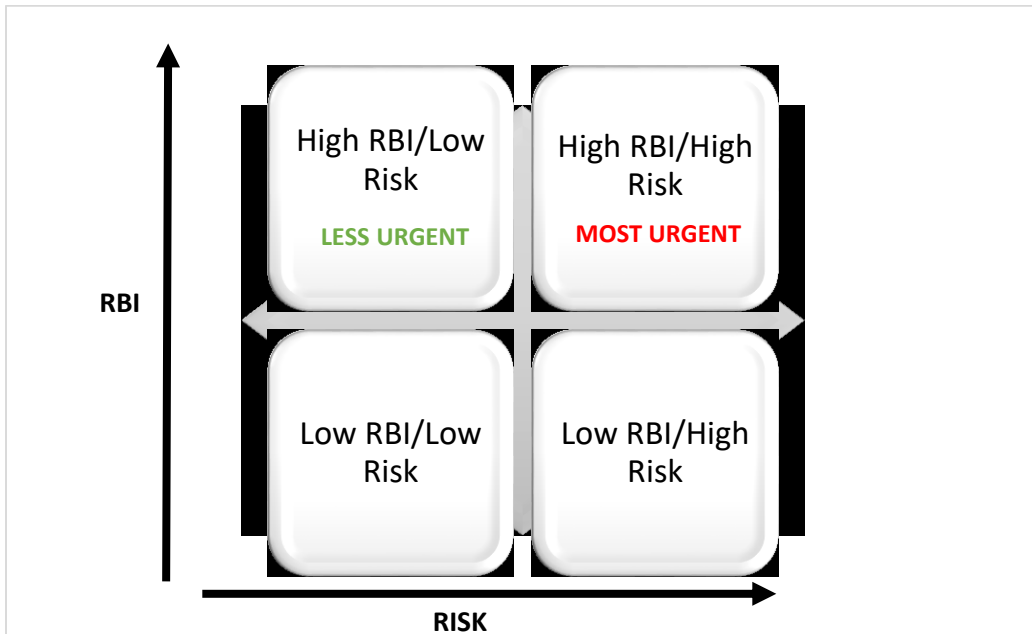
In order to determine biodiversity indices, the work will be based on species reports in the study areas, either by country or by the overall MAR region.

We propose that the biodiversity index used is a Normalized Relative Biodiversity Index (nRBI). This Relative Biodiversity Index (RBI) will be developed by using the PAT v3 tool designed by TNC (Schill and Raber, 2008) and used by means of ArcGis.

After determining the zones with high biodiversity indices, the layer created in Objective 3 will be used; that is the layer on environmental risks or threats.

The aim is to use the nRBI layer developed in the previous process and to cross it by means of geo-spatial processes, with the aim of determining priority conservation zones and guiding many of the actions required by MAR.

Consequently, we propose that, when combining the environmental risk with the Relative Biodiversity Index, we obtain:



This type of quadrant analysis can be combined with sites that have already been declared as a conservation priority or sites with high risks and threats, in order to guide priority establishment with respect to the areas in most urgent need of conservation. The High RBI / High Risk areas could be the costliest to address or treat, but they are species that could be lost irretrievably if measures are not taken imminently.

In summary, in most of the taxa that were analysed, where the planning units with highest RBNT1 are located, they have one or several protection categories.

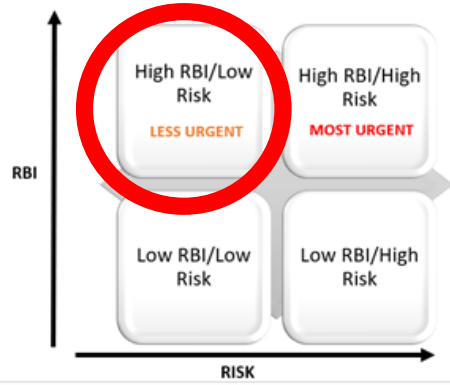
In the next picture, we can see that, when combining the environmental risk with the relative biodiversity index we obtain:

**High RBI/Low Risk  
Less urgent**

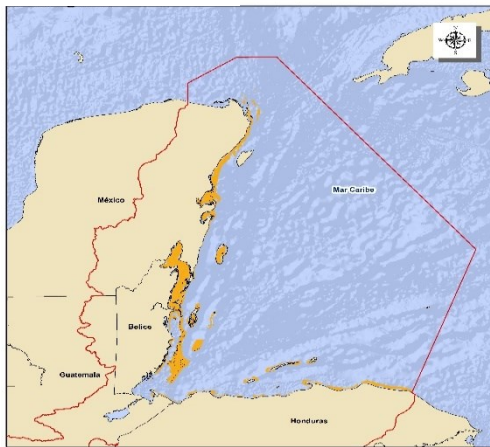


High RBI/Low Risk

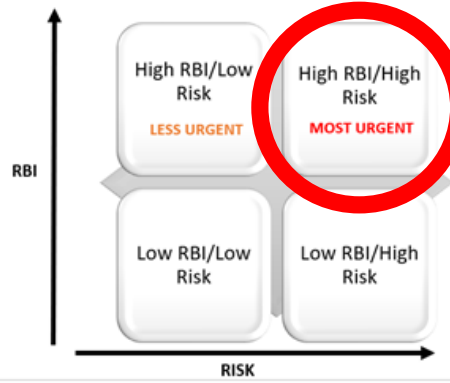
High RBI/Low Risk



**High RBI/High Risk  
More urgent**

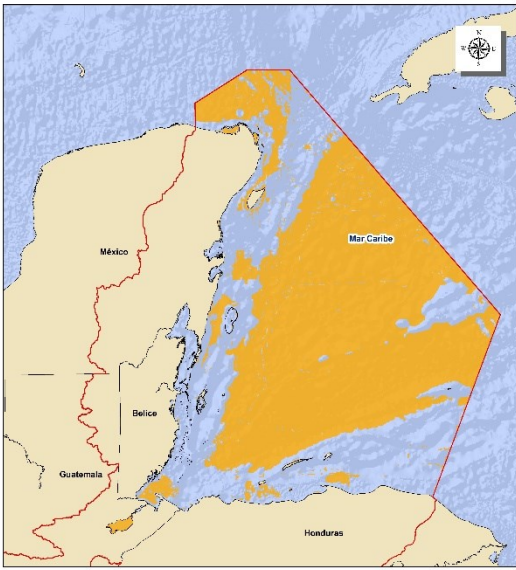


High RBI/High Risk

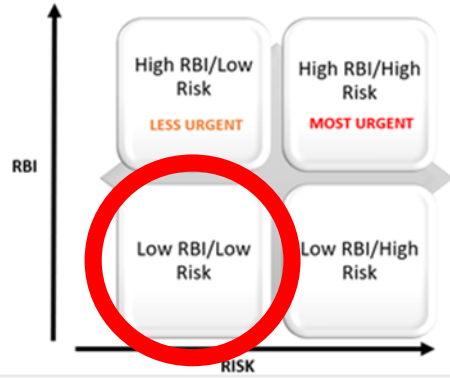




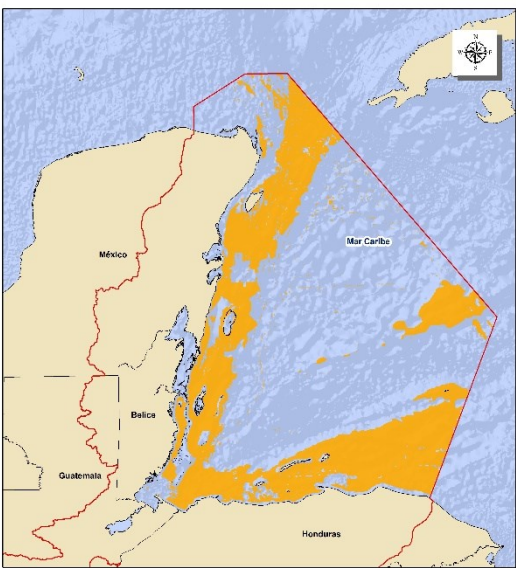
**Low RBI/Low Risk**



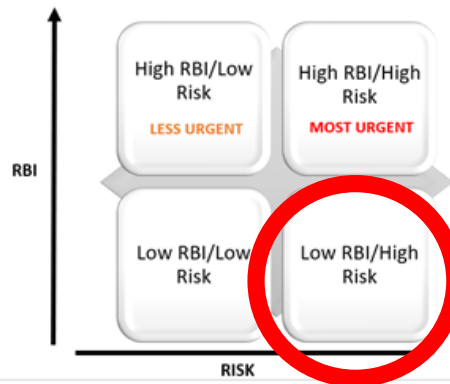
Low RBI/Low Risk



**Low RBI/High Risk**



Low RBI/High Risk



This type of analysis by quartiles (T.N. I did not find the Spanish word “cuadril” applied to statistics; thus, I interpreted it as “cuartil”=quartile) may be combined with the results obtained in conservation gaps to guide priority establishment with respect to the most urgent conservation areas. The High RBI/High risk areas could be costlier to acquire, but they are species that could be lost irretrievably if measures are not taken imminently.

Each one of the analysis scenarios by quadrants shows the areas in the MAR region whose conservation is important. However, the most important scenario is the one referred to as the most urgent, which shows a High RBI/High Risk. As the name of the scenario indicates, these areas contain a high biodiversity or a high concentration of living organisms and substantial risk or threats within the MAR region.

### **3.6. Conclusions**

1. The groundings, water-pollution and water-temperature variables are the ones most related to risks / threats to coral reefs, according to the threat analysis performed with MaxEnt.
2. It is necessary for Guatemala to finish refining the coral-reef layer that it started to generate with HRI. Nevertheless, its details should be improved in order to compare it with the information from the other 3 countries.
3. More detailed analyses could be undertaken if there were more time because the area is very extensive, and the data files are very heavy if they are to be used at a finer scale.
4. It is essential to pay more attention to the scenario for the quadrant analysis named “most urgent”, since it has a high degree of biodiversity and a higher degree of threat according to the analysis performed by MaxEnt and by quadrants.

### **3.7. Recommendations**

Perform constant monitoring, both in navigation routes and in wind speeds, in order to update the data in threat maps a least every quarter, since it was detected that these data are the ones that vary the most in the MAR region.

Establish monitoring with remote sensors by using the SENTINEL2A (satellite images) of coral bleaching, which will reinforce the work already being performed by HRI but will reduce costs and time and can be performed monthly.

### **3.8. Indicate the progress achieved by the Project, comparing it with the original timeline submitted and explain any delays**

To date, there have been no delays in programmed activities, according to the original timeline. The chlorophyll layer request by the committee could not be obtained. It was only possible to consult data on line, but an editable digital layer could not be generated. However, this has not delayed submittal of deliverables.

### **4. Obstacles:**

There were no obstacles during this phase of the work. All objectives were achieved.

However, it was difficult to find some of the thematic layers contained in the agreement, such as:

- a. Ship groundings (at least 3 types of vessels, including commercial, private tourism and passenger-transport vessels): There has been no answer from the various institutions consulted for this layer, among them, COCATRAM, port authorities in the 4 countries and others related to the topic.
  - i. We visited the department of Izabal, in the municipality of Puerto Barrios, where we participated in a fishing-governance workshop and obtained information that was still missing.
  - ii. This groundings layer had very little information. There was only information for certain areas in Mexico and 3 locations in Roatán, Honduras, so that we submitted a proposal to the Committee to develop a map of a model for the probability of grounding occurrence for the MAR region, which was developed by means of the MaxEnt software.
- b. Oil exploration sites: These were only found in Guatemala. The data for Mexico were reviewed, and there is no oil exploration along the Caribbean; this activity is only undertaken in the Gulf of Mexico. No information was found for Belize and Honduras. E-mails were sent to various entities handling this information in each one of the countries; however, to date, there has been no response to our queries on these data, and there is nothing in the web to digitalize this information if the layers were not available in editable format. The Committee recommended keeping to the data that had been found at the time, with the comment that areas in Belize would be removed due to a new Decree issued in regard to oil exploration in the area.
- c. Main fishing zones (lobster, conch, scale fish): In regard to this layer, polygons or fishing locations were obtained for some countries. In the case of Guatemala, because there was no editable-format information (shapes) an existing MAR Fund map on fish replenishment areas was digitalized, and the information was obtained. For this feature, two maps were specified: one for zones of fishing importance and another one for fishing reserve zones.
- d. Fishing Areas (Managed Access): We tried to contact Adriel Castañeda, who is the Fisheries Officer and Coordinator of the Ecosystems-Based Management Unit of Belize, and who is responsible for this issue, in order to develop this map; however, she never provided the information, so that we opted for digitalizing all the map information in .JPG format with the aim of achieving this objective.
- e. Reef restoration projects (nurseries and other that are being executed in the region): Both the Technical working team for this consultancy and MAR Fund's Claudia Ruiz made our best efforts to contact OCEANUS in order to obtain information on the topic. However, after several attempts, Miguel García from OCEANUS answered: *"As Oceanus A.C, we are working on a publication on the restoration program being implemented by Oceanus A.C. As soon as it is published, we will gladly send you the publication with the information you request"*.

Therefore, we are still waiting for them to share this information, since we have not found any information on the issue that can be digitalized. In the last week of November and owing to the support of María del Carmen García Rivas, Director of the Parque Nacional Isla Contoy and the Parque Nacional Arrecife de Puerto Morelos, Quintana Roo, Mexico, and Claudia Ruiz, we were able to obtain the data to generate the map.

- f. Intensity and quality of tourism use (e.g. number of visitors, type of tourist business, cruise embarking and disembarking sites, and others): To obtain this information, we contacted the tourism institutes of the 4 countries several times and none of them answered. However, we digitalized all the information from Google Earth, securing the location of various tourism services, according to the type of business, cruise disembarking locations and others that provide data to generate the map, thus achieving this objective.
  - g. Larva collection indicators in the region: In regard to this layer, owing to MAR Fund efforts, we obtained the Excel tables with the data provided by Lourdes Vásquez, Zooplankton & Oceanography of the Aquatic Systematic and Ecology Department at the Colegio de la Frontera Sur, Chetumal Unit, Mexico
5. **Organizational Links:** Describe any partnership established as a result of project implementation.

No organizational links were established due to the nature of the consultancy, which is to develop a baseline and generate maps. However, it was possible to coordinate support for the consultancy with members of the HRI (Healthy Reefs for Healthy People) staff, who have cooperated by providing all their databases relating to the reefs and data on the species linked to the MAR region. We also coordinated with COCATRAM (Central American Commission for Maritime Transport), which provided all the information –both the editable layers and documentation– on their project Environmental Protection and Control of the Pollution Generated by Maritime Transport in the Gulf of Honduras: “Evaluation of Navigation Risks and Harmonizing the Regulations Referring to Navigational Safety” (BELIZE, GUATEMALA AND HONDURAS)”, Final Report October 2009, and the Regional Information Module of said institution.

Following is a table summarizing the individuals who were contacted and provided information and layers to perform the consultancy.

Table 6: Organizational Links

Name	Institution	Contact
María Carmen García Rivas	Parque Nacional Puerto Morelos	mcgarcia@conanp.gob.mx
Lourdes Vásquez	ECOSUR	lula.vaye@gmail.com
Otto Noack	COCATRAM	onoack@cocatram.org.ni
Edas Muñoz Galeano	COCATRAM	edasmunozg@hotmail.com

Lorenzo Álvarez	HRI	lorenzoaf@gmail.com
Ian Drysdale	HRI	drysdale@healthyreefs.org
Ana Giró	HRI	anapiro@gmail.com
Melanie McField	HRI	mcfield@healthyreefs.org
Kathya Mejía	FUNDAECO	k.mejia@fundaeco.org.gt
Karen Aguilar	FUNDAECO	k.aguilar@fundaeco.org.gt
Silja Ramírez	FUNDAECO	s.ramirez@fundaeco.org.gt
Alianza Kanankay	Alianza Kanankay	akanankay@gmail.com
Adriel Castañeda	Fisheries Officer, Belize	adrielcast@gmail.com
Gerrit Hartman	Fundación Defensores de la Naturaleza	cigdef@defensores.org.gt
Airam López	CONAP Guatemala	airamzoo@hotmail.com
OCEANUS Mexico	OCEANUS, AC	info@oceanus.org.mx
Belizean Government	Fishery Secretariat, Belize	secretary@gpd.gov.bz

## 6. Lessons

To follow up variables such as coral bleaching with other GIS tools to engage in low-cost, monthly monitoring by using satellite Sentinel 2A images (remote sensors).

To hold workshops similar to the one in which the local staff participated (Fishermen Governance Group in Guatemala) in other countries, with the aim of locating other extractive activities that take place in the MAR region.

## 7. Project Effects

This section is not provided for in this consultancy due to the nature of its data, and it was not included in the activities contained in the work plan. The consultancy only had to develop thematic maps of the MAR region included in the specific Terms of Reference.

However, by means of its deliverables, it will be possible to generate important changes at the environmental and decision-making levels.

## 8. Communicating results:

This section is not provided for in this consultancy due to the nature of its data, and it was not included in the activities contained in the work plan. However, the information may be found in the thematic maps that were developed as requested.

The target audience are technicians and state politicians who make decisions.

**9. Continuity of the Project: Will the process established by this project continue to operate?  
Who will follow it up?**

This section is not provided for in this consultancy due to the nature of its data, and it was not included in the activities contained in the work plan. The consultancy was only aimed at developing the thematic maps of the MAR region included in the specific Terms of Reference. However, it is recommended that the information generated is followed-up and continuously updated to foster better decision making in the future.

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COCATRAM. International MAR Consult y CSI Ingenieros. 2010. *Proyecto para la Protección Ambiental y Control de la Contaminación Originada en el Transporte Marítimo en el Golfo de Honduras. Sistema de Manejo de Datos e Información, Establecimiento de una Línea de Base, Preparación de un Análisis Diagnóstico Transfronterizo y un Plan de Acción Estratégico. (Project for Environmental Protection and Control of the Pollution Generated by Maritime Transport in the Gulf of Honduras. Data and Information Management System, Establishing a Baseline, Preparing a Transborder Diagnosis and a Strategic Action Plan)*. Final Report. 923 pp

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**Attach appendices and other annexes, such as publications and photographs produced during the project:**

**Annex 1. Field Visit Report**

The field visit is included in the planning of the project.

It took place on October 17-20, 2017. The following itinerary had been planned:

Guatemala City-Puerto Barrios-Santo Tomás de Castilla-Livingston-internal trips-Puerto Barrios-Guatemala City.

However, due to the heavy rains in the area during the field trip, it was not possible to visit Livingston.

Notwithstanding the weather, the objectives were achieved.

At the invitation of Hendric Acevedo, from CONAP Izabal, the team participated in a workshop called “Governance Groups for Fishery Resources such as Lobster, Sharks and Rays in the Guatemalan Caribbean” held in Puerto Barrios, Izabal on October 18, 2017. During the workshop, fishermen were interviewed, and they provided information on various fisheries. In addition, an activity was held so that, at the request of DIPESCA, fishermen would draw on maps the zones of the Guatemalan Caribbean where rays, sharks and lobsters are harvested.

The team coordinated participation and venue for this activity with DIPESCA staff.

On the 19<sup>th</sup>, the team participated in a workshop on governance, fishing and field-data gathering with the rangers in the areas of the department.

At these two events it was possible to gather the information needed to continue with the desk research and create the fishery maps that were outstanding.

The objective was to obtain information from local people on fishing, ship groundings and other data that was essential to develop the maps and, mainly, to develop a model for the probability of grounding occurrence in the MAR region.

The team returned on the evening of October 19th since they would not visit Livingston due to the heavy rainfall. However, they had to stay overnight in Teculután, Zacapa, because there had been an accident and a trailer truck was blocking the road to Guatemala City. The road would not be cleared until after midnight, so the team decided to stay overnight.

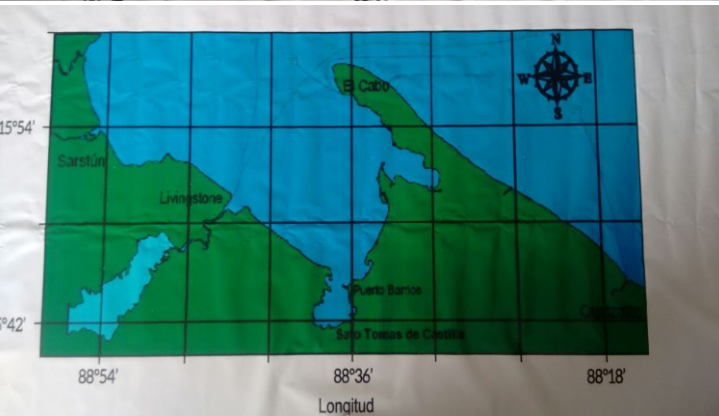
The equipment purchased was used to carry the equipment to take photographs with the drone and high-resolution photographs that would provide information for the work being performed. However, due to the heavy rainfall, it was not possible to take them.

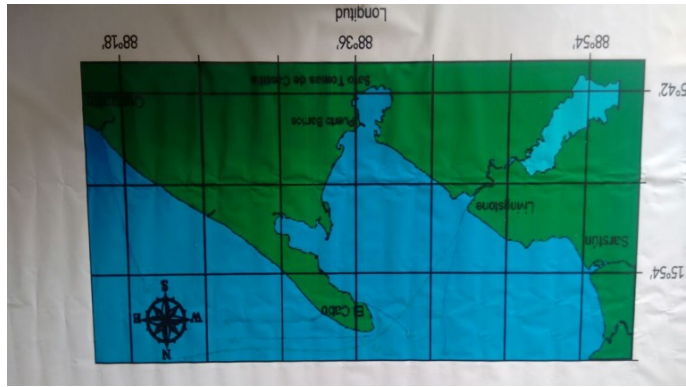
Attached are 15 invoices for payment.



Photographs:







## Annex 2. Table Detailing Layers to Create Thematic Maps:

Map	Control of Development										Total	Source	Year
	Spanish					English							
Name of Map	General	Belize	Guatemala	Honduras	Mexico	General	Belize	Guatemala	Honduras	Mexico			
Fishing areas/ Áreas de pesca		x					x				2	Fishing Department, Belize	2016
Marine coastal protected areas/ Áreas protegidas costero marinas	x	x	x	x	x	x	x	x	x	x	10	CONANP, Coastal zone management authority and institute, CONAP and ICF	2017, 2015, 2016, 2017
Bathymetry/ Batimetría	x					x					2	USGS-EROS	2014
Blanqueamiento de corales/ Bleaching coral (AGRRA-HRI)	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016
Bleaching coral/ Blanqueamiento de corales (ReefBase)	x	x		x	x	x	x		x	x	8	ReefBase	2013
Water quality- Pollution/ Calidad de agua - Contaminación	x					x					2	doi:10.5063/F1S180FS	2013
Water quality- Chlorophyll/Calidad de agua-Clorofila	x					x					2	CONABIO	2013
Water quality- pH/ Calidad de agua-pH	x					x					2	NODC-NOAA	2013
Water quality- salinity/ Calidad de agua-Salinidad	x					x					2	NODC-NOAA	2013
Water quality- temperature/ Calidad de agua-Temperatura	x					x					2	NODC-NOAA	2013
Coral coverage/ Cobertura de corales	x	x	x	x	x	x	x	x	x	x	10	Millennium coral reef and AGRRA HRI	2013 y 2016
Mangrove cover and river mouth/ Cobertura de manglares y desembocadura de ríos	x	x	x	x	x	x	x	x	x	x	10	CONABIO, Biodiversity.bz, INAB and CONAP, ICF, MAR Fund	2015 (2016), 2015, 2012(2015), 2012 (2014), 2015
Mangrove, beaches and seagrass cover/ Cobertura de manglares, playas y pastos marinos	x	x	x	x	x	x	x	x	x	x	10	CONABIO, Biodiversity.bz, INAB and CONAP, ICF, MAR Fund, COCATRAM, ReefBase	2015 (2016), 2015, 2012(2015), 2012 (2014), 2015, 2012, 2013
Ocean currents east/ Corrientes marinas este	x					x					2	ECOWATCH-NCDDC-NOAA	2017
Ocean currents north/ Corrientes marinas norte	x					x					2	ECOWATCH-NCDDC-NOAA	2017
Distribution of marine algae/ Distribución de algas marinas	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016
Coral disease/ Enfermedades de coral	x	x		x	x	x	x		x	x	8	AGRRA-HRI	2016
Hurricane(9)/ Huracanes (9)	x					x					18	NOAA	2017
Mangroves, beaches, rivers and tourist sites/ Manglares, playas, ríos y sitios turísticos	x	x	x	x	x	x	x	x	x	x	10	CONABIO, Biodiversity.bz, INAB y CONAP, ICF, MAR Fund, COCATRAM, TopoSIG	2015 (2016), 2015, 2012(2015), 2012 (2014),

															2015, 2012, 2017
Surgeon fish/ Pez cirujano	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016		
Lion fish/ Pez león	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016		
Parrot fish/ Pez loro	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016		
Probability of groundings/ Probabilidad de encallamientos	x					x					2	TopoSIG	2017		
Reef restoration projects/ Proyectos de restauración de arrecifes	x					x					2	Red de Restauración de Arrecifes Biennial	2017		
Illegal navigation routes/ Rutas de navegación ilegal	x					x					2	vaventura.com	2014		
Navigation routes/ Rutas de navegación Coastal zone management authority and institute		x					x				2	Coastal Zone Management Authority and Institute	2010		
Hurricane recurrence/ Recurrencia de huracanes	x					x					2	NOAA	2017		
Navigation routes/ Rutas de navegación COCATRAM	x	x	x	x		x	x	x	x		8	COCATRAM	2012		
Frequency of navigation routes/ Frecuencia de rutas de navegación	x					x					2	doi:10.5063/F1S180FS	2013		
Navigation routes per vessel type/ Rutas de navegación por tipo de barco	x	x	x	x		x	x	x	x		8	COCATRAM	2012		
Sitios de agregación de peces/ Fish aggregation sites	x	x	x	x	x		x	x	x	x	10	AGRRA-HRI	2016		
Fish monitoring sites/ Sitios de monitoreo de peces		x					x				2	ECOSUR	2017		
Whale shark aggregation sites/ Sitios de agregación del tiburón ballena	x	x		x	x	x	x		x	x	8	COCATRAM	2012		
Bird nesting sites/ Sitios de anidación de aves	x	x		x	x	x	x		x	x	8	COCATRAM	2012		
Turtle nesting sites/ Sitios de anidación de tortugas	x	x	x	x	x	x	x	x	x	x	10	COCATRAM and CONABIO, (Coastal Zone Management Authority and Institute)	2017, (2007)		
Manatee sighting sites/ Sitios de avistamiento de manatí	x	x	x	x	x	x	x	x	x	x	10	COCATRAM y FUNDAECO, CONABIO, Coastal Zone Management Authority and Institute	2017, 2008, 2012		
Larva collection sites/ Sitios de colecta de larvas	x					x					2	AGRRA-HRI	2017		
Oil exploration sites/ Sitios de exploración petrolera			x					x			2	Ministry of Energy and Mines	2017		
HRI/Monitoring sites AGRRA-HRI/ Sitios de monitoreo AGRRA-	x	x	x	x	x	x	x	x	x	x	10	AGRRA-HRI	2016		

Monitoring sites ReefBase/ Sitios de monitoreo ReefBase	x					x					2	ReefBase	2017
Tourist sites and type of tourism use/ Sitios y tipo de uso turístico	x	x	x	x	x	x	x	x	x	x	10	TopoSIG	2017
Fish replenishment zones/ Zonas de recuperación pesquera	x	x	x	x	x	x	x	x	x	x	10	Mexico: CONANP/2015, Belize: MAR Fund and TNC/2015, Guatemala: MAR Fund 2015, Honduras: Martín Galo and Pablo Ricco/2017 (RVS Barra Cuero y Salado), Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre/2015 (Pamuch)	
Fishing zones/ Zonas de pesca	x		x	x	x	x		x	x	x	8	MAR Fund, FUNDAECO, CEM	2015, 2015, 2017
Normalized Relative Biodiversity Index/ Índice de biodiversidad relativa	x					x					2	TopoSIG	2018
Mean environmental risk threats/ Media de riesgo y amenazas ambientales	x					x					2	TopoSIG	2018
Risk of environmental threats/ Riesgo de amenazas ambientales	x					x					2	TopoSIG	2018
<b>Total</b>	47	25	20	23	21	47	25	20	23	21	278		

## Annex 3: Description of the Digital Content of the Deliverables

### DIRECTORY SUMMARY

**Note: For templates to be used correctly to connect with all the layers linked to them, it is necessary to link the external unit as a unit (E). If it is not connected this way, it will be necessary to re-direct each template element.**

- **E:\ Consultoría MAR FUND – Copy**

It is the parent directory of all the information, within this carpet, you will find four files that are described below. In addition, there are the following files:

- **Control de mapas (Map Control):** It contains a table summarizing the maps created for each one of the countries and the total MAR region, both in Spanish and English.
- **Informe final (Final Report):** Final consultancy report (detail of the sources and processes undertaken throughout the consultancy)
- **Resumen directorio (Directory summary):** It contains a description of each one of the directories stored in the removable disk.
- **Tablas MARFund (MAR Fund tables):** It contains a summary of the tabular databases used in the maps. Each dataset has a xxxx\_td that contains a dynamic table for it, to make data queries easier. The databases that are not included here can be taken from .dbf files for each one of the shapefiles.

- **E:\ Consultoría MAR FUND - Copy\English**

This directory stores all consultancy information in English, with a total of 12 files containing the following:

- **General features:** It contains the following shapelines: MAR 2007 boundaries, Caribbean Sea, official country borders, international boundaries and oceans.
- **Logos of Project:** It contains high-resolution pictures of the logos of the institutions participating in and contributing to this consultancy
- **Templates:** It contains the templates for all the maps created for the whole MAR region.
- **Templates Belize:** It contains the templates for all the maps created for Belize
- **Templates Guatemala:** It contains the templates for all the maps created for Guatemala
- **Templates Honduras:** It contains the templates for all the maps created for Honduras
- **Templates Mexico:** It contains the templates for all the maps created for Mexico
- **Maps:** It contains the .jpg maps created for the whole MAR region, based on the templates stored in the **Templates** file.
- **Maps Belize:** It contains the .jpg maps created for Belize based on the templates stored in the **Templates Belize** file.
- **Maps Guatemala:** It contains the .jpg maps created for Guatemala based on the templates stored in the **Templates Guatemala** file.

- **Maps Honduras:** It contains the .jpg maps created for Honduras based on the templates stored in the **Templates Honduras** file.
- **Maps Mexico:** It contains the .jpg maps created for Mexico based on the templates stored in the **Templates Mexico** file.
- **E:\ Consultoría MAR FUND - Copy\Spanish**

This directory stores all consultancy information in English, with a total of 12 files containing the following:

  - **Shapes generales:** It contains the following shapelines: MAR 2007 boundaries, Caribbean Sea, official country borders, international boundaries and oceans.
  - **Logos del proyecto:** It contains high-resolution pictures of the logos of the institutions participating in and contributing to this consultancy.
  - **Plantillas:** It contains the templates for all the maps created for the whole MAR region.
  - **Plantillas Belice:** It contains the templates for all the maps created for Belize.
  - **Plantillas Guatemala:** It contains the templates for all the maps created for Guatemala
  - **Plantillas Honduras:** It contains the templates for all the maps created for Honduras
  - **Plantillas Mexico:** It contains the templates for all the maps created for Mexico
  - **Mapas:** It contains the .jpg maps created for the whole MAR region, based on the templates stored in the **Plantillas** file.
  - **Mapas Belice:** It contains the .jpg maps created for Belize based on the templates stored in the **Plantillas Belice** file.
  - **Mapas Guatemala:** It contains the .jpg maps created for Guatemala based on the templates stored in the **Plantillas Guatemala** file.
  - **Mapas Honduras:** It contains the .jpg maps created for Honduras based on the templates stored in the **Plantillas Honduras** file.
  - **Mapas Mexico:** It contains the .jpg maps created for Mexico based on the templates stored in the **Plantillas Mexico** file.
- **E:\Consultoría MAR FUND - Copy\Objetivo 3 y 4 (Objectives 3 and 4)**

This file contains the final results of objectives 3 and 4, and it is composed of 4 files containing the following information:

  - **Índice de biodiversidad relativa (Relative Biodiversity Index):** It contains the NRBI of conservation targets.
  - **Mapa de riesgo amenazas (Risk/Threats Map):** It contains an NRBI (Normalized Relative Biodiversity Index) / Environmental Risks and Threats
  - **Mapas (Maps):** It contains four .jpg files directly linked to the **Plantillas (Templates)** files.
  - **Plantillas (Templates):** It contains the templates for the **Mapas (Maps)** file
- **E:\Consultoría MAR FUND - Copy\TDR (ToR)**

This file contains all the shapes used for the consultancy, clearly identifying each file with the file corresponding to the information requested in the ToRs of the consultancy. All the data that were included during the consultancy are numbered and clearly identified in a file.



#### Annex 4. Control of Developed Maps

Map	Development Control									
	Spanish					English				
Name	General	Belize	Guatemala	Honduras	Mexico	General	Belize	Guatemala	Honduras	Mexico
Fishing areas (Managed Access) / Áreas de pesca manejadas	X	X				X	X			
Protected areas/ Áreas protegidas	X	X	X	X	X	X	X	X	X	X
Bathymetry/ Batimetría	X					X				
Coral bleaching / Blanqueamiento de corales (AGRRA-HRI)	X	X	X	X	X	X	X	X	X	X
Coral bleaching / Blanqueamiento de corales (ReefBase)	X	X		X	X	X	X		X	X
Water quality –pH/ Calidad de agua –pH	X					X				
Water quality –salinity/ Calidad de agua –Salinidad	X					X				
Water quality –temperature/ Calidad de agua –Temperatura	X					X				
Coral coverage/ Cobertura de corales	X	X	X	X	X	X	X	X	X	X
Mangrove cover and river mouth/ Cobertura de manglares y desembocadura de ríos	X	X	X	X	X	X	X	X	X	X
Mangrove, beaches and seagrass cover/ Cobertura de mangle, playas y pastos marinos	X	X	X	X	X	X	X	X	X	X
Ocean currents east/ Corrientes marinas este	X					X				
Ocean currents north/ Corrientes marinas norte	X					X				
Distribution of algae/ Distribución de algas marinas	X	X	X	X	X	X	X	X	X	X
Coral disease/ Enfermedades de coral	X	X		X	X	X	X		X	X
Hurricane (8)/ Huracanes (8)	X					X				
Mangrove, beaches, rivers and tourist sites/ Manglares, playas, ríos y sitios turísticos/	X	X	X	X	X	X	X	X	X	X
Surgeon fish/ Pez cirujano	X	X	X	X	X	X	X	X	X	X
Lion fish/ Pez león	X	X	X	X	X	X	X	X	X	X
Parrot fish/ Pez loro	X	X	X	X	X	X	X	X	X	X

Reef restoration projects/ Proyectos de restauración de arrecifes	x					x				
Hurricane recurrence/ Recurrencia de huracanes	x					x				
Illegal navigation routes/ Rutas de navegación ilegales	x					x				
Navigation routes/ Rutas de navegación	x	x	x	x		x	x	x	x	
Navigation routes 2/ Rutas de navegación 2	x	x		x	x	x	x		x	x
Navigation routes 3/ Rutas de navegación 3	x	x	x	x		x	x	x	x	
Fish aggregation sites/ Sitios de agregación de peces	x	x	x	x	x	x	x	x	x	x
Whale shark aggregation sites/ Sitios de agregación del tiburón ballena	x	x		x	x	x	x		x	x
Bird nesting sites/ Sitios de anidación de aves		x					x			
Turtle nesting sites/ Sitios de anidación de tortugas	x	x	x	x	x	x	x	x	x	x
Manatee sighting sites/ Sitios de avistamiento de manatí	x	x	x	x	x	x	x	x	x	x
Oil exploration sites/ Sitios de exploración petrolera			x					x		
Monitoring sites AGRRA-HRI/ Sitios de monitoreo AGRRA-HRI	x	x	x	x	x	x	x	x	x	x
Monitoring sites ReefBase/ Sitios de monitoreo ReefBase	x					x				
Tourism/ Turismo	x	x	x	x	x	x	x	x	x	x
Areas of fishing importance/ Zonas de importancia pesquera	x		x		x	x		x		x
Fishing reserve areas/ Zonas de reserva de pesca	x		x			x		x		
Probability of groundings/ Probabilidad de encallamientos	x					x				
Larva collection sites/ Sitios de colecta de larvas	x					x				
Biodiversity Index Map	x					x				
Threats Map	x					x				

## Annex 5. MaxEntm Results Threats 2 (corals)



Maxent model for  
Arrecifes\_de\_coral.pdf

**Click on the icon to open the document.**