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Is my fishing gear impacting the habitat? An impact assessment in four fisheries in the Northwest Mexican Pacific

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Corresponding Author:	Frida Cisneros Soberanis, MSc World Wildlife Fund Mexico La Paz, Baja California Sur MEXICO
First Author:	Frida Cisneros Soberanis, MSc
Order of Authors:	Frida Cisneros Soberanis, MSc
	Mercedes Yamily Chi Chan
	Emiliano García Rodríguez
	Raziel Hernández Pimienta
	Alesa Flores Guzmán
	Lorena Rocha Tejeda
	Inés López Ercilla
Abstract:	The impacts of fishing activities on important habitats for commercially important species may directly and indirectly cause effects on species and the communities using them. These effects include those impacting directly target, bycatch species and habitats. In this study, we evaluate the impact of three fishing gear on habitats in four fishing communities from the Northwest Mexican Pacific. We characterized the species and size selectivity of fishing gear and determined the spatial distribution of catches to assess the impacts of fishing gears using a CSA. Our results show that finfish fisheries from Guaymas, Isla Natividad and El Rosario, the catch of the target species represents more than 75% of the total catch. We assess 42 habitat types in four communities, which were qualified with low-risk scores. The fishing gears used for the catch of target species are selective to optimal sizes above their maturity size. The results help to evaluate fishing impacts on habitats in data-poor fisheries and are discussed in the context of management uptake.
Suggested Reviewers:	Fiorenza Micheli micheli@stanford.edu Fiorenza Micheli has studied the region and some fisheries of this manuscript. Also, she has an article about fishing gear impacts in Natividad that is a reference for this work.
	Andrea Arroyo Sáenz msaenz@ecosur.mx Andrea Arroyo has been researching the interactions between humans and nature, especially for fisheries in the Gulf of California. Most of their studies are related to traditional ecological knowledge.
	Andres Cisneros Montemayor a_cisneros@sfu.ca Andrés Cisneros Montemayor has specialized in ocean and coastal social-ecological systems. He has been working on developing sustainable strategies in Mexico.
	Juan Carlos Perez Jiménez jcperez@ecosur.mx Juan Carlos Perez, has studied socioeconomic factors in fisheries through traditional ecological knowledge.

Cover letter

March 26, 2023

Dear Editing team,

We wish to submit an original research article entitled "**Is my fishing gear impacting the habitat? An impact assessment in four fisheries in the Northwest Mexican Pacific**" for consideration by **Ocean and Coastal Management**.

In this paper, we report the impact of three fishing gear on habitats in four fishing communities from the Northwest Mexican Pacific. These fisheries are under a Fishery Improvement Project scheme following the three MSC principles. We characterized the species and size selectivity of fishing gear and determined the spatial distribution of catches to assess the impacts of fishing gears using a CSA. We believe that this manuscript is appropriate for publication by **Ocean and Coastal Management** because it assess environmental impacts due to development of fishing emphasizing the role of traditional knowledge, local knowledge in science for coastal management.

There are many studies of stock assessments under principle 1 of the MSC, but few of them focus on the second principle. In Mexico, the characterization and impacts of the habitat have been understudied. Our results support the contributions of Fishery Improvement Projects to secure the sustainability of small-scale fisheries, as well as the importance of combining LEK with scientific data, especially in data-poor areas.

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

All authors have approved the manuscript and agree with its submission to **Ocean and Coastal Management.** We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at soberanis.frida@gmail.com

Thank you for your consideration of this manuscript.

Sincerely,

Frida Cisneros Soberanis

Is my fishing gear impacting the habitat? An impact assessment in four fisheries in the Northwest Mexican Pacific.

Frida Cisneros Soberanis[a], Mercedes Yamily Chi Chan[b], Emiliano García Rodríguez[b], Raziel Hernández Pimienta[c,*], Alesa Flores Guzmán[c], Lorena Rocha Tejeda[c], Inés López Ercilla[c].

[a] WWF Mexico, Francisco I. Madero 2054, Centro, La Paz, Baja California Sur, 23000, Mexico

[b] Department of Biological Oceanography, CICESE, Carretera Ensenada-Tijuana 3918, Ensenada, Baja California, 22860, Mexico.

[c] Comunidad y Biodiversidad A. C., Isla del Peruano 215, Lomas de Miramar, Guaymas, Sonora, 85448, Mexico.

* Correspondence author: soberanis.frida@gmail.com

Highlights

- We evaluated the impact of handline, hookah diving and traps on habitats in four fisheries under a Fishery Improvement Project scheme.
- We characterized the catch and size selectivity of finfish and penshell fisheries from El Rosario, Isla Natividad, Bahia Kino and Guaymas.
- The catch of the target species from Guaymas, Isla Natividad and El Rosario represents more than 75% of the total catch.
- 42 habitat types were assessed for the four fisheries, which were qualified with low-risk scores.

Abstract

The impacts of fishing activities on important habitats for commercially important species may directly and indirectly cause effects on species and the communities using them. These effects include those impacting directly target, bycatch species and habitats. In this study, we evaluate the impact of three fishing gear on habitats in four fishing communities from the Northwest Mexican Pacific. We characterized the species and size selectivity of fishing gear and determined the spatial distribution of catches to assess the impacts of fishing gears using a CSA. Our results show that finfish fisheries from Guaymas, Isla Natividad and El Rosario, the catch of the target species represents more than 75% of the total catch. We assess 42 habitat types in four communities, which were qualified with low-risk scores. The fishing gears used for the catch of target species are selective to optimal sizes above their maturity size. The results help to evaluate fishing impacts on habitats in data-poor fisheries and are discussed in the context of management uptake.

Keywords

Small-scale fisheries; Fishery Improvement Project; data limited fisheries; selectivity

1. Introduction

Mexico is among the top 20 fishing producers worldwide (FAO, 2022), with the majority of landings coming from small-scale fisheries (Saldaña-Ruiz et al., 2022). The Northwest Mexican Pacific is recognized as a biodiversity hotspot for conservation, accounting 66% of annual fisheries production in Mexico with a contribution of landings by small-scale vessels of 97% (DOF, 2018a; Lluch Cota et al., 2009). The impacts of fishing activities on important habitats (including the seabed) for commercially important species may directly and indirectly cause effects on species and the human communities using them. These effects include those impacting directly target, bycatch species and habitats, and the indirect impacts of widespread removals on the broader ecosystem (Francis et al., 2011; Hilborn, 2011). Negative effects of fishing on the environment have been comprehensively reviewed, including abundance reductions of target species, reduced spawning potential, decrease in sizes, earlier maturity, and elevated reproductive effort. Species associated with the target species are also affected, by bycatch changing their relative abundances, or through changes in predator-prey dynamics, competitive interactions, and other ecological relationships (Garcia and Cochrane, 2005; Jørgensen et al., 2007).

The degree and severity of fishing activities effects on biodiversity and the seabed depend on a variety of factors, including the spatial extent of fishing, the level of fishing effort, the type of seabed, and the fishing gear used. Understanding the impacts of fishing on habitats have been documented to illustrate impacts from a variety of different gears in different habitats (e.g. Collie et al., 2000; Kaiser et al., 2006) and have observed the relatively high impacts of gears (e.g. Auster, 2001; Jennings and Kaiser, 1998; Shester and Micheli, 2011; Thrush and Dayton, 2010). Nevertheless, multi-scale data that describe the types and distributions of habitats, and their interactions with fishing activities, are typically limited or entirely lacking, especially in data-poor areas. Filling this knowledge gap is crucial to ensure that stakeholders incorporate how fishing affects habitats in management actions (Armstrong and Falk-petersen, 2008).

To address these gaps, some approaches have been developed for data-limited scenarios. Among these methods, the Marine Stewardship Council (MSC) has developed a risk-based approach as an alternative to its analytical assessment requirements, the Consequence Spatial Analysis (CSA) (MSC, 2018). The CSA methodology and attributes are based on the habitat Productivity and Susceptibility component of the Ecological Risk Assessment of Effect of Fishing (ERAEF) (Hobday et al., 2011; Williams et al., 2011). The CSA examines attributes for each gear-habitat combination within the fishery to provide a relative measure of the risk to that habitat to fishing activities. This analysis provides a relative measure to evaluate the sustainability of fishing habitats.

The CSA has been adopted to provide a semi-quantitative score to the level of fishing gear impact according to the indicators established by the MSC to evaluate Fishery Improvement Projects (FIP). The FIP are schemes that lead to the sustainability of fisheries by addressing environmental, social, and effective management challenges. The implementation of FIP is guided by the three principles of the MSC standard (sustainable stocks, minimization of environmental impact, and effective fisheries management) to achieve sustainability in their fisheries. To meet the standards, more fishers are getting involved in data generation (Fairclough et al., 2014; Fulton et al., 2019; Mendoza-Carranza et al., 2018) which produces reliable data and information that scientists and policymakers can use since it is generated under the same procedures as conventional science (Conrad and Hilchey, 2011; Fulton et al., 2019). Additionally, as citizen science is supported by local ecological knowledge (LEK) (Giovos et al., 2019; Reyes-García et al., 2020) confers confidence in data acquisition since fishers have broad knowledge about species ecology, oceanographic conditions, fishing gears, and habitat characteristics (Lima et al., 2017; Martins et al., 2018).

In this study, we evaluate the impact of three fishing gear on habitats in four fishing communities from the Northwest Mexican Pacific. These fisheries are under a FIP scheme following the three MSC principles, and this study focused on the evaluation of the second principle “Minimizing environmental impact”. We characterized the species and size selectivity of fishing gear and determined the spatial distribution of catches to assess the impacts of fishing gears using a CSA. The results help to evaluate fishing impacts on habitats in data-poor fisheries and are discussed in the context of management uptake.

2. Methods

2.1. Study cases

We evaluated four fishing communities in the Northwest Mexican Pacific involved in Fishery Improvement Projects. Fishing activities in this communities are multi-species and similar size fishing vessels operate on surroundings fishing areas. The fisheries evaluated were the finfish by trap/handline in El Rosario, the ocean whitefish by trap/handline in Isla Natividad, the finfish by handline in Guaymas, and penshell by hookah diving in Bahia Kino.

El Rosario and Isla Natividad are found on the west coast of the Baja California Peninsula. Waters and complex fauna from the north and south are mixed in the region, characterized by a relatively high diversity of species (Wilkinson et al., 2009). Isla Natividad is considered a core area within the protected area of El Vizcaíno Biosphere Reserve in which special conditions are established because it is inhabited by a cooperative fishery production society that has had its concessions around the island for several decades (INE, 2000). Bahía Kino and Guaymas are within the Gulf of California in the state of Sonora, that is characterized by a variety of different marine environments, from deep-sea trenches and rocky coastal and insular reefs to the shallow, sandy waters of the Colorado River Delta (Fig. 1).

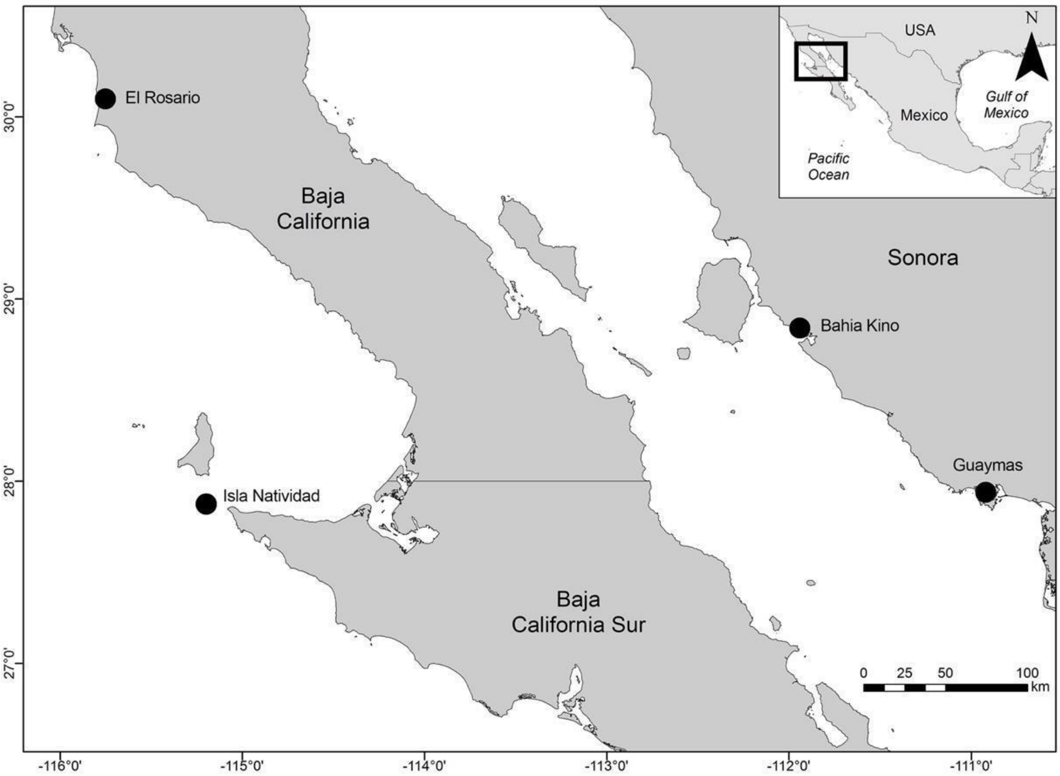

Fig. 1. Fishing communities involved in Fishery Improvement Projects in this study: El Rosario, Isla Natividad, Bahia Kino, and Guaymas. See Table 1 for fisheries characterization.

2.2. Fishing characterization

The data used for the fishery characterization was obtained from fishing logbooks recorded as part of the data-collection system established by fishing cooperatives involved in FIP. As part of the monitoring system for the FIP, landing records include information about name, depth, and bottom type of the fishing site, duration of the trip (hours), total weight landed (kg) per fishing trip for target and non-target species, and fishing gear characteristics (Table 1). Landings and bycatch were expressed as numbers of individuals and biomass (kg). Additionally, for each of the defined landing and bycatch, biomass percentages were calculated. Subsequently, non-target species were classified according to the MSC as primary, secondary, and endangered, threatened, or protected species (ETP), and main (>5% of the total catch by weight) and minor species (< 5% of the total catch)

Table 1. Characteristics from logbooks fisheries from El Rosario, Isla Natividad, Bahía de Kino and, Guaymas.

Fishery	**El Rosario**	**Isla Natividad**	**Bahía Kino**	**Guaymas**
Target species	*Caulolatilus princeps, Semicossyphus pulcher, Paralabrax nebulifer, Sebastes constellatus, S. miniatus*	*Caulolatilus princeps*	*Atrina tuberculosa*	*Caulolatilus princeps, Lutjanus peru, Hyporthodus acanthistius, Paralabrax auroguttatus, Seriola lalandi*
Period of records	2019 - 2021	2018 - 2020	2020 - 2021	2015-2021
Fishing trips recorded	1,975	500	334	2,813
Fishing sites identified	36	42	33	14
Average duration of fishing trips (hours)	7.54 ± 2.05	5.21 ± 2.00	--	26.44 ± 18.67
Average depth (m)	78.19 ± 32.57	50.84 ± 27.50	Between 3–20	81.77 ± 26.71
Fishing gear	Handline w/ hook #4 to #14; trap mesh 1”, 2” and 4”	Handline w/ hooks #6, #7 and #8; trap mesh 4”	Hookah diving	Handline w/ hooks #4 to #10
Fishing trips by gear	Handline 1,636; trap: 124; mix:13; ND:30	Handline 249; trap: 138; ND:111	334	Handline 1,428; ND:1385
Catch (kg)	65336.02	32194.52	103	34885.7
Catch percentage of target species	17.03	88.54	45.57	15.35

2.3. Fishing gear selectivity for target species

The size selectivity of the fishing gear was evaluated according to the models proposed by Millar & Holst (1997). Selectivity analyzes were only carried out for barred sea bass and ocean whitefish from El Rosario and Isla Natividad because there was detailed information on their sizes and in relation to the fishing gear used. For other species, there was no sufficient size information, or the fishing gear was not differentiated. All measurements were analyzed as a single group because the data from logbooks were not sex disaggregated. The parameters of the selectivity models were estimated by fitting a log-linear model (Millar and Holst, 1997):

$$log\ log\ (v_{Lj}) = factor\ (L) + \beta_1 x_{Lj} + \beta_2 x^2{}_{Lj}$$

Where XLj = L/mj and mj is the size of fishing gear j. Factor (L) is the size class fitted as a factor in the model. For the analyzes, the "gillnetfunctions" package was used in the R software, where the estimation of the selectivity parameters was allowed. A maximum likelihood estimation was used to adjust the selectivity models to the proportional catch made by each fishing gear in each size class. For this, it was assumed that the selectivity curves could be of four types: normal (fixed spread), normal (proportional spread), gamma, and lognormal. To evaluate the most appropriate model, the value of the model deviation (deviation of the adjusted model with respect to the observed data) was used, estimated from the sum of the squared values of the residuals.

2.4. Catch spatial distribution

Inverse distance weighting (IDW) interpolation was used to estimate the spatial distribution of the catch by habitat type. The interpolation result is a distance-weighted average the weighted the values available at known points (Li and Dehler, 2015). This method has been used to estimate the abundance of fishing resources and interpolation of physical variables (Cheung et al., 2009; Coley and Clabburn, 2005; Cumplido et al., 2022). Interpolation and clipping of fishing polygons were delimited according to previously reported fishing areas (Castro-Salgado et al., 2017; Moreno et al., 2005) and logbooks fishing sites. Habitat spatial layers were obtained from open access sources: geomorphology of seafloor (Harris et al., 2014), kelp biome (Jayathilake and Costello, 2020), seagrasses records (UNEP-WCMC and FT, 2021), coral reef records (UNEP-WCMC, WorldFish Centre, WRI, 2021) and mangroves distribution (CONABIO, 2022).

For penshell, the classification of the catch zones was based on the minimum profitable catch by Moreno et al., 2005. For finfish, low and high catch zones were classified using the Jenks natural breaks method, which grouped the data, maximizing the variation between groups and minimizing the standard deviation within them (Jenks, 1967). The output of the interpolation and the habitat layers were standardized to geographic coordinates (Datum WGS-84) at a spatial resolution of ~1 km.

2.5. Consequence-Spatial Analysis

We assessed fishing risk to habitats based on a habitat vulnerability model proposed by Bax and Williams (2001). The model estimates a relative habitat vulnerability in qualitative terms using two axes: resistance (to physical modification) and resilience (estimated as the time it takes for the habitat to recover its original state once modified). We applied a set of quantifiable attributes to describe a habitat's resistance to specific fishing gear such as its susceptibility (ability to avoid damage by the gear) and its productivity (ability to recover from damage) (Hobday et al., 2011). The calculated risk equates to the potential vulnerability of each habitat type to being affected by different fishing gear.

The inferential method of Hobday et al. (2007) was used to develop a list of fishing habitats. Six characteristics were used to classify the type of habitat according to the fishing sites recorded in the logbooks: type of substrate (S), geomorphology (G), dominant fauna (F), Biome (B), sub-biome (SB) and feature (R) (Kloser et al., 2007). The first three features were obtained from videos recorded by fishers during the fishing activity and interviews directed to them. Geographic Information System was used to determinate the other three features. All attributes are scored as 1 (low risk), 2 (medium risk), or 3 (high risk), except for spatial overlap and encounterability, which are scored from 0.5 to 3. Overall risk score for each habitat type is the Euclidean distance from the origin (0, 0) on a two-axes plot of susceptibility and productivity. Based on their vulnerability, habitat types are classified into three categories: low risk (<2.64), medium risk (2.64 < risk value < 3.18), and high risk (>3.18) (Hobday et al., 2011). The resulting conservatively large habitat lists are intentionally precautionary and contain habitat types that will be included or removed as more data becomes available in the future.

3. Results

3.1. Fishing characterization

In El Rosario, 24 non-target fishes were recorded (equivalent to 23.36% of the total catch) in fishing trips monitored between 2019 and 2021 (Table 2). *Sphyrna* spp (0.03%) and *Alopias vulpinus* (0.75%) catches were reported in logbooks between 2019 and 2021, the latter shark listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and classified as 'Vulnerable' on the IUCN's Red List (Annex 1). Seven non-target fishes (representing 11.45% of the total catch) were recorded in fishing trips from 2018 to 2020 in Isla Natividad. In Bahia Kino, seven non-target fish species (total catches represented 57.08% of the total catch by weight) were identified in fishing trips between 2020 and 2021. For Guaymas, 29 non-target species (15.27% of total catch) were recorded in fishing trips between 2015 and 2021.

Table 2. Catch by species recorded in logbooks by communities involved in FIPs. Species with catch lower than 1% are classified as 'others'. Data in bold refer to target species.

Fishery	Scientific name	Common name	Total	
			Catch (kg)	Percentage
El Rosario finfish by trap/handline	***Caulolatilus princeps***	**Ocean whitefish**	**65,336.02**	**16.96**
	Atractoscion nobilis	White sea bass	5,170.02	1.34
	Seriola lalandi	Yellowtail	3,864.05	1.00
	Citharichthys sordidus	Pacific sanddab	13,704.9	3.56
	Sebastes constellatus	**Starry rockfish**	**609**	**0.16**
	Sebastes miniatus	**Vermillion rockfish**	**267,414.61**	**69.43**
	Paralabrax nebulifer	**Barred sand bass**	**9,503.42**	**2.47**
	Semicossyphus pulcher	**California sheephead**	**7,007.45**	**1.82**

	Other		372,000.47	3.42
Isla Natividad ocean whitefish by trap/handline	***Caulolatilus princeps***	**Ocean whitefish**	**32,194.52**	**88.54**
	Paralabrax nebulifer	Barred sand bass	399.5	1.10
	Semicossyphus pulcher	California sheephead	957	2.63
	Seriola lalandi	Yellowtail	2,606.43	7.17
	Other		36,157.45	0.56
Bahia Kino penshell by hookah	*Megapitaria squalida*	Chocolate clam	35	14.58
	Atrina tuberculosa	**Tuberculate penshell**	**103**	**42.92**
	Hexaplex erythrostomus	Pink-mouthed murex	19	7.92
	Hexaplex nigritus	Black murex	7	2.92
	Hexaplex sp	Murex	65	27.08
	Octopus sp	Octopus	2	0.83
	Panulirus interruptus	California spiny lobster	3	1.25
	Pinna rugosa	Wrinkled pen	6	2.50
Guaymas finfish by handline	*Caulolatilus affinis*	Bighead tilefish	3,459.32	1.52
	Caulolatilus princeps	**Ocean whitefish**	**34,885.7**	**15.35**
	Hyporthodus acanthistius	**Rooster hind**	**9,129.4**	**4.02**
	Lutjanus peru	**Pacific red snapper**	**22,020.7**	**9.69**
	Lutjanus spp	Snapper	9,015.74	3.97
	Paralabrax auroguttatus	**Gold spotted sand bass**	**60,007.6**	**26.41**
	Seriola lalandi	**Yellowtail**	**67260.9**	**29.6**
	Squatina californica	Pacific angelshark	8,877.9	3.91
	Other		214, 657.26	5.53

3.2. Fishing gear selectivity for target species

For barred sand bass and ocean whitefish in El Rosario, the deviance was lower in the normal model (fixed-spread) and gamma, respectively, so these models had a better fit (Table 3). The optimal sizes for the ocean whitefish were 38.5, 57.5, and 66.5 cm TL for traps and handline with hooks 6 and 7 respectively (Fig. 2). These optimal sizes are above the size at maturity (L50) reported for the 39 cm TL species (ASCIMAR, 2020). For this species, it was observed, from the residuals, that the fishing power is greater than estimated, with the largest residuals (positive) in the size classes around 40 cm TL, suggesting that a greater proportion than expected of these fish are caught (Fig. 2). For barred sand bass, the optimal sizes estimated were 27.1, 43.5, and 51.3 cm TL for the fishing gear described above, which are also above the size at maturity reported for females (23.9 cm TL) and males (21.9 cm TL; Love et al. 1996). The residuals showed positive values for all fishing gear (Fig. 2). In the case of the traps, it is observed that larger sizes than expected are captured.

For the ocean whitefish fishery from Isla Natividad, the model with the best fit was the normal model (fixed-spread) since it had the least deviance (Table 3). An optimal size (length at maximum selectivity) of 7.5 cm TL was estimated for traps and 11.5, 12.5, and 14.5 cm TL for the hand lines with hooks 6, 7, and 8, respectively. These optimal sizes are below the size at maturity (L50) reported for the 39 cm TL species (ASCIMAR, 2020). The residuals show that the fishing power is greater than modeled for traps and hooks 7 and 8 (Fig. 2).

Table 3. Estimated selectivity parameters for different models. The models in bold are the ones that showed a better fit.

Species	**Model**	**Parameters**	**Deviation**
Ocean whitefish – El Rosario	Normal (fixed-spread)	k = 2.182, σ = 9.078	301.532
	Normal (proportional spread)	$k1$= -1.966, $k2$= 11.715	236.850
	Gama	**α = 2.530, k = 1.033**	**230.680**
	Log normal	μ= 2.404, α = 0.475	248.217
Barred sand bass – El Rosario	**Normal (fixed-spread)**	**k = 6.756, σ = 9.665**	**40.565**
	Normal (proportional spread)	$k1$= 6.746, $k2$ = 6.825	43.817
	Gama	α = 12.223, k = 0.609	41.840
	Log normal	μ= 3.378, α = 0.271	40.604
Ocean whitefish – Isla Natividad	**Normal (fixed-spread)**	**k = 8.537, σ = 14.516**	**774.855**
	Normal (proportional spread)	$k1$= 8.845, $k2$ = 12.280	873.137
	Gama	α = 9.518, k = 1.004	816.886
	Log normal	μ= 3.617, α = 0.015	788.415

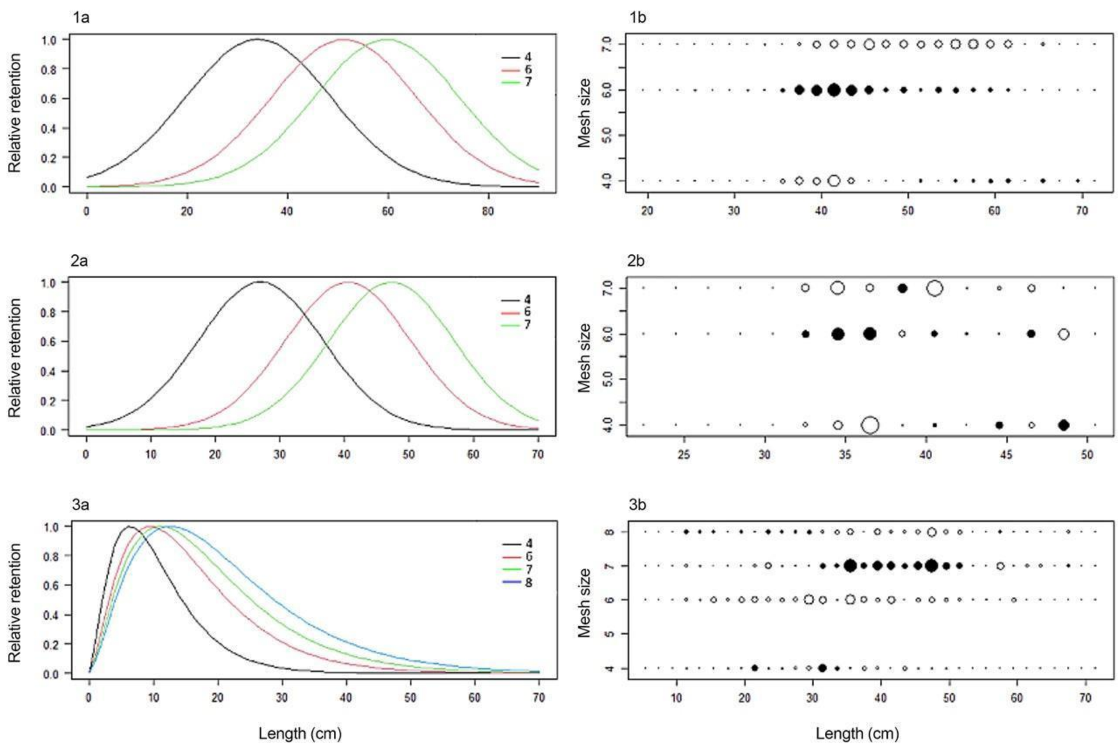

Fig. 2. Selectivity curves (a) and residuals (b) for 1) ocean whitefish captured in El Rosario, 2) barred sand bass captured in El Rosario and, 3) ocean whitefish captured in Isla Natividad. White and dark circles represent negative and positive residuals, respectively. The colors in the curves correspond to the different fishing gear: black = traps, red = lines with hook #6, green = lines with hook #7, and blue line with hook #8. White and dark circles represent negative and positive residuals, respectively.

3.3. Catch spatial distribution

For the ocean whitefish and California sheephead in El Rosario, the percentage for the highest catches represented 5.7% and 22.3% in the fishing zone, respectively. Regarding the overlap of the catches with the habitat types, the highest percentages occurred in the high shelf with 3.3% and slope with 11.4 %, respectively, followed by kelp forest and slope. Habitats points such as coral reefs and seagrass were in high and low catch zones (Fig. 3; 1a, 1b). For the barred sand bass, starry rockfish, and vermillion rockfish the percentage of high catch zone represented 74.3%, 66.4% y 68.6% of the fishing zone, respectively. The highest overlaps between habitat types occurred in the medium shelf. Coral reefs and seagrass points were in low and high catch zones (Fig.3; 1c, 1d, 1e).

The high catch area represented 52.6% of the whole fishing polygon for the ocean whitefish fishery in Isla Natividad. Regarding the overlap between the habitat types, the highest percentages of the catches occurred in the high shelf with 32.6%. Coral reef points were in the zone with the lowest (Fig. 3; 2a) (Annex 2).

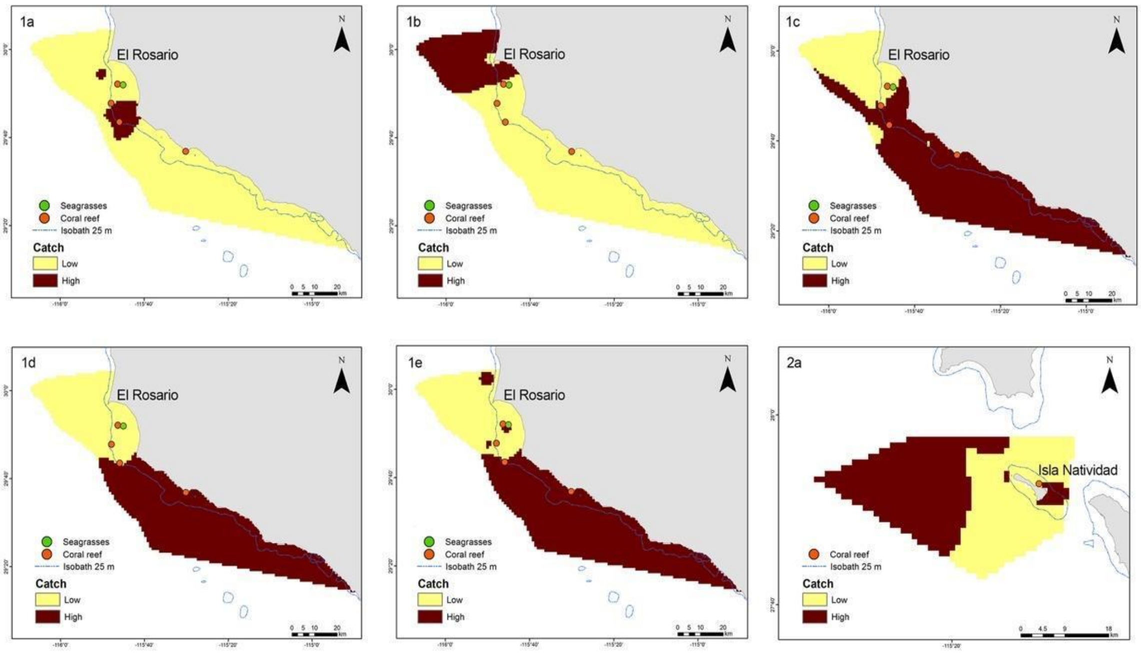

Fig. 3. Spatial distribution of the fishery catches of (1a) ocean whitefish, (1b) California sheephead, (1c) barred sand bass, (1d) starry rockfish and (1e) vermillion rockfish in El Rosario and (2a) ocean whitefish in Isla Natividad.

For the tuberculate penshell, the percentage of the minimum profitable catch zone was 30.2%. The area with less than minimum profitable catch was 56.5% in the fishing zone. Regarding the overlap of the catch between the habitat types, the highest percentage of catch occurred in the medium shelf, 41.1% for high than minimum profitable catch and 25.4% for the minimum profitable catch. Mangroves, seagrasses, and coral reefs points were recorded in low, high, and minimum profitable catch zones (Fig. 4;1a).

The percentage of the fishing zone with the highest catches for ocean whitefish was 14.4%. The highest overlaps between habitat types occurred on the shelf. Coral reef points were in a high catch zone (Fig. 5; 2a). The percentage of the fishing zone with the highest catches for Pacific red snapper, rooster hind, gold spotted sand bass, and yellowtail were 36%, 37.3%, 38.5%, and 46.1%, respectively. The highest overlaps between habitat types occurred on the slope. Coral reef points were recorded in the low catch zone (Fig. 5;2b, 2c, 2d, 2e) (Annex 2).

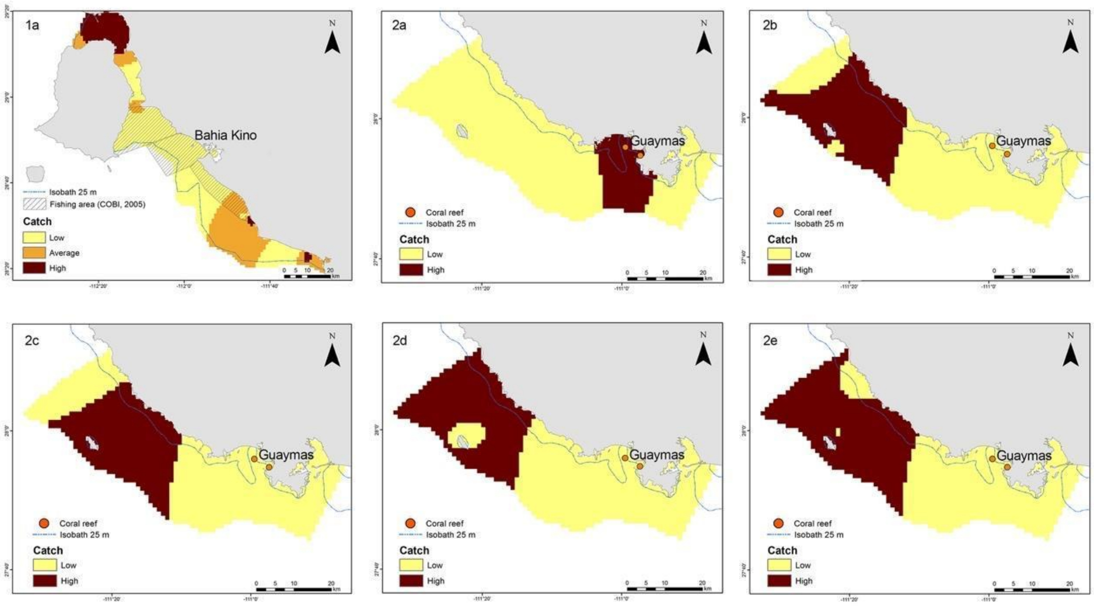

Fig. 4. Spatial distribution of the fishery catches of (1a) penshell fishery in Bahía Kino; (2a) ocean whitefish, (2b) red snapper, (2c) rooster hind, (2d) gold spotted sand bass, and (2e) yellowtail in Guaymas.

3.4. Consecuence Spatial Analisys

An overview of results for 42 habitat types is provided and assessed for the four fisheries, which were qualified with low-risk scores (<2.64) (Annex 3).

For El Rosario, it was assumed that the fishing sites used both fishing gear, therefore, a total of nine habitat types were found for the handline fishery and nine habitat types for the trap fishery. A total of 18 types of habitats were obtained with an average of 2.08 score risk for traps and 1.94 score risk for handline. A total of 14 types of habitats were obtained, 7 habitat types for the trap and 7 for handline fishery in Isla Natividad. Same as above, it was assumed that both fishing gears were used in the fishing sites. Comparing the risk between gears, it was found that the traps have a higher average risk (2.06) than handline (1.88). For Bahía Kino, a total of five types of habitats were identified for the penshell fishery with an average risk of 1.4. Five types of habitats were found for the finfish handline fishery in Guaymas with an average risk of 1.97 (Fig. 5).

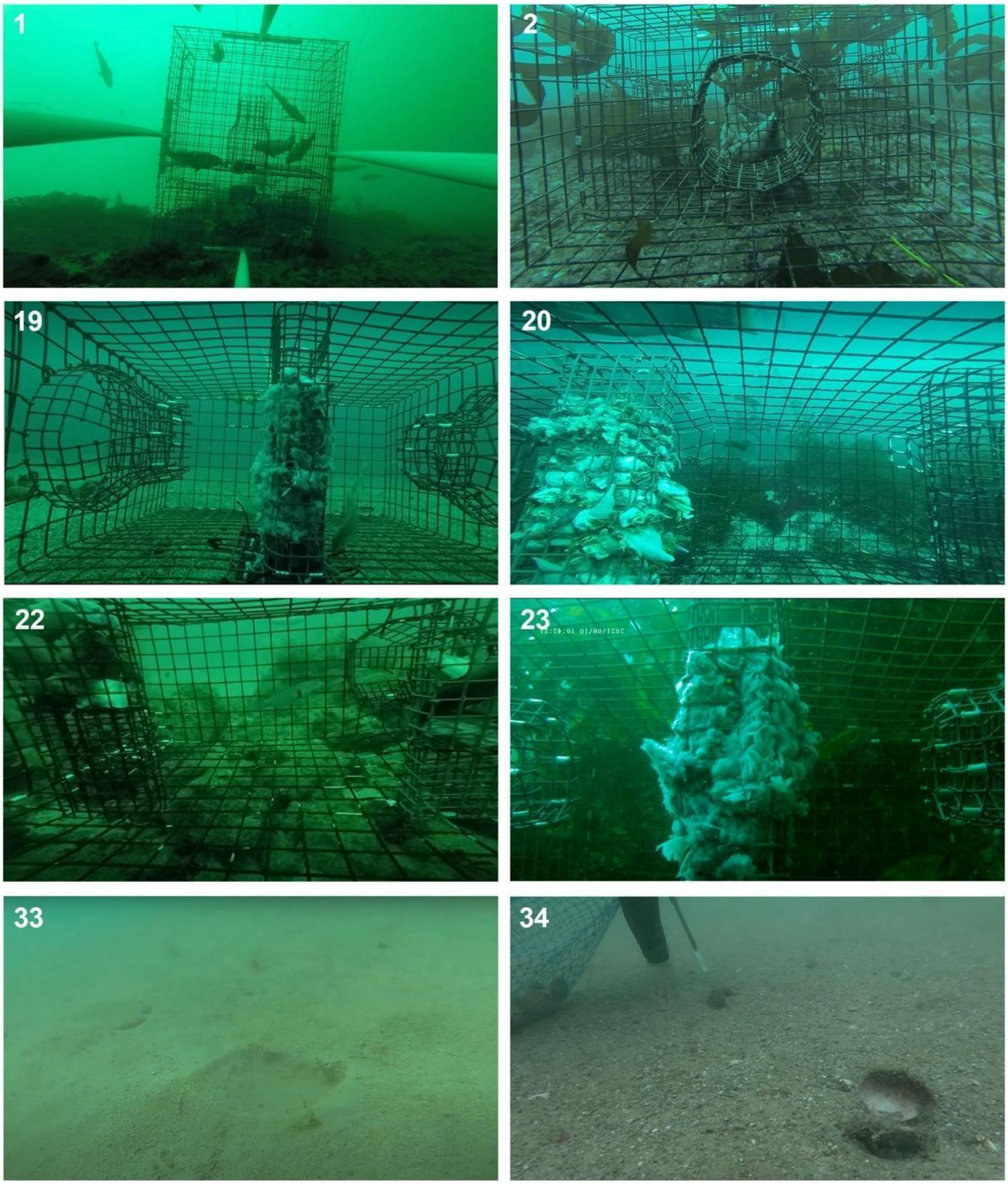

Fig. 5. Subset of habitat types for El Rosario finfish by trap: Medium-Gravel/pebble / Outcrop-Low-relief outcrop / Small erect-Mixed small/low-encrusting invertebrate communities (ID: 1) and Fine-Coarse sediments / Flat-Simple surface structure / Small erect-Mixed small/low-encrusting invertebrate communities (ID: 2); Isla Natividad ocean whitefish by trap Fine-Coarse sediments / Flat-Simple surface structure / Large erect-Mixed large or erect communities (ID: 19), Large-Cobble/boulders / High relief-High outcrop / Large erect-Mixed large or erect communities (ID: 20), Large-Cobble/boulders / Outcrop-Low-relief outcrop / Small erect-Mixed small/low-encrusting invertebrate communities (ID: 22) and, Large-Cobble/boulders / Outcrop-Low-relief outcrop / Flora dominated by Seagrass species (ID: 23) and; Bahia Kino penshell by hookah diving Fine-Coarse sediments / Flat-Simple surface structure / Small erect-Consolidated and unconsolidated bivalve beds (ID: 33) and, Fine-Coarse sediments / Flat-Simple surface

structure / Small erect-Mixed small/low-encrusting invertebrate communities (ID: 34). The classification of each ID is provided in Annex 3.

4. Discussion

4.1. Fishing characterization

Despite the great diversity of species caught by the finfish fishery from Guaymas, Isla Natividad and El Rosario, these fisheries could be considered selective because the catch of the target species represents more than 75% of the total catch. These finfish fisheries are multi-specific, as reported in the National Fishing Charter. For example, the rockfish and barred sand bass fisheries have 16 and one species of bycatch, respectively (DOF, 2018a, 2012). The ocean whitefish and California sheephead are considered incidental species in the rockfish fishery (DOF, 2012). However, for these sites, they are target species and may have bigger fishing importance than other regions in Mexico.

The catch of the target fishery in Bahía Kino represents less than 50% of the total catch. There is a temporarily closed area in Bahía de Kino from July 1 to November 30 of each year (DOF, 2018b). During this period other species such as the murex snail are targeted and recorded in the fishing logbooks. In this study, the catch of murex snails represents 37.92% of the total catch and the harvest occurs during the months of July to November, which coincides with the closed season for penshell. The hookah diving manual harvesting method has minimal impact on the environment, and prevents bycatch of non-target species (AFMA, 2020). This switch in the species represents a decrease in the fishing effort applied to the penshell and an opportunity for the species to recover. However, increased of murex snail fishing and the temporal switch of species needs to be monitored over time to safeguard both fisheries.

4.2. Fishing gear selectivity for target species

Size regulation is an important measurement for fisheries management to harvest individuals of desired species and sizes, and also to decrease unwanted bycatch and discards (Hall, 1996). Our estimations showed that the fishing gears used for the catch of target species are selective to optimal sizes above their maturity size. These findings suggest that the fishing gears are selecting sizes that allow the juvenile fish to reach maturity size before being incorporated into the catch biomass. For example, for the ocean whitefish from Isla Natividad, fishing gears are catching sizes bigger than the estimated optimal sizes.

Studies on hook selectivity show a direct proportional link to hook sizes (Peksu et al., 2020). We observed that the fish length increased with the increasing hook size and the selectivity curve was widened. Factors causing variation in the vulnerability of different species and size groups to different fishing gears are important for the development of optimal fishing strategies (Erzini et al., 2003). Catch rates, catch composition, and length frequency distributions are affected by the type and size of the hooks and catch strategy (Garner et al., 2014; Patterson III et al., 2012).

The selectivity analysis was not performed for all target species since there was no detailed information on sizes and their relationship to the fishing gear used on logbooks for all the species. Selectivity assessment of fishing gears and the development of methods for selective capture are urgently required (Hall et al., 2000). This analysis could only be done with the information recorded by fishers involved in the FIP. Official statistics collected and reported by fishing authorities do not include size data preventing the evaluation of how fishing gear could affect different sizes and age classes. The collection of this data is critical to evaluate which fishing gear is more efficient to catch the target species while allowing the population to continue producing new recruits.

4.3 Catch spatial distribution

The percentages of overlap between the continental shelf (medium and high), kelp forests, and high capture areas were low in El Rosario. Although these habitats can support higher species richness due to their ecological heterogeneity, factors such as habitat productivity, level of disturbance, the interaction between regional and historical anthropological effects, and morphological characteristics, such as shelf width, could condition the extirpation risk and species richness (Cornell and Karlson, 2000; Kitchel et al., 2022; Yan et al., 2021). Many of these factors could not be evaluated in the present study, and our maps are static representations, so the results could be a basis for directing research efforts to these habitats.

Regarding Isla Natividad, the ocean whitefish is an associated species with reefs, rocky, and sandy bottoms, and depths of 100 m (Humann and Deloach, 1993; Schneider and Krupp, 1995). It is recognized as a healthy fishery with minimal impact on the habitat and other species (Castro-Salgado et al., 2017; Zetina-Rejón et al., 2022). Therefore, the health of their habitats could be contributed to the ecological habitat heterogeneity, current management, and the selective fishing gear.

Our results map the catch distribution of fisheries, with limited or poor data, on habitats. In Bahía Kino and Isla Natividad, the continental shelf was an important habitat for the target species. Shallow waters with fine-grained sediment are suitable habitats for bivalves (Kostylev et al., 2001). Despite this, sediment dynamics contain epifauna to establish and proliferate, causing low abundance and diversity of organisms (Kostylev et al., 2001). This could contribute to the signs of resource depletion in Bahía Kino (Moreno et al., 2005).

In Guaymas, the slope had high percentages in the high catch zone compared to the continental shelf. This coincides with the demersal and benthopelagic preferences of the studied species (Allen, 1995; Eschmeyer et al., 1983; Heemstra, 1995; Humann and Deloach, 1993). The slope can make a good contribution to stream flow and thus to the food supply of benthic fauna (Mohn and Beckmann, 2002; Wilson et al., 2007). The complex topographic feature is also associated with hard substrates that are colonized by corals and sponges, contributing to the formation of coral reefs.

4.4. CSA

The Spatial and Consequence Analysis for the four communities resulted in low risk. Video recording was an important monitoring method to have accurate information and, also, fishers' interviews to verify and complement habitat information.

In El Rosario, we observed that there are fishing sites associated with coral and hard bottom habitats, of which the traps can generate an impact and degradation of the habitat. Gomez et al., (1987) pointed out that the incidental breaking of the corals on which the traps can fall or settle constitutes the destructive impact of this gear. Recovery depends on the type of habitat the trap is deployed in and the amount of damage dealt. Mascarelli and Bunkley-Will (1999) stated that only 30% of corals recovered from damage after 120 days. While Van der Knaap (1993) observed complete recovery of gorgonians from trap impacts within a month. Impacted corals would also be expected to have a variable recovery time depending on the individual species. While it seems prudent not to deploy traps in coral habitat, that recommendation can be difficult to enforce. To limit trap impacts, Stewart (1999) advised that traps should not be heavier than necessary to land upright on the seabed.

In Isla Natividad, it was observed that there are some fishing sites with low catches associated with the reef, where the traps can generate an impact and degradation of the habitat. Within the same area, Shester et al. (2008) evaluated the impact of traps on the benthic habitat of the Baja California red lobster fishery, who concluded that the traps do not appear to cause short-term changes in benthic habitat cover when set over a 24-hour period. In the videos, we observed that the fishing sites are dominated by macroalgae and mixed communities. In them, the traps use weights in order for them to sink, which when retrieved are dragged along the bottom for a few seconds. Removal of biota and lifting of sediment is observed, which can cause negative impacts on sensitive marine organisms, such as corals and bryozoans (Medeiros et al., 2007). The authors suggest that can be carried out to see the resilience time of the associated species, this would also serve to add it to the CSA and make it more robust.

For Bahia Kino, the main habitat observed was coastal and internal platform with fine sediments and medium gravel. Although the videos do not allow to define the associated biota, fishers mentioned on interviews that there are small communities of invertebrates and bivalve beds in their fishing grounds. It was observed that the use of the bags ("chango" in spanish), fins, and hooks causes agitation in the sediment, which is relevant because areas that overlap with coral reefs and grasses were recorded. Although, there is some evidence sediment agitation have effects on sensitive marine organisms, such as corals and bryozoans (Medeiros et al., 2007), the damage caused by diving is often minor compared to other fishing gear such as mobile gears that can remove biogenic and sedentary structures (trawls and dredges) (Auster et al., 2011). This process can cause suffocation, reduction in coral skeleton growth rates, abrasion, recruitment inhibition, reduction in live coral cover, changes in zoning, among others (Bellwood and Hughes, 2001). Buoyancy adjustment and equipment securing can prevent bottom contact or sediment uplift during diving. Also, we observed the disposal of shells in the soft bottom, some authors have mentioned that this increase of organic matter and the percentage of fine grain mud, cause the sediment to be poorly sorted (i.e. lower porosity and permeability) (Urra et al., 2018). It would be essential to adopt a disposal residue strategy and a monitoring program to facilitate benthic habitat recovery.

In Guaymas, the description of the types of SGF of habitats was based on interviews with fishers that mentioned that the fishery is carried out on boulders and/or large stones, high relief, and mixed communities. What varied in the characterization was the biome and sub-biome of the sites, where it is usually carried out on slopes and on the coast due to the geography of the region. These areas are considered resilience zones under which the impact on the habitat can be greater compared to the continental shelf with the fishing gear (Hobday et al., 2011). However, the ocean whitefish fishery was found to have high catches in regions with corals. The presence of pine coral (*Antipathes grandis)* has been reported in the area (EOL, 2018), this specie is found in NOM-059-SEMARNAT-2010 under the category of special protection. The handline is considered a low-impact fishing gear (Chuenpagdee, 2003; FAO, 2005); nevertheless, few studies have focused on the physical habitat impacts of handlines. Impacts can include entanglement and minor degradation of benthic species due to line abrasion and the use of weights (leads). Schleyer and Tomalin (2000) noted that discarded or lost fishing lines appeared to easily entangle branching and digitate corals and were accompanied by progressive algal growth. Tangled lines between corals can break gorgonians and similar species. Due to the widespread use of weights over coral reef or hard bottom habitats and the concentration of fishers' effort over these habitat areas, the cumulative impact can result in significant impacts resulting from the use of these gear types. It is important to verify the sites where fishing is taking place based on coordinates to identify the type of habitat and to know the impacts that can be generated in the region.

5. Implications for management and conclusions

The catch spatial distribution, CSA and selectivity analysis show that the assessed fisheries have a low impact because they do not drag and highly selective. Also, they do not interact with vulnerable habitats. Maps of habitat distributions are required to move beyond purely qualitative assessments of fishing risks to benthic habitats (e.g., Astles et al., 2009), but this is problematic as detailed habitat maps are rarely available at the fishery scale. A quantitative framework that assesses gear-specific impacts on biological and geological features associated with particular substrates and natural disturbance regimes would facilitate ongoing and future marine spatial management in data-poor scenarios (Grabowski et al., 2014). In addition, we can evaluate which habitats are most vulnerable and identify those that improve the productivity of fishing species. To achieve sustainable fisheries there must be better distribution of space, use of gear that captures the largest individuals, and little overlap in gear selectivity.

In this study, local ecological knowledge (LEK) was essential to build solid analyses. Fishers' knowledge provided many insights into species-habitat associations and the ecological roles of habitats. Fisher's incentive to provide information is to have a greater understanding to reduced levels of precautionary management and improve fisheries policies (Auster, 2001). In data-poor scenarios, fishers can propose solutions and they could be replicated in other regions, once they know they are making an impact with fishing gears, based on their LEK. In the absence of scientific mapping, quality-assured fishing data could be used to produce useful fishery-scale maps. This inferential approach is less satisfactory, but it is feasible for data-poor situations and is precautionary since it contains habitat types that may be integrated as additional data are incorporated.

Our results support the contributions of Fishery Improvement Projects to secure the sustainability of small-scale fisheries, as well as the importance of combining LEK with scientific data, especially in data-poor areas. In Mexico, the official monitoring of fishing activities has many limitations (there are very few fisheries officers on the coast and monitoring is not constant) that prevent a better understanding of the state of the fisheries and their impacts. In order to prove that fishing gears are highly selective and increase the fisheries' efficiency, we need more information on catch sizes and gear characteristics. When FIPs are correctly executed, they can promote the collection of data that otherwise would not be available from official sources. The monitoring of fishing, biological, and ecosystem features related to fishing activities will allow to empower local communities and promote a bottom-up initiative to directly evaluate if their activities do not threaten associated habitats, and if negative effects are identified, will allow proposing management actions to lessen its impact.

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Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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