Reporte parcial para evaluar el impacto de pesquerias artesanales en el ecosistema.

# An ecosystem impact evaluation framework for data-limited artisanal fisheries: Merging traditional and scientific knowledge

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## Abstract

Ecosystem approaches to fisheries management (*EAF*) are increasingly prevalent in intergovernmental fisheries policies, national management plans, and seafood certification guidelines, and are indeed very relevant and useful for multi-species artisanal fisheries. To aid in integration of *EAF*, this study evaluates potential ecosystem impacts from artisanal fisheries, adjusting core methods depending on available qualitative and quantitative data. We analyze four case fisheries with different ecological characteristics (kelp forest, sandy shore, pelagic, and reef ecosystems) in Mexico, using existing quantitative ecosystem models (Ecopath with Ecosim) and a qualitative ecosystem developed with fishers. Target species include penshell (*Atrina maura*), ponderosus dosinia clam (*Dosinia ponderosa*), squalid callista and golden callista clams (*Megapitaria squalida and Megapitaria aurantiaca*), Humboldt squid (*Dosidicus gigas*), yellowtail amberjack (*Seriola lalandi*), spiny lobster (*Panulirus argus*), and ocean whitefish (*Caulolatilus princeps*). Results show that, at current fishing levels, these fisheries do not have significant ecosystem impacts, though our method allows to identify potential species that could be impacted if fishing effort were to considerably increase. Incorporating ecological interactions into management models can support ecologically sustainable fisheries, in addition to social and economic objectives of artisanal fishers.

## Methods

This study outlines an approach for anticipating and partially quantitively evaluating the most likely and potentially significant ecosystem effects of artisanal fisheries within a tropical developing region. We are keenly aware of the usefulness of qualitative fisheries assessment methods (e.g. Fletcher 2005, Pascoe et al. 2009), yet our aim was to offer a way to assess fisheries using a well-established quantitative platform as well as qualitative empirical knowledge. We focus specifically on the four types of impacts outlined in Figure 1. Direct impacts obviously include fishing mortality rate of target and non-target species; these impacts are the most commonly studied and estimable and are indeed the focus of most management actions. Another form of direct impact is on habitat, either through degradation, modification, or outright destruction, any of which leads to decreased stock or ecosystem production potential. The main form of indirect impact that we focus on in this study is that occurring through trophic relationships between target and bycaught species and the rest of the ecosystem. This is addressed through the use of ecosystem models as detailed below. A second type of indirect impact is a reduction in foraging efficiency due to fisheries effects; this entails a more complex set of interactions for which generally there is less available data. Therefore, here we include qualitative information derived from observations for the case studies considered.

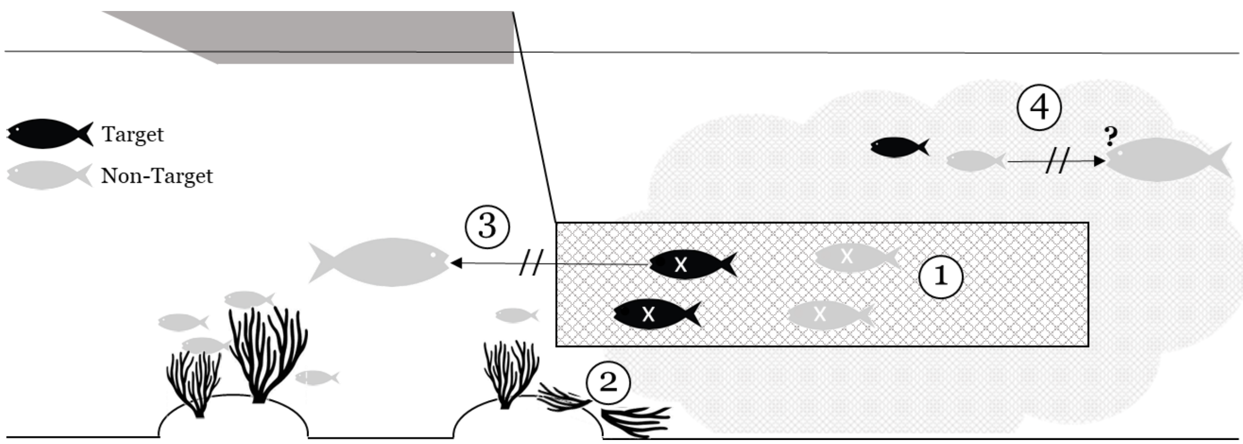


Figure 1. Typology of ecosystem impacts from targeted fisheries considered in this study. Direct impacts include 1) removal of target and non-target species and 2) habitat alteration leading to decreased productivity. Indirect impacts include 3) reduced prey availability for non-target species through trophic linkages and 4) reduction in foraging efficiency of non-target species through behavioral or habitat-linked effects (for example, increased turbidity, ambient noise, or changes in relative abundances that hinder predators' ability to find prey).

*Evaluating direct and indirect impacts*

As implied in Figure 1, evaluating direct and indirect ecosystem impacts from a given fishery depends on available information regarding the catch structure and size, and gear used by the fishery (for direct impacts), and the underlying structure of the ecosystem (for indirect impacts). Understanding the first set of impacts is relatively straightforward as it depends on knowing what species are caught in the fishery and, if possible, how much. When this information is not available from monitoring programs (as is common in global fisheries; Pauly and Zeller 2016) it can be obtained from fishers (Fig. 2), particularly as exact catch amounts are not essential in this analysis that focuses on the relative strengths of fishery system interactions.

Many fishers are knowledgeable about their surrounding ecosystems, including regarding aspects of the food web they often observe in stomach contents of their target species; this is particularly true when it is a dive fishery because fishers can are able to see species interact. However, other trophic relationships may be less apparent or of less general interest to fishers, so considering indirect impacts usually requires additional information from scientific research to fully represent the trophic structure of an ecosystem (cf., Fig. 2).

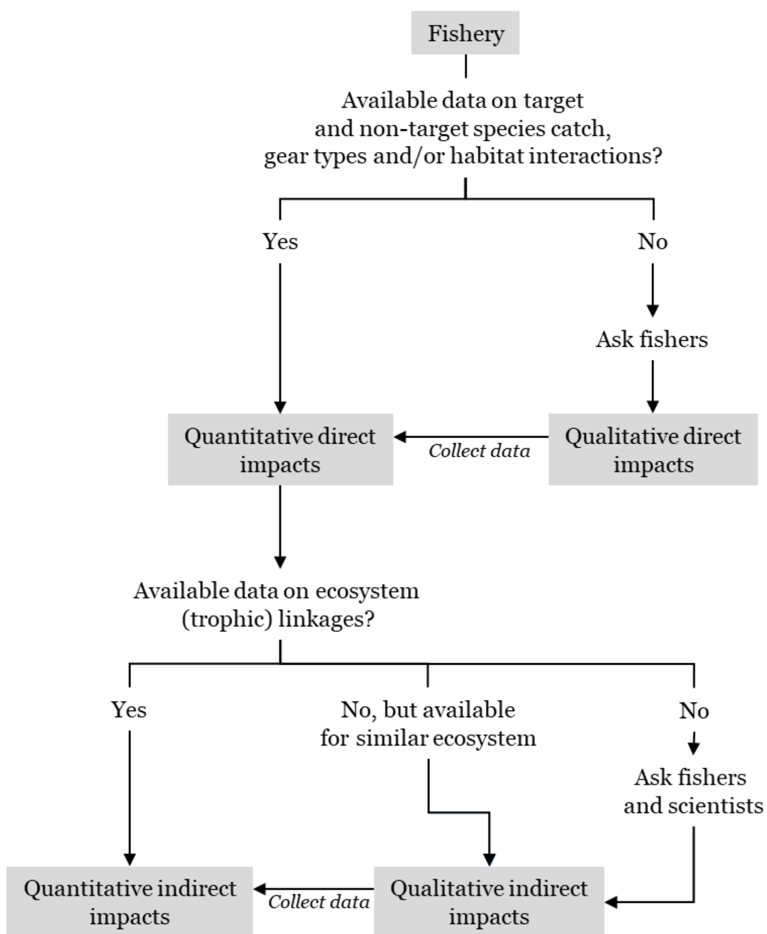


Figure 2. Decision tree for evaluating potential direct and indirect ecosystem impacts from artisanal fisheries.

In this study we use existing peer-reviewed ecosystem models for our case studies built using the Ecopath with Ecosim (*EwE*) platform (*EwE* 6.5; www.*ecopath.org*), which represents an ecosystem within a predetermined area, based on functional groups (single species or groups of species with similar ecosystem function), their production and consumption rates, and their ecotrophic efficiency (the proportion of total group production that is used within an ecosystem) (Christensen and Walters 2004). Functional groups are linked through their diets, where each group (except for primary producers) must feed on other groups; a balanced model requires that every group's productivity be at least sufficient to sustain predation, and any additional fishing mortality. *EwE* is the most widely used ecosystem modelling platform because of its relatively straightforward development compared with other types of ecological modelling approaches (Plaganyi 2007), and the fact that it is open-access and has extensive documentation, a global network of users, and a large and growing repository of existing models (Colleter et al. 2013).

*Simulation of fishing effects*

In order to project potential ecosystem effects on the food web, we simulate different fishing mortality rates on the exploited species (functional group). We designed an experiment using the *EwE* approach when a previous model was available. For each case of study, we create a gradually increasing time series of annual harvest rate ($HR_t$) for the focused group. The $HR_t$ for each exploited group is expressed as (Ricker 1975):

$$HR_t = \frac{F_t}{M+F_t}\left[1 - e^{-(M+F_t)}\right] \qquad [1]$$

where $M$ and $F$ are natural and fishing annual mortality rates. Here, we run an *EwE* simulation gradually increasing $HR$ from 0 to 0.98 for a period of 50 years (a 0.02 $year^{-1}$ increase in $HR$). For each year, $F_t$ was estimated solving equation (1). $M$ was obtained from the Ecopath base model and remained constant over time.

Assuming the Ecopath base model represents a baseline, the first step was to set the initial year of simulation with no fishing mortality, that is $P/B = M$. In this case, the catches of the exploited group are summed to the original biomass for setting $F_0 = 0$. After simulating the $HR$ time series using *EwE*, for each year we extracted the ecosystem indicators to evaluate the effect of the increasing exploitation on the ecosystem. In this study, we used four ecosystem indicators, one related to catch (total catch), one reflecting biological ecosystem components (Shannon's Diversity Index, *SDI*) and two reflecting ecosystem functioning (mean transfer efficiency between trophic levels, *MTE*, and the ascendancy/capacity ratio, *AC*, which is an index of ecosystem organization). This allowed us to identify the maximum fishing mortality that can be sustained by the ecosystem and to compare this limit reference point with the current fishing mortality. Additionally, in order to evaluate the impact of fishing on the ecosystem community of species, we analyze the trophic level (*TL*) of the community indicator (*TLco*) (Coll and Steenbeek 2017). This index is the ¿weighted? average of the *TL*s of the community and varies when fishing removes biomass of the food web components affecting the ecosystem structure.

*Case studies*

We apply the framework as described above to fisheries in four ecosystem types—kelp forest, sandy bottom, coastal pelagic, coral reef— within Mexico (Fig. 3). These include fishing done by cooperatives on the western coast of the Baja California Peninsula (Bahía El Rosario), the eastern coast of the Gulf of California (Puerto Libertad and Bahía Kino), the Caribbean coast of the Yucatán Peninsula (Sian Ka'an), and a wider fishing area in the central Gulf of California. All of these fishing cooperatives are associations of artisanal fishers, which in Mexico are generally defined as using open-deck fiberglass boats (7-10 m length) with an outboard engine, operated by 2 to 3 fishers. These fisheries usually change their gear and main target species throughout the year depending on seasonal availability, market demand and weather conditions. Here we focus on fisheries directing effort to target species (Table 1).

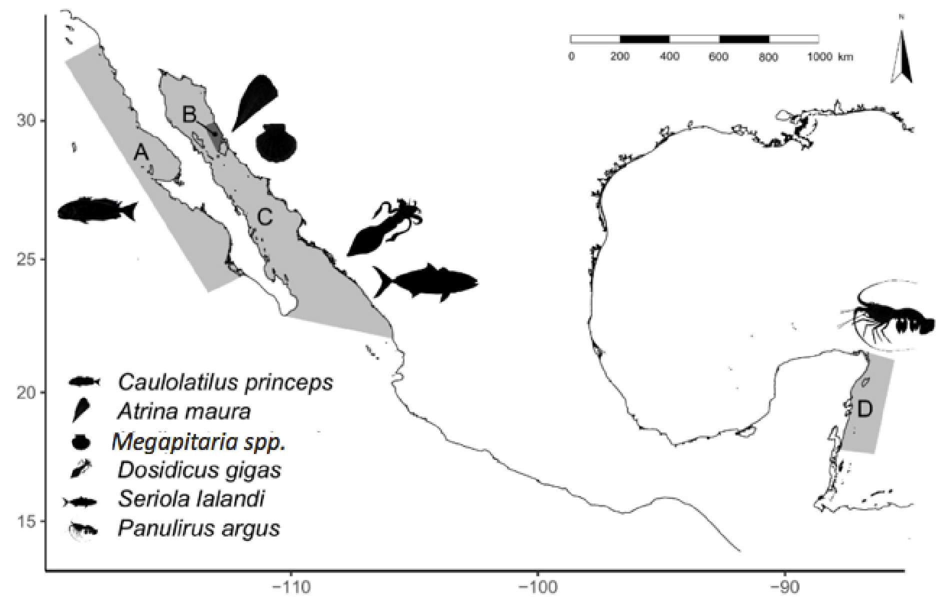


Figure 3. Case study areas where ecosystem impacts from directed artisanal fisheries where evaluated. Ecosystem types include A) kelp forest, B) coastal pelagic, C) sandy bottom, D) coral reef.

Ecopath with Ecosim (*EwE*) models were available for each of the case studies (specific references in Table 1), except for the clam dive fishery in Puerto Libertad. For this case study, we used a fisher-developed ecosystem model that was then further complemented with scientific information (COBI 2012). Information was generated in a workshop with 22 fishers (divers and fishermen). A total of 37 main species or groups of species were recorded, 25 commercial and 12 non-target. Fishers were asked to describe predator-prey relationships between local species to the best of their knowledge. Trophic relationships between those same species groups were separately assumed using available *EwE* models for similar ecosystems. A network diagram was then created based on qualitative linkages similar to the quantitative trophic networks produced by EwE. This approach, which encourages fishers and makes them more aware of how their knowledge is used within the model for subsequent management advice, has been used to complement scientific data in ecosystem models of Scottish fisheries (Bentley et al. 2018).

Table 1. Species and dynamics of ecological impacts identified for each fishery. The evaluation methods follow from available data as outlined in Figure 2.

| **Area** | **Ecotype** | **Target Species** | **Fishing gear** | **Bycatch species** | **Model available** |
|---|---|---|---|---|---|
| Bahia El Rosario, Baja California | Kelp forest | Ocean whitefish (*Caulolatilus princeps*) | Hand lines, traps | Traps Barred sand bass, California sheephead | Quantitative (Vilalta-Navas 2017) |
| Gulf of California | Pelagic | Yellowtail amberjack (*Seriola lalandi*)<br><br>Humboldt squid (*Dosidicus gigas*) | Handline<br><br>Squid jigs | Occasionally skipjack, but limited due to different seasonality<br><br>None | Quantitative (Rosas-Luis et al. 2008) |
| Puerto Libertad-Bahia Kino, Sonora | Sandy bottom | Squalidad callista clam [chocolata] (*Megapitaria squalida*)<br><br>Golden callista [roja] (*Megapitaria aurantiaca*)<br><br>Ponderous dosinia clam [blanca] (*Dosinia ponderosa*)<br><br>Penshell (*Atrina maura*) | Hand collection in hooka diving | None, though snails and sea cucumbers may be collected if encountered | Qualitative (COBI 2012) |
| Sian Ka'an, Quintana Roo | Coral and rocky reef | Lobster (*Panulirus argus*) | Hand collection from "casitas," artificial lobster shelters built and managed by fishers | Occasional fish spearing for home consumption, no other bycatch | Quantitative (Vidal and Basurto 2003) |