Mapping the Cost of an Artisanal Fishery

Mapeando el Costo de una Pesquería Artesanal

Cartographier les Coûts d'une Pêcherie Artisanale

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ABSTRACT

The mapping of costs is central to marine spatial planning, which is based on identifying trade-offs between the achievement of conservation targets (e.g. protect certain amount of the available reef) while minimising the costs to the users that depend on the ecosystem (e.g. avoiding setting a no-take area in the best fishing sites). Mapping costs is an easy task on land, where each property has a dollar value and an associated land acquisition cost. In the sea, opportunity costs are commonly used, and areas where more fishing effort occurs have a larger cost and should be avoided when setting a reserve. Spatial fishing effort is largely available for industrial fisheries from logs or satellite tracks, but spatially explicit information is generally not available for artisanal and small scale fisheries. Here we propose a method to quantify the cost of an artisanal fishery based on biological (location of fishing grounds based on satellite imagery), physical (wave exposure that restricts the access to rough locations) and economic (fuel consumption from home port) constraints. Lower costs are associated to habitats not targeted by the fishery, areas where the sea is generally rough, and regions far away from port and therefore expensive to get to in terms of fuel. We demonstrate the method in the Honduran Miskito Cays, where a marine protected area will be established and new artisanal fisheries are to be developed. By mapping the costs of the fishery we minimize the socioeconomic impacts of conservation activities and avoid expensive conservation mistakes.

KEY WORDS: Artisanal fisheries, wave exposure, fuel prices, habitat mapping, marine spatial planning

INTRODUCTION

Marine spatial planning brings together multiple users of the ocean to make informed and coordinated decisions about how to use marine resources sustainably. To do this the emphasis is placed in minimizing the impacts on the users of the resources (i.e. the "costs") while achieving conservation targets (Carwardine et al. 2008). This trade-off will not only minimize the conflict between resource users and conservationists and increase the probability of compliance and support to conservation measures, but will produce plans that are cost-effective to implement and manage.

To make spatial plans we need maps. The maps need to be spatially explicit and at a scale fine enough to fulfil the level of detail required in the management plans (Ban and Klein 2009). Because marine spatial planning trades-off conservation and use of marine resources, it requires as inputs maps for both components. Conservation targets are generally represented by maps of distribution of key species or habitats. On the other hand, the use of marine resources, generally represented by fishing (although in some other areas other sectors, such as tourism, might be more relevant), is represented as opportunity costs.

Opportunity costs or foregone revenues are generally used to describe the usage of an area for marine spatial planning (Naidoo et al. 2006). Several approaches have been used to map opportunity costs, from very simple proxies as area (assuming a uniform cost across the seascape), coastal population density, the number of fishers or fishing boats in a region, or more representative proxies such as catch or effort per unit area obtained through logbooks or vessel monitoring system data. However, this type of information is rarely available for artisanal fisheries, which frustrate conservation planning in areas subjected to these data-poor activities (Weeks et al. 2010). This work aims to fill this gap and guarantee the interests of the fishers are represented in marine spatial planning. We demonstrate the method in the Honduran Miskito Cays (Figure 1), where a marine protected area will be established and new artisanal fisheries are to be developed (Chollett et al. 2014).

MATERIALS AND METHODS

To map the cost of artisanal fisheries we took biological, physical and economic aspects into consideration. We show the general guidelines here, and we implement the method in the Miskito Cays, eastern Honduras (Figure 1). In this area, artisanal fisheries with selective gears will be developed: hook and line targeting yellowtail snapper and other reef fish, and skin diving for conch and lobster. Anticipated fishing fleets include port-based motorized fleets and sailing fleets with a broader movement range. As a result two cost layers were produced, one for each type of fleet.

Biological — Fishers aim at different areas according to their target, making habitat distribution an important factor in defining spatial patterns of fishing effort (Lynch 2006). To identify the location of potential fishing grounds we used the location of consolidated habitats according to the Millennium Coral Reef Mapping Project (Andréfouët et al. 2006).

Physical — The most important environmental constraint to fishing activity is wave exposure, with very exposed areas avoided by fishers (Chollett et al. accepted). To model the avoidance of fishers to harsh seas, we used a simple logistic regression (Equation 1) and wave exposure (*exp*) as the only explanatory variable.

$$P = \frac{1}{(1 + 10^{5exp-2.5})} \quad \text{(Eq. 1)}$$

A map of wave exposure for the area of interest was calculated using the Relative Exposure Index (REI, Malhotra and Fonseca 2007). REI is an empirical approached that includes fetch, wind speed, wind direction and depth into wave exposure calculations. The method uses an inverse distance weighting function where bottom depth variations close to a site have more effects on the exposure values than far away depth variations. REI values were calculated using the WeMo v4 software. Wind speed and direction data were obtained for the closest meteorological station in Puerto Lempira (15.3°N, 83.8°W for the period 1/07/1996 - 31/12/2012). Coastline and bathymetry data were obtained from all available National Geospatial Intelligence Agency nautical charts, coastline information from Landsat satellite imagery and depth information for shallow areas also from Landsat satellite imagery (Stumpf et al. 2003). All these data sources were combined using spatial interpolation to create a grid at a spatial resolution of 50 m. For this work, we used natural neighbour interpolation: this method finds the closest subset of input samples and applies weights to them based on proportional areas in order to interpolate a value. The method is local and does not infer trends; therefore, it does not produce peaks or valleys that are not already represented in the input samples. All analyses were carried out using ArcGIS 10 software.

Economic — Two different fishing vessels are considered to be used in the Miskito Cays: either motorized fleets or sailing boats. Motorized fleets with boats of up to 12 meter long powered by outboard diesel engines of up to 70 horse power and crewed by 2 - 3 fishers, similar to the one observed today in the Utila Cays (Chollett et al. accepted). Sailing boats of about 7 m long, holding 8 - 12 crew, similar to the ones observed today in Sarteneja, Belize (Huitric 2005).

Ports and catch collection points will be developed at seven different cays: Bogas (Vivorillos), Caratasca (Caratasca), Hobbies (Cajones), Silk (Becerros), unnamed (Cocorucuma), Savanna and Porpoise (Media Luna). All cays are larger than 0.7 hectares with woody vegetation that can provide some protection from the weather and

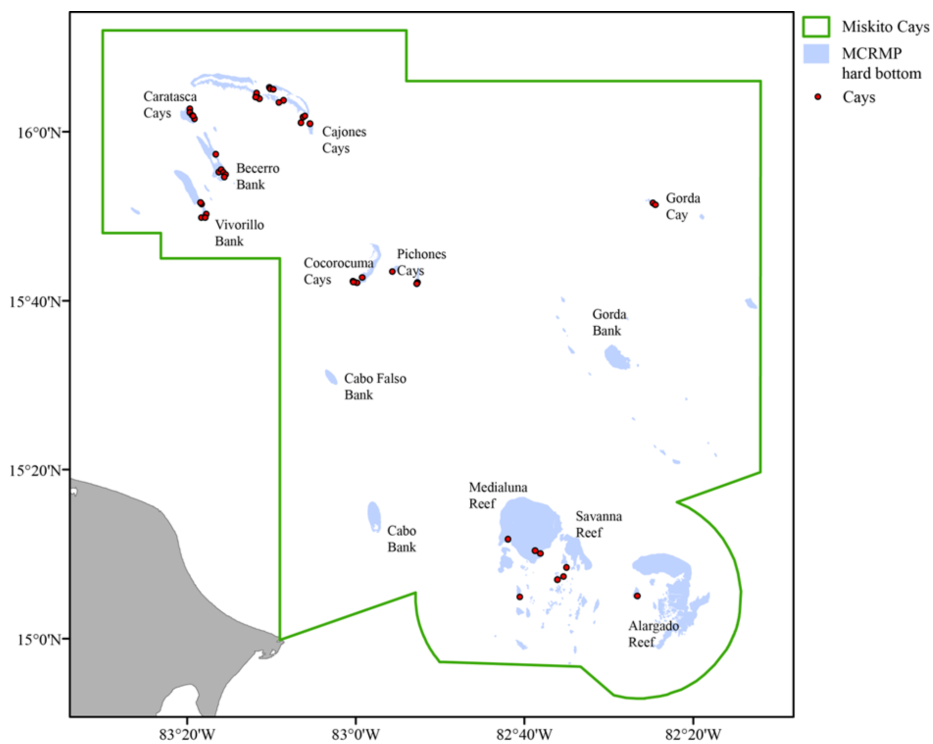

Figure 1. Location of the Miskito Cays, Honduras, mapped with medium and high resolution satellite imagery, and the consolidated shallow benthic habitats (Andréfouët et al. 2006) in the Area of Exclusive Use for Artisanal Fishing of the Miskito Cays.

guarantee the cay's permanence: many cays in the area are just temporary rubble accumulations that are not a suitable location for fishing camps.

Effort function for motorized fleets - The spatial distribution of fishing effort around home ports was modelled following the Gaussian Effort Allocation Model (GEAM) by Caddy and Carocci (1999). The model assumes that the impacts of a port-based fleet on local resources decrease with distance in an exponential fashion. The decision to fish near or far from fishers' home ports is a trade-off between travel cost and expected profits, with larger distances from port associated to higher costs (i.e. fuel) and therefore avoided. This spatial pattern has been evidenced with decreased abundance and size of target species associated to areas close to the port (Stuart-Smith et al. 2008). With time since the onset of a fishery, however, resources close to port are depleted and fishers tend to go further away from home.

Changes in effort with distance and time since the onset of the fishery are given by Equation 2:

$$E_x = P_R * e^{-\left(\frac{x-v(T-T_0)}{S}\right)^2} \quad \text{(Eq. 2)}$$

Where E_x is the fishing effort exerted at distance x from port, P_R is the change in fishing power since the onset of the fishery, S is the dispersion parameter, v indicate the velocity with which fish resources are exhausted and $(T\text{-}T_0)$ the time since the onset of the fishery. For a new fishery effort depends only on distance from port and the dispersion parameter, and Equation 2 is simply:

$$E_x = e^{-\left(\frac{x}{S}\right)^2} \quad \text{(Eq. 3)}$$

We parameterized the model for the Miskito Cays using spatially explicit data of artisanal fisheries at the Utila Cays, with similar fishing methods and fishing power to the one to be developed (Chollett et al. 2012). Current spatial fishing effort in the Utila Cays corresponds to an early depleted system where areas close to the port have been exhausted (Figure 2). We used non-linear least squares to fit Equation 1 to data in Utila. Changes in fishing power since the onset of the fishery have been minimal so P_R was assumed to be 1. The dispersion parameter S was estimated to be 18.13 and the changes in fish resource, $v\text{-}(T\text{-}T_0)$, 9.58 ($p < 0.05$, residual sum-of-squares: 1.466). For this fishery, maximum effort is concentrated in about 15 km from shore and effort is minimal at distances larger than 50 km. Using the estimated value for S we then fitted Equation 3 to estimate changes in effort with distance in a similar fishery in which depletion has not taken place (Figure 2), where maximum effort occurs close to port and maximum distances are about 45 km.

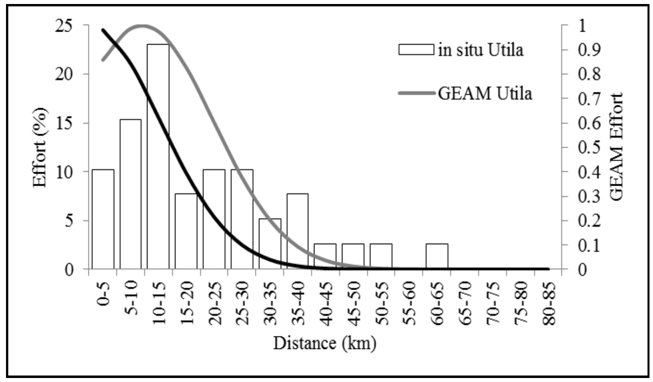

Figure 2. Percentage effort (number of trips) at different distances from port in Utila, and modelled effort using the Gaussian Effort Allocation Model (GEAM) for Utila fisheries and the new Miskito Cays fishery to be developed.

This functional relationship was then used to model spatial effort in the Miskito Cays. Each port was assumed to have constant fishing power. Distances were calculated in a realistic fashion, and fishing boats travel from the home port to each location through the seascape by avoiding islands. Spatial changes in effort with distance were calculated for each potential port and then the data for all ports was totalized.

Effort function for sail boats — Sailing boats can have access to distant fishing grounds: the distance travelled is not limited by the cost of fuel, but is restricted by how long the catch can remain fresh before reaching the markets (Huitric 2005). This method allows a more uniform distribution of fishing effort across the seascape and a less likely deterministic spatial pattern of depletion closer to port as has been described by port-based motorised fleets (Caddy and Carocci 1999).

We modelled the effort of sailing boats uniform over their entire range. The range was defined using two distance thresholds: a trip-based and a daily-based threshold. On a trip base, the distance a vessel can reach is limited by the number of days of boat autonomy (5 days), the number of daily hours of traveling (8 hours) and the average speed of the vessel (5 knots), and it was calculated as 370 km. Many times, however, boats do not reach that potential because of the need of refugia during the night. The range of a vessel will reach an actual threshold according to the characteristics of the seascape: if there are no other islands within a one-day reach then the boats will not go further away.

RESULTS AND DISCUSSION

The inputs for the cost layer show distinct spatial patterns (Figure 3). Shallow habitats targeted are scattered across the entire Area of Exclusive Use for Artisanal Fishing of the Miskito Cays (Figure 3a). Wave energy in the region is defined by the exposure to prevalent easterly winds and bathymetry, with leeward and shallow areas relatively protected from the waves (Figure 3b). Finally, the modelled effort for motorized and sailing fleets is radically different (Figures 3c, 3d). While fuel limits the area used by the fishers to locations close to the ports (Figure 3c), a sailing fleet can access the entire area without restrictions (Figure 3d).

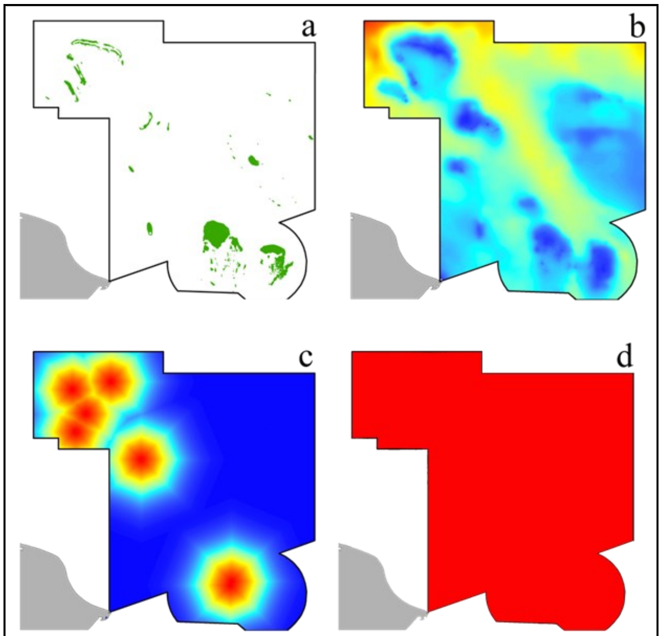

Figure 3. Inputs of the cost layer in the Area of Exclusive Use for Artisanal Fishing of the Miskito Cays: (a) targeted fishing grounds; (b) wave exposure map; (c) modelled effort for the motorized fleet; (d) modelled effort for sailing fleet. Red colours indicate high values and blue colours low values for each variable.

As a result of these patterns, the cost layer for the motorized fleet (Figure 4a) is much more heterogeneous than the cost layer for the sailing fleet (Figure 4b). In the Miskito Cays the challenge now is to combine the maps of opportunity costs for the different fisheries while maintaining equitable impacts for each fishery (Klein et al. 2009) and use this information for marine protected area design in the region.

This work shows that the lack of spatially explicit information is not an excuse to use rough proxies that will produce adverse outcomes for particular stakeholders. It **is** possible to parameterize models with relevant factors and appropriated relationships to make sure we are representing all activities and stakeholders in the best possible way in conservation plans for a win-win result.

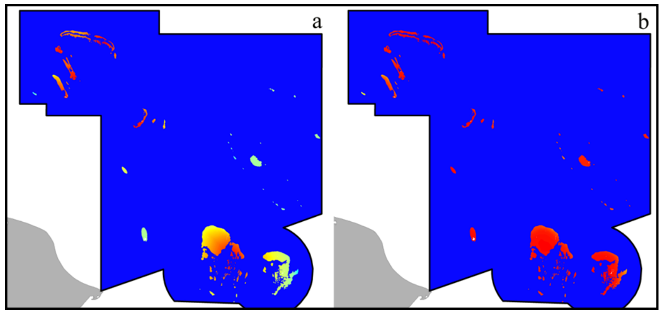

Figure 4. Cost layer for artisanal fisheries in the Miskito Cays: (a) skin-diving, motorized fleet; (b) skin-diving, sailing fleet. Red colours indicate high costs and blue colours low costs.

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