

# Mapping Ocean Wealth – Gulf of California

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First Interim Report To  
The Nature Conservancy

Report Period: July 1<sup>st</sup>, 2015 to June 15<sup>th</sup>, 2016

By



**Centro Para la Biodiversidad Marina y la Conservación**

Marcia Moreno-Báez and Andrés Cisneros-Montemayor

Institute for the Oceans and Fisheries, The University of British Columbia

In Collaboration with

Octavio Aburto-Oropeza, Andrew Frederick Johnson, Alfredo Girón



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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## 1. SUMMARY

A number of recent studies and global initiatives such as the Millennium Ecosystem Assessment and The Economics of Ecosystems and Biodiversity (TEEB) have significantly raised awareness of the value of nature and its contribution to wellbeing and development outcomes. A key approach to accomplish this will be to demonstrate how to incorporate ecosystem benefits and values in integrated ocean management through regional applications, devised based on local needs assessments and opportunities for policy reform. This includes the development of new data, the use of decision support tools, and trade-off analyses.

The Mapping Ocean Wealth - Gulf of California project has contributed to addressing these aspects in the region and is improving our understanding of the key factors (habitat types and processes) by producing new “ocean wealth” data layers. One of the main goals was to develop and communicate these “ocean-wealth” data layers, especially for fisheries and tourism-recreation services derived from key habitats in the Gulf of California: rocky reefs/sargasso, mangroves and the pelagic habitat.

The Gulf of California Marine Program (i.e., Centro para la Biodiversidad Marina y la Conservación, Scripps Institution of Oceanography) supported this initiative by 1) Reviewing and gathering data on the value of rocky reefs and mangroves for fisheries productivity; 2) Developing models, including drivers, algorithms and expert opinion, for fisheries activities; and 3) Producing “ocean-wealth” maps. In the near future, we will also produce and distribute communication materials (peer-reviewed papers, technical reports and public outreach papers, including value of nature and examples of trade-offs) that will allow us to reach a wider public.



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»  
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## **2. MAIN OBJECTIVES ESTABLISHED FOR THE PROJECT**

**Objective 1:** Reviewing and gathering data on the value of rocky reefs and mangroves for fisheries productivity.

**Objective 2:** Calculate total fisheries landings in the Gulf of California.

**Objective 3:** Produce models to estimate economic values of ecosystem services in the Gulf of California.

## **3. ACCOMPLISHMENTS AND PROBLEMS DURING THE PROJECT'S PERIOD**

Accomplishments:

- We compiled and reviewed 25 datasets from 19 different sources.
- We harmonized existing datasets on a range of topics to aid in this and future analyses. This involved spatial, temporal, and unit standardization to produce a single consistent dataset.
- We were able to produce a layer with the estimated area of rocky reef for the Gulf of California.
- We were able to generate a layer with an estimate of sargassum for the Gulf of California.
- We obtained the most updated layer of mangroves' distribution from CONABIO.
- We obtained the most updated data from CONAPESCA, and were able to calculate the geographic distribution of fishing catch for 22 different groups of species based on fishery landings data.



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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- We produced bioeconomic models to map the added value of achieving sustainable fisheries in the Gulf of California.
- We obtained updated data on nature-based tourism expenditures and were able to map the spatial distribution of this industry in the Gulf of California.

#### Problems:

- Systematization and standardization of data was difficult given the many different sources the data came from. For example, the scale at which some of the datasets were generated varied greatly. This complicated a simple calculation of areas or the integration of data without some sort of transformation or interpretation.
- Fisheries data (landings) are reported by office and this becomes a problem when trying to understand the spatial distribution of fishing effort. This is a well-known problem with no straightforward solution. It wasn't easy to decide the best approach to estimate a potential distribution of catch for the Gulf of California.
- Bioeconomic models rely on available fishing cost and species abundance and distribution data, which can be uncertain in the region. Monitoring efforts and prior research did provide highly useful data to parameterize models, but results are best interpreted in relative rather than absolute terms. This can be improved as more data become available, but for now it does allow for useful spatial visualization of results through maps.



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T. +52 «Phone»

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## **4. GENERAL DESCRIPTION OF MAIN ACTIVITIES AND METHODS**

### **a) Data collection**

Different repositories and data sources available were collected and reviewed in order to define the baseline in terms of available information on various themes related to fisheries and habitats in the Gulf of California. Table 1 summarizes the information collected. Based on these data, we defined a broad layer classification as specified by TNC/MOW team.



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

[www.gocmarineprogram.org](http://www.gocmarineprogram.org)  
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**Table 1. Data layers (currently available) and sources**

Theme	Source	Citation	Brief description
Rocky reefs	CEDO	Yes	Location of rocky reefs habitats. Expert and local knowledge. Fishing sites (2004).
	CBMC / Scripps	Yes (various)	Location of rocky reefs habitats. Monitoring program (1998 - 2014).
	PANGAS project	Yes (various)	Location of rocky reefs habitats. Monitoring program (2007 - 2011).
	PANGAS project	Yes (various)	Local knowledge - rapid appraisal. Location of fishing grounds related to rocky habitats.
	Halpern et al.,	Yes	Seafloor type.
	COBI / TNC	Yes	Coastline type (2006).
Seamounts	Halpern et al.,	Yes	Seafloor type.
	NCEAS	N/A	Location of seamounts (attributes).
	Sala et al.,	Yes	Location of seamounts. Expert knowledge.
Mangrove	CONABIO	Yes	Area of mangrove. Raster analysis (1970, 2005, 2010).
	Semarnat - UNAM	Yes	Area of mangrove mapped (land-use analysis).
	Packard / UofA	Yes	Location of esteros and estuarios. Expert knowledge (2004).
	Ramsar	Yes	Location of important .
Rodoliths	COBI	Yes	Location of rodoliths (monitoring effort, various years).
	Sala et al.,	Yes	Location of rodoliths.
	SNIB	Yes	Location of rodoliths.
	Rafael Riosmena	Yes	Location of rodoliths.
Sargassum	Alvin Suarez et al.,	Yes	Location of sargassum.
	Reyes et al.,	No	Potential sargassum presence. Model in construction.
Fisheries	CONAPESCA	Yes	Fisheries data including species, catch, date, fishing office.
	INEGI	Yes	Fisheries economic data including landed value, value added, wages, and employment
	WWF / Plomozo	Yes	Number of vessels (pangas) counted in the Gulf of California.
Nature-based tourism	TNC / UBC/ CBMC		Location of nature-based tourism expenditures in the Gulf of California (mainly Baja California Sur)
Biomass	CBMC / Scripps	Yes	Layer generated from the location of rocky reefs habitats. Monitoring program (1998 - 2014).
Richness	CBMC / Scripps	Yes	Layer generated from the location of rocky reefs habitats. Monitoring program (1998 - 2014).



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 T. +52 «Phone»

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Theme	Source	Citation	Brief description
Potential Fishing Effort	CBMC / Scripps	Yes	Johnson et al., in review. A simple spatial method to estimate the extent of natural resource extractions.

## b) Data layers

The data layer definition was based on an expert workshop held in 2014 where independent ecological researchers along with the Mexican organizations CONANP (national commission of natural protected areas), COBI (community and biodiversity), PRONATURA discussed future plans for the protection of the Gulf of California's Grandes Islas region under future climate change stresses. One of the outcomes of the workshop was a list of all ecosystem services provided by this region in the Gulf.

Once the list was evaluated and agreed, all data layers were reviewed by experts from the Scripps Institution of Oceanography, Institute for the Oceans and Fisheries (University of British Columbia), Centro de Biodiversidad Marina y Conservación, A.C. (México), Arizona State University, and Comunidad y Biodiversidad, A.C. (México), during a workshop organized in San Diego during August 24th–28th, 2015.

### Rocky Reefs

This layer is the compilation of the layers listed in Table 1 that included rocky reefs and seamounts. The spatial layers were generated based on different spatial scales and methods. Additionally, an exhaustive review of satellite images from Google Earth Pro was performed to map additional rocky reefs throughout the coastline and around islands.

The different data layers were transformed to a point layer and an advanced geostatistical procedure called Kriging interpolation method (Oliver & Webster 1990) was used to generate a layer of potential rocky reef area / km<sup>2</sup>. This



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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interpolation method generates an estimated surface from a scattered set of points with z-values (ha per km<sup>2</sup>) and effectively involves an interactive investigation of the spatial behavior of the phenomenon represented by the z-values.

Once the raster layer from the Kriging analysis was generated, an estimated area by spatial unit of (500km<sup>2</sup>) was calculated (Figure 1a).

### Sargassum

This layer is a combination of a sargassum habitat model by Suárez-Castillo et al., (*in prep.*) and the rocky reef layer generated.

The model of potential distribution by Suárez-Castillo et al., (*in prep.*) was generated using a software called MaxEnt 3.3.3k. This model works under an algorithm of maximum entropy of species geographic distributions (Phillips, Anderson and Schapire, 2006)<sup>1</sup>. See also Appendix 1 for details in methods.

The rocky reefs layer was then utilize to multiply the potential area of rocky reef by the probability of sargassum occurrence. A final layer of potential sargassum area was generated and represented by spatial unit (500km<sup>2</sup>) (Figure 1b).

### Mangroves

The mangroves layer was provided by CONABIO and no analytical process was performed other than transforming the information into our spatial units of 500km<sup>2</sup> (Figure 1c).

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<sup>1</sup> More information about the model can be found in supplemental information.

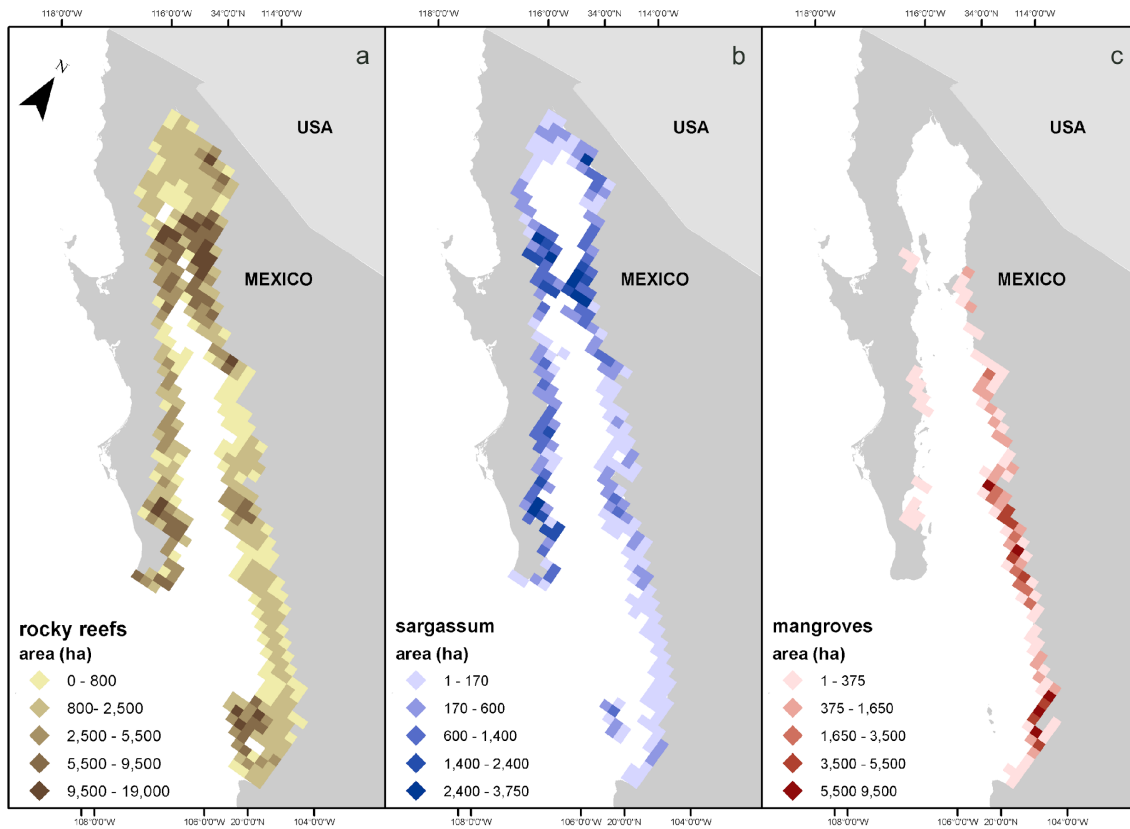


Figure 1. Habitats: 1) rocky reefs and areas in ha; b) sargassum; c) mangroves.

## SPATIAL DISTRIBUTION OF FISHING LANDINGS FROM CONAPESCA

### Data

Five years of fishing landings from CONAPESCA (2009-2013) were used to calculate the mean catch, revenue and prices. The data include 22 offices within the Gulf of California Region. Appendix 2 shows the 22 different groups of species used and the common names - according to CONAPESCA - of the species included within each group. This list of groups of species was selected based on clusters of species that were commercially important and that could be identified in both, the fisheries landings from CONAPESCA and the monitoring program data.



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

[www.gocmarineprogram.org](http://www.gocmarineprogram.org)  
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The average annual catch and the average price per kilogram for each species as reported by CONAPESCA (2009-2013) were also calculated for the group of species. Revenues were obtained for each group of species using the average of 2009 – 2013 for each group of species in dollars.

### **Spatial Analysis**

The Kernel Interpolation method (Silverman, 1986) was used to predict the potential distribution of catch based on the CONAPESCA data. The parameters used were the following:

- Output cell size: 1km
- Kernel function: Fifth order polynomial function (Polynomial5)
- Order polynomial: 1
- Ridge parameter: 50
- Bandwidth<sup>2</sup>: 200,000m or 150,000m
- Output surface type: Prediction
- Barrier type: feature class coastline (INEGI) and depths > ~200m (NOAA)<sup>3</sup>

The fifth order polynomial function was selected

The bandwidth used for our analysis was based on the criteria of the minimal distance between offices in order to cover all potential communities reporting in the closest office. In data poor cases or for sessile species, we used 150km distance.

Two examples show the distribution of catch using this method. Figure 2 shows the distribution of catch for *groupers*, a species well represented in all CONAPESCA

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<sup>2</sup> Bandwidth is used to specify the maximum distance at which data points are used for prediction. With increasing bandwidth, prediction bias increases and prediction variance decreases.

<sup>3</sup> This barrier was represented in a 500km<sup>2</sup> cell size file generated for the Gulf of California; all cells that fall under the coastline or in isobaths deeper than 200m were excluded.

offices and, Figure 3 show the distribution of *surgeon fish*, a species that is only reported in the southern offices in the Gulf of California.

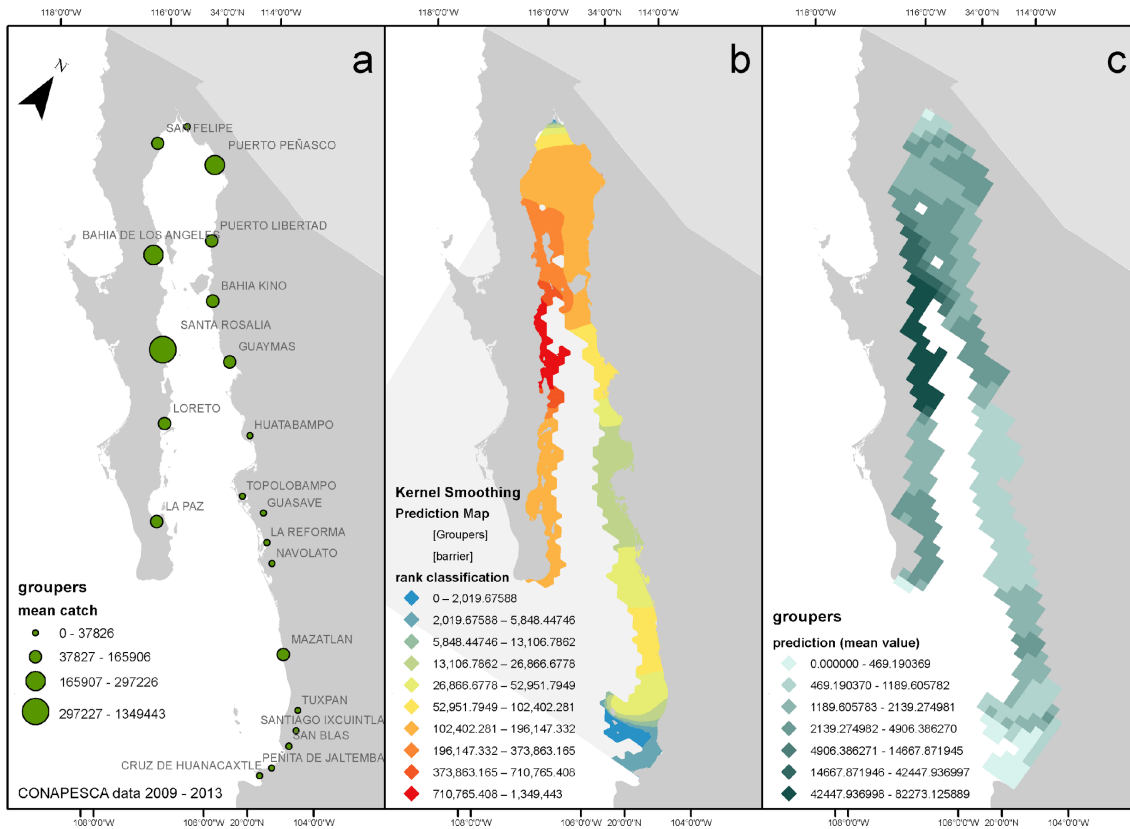


Figure 2. Spatial representation of CONAPESCA data for groupers. a) mean catch for CONAPESCA offices that reported catch for this species; b) visual representation of kernel interpolation analysis and the different classification of catch distribution (min and max) by area; c) mean catch by spatial unit (500km<sup>2</sup>)

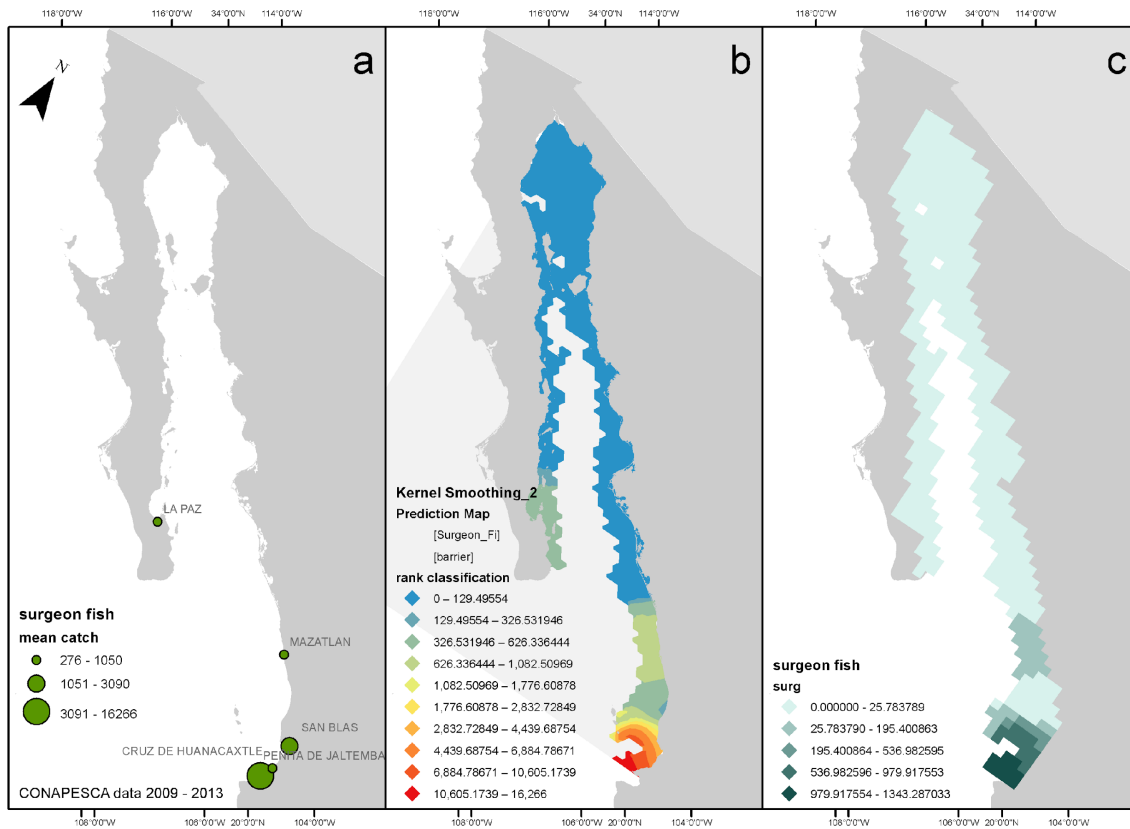


Figure 3. Spatial representation of CONAPESCA data for *surgeon fish*: a) mean catch for CONAPESCA offices that reported catch for this species; b) visual representation of kernel interpolation analysis and the different classification of catch distribution (min and max) by area; c) mean catch by spatial unit (500km<sup>2</sup>)

Once data was interpolated, a layer was generated to calculate zonal spatial statistics by each of the spatial units of 500km<sup>2</sup> for the Gulf of California being used in this exercise. Layers of min, mean and max values were generated for each of the group of species.

Average price and revenue were calculated by CONAPESCA office. In order to have a spatial distribution of this information, we defined an area of influence by fishing office. A Thiessen polygon tool was used to create areas of influence using the CONAPESCA offices, which represented the input features needed to calculate the polygons (Figure 4a). The tool works performing an analysis where any location within a Thiessen polygon is closer to its associated point than to any other point input feature. Every Thiessen polygon was then used to select the

spatial units (500km<sup>2</sup>) using “Select by location” in ArcGIS that intersected with every CONAPESCA office. A discrete value (name) was assigned and spatial units were classified by area of each CONAPESCA office influence (Figure 4b).

Average price per species group and average annual revenues per species group were distributed to all spatial units of 500 km<sup>2</sup> using the calculated Thiessen polygons (Figure 4b). The price of a species group per office was assigned to all the cells under the influence area of each office (e.g. price per species = 20; Number of spatial units corresponding to a specific CONAPESCA office= 10; Price assigned by spatial unit = 20). Values of total revenue by office / group of species, were evenly divided by the number of spatial units that correspond to each CONAPESCA office (e.g. Total revenue = 1000; Number of cells in the influence area = 10; Revenue per cell = 1000/10 = 100).

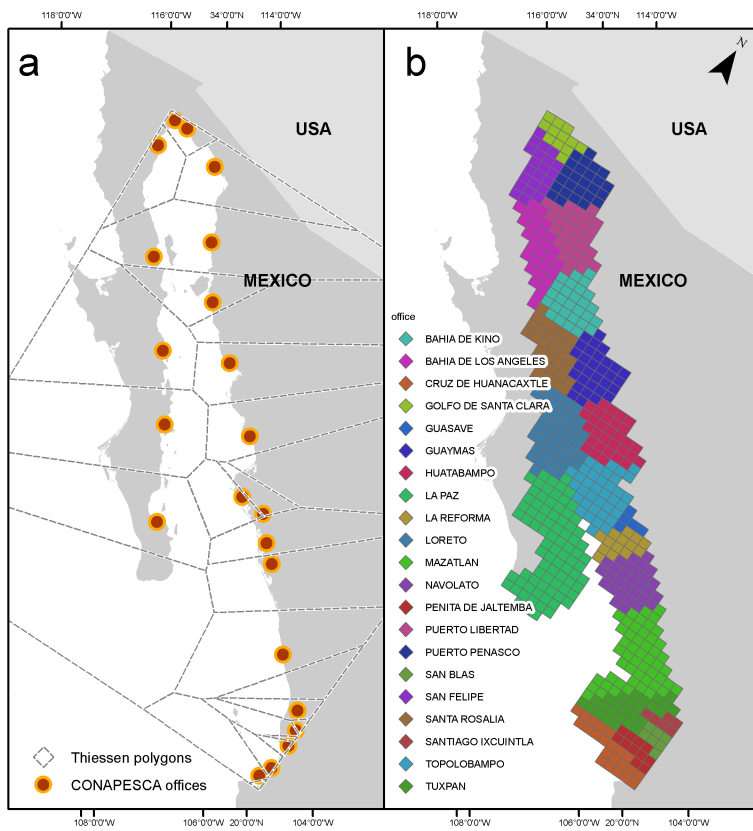


Figure 4. Spatial representation of CONAPESCA offices' area of influence: a) Thiessen polygons generated using the CONAPESCA offices; b) spatial units (500km<sup>2</sup>) classified by area of influence.

## SPECIES RICHNESS

Species richness was calculated using the total number of species found on each point of the monitoring program data sets (Gulf Program, PANGAS and COBI). Data included years of 1999, 2009 and 2010, which comprised the largest spatial sampling extent in the Gulf of California. The data was then used to feed the Inverse Distance Weighting (IDW), which is a type of deterministic method for multivariate interpolation with a known scattered set of points. The assigned values to unknown points were calculated with a weighted average using richness as values (Figure 5).

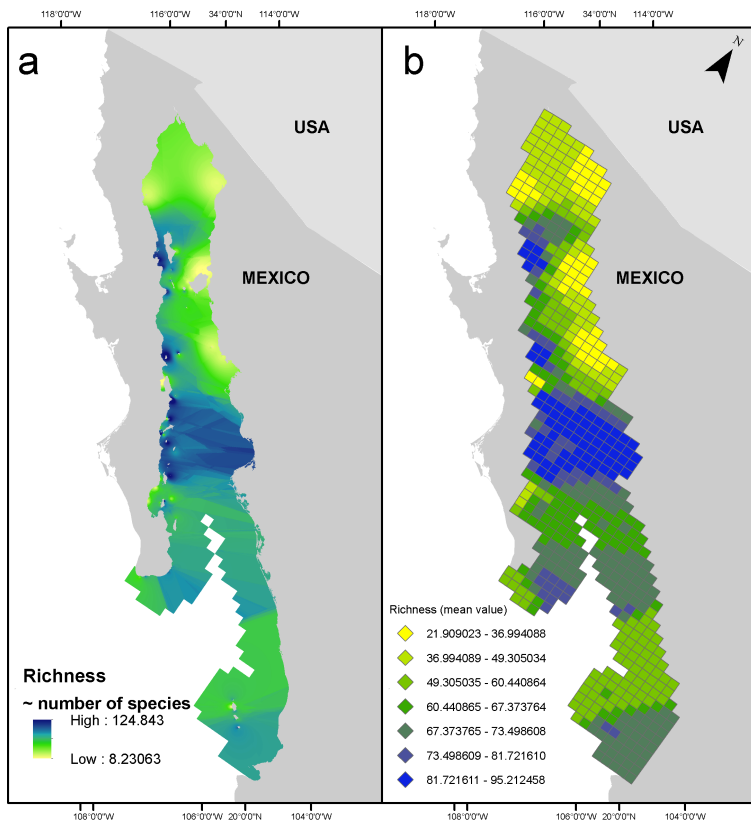


Figure 5. Spatial distributio of richness for the Gulf of California: a) IDW results; b) richness represented on the spatial units (500km<sup>2</sup>).

## VESSEL TRAFFIC

### Data

The AIS vessel-tracking image was provided by the organization AIS tracking system in a JPEG format with a spatial resolution of 0.1 degree raster (see K.Boerder & D.Kroodsma). The image was under the coordinates latitude 19.121 to 32.159, longitude -119.387 to 105.439 and it was classified with colors representing counts of positions by square (Figure 6). However, the authors suggested to be cautious about the information given that satellites used to map the traffic are sometimes not present in an area of traffic, hence some gaps in coverage might exist.

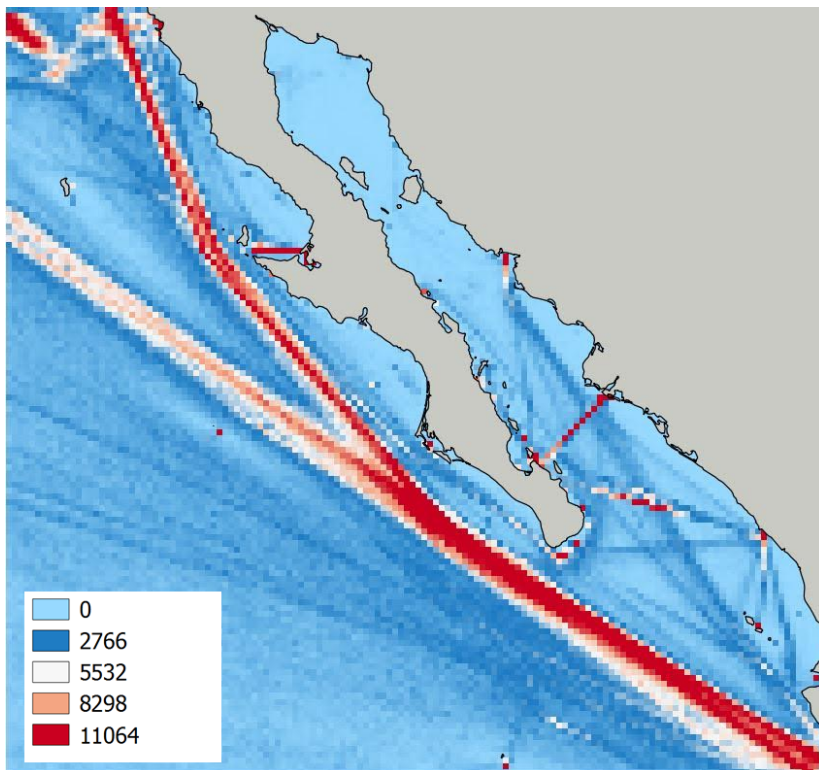


Figure 6. Vessel traffic in the Gulf of California and Pacific Ocean.

The image was georeferenced<sup>4</sup> and converted to a shapefile (Figure 7). Classes were assigned based on the same classification provided with a note by the authors suggesting as maximum value: 582,319.

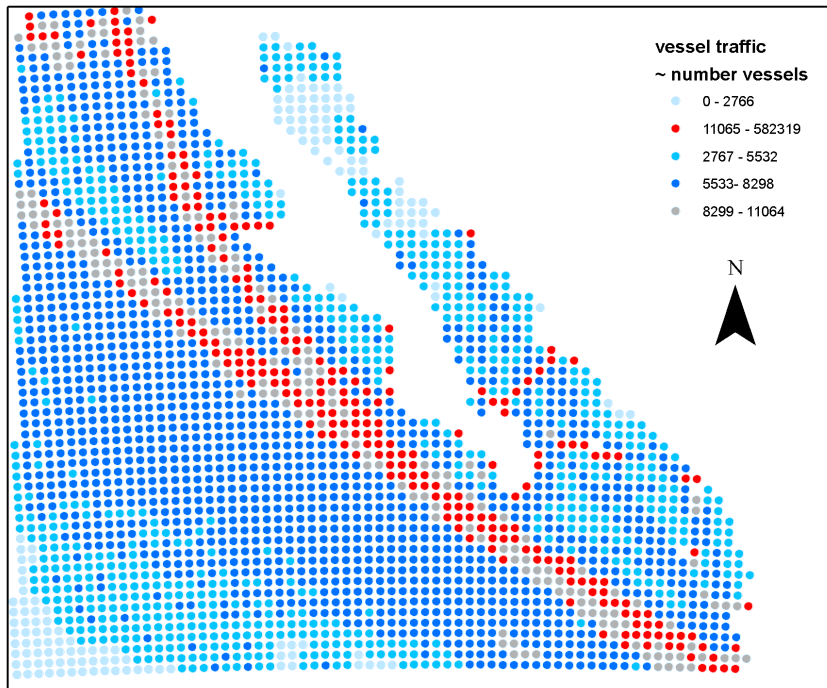


Figure 7. Vessel traffic shapefile with an approximate classification provided by the source AIS traffic.

## ADDED VALUE FROM FISHERIES MANAGEMENT

### Data

Given that the majority of Mexican fish stocks are fished at or above MSY levels (DOF, 2012) and under-regulated (Cisneros-Montemayor et al. 2013), current fisheries wealth could likely be increased through improved management. We estimated the theoretical outcomes of maximizing a) yield and b) profit (Figure 8) using a Gordon-Schaefer-type bioeconomic model (Clark 2006), which requires

<sup>4</sup> Process of associating an image of a map with spatial locations in geographic information system.

that carrying capacity and intrinsic population growth are known or at least estimated.

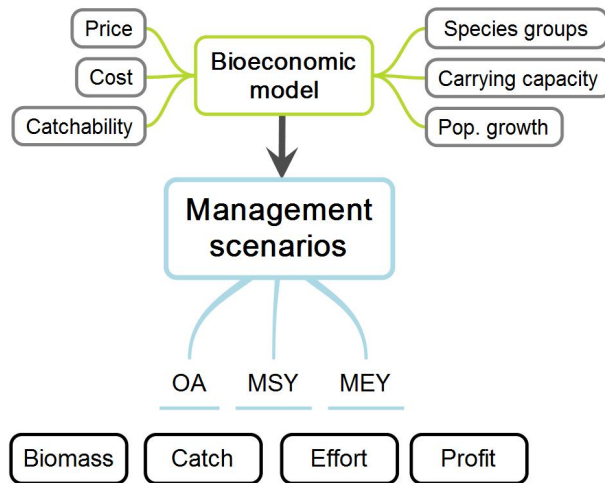


Figure 8. Methodological framework for estimating potential fisheries wealth in the Gulf of California. OA = Open Access, MSY =Maximum Sustainable Yield, MEY = Maximum Economic Yield.

We limited the analysis to key fisheries target species groups ( $n=19$ ) with robust information available for these parameters through monitoring efforts (Table 1).

Table 1. Fisheries target species groups included in Gulf of California bioeconomic model.  $K_{max}$ = maximum carrying capacity observed from the monitoring program data (estimated as the maximum biomass per hectare for each species group between 1998-2013) (tonnes/ha.);  $r$  = intrinsic population growth rate calculated from the same monitoring data (estimated from a logistic population growth model with data between 1998-2013). A list of all species within each group is provided in Appendix 1.

Group	K	r
Barracuda	4.43	0.20
Botetes	0.18	0.37
Cardenal	2.46	0.22



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 La Paz, B.C.S., México  
 CP. 23090  
 T. +52 «Phone»

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Chivatos	0.54	0.29
Chopas	1.61	0.34
Cochis	0.56	0.20
Groupers	2.19	0.28
Grunts	1.31	0.73
Jacks	2.65	0.15
Lisas	0.12	0.56
Mojarras	0.07	0.27
Morenas	0.12	0.20
Mulegino	0.70	0.21
Myripristis	0.19	0.33
Parrots	0.39	0.21
Scorpions	0.02	0.04
Snappers	1.44	0.25
Surgeons	1.01	0.31

## Method

Maximizing fisheries yield (fishing at MSY levels) only requires information on species productivity in a given spatial cell. This reference point has been criticized in light of the push for ecosystem-based management (C. Walters et al. 2005), yet MSY continues to be a widespread benchmark for fisheries worldwide (Walters and Martell 2004). Assuming a Schaefer (logistic) population growth function, fishing a population down to half of its carrying capacity allows for the highest yearly productivity and subsequent fisheries catch. It is important to note that a species can be sustainably overfished at a higher fishing effort—and, all things being equal, employment—than that required for MSY, yet overall catch would be reduced (Figure 9 below).

Maximizing the economic yield (fishing at MEY levels) or economic rent maximization involves the incorporation of economic parameters to add realism to fishery dynamics. In this analysis, these are represented using a bioeconomic model that assumes that active effort will seek to maximize profits from a fishery



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La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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given the price of catch and cost of fishing effort. Within a given year, profit-maximizing vessels will thus choose where to fish, considering the travel costs from their home port to a given fishing ground, the variable costs of their selected fishing gear, and their expected revenue given the abundance and market price of the specific species at the fishing ground. Note that, for this exercise, we do not account for longer-term dynamics affecting total fishing capacity, such as fleet growth or infrastructure and technological development. Due to data availability, we only considered fuel costs in the estimation of variable vessel costs as fuel represents the largest component of total costs for artisanal fishing vessels (Lam et al. 2011; Johnson et al., *In review*).

In order to calculate open access (OA) outcomes for fisheries in the Gulf, we use the same set of parameters. Given that artisanal fisheries in Mexico are mostly *de facto* open access (i.e. have very little management regulation of any kind), this estimate can be compared to independent estimates of catch and effort (and, where available, biomass) to evaluate the results of our model. Estimations for the scenarios above—and for current and potential ecological status—were performed using the parameters and equations outlined below (Table 2), for each grid cell (500 km<sup>2</sup>) in the Gulf of California.



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La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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Table 2. Fleet dynamics model parameters, definitions, and units (where applicable).

Parameter	Definition	Source	Units
$K_{max}$	Maximum carrying capacity	Underwater monitoring	Metric tonnes
$r$	Intrinsic population growth	Estimated from underwater monitoring abundance	
$q$	Catchability	Assumed equal to reported $q$ for artisanal snapper fishery (Instituto Nacional de la Pesca 2006).	Metric tonnes /unit effort
$B$	Biomass	Model output	Metric tonnes
$Y$	Yield	CONAPESCA (2009 - 2013)	Metric tonnes
$i$	Spatial cell	Model input	500 km <sup>2</sup>
$j$	Species group		
$P$	Ex-vessel (unit) price	CONAPESCA (2016)	USD/ metric tonne
$c$	Unit cost of effort	Calculated based on cell distance (Euclidian Distance ArcGIS) to closest port, fuel efficiency of artisanal vessels (km/L), and fuel cost (0.75 USD/L)	USD/vessel
$R$	Total fishing revenue	Model output	USD
$C$	Total cost of effort	Model output	USD
$\Pi$	Total profit	Model output	USD

Below are generalized equations from the Gordon-Schaefer model to support the equilibrium equations in Table 2. Note that we do not incorporate temporal dynamics into our estimates, i.e. we do not factor in the time it would take to rebuild ecosystems and fish populations to MSY or MEY levels, though this would be possible in a future analysis (e.g. Sumaila et al. 2012).

$$Y_{i,j} = B_{i,j} \cdot q_i \cdot E_i \quad [1]$$



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 T. +52 «Phone»

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$$R_{i,j} = Y_{i,j} \cdot p_j \quad [2]$$

$$C_i = E_i \cdot c_i \quad [3]$$

$$\Pi_i = [p_j \cdot Y_{i,j}] - [c_i \cdot E_i] = R_{i,j} - C_i \quad [4]$$

The equations above result in estimates of effort, catch, biomass, and profits for a fishery targeting a given species in a given cell. However, artisanal fisheries in the Gulf of California (as in most places) target multiple species sequentially or simultaneously throughout the year (DOF 2012; Cheung and Sumaila 2008). Thus, at any given time and level of effort, total revenue  $R$  over all species  $i$  from a particular spatial area  $j$  becomes:

$$R_j = \sum_i [K_{max_{i,j}} \cdot (1 - q_i \cdot E_j / r_i)] \cdot q_i \cdot p_{i,j} \cdot E_j \quad [5]$$

For any level of effort (i.e.  $E_{OA}$ ,  $E_{MSY}$ ,  $E_{MEY}$ ), biomass is estimated in the first component of Eq. 5. This numerical approach to estimating bioeconomic dynamics is useful in that it allows for a straightforward visualization of multi-species fisheries in an area (Figure 9), and simplifies calculations and relationships between outcomes at various reference points.

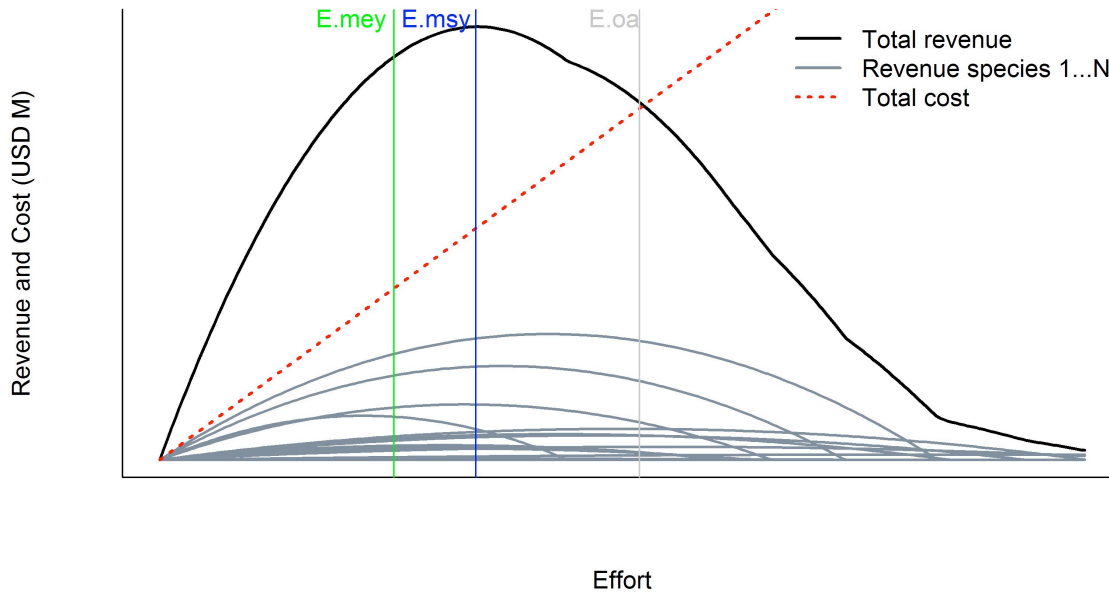


Figure 9. Example of multi-species revenue and total cost for a single spatial area. For each such cell in the Gulf of California, open access equilibrium is reached when fishers' total revenue and cost are equal. Total revenue is the sum over revenue from all species in the particular spatial cell. E.msy= effort at maximum sustainable yield. E.mey= effort at maximum economic yield. E.oa= effort at open access equilibrium.

The methods described above are repeated for every spatial unit (500km<sup>2</sup>) using biological parameters for each fish species analyzed, ex-vessel prices, and fishing costs. We thus estimate the resulting biomass, effort, catch, revenue, and profit, both for the total cell and for each species, given effort at open access equilibrium, maximum sustainable yield, and maximum economic yield.

Due to the quality and quantity of available data (e.g. the “true” amount of current catch; (Cisneros-Montemayor et al. 2013), final outputs are best visualized in relative rather than absolute terms, spatially over the Gulf of California. Final layers (including each spatial unit in the Gulf of California) are the current estimated landed value of fisheries (Figure 10a); the potential fisheries landed value (Figure

10b) and catch (Figure 10c) if cells were fished at MSY (joint over all species), and the change in profit if cells were fished at MSY (Figure 10d), i.e. the added value from improved management.

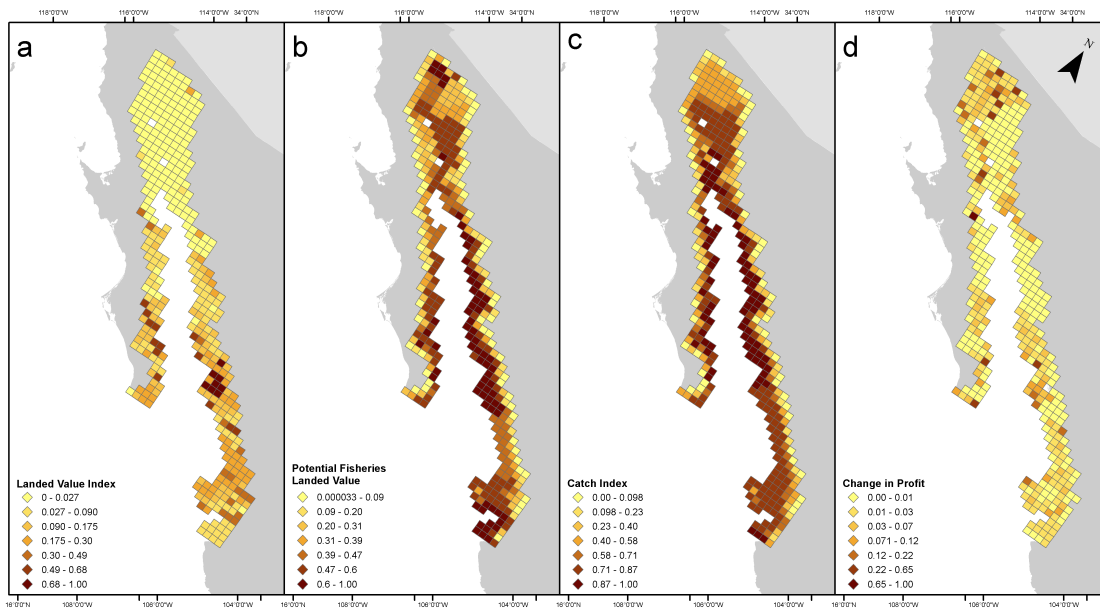


Figure 10. Spatial bioeconomic fisheries model results for the Gulf of California. Each spatial unit area is 500km<sup>2</sup>; results are shown scaled to the maximum value in each figure. **a)** Current estimated landed value of fisheries (data from CONAPESCA 2009-2013). **b)** Potential fisheries landed value and **c)** catch if cells were fished at MSY (joint over all species). **d)** Change in profit if cells were fished at MSY relative to open access equilibrium.

Aside from issues of data availability, that can be addressed and improved over time, the approach outlined allows for highlighting priority areas for concern (in terms of biological or economic overfishing), but also priority areas for action where gains from improved management are expected to be greatest. Most importantly, our methods can be scaled down as needed, maximizing use of available local data and qualitative information in order to advise stakeholders and policy.



Calle del Pirata #420  
Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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## **NATURE-BASED TOURISM EXPENDITURES**

### **Data**

As part of the Mapping Ocean Wealth project, a recent survey effort estimated the economic contribution (in terms of participation, employment, and expenditures) of nature-based tourism in the Gulf of California and Baja California Peninsula (Cisneros-Montemayor et al. 2016). This study provided data aggregated by cities (or towns) where operators were located, and also collected information on their preferred tourism sites (for example, a particular reef, island, or bay). These sites were ranked by operators asked to identify the most important sites for their business (for example, where they brought tourists most often).

### **Method**

Based on the data above, we compiled a set of shapefiles of nature-based tourism sites named by operators (n=98) based out of each town surveyed (n=18) in the Gulf of California region. Total expenditures reported at each location were split out into specific sites (n=71) based on operator rankings, and then mapped on to corresponding spatial areas. This allows for identifying sites where operators based out of different locations overlap, highlighting key areas generating nature-based tourism value (Figure 11).

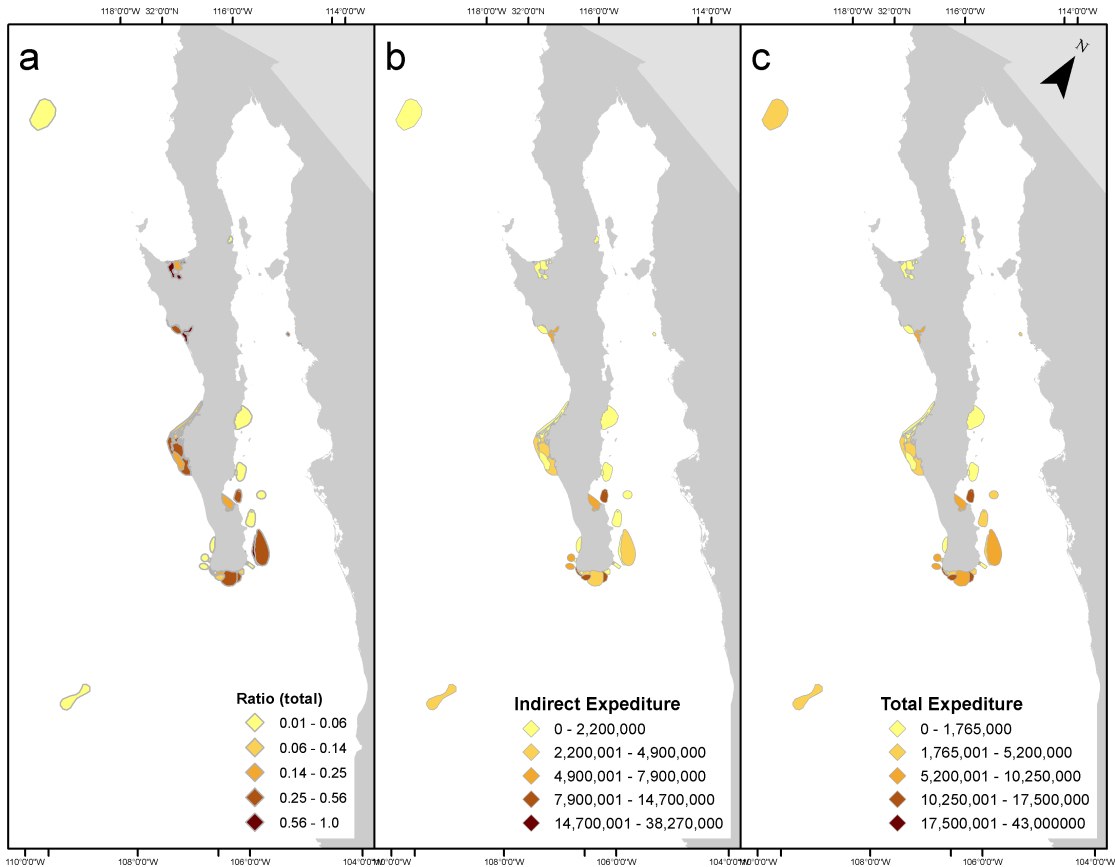


Figure 11. Nature-based tourism expenditures in the Gulf of California. Data from operator and tourist surveys (Cisneros-Montemayor et al. 2016), spatialized based on operator site rankings.

## 5. OUTPUTS

Copies of all outputs (maps, shapefiles and any other document) will be delivered in a hard drive and through dropbox.

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Col. Benito Juárez  
La Paz, B.C.S., México  
CP. 23090  
T. +52 «Phone»

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CP. 23090  
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## **Appendix 1. Sargassum Probability Layer (methodology)**

### **Metodología**

Para la generación de los modelos es necesario contar con información precisa sobre las ocurrencias georeferenciadas para la especie en el sitio de interés, por lo tanto para la primera etapa de la modelación fue generar bases de datos con dicha información, la cual fue obtenida en campo y publicaciones arbitradas.

Para la modelación biogeográfica se empleó como marco espacial la totalidad del Golfo de California, con las coordenadas extremas de latitud en 31.9 N y 18.9 S, y en longitud el -18.03 O y la zona costera continental de América.

### **Análisis de nicho ecológico y distribución potencial**

Para la elaboración de los mapas de distribución potencial para la especie, se empleó el programa MaxEnt 3.3.3k, que trabaja bajo un algoritmo de máxima entropía con el fin de crear modelos de nicho ecológico fundamentados en datos detallados sobre presencia de las especies, y en información sobre las condiciones ambientales que presentan en sus sitios de ocurrencia (Franklin, 2010, Elith et al. 2011). Para conducir la modelación se utilizaron 58 variables ambientales con sus valores promedios, máximos, mínimos y rangos mensuales; dichas variables ambientales fueron tomadas de distintas fuentes, según el factor (ver tabla).

La precisión geográfica que se empleó en los modelos generados fue de 4 km de pixel. Para la modelación de la distribución de cada especie se utilizó un 25% de los datos de ocurrencia como información de prueba y 75% fueron registros de entrenamiento para Maxent (recomendación de Franklin 2010). Finalmente, se revisó el área bajo la curva (AUC) del análisis de características operativas (ROC), ya que esto nos ayuda a definir la calidad relativa del modelo obtenido (Peterson et al. 2011; Elith et al. 2011).



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Col. Benito Juárez  
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T. +52 «Phone»

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La modelación se hizo en dos pasos, debido a que inicialmente se tenía acceso a un número muy elevado de variables oceanográficas y a que esta situación tiende a sobre parametrizar el modelo y arrojar resultados poco confiables (Peterson et al., 2011). El primer modelo se generó utilizando los puntos de ocurrencia para la especie, junto con las 58 variables ambientales, esto es con el fin de calcular el valor de importancia de cada una de estas últimas sobre los resultados de un modelo preliminar.

Hecho esto y demostrando que muchos factores no tenían relevancia mayor para estimar los sitios de presencia para la especie, se continuo por elegir las 16 variables oceánicas más relevantes, y a partir de ellas se volvieron a correr un segundo modelo definitivo que nos permitiera conocer la distribución potencial actual de *Sargassum* en el área de estudio.

Los productos de salida del programa Maxent son capas raster de probabilidad de ocurrencia para el Golfo de California, basados en un análisis de transformación logística que ajusta los valores en una escala de 0 a 1 (Elith et al. 2011; Phillips y Dudik 2008).

La parte final del análisis consistió en repetir el modelo para la especie, pero intercambiando las capas relativas a la temperatura esperada (promedio, máxima, mínima o rango, según el caso), en el horizonte del año 2050. Los nuevos mapas presentaron la distribución esperada de *Sargassum* como resultado de cambios térmicos en el océano, y se basaron en los pronósticos de temperatura de los escenarios de calentamiento (RCP 2.6, 4.5 y 8.5 equivalente a un aumento térmico de 2.6, 4.5 y 8.5 watts/m<sup>2</sup>) (IPCC, 2007)). La información provino de un ensamblaje de siete modelos de cambio climático parte del Proyecto de Comparación de Modelos Acoplados Fase 5 (*Coupled Model Intercomparison Project Phase 5; CMIP5*), realizado por el método Delta, que permite un ajuste de escala (“downscaling”) al tamaño de pixel de 4 km.

VARIABLE AMBIENTAL (FUENTE)



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Col. Benito Juárez  
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Temperatura, radiación fotosintéticamente activa, concentración de clorofila y transparencia del agua. Imágenes del satélite MODIS-Aqua entre 2002 y 2012 ([http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance\\_id=ocean\\_month](http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month)

Oxígeno, nutrientes (silicatos, fosfatos y nitratos;) y salinidad. Atlas Mundial de los Océanos 2013

(<http://www.nodc.noaa.gov/OC5/SELECT/woaselect/woaselect.html>)

Productividad primaria (2003 a 2014) Programa de Productividad Oceánica de la Universidad Estatal de Oregón

([www.science.oregonstate.edu/ocean.productivity/index.php](http://www.science.oregonstate.edu/ocean.productivity/index.php))

pH, el nivel de saturación de calcita, de aragonita, y alcalinidad Se calcularon con base en la temperatura, los nutrientes y la salinidad empleando el programa CO2SYS ([http://cdiac.ornl.gov/ftp/co2sys/CO2YS\\_calc\\_XLS\\_v2.1/](http://cdiac.ornl.gov/ftp/co2sys/CO2YS_calc_XLS_v2.1/)).

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Col. Benito Juárez  
La Paz, B.C.S., México  
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## Appendix 2. Species groups and common names from CONAPESCA

Group ID	Group	Species common names
1	Groupers	CABRILLA
		EXTRANJERO
2	Grunts	BACOCA
		BACOCO
		BURRIQUETE
		BURRITO
		BURRO
		CODORNIZ
		JOPATON
		MOJARRA PIEDRERA
		MOJARRA PRIETA
		RAYADILLO
		RONCADINA
		RONCADOR
		RONCO
		RONCO AMARILLO
RONCO ARARA		
RONCO BLANCO		



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 La Paz, B.C.S., México  
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		RONCO PRIETO
		RONCO RAYADO
		SARANGOLA
<b>3</b>	Tunnas	ALBACORA
		BARRILETE
		BARRILETE NEGRO
		BARRILETE RAYADO
<b>4</b>	Botetes	BOTETE
		BOTETE AMARILLO
		BOTETE NEGRO
		PEZ GLOBO
		TAMBOR
<b>5</b>	Snappers	PARGO
		PARGO ALAZAN
		PARGO AMARILLO
<b>6</b>	Cochis	COCHI
		COCHITO
<b>7</b>	Snails	CARACOL
		CARACOL BURRO
		CARACOL CHILE



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		CARACOL CHINO
		CARACOL CHINO NEGRO
		CARACOL CHINO ROSADO
		CARACOL DE UNA
		CARACOL GORRITO
		CARACOL OLIVO
		CARACOL PANOCHA
		CARACOL TEGOGOLO
		CARACOL TOMBURRO
		CARACOL TURBO
<b>8</b>	Jacks	BONITO
		CHICHARRO
		CHOCHO
		COCINERO
		COJINUDA
		CORONADO
		JUREL
		JUREL DE CASTILLA
		JUREL NEGRO
		JUREL PRIETO



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 Col. Benito Juárez  
 La Paz, B.C.S., México  
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		JURELETE
		MEDREGAL
		OJO DE PERRA
		OJOTON
		PALMILLA
		PALOMETA
		PAMPANERA
		PAMPANO
		PAMPANO DE HEBRA
		PAMPANO RAYADO
<b>9</b>	Cardinals	CARDENAL
		CORUCO
		CRIOLLO
		INDIO
		SANDIA
<b>10</b>	Goatfish	CHIVATO
		CHIVO
		SALMONETE
<b>11</b>	Scorpionfish	ESCORPION
		LAPON



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		RASCACIO
<b>12</b>	Chubs	CHOPA
		CHOPA ESPINA
		CHOPA GRIS
<b>13</b>	Lobsters	LANGOSTA
		LANGOSTA AZUL
		LANGOSTA CABEZA
		LANGOSTA CARIBE
		LANGOSTA ROJA
		LANGOSTA VERDE
<b>14</b>	Rays	BALA
		CHUCHO
		GUITARRA
		MANTARRAYA
		MANTARRAYA ALETA
		PEZ GUITARRA
		RAYA
		RAYA ALETA
		RAYA BLANCA
RAYA COLA		



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		RAYA CUBANITA
		RAYA MANCHADA
		RAYA MARIPOSA
		RAYA PINTA
		RAYA TORPEDO
		VIOLA
<b>15</b>	Mullets	LEBRANCHA
		LISA
		LISA MACHO
		LISETA
<b>16</b>	Parrotfish	GUACAMAYA
		LORO
		LORO JABONERO
		PERICO
<b>17</b>	Surgeons	BARBERO
		CIRUJANO
<b>18</b>	Sea urchins	AGUJA
		AGUJILLA
		ERIZO
		ERIZO MORADO



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		ERIZO ROJO
<b>19</b>	Barracudas	BARRACUDA
		BUZO
		PICUA CORSARIA
<b>20</b>	Moray eels	ANGUILA
		MORENA
<b>21</b>	Sergeants	MULEGINO
<b>22</b>	Sea cucumbers	PEPINO DE MAR
<b>23</b>	Soldierfish	SOLDADITO
<b>24</b>	Mojarras	MOJARRA GARABATA
		MOJARRA GUAPOTA
		MOJARRA MUELUDA
		MOJARRON