Assessment of the impacts by three fishing gears in four communities on habitats in the Northwest of Mexico, under the indicators of principle 2 of the MSC

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] Independent consultant, Ignacio Allende 770, Zona Central, La Paz, Baja Califorinia 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

Abstract

Keywords

Small-scale fisheries; Fishery Improvement Project; habitat type; Data limited fisheries

1. Introduction

Ecosystem-based management (EBM) approach considers impacts on all the elements involved in the exploitation of marine ecosystems, ecological and socioeconomic, and has been applied to wild capture fisheries worldwide (Curtin and Prellezo, 2010; Pikitch et al., 2004) . This approach represents a shift away from single-species management toward the incorporation of all the effects of fishing activities. 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 or through changes in predator-prey dynamics, competitive interactions, relative species abundance, and other ecological relationships (Garcia and Cochrane, 2005; Jørgensen et al., 2007). The degree and severity of these adverse effects on biodiversity and the seabed depend on a variety of factors, including the spatial extent of fishing, the level of fishing effort, type of seabed, and the fishing method used.

As part of socioecological systems, the impacts of fishing activities on important habitats for commercially important species, also translate to human communities depending on them (Curtin and Prellezo, 2010). Hence, fishing activities may indirectly be damaging species caught and the human communities using them. Understanding the impacts of fishing on habitats is a necessary part of adopting EBM, but multi-scale data that describe the types and distributions of habitats, and the interactions of fishing with them, 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 ocean habitats in management actions (Armstrong and Falk-petersen, 2008).

The importance of habitats for fisheries has been recognized for a long time, but the impacts on habitats are less commonly assessed in fisheries management. Assessing benthic habitats acknowledges the many essential roles habitats can have for fishery ecosystems (Rice and Rivard, 2007; Thrush and Dayton, 2010). Documented examples 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). Impacts on benthic habitats range from the intertidal zone to the deep sea (Clark et al., 2010; Kaiser et al., 2006; Morais et al., 2007; Morell, 2007).

Mexico is among the top 20 fishing producers worldwide (FAO, 2022), and the majority is from small-scale fisheries (Saldaña-Ruiz et al., 2022). The Northwest Mexican Pacific is recognized as a biodiversity hotspot for conservation and accounts 66% of the annual fisheries production in Mexico and 97% are small-scale vessels (DOF, 2018a; Lluch Cota et al., 2009). Despite the importance of artisanal fishing activities in this region, the information regarding the impacts of these activities on benthic environments is quite scarce and mainly related to the collapse of some artisanal fisheries (Cisneros-Mata, 2010; Sáenz-Arroyo et al., 2005; Sala et al., 2004). There is a general lack of information regarding the specific environmental impacts of fisheries, and more studies are needed to set sustainable fisheries regulations.

Mapping of habitats is absent in the majority of important fishing areas as well as specific details on gear-habitat interactions, but the information needed to describe these elements is often difficult to acquire. To address these gaps, some approaches have been developed for data-limited scenarios, like Mexico. 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 Marine Stewardship Council (MSC) standard (sustainable stocks, minimization of environmental impact, and effective fisheries management) to achieve sustainability in their fisheries. These projects generally use the market to encourage changes towards sustainability, ensuring that they transcend into better fishing practices. Although they can bring economic benefits, they can also promote solid governance structures, such as more inclusive, transparent, and collaborative processes (Espinosa-Romero et al., 2017). 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 fishing ground characteristics (Lima et al., 2017; Martins et al., 2018).

In this study, we evaluate the impact of fishing gear on habitats in four fishing communities in the Northwest Mexican Pacific. The fishing gears evaluated are hand-collected by hookah diving (penshell in Bahía de Kino), traps (multispecies in El Rosario and ocean whitefish in Isla Natividad), and handline (multispecies in El Rosario and Guaymas and ocean whitefish in Isla Natividad). 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 under the ERAEF approach. 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

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 (Fig. 1). 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. Due to its constant tidal and wind-driven upwelling systems, the Gulf is highly productive, providing 60-70% of Mexico's national fisheries (Carvajal et al., 2004). More than 6,000 species of fauna have been recorded in the Gulf, with more than 4,800 species of invertebrates (Garcia and Gastelum, 2015). The continental shelf off Sonora is generally narrow and irregular and varies in width from ~5 to 70 km, with the widest regions occurring in the northern part of the state (Dauphin and Ness, 1991). The bottom consists of alluvial deposits from the broad coastal plains that border the adjacent coast (Moreno et al., 2005).

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. It is characterized by a very narrow continental shelf, which widens to the south, reaching between 110 and 140 kilometers in Bahía Sebastián Vizcaíno and to the north in Bahía Magdalena. From the rupture of the continental platform, the seabed descends abruptly to depths of 1,000 and 3,000 meters. In oceanographic terms, it is dominated by the California Current, which flows from north to south, carrying relatively cold and nutrient-rich water (Wilkinson et al., 2009). This makes the South Pacific-Californian a complex zone of biotic transition, characterized by a relatively high diversity of species, also including mangroves and macroalgae forests (Wilkinson et al., 2009). Isla Natividad is considered a core area within the 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). Permitted and prohibited activities, as well as zoning, are described in the Reserve Management Plan (DOF, 2000).

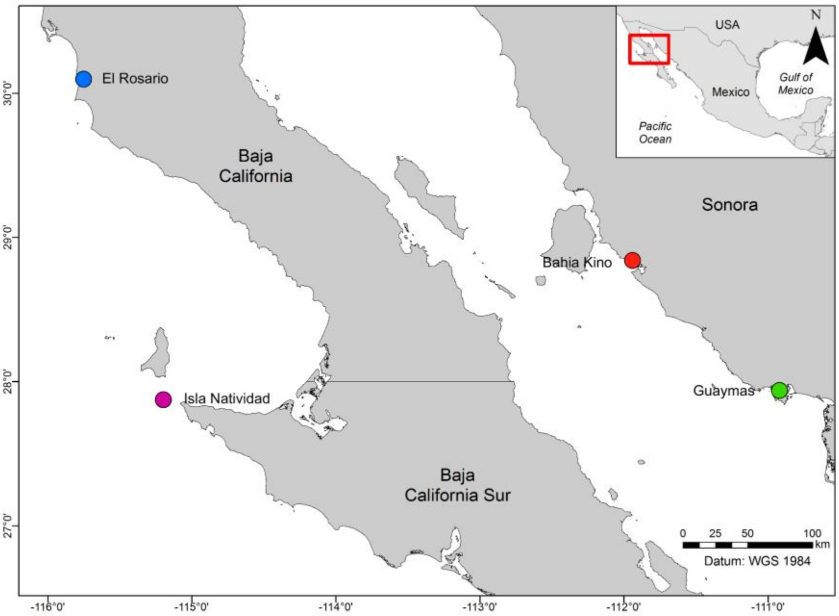

Fig. 1. Study area showing the fishing sites of each location: Bahía de Kino, Guaymas, Isla Natividad, and El Rosario.

2.2. Species and size selectivity

The data used for the fishery characterization was obtained from logbooks, system established by fishing cooperatives involved in FIP. The fishing cooperatives were already used to record information about their activities as part of the reporting system of landing data must to the fishing authority (CONAPESCA), but the detail of data recorded was low. A part of the monitoring system for the FIP, landing records include information about location, depth, and bottom type in the fishing area, duration of the trip (hours), total weight landed (kg) per fishing trip for target and non-target species, and fishing gear characteristics (Table 1).

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

Fishery	**Bahía Kino, Son**	**Guaymas, Son**	**Isla Natividad, BCS**	**El Rosario, BC**
Target species	*Atrina tuberculosa*	*Caulolatilus princeps, Lutjanus peru, Hyporthodus acanthistius, Paralabrax auroguttatus, Seriola lalandi*	*Caulolatilus princeps*	*Caulolatilus princeps, Semicossyphus pulcher, Paralabrax nebulifer, Sebastes constellatus, S. miniatus*

Period of records	2020 - 2021	2015-2021	2018 - 2020	2019 - 2021
Fishing trips recorded	334	2813	500	1975
Fishing sites identified	33	14	42	36
Duration of fishing trips (hours)	--	Average of 26.44 ± 18.67	Average of 5.21 ± 2.00	Average of 7.54 ± 2.05
Depth (m)	From 3 to 20 meters	Average of 81.77 ± 26.71	Average of 50.84 ± 27.50	Average of 78.19 ± 32.57
Fishing gear	Hookah diving	Handline w/ hooks #4 to #10	Handline w/ hooks #6, #7 and #8; trap mesh 4”	Handline w/ hook #4 to #14; trap mesh 1”, 2” and 4”
Fishing trips by gear	334	Handline 1428; ND:1385	Handline 249; trap: 138; ND:111	Handline 1636; trap: 124; mix:13; ND:30
Catch (kg)	103	34885.7	32194.52	65336.02
Catch percentage of target species	45.57	15.35	88.54	17.03

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 because there was detailed information on their sizes and in relation to the fishing gear used. However, for other species, despite having sufficient information from the measurements, the fishing gear was not well differentiated. All measurements were analyzed as a single group because the data from logbooks were not disaggregated by sex. 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 analyses, 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.

2.3 Consequence-Spacial Analysis

The ERAEF method for assessing fishing risk to habitats is based on a habitat vulnerability model proposed by Bax and Williams (2001). The model estimates a relative vulnerability in qualitative terms using two axes (i) the resistance of the habitat (to physical modification) and (ii) its resilience (estimated as the time it takes for the habitat to recover its original state once modified). The ERAEF for habitats was applied by using 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 particular habitat type to being affected by different fishing gear.

Habitat spatial layers were obtained from open access sources such as Blue habits (Harris et al., 2014), Ocean data viewer (UNEP-WCMC, 2022), and Geoinformation portal (CONABIO, 2022). Habitat types were delimited using the fishing area and sites of each fishery. To develop a list of fishing habitats, the inferential method of Hobday et al. (2007) was used. 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 during the fishing activity (Link to videos) and interviews with fishers. Distributions of habitat types were defined by depth zones and association with particular geomorphic features of the seafloor, bathymetry and coarse-scale geomorphology. Habitat mapping was performed using GIS. 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. Therefore, even in the absence of image data, a set of potential habitats can be assembled for use in the ERAEF.

The CSA consists of 10 attributes that consider the gear’s impacts and the characteristics of the habitat being affected by the fishing gear. Qualitative and semiquantitative data are collected via stakeholder (e.g., fishers, community members) involvement to assist in the identification of the habitat(s) and in the scoring of the attributes. 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.The 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).

2.4 Catch spatial distribution

Inverse distance weighting (IDW) was used to estimate the spatial distribution of the catch. 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 habitat layers were delimited according to the recognized fishing zones and previously reported by fishers from the corresponding fishing communities (Castro-Salgado et al., 2017; Moreno et al., 2005). In fisheries where there are no reports of fishing polygons, an adjustment had to be done according to the limits of the capture points and bathymetry. 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 (Table 2).

Table 2. Data sources and spatial resolution for habitat characterization in this study.

Habitat layer	Source	Spatial resolution
Global seafloor (Harris et al., 2014)	Blue habitats	30 arcsec
Kelp biome (Jayathilake and Costello, 2020)	Ocean Data Viewer	30 arcsec
Seagrasses records (UNEP-WCMC and FT, 2021)	Ocean Data Viewer	-
Coral reef records (UNEP-WCMC, WorldFish Centre, WRI, 2021)	Ocean Data Viewer	-
Mangroves (CONABIO, 2022)	CONABIO	-

3. Results

3.1 Species and size selectivity

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. Seven non-target fishes (representing 11.45% of the total catch) were recorded in fishing trips from 2018 to 2020 in Isla Natividad. 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 3). *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).

Table 3. 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
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
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
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

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 4). 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 (Fig. 2). 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).

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 4). 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.

Table 4. Estimated selectivity parameters for different models. The models in bold are the ones that showed a better fit.

Specie	Model	Parameters	Deviation

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

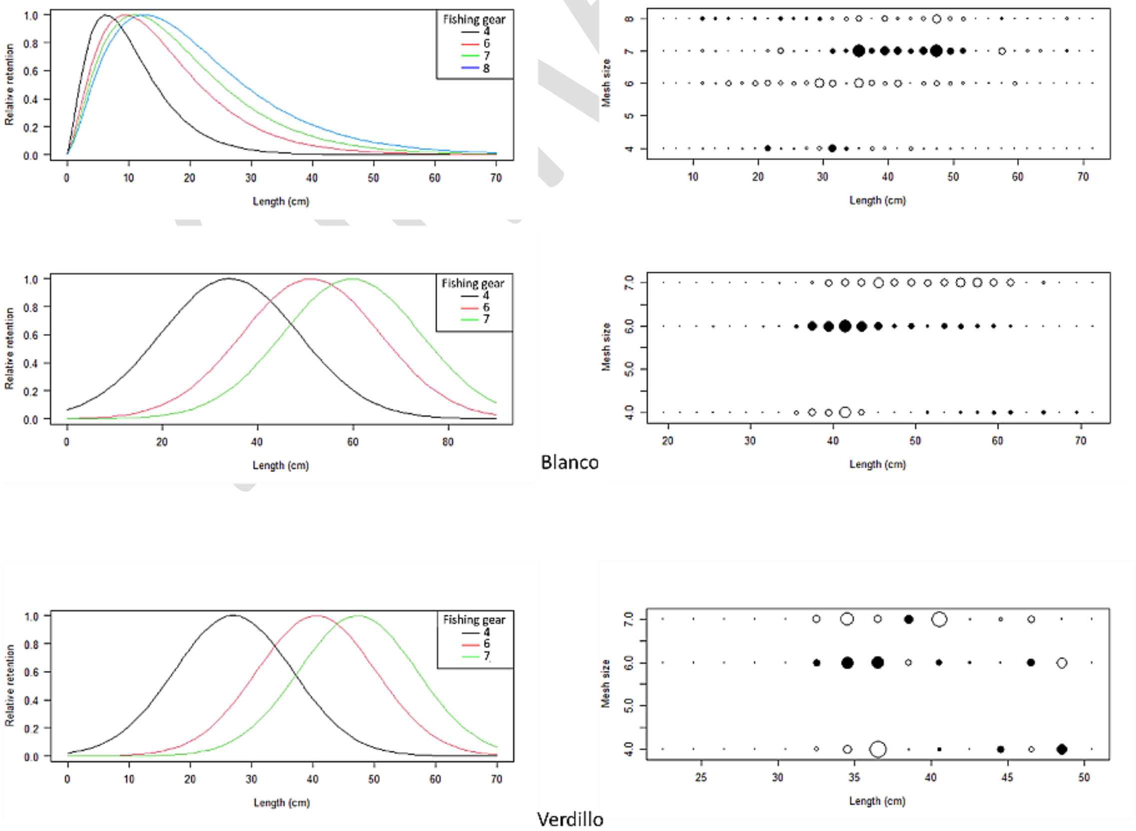

Fig. 2. Selectivity curves (a) and residuals (b) for 1) ocean whitefish captured in Isla Natividad, 2) ocean whitefish captured in El Rosario and, 3) barred sand bass captured in El Rosario. White

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.

3.2 CSA

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 2). 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. For Isla Natividad, it was assumed that the fishing sites used both fishing gear, therefore, a total of 14 types of habitats were obtained, 7 habitat types for the trap and 7 for handline fishery in Isla Natividad. Comparing the risk between the two-fishing gear, it was found that the traps have a higher average risk (2.06) than handline (1.88). A total of nine habitat types were found for the handline fishery and nine habitat types for the trap fishery in El Rosario. Same as above, it was assumed that both fishing gears were used in the fishing sites, therefore, a total of 18 types of habitats were obtained with an average of 2.08 for traps and 1.94 for handline (Fig. 3).

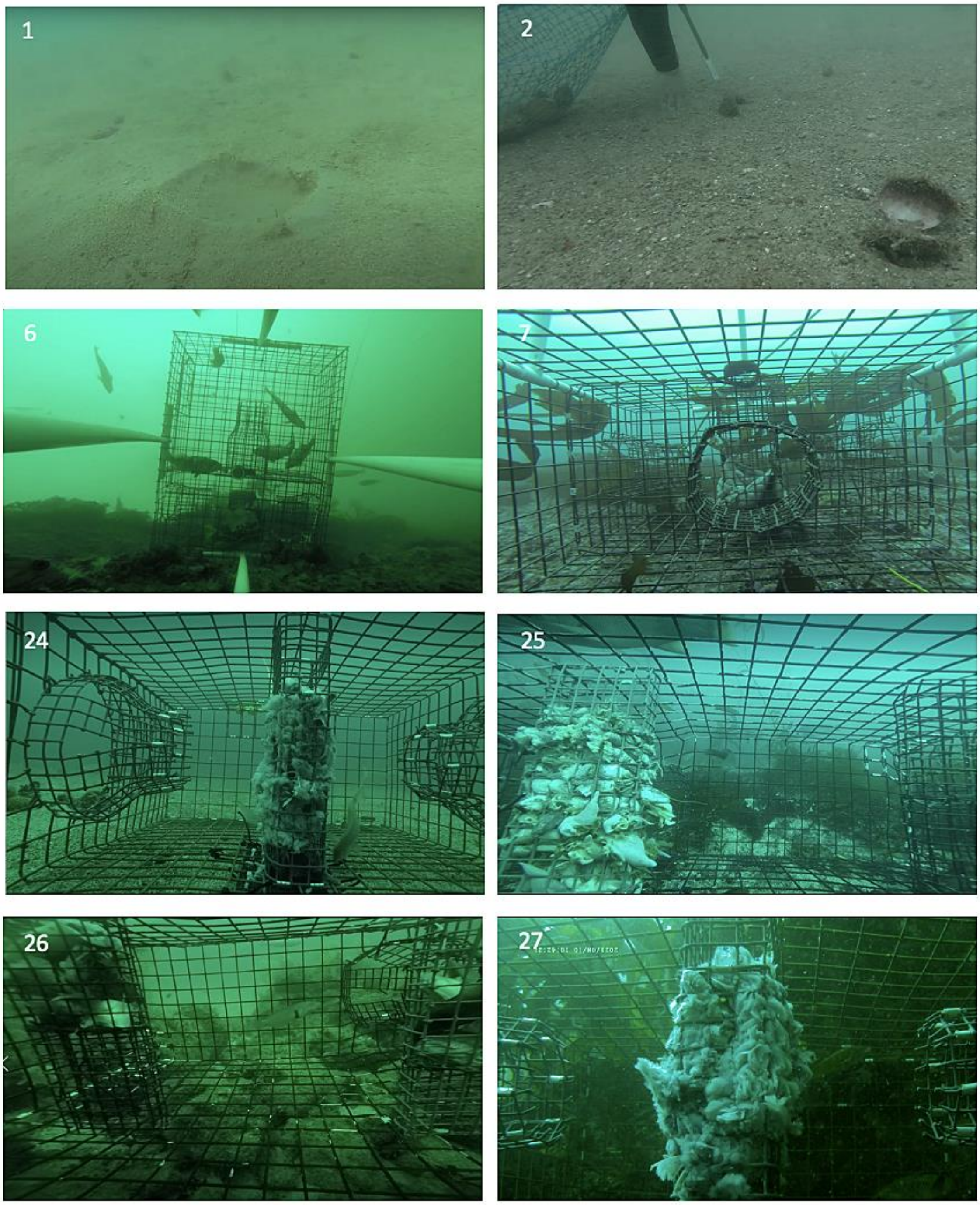

Fig. 3. Subset of habitat types for Bahia Kino penshell by hookah diving (ID: 1) Fine-Coarse sediments / Flat-Simple surface structure / Small erect-Consolidated and unconsolidated bivalve beds and 2) Fine-Coarse sediments / Flat-Simple surface structure / Small erect-Mixed small/low-encrusting invertebrate communities), El Rosario finfish by trap (ID: 6) Medium-Gravel/pebble / Outcrop-Low-relief outcrop / Small erect-Mixed small/low-encrusting invertebrate communities and 7)Fine-Coarse sediments / Flat-Simple surface structure / Small erect-Mixed small/low-encrusting invertebrate communities), and Isla Natividad ocean whitefish by trap (ID: 24)Fine-Coarse sediments / Flat-Simple surface structure / Large erect-Mixed large or erect communities, 25) Large-Cobble/boulders / High relief-High outcrop / Large erect-Mixed large or erect communities, 26) Large-Cobble/boulders / Outcrop-Low-relief

outcrop / Small erect-Mixed small/low-encrusting invertebrate communities, 27) Large-Cobble/boulders / Outcrop-Low-relief outcrop / Flora dominated by Seagrass species). The classification of each ID is provided in Annex XX.

3.3 Catch spatial distribution

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).

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 located in high and low catch zones (Fig. 4). 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 located in low and high catch zones (Fig. 4; Annex 3).

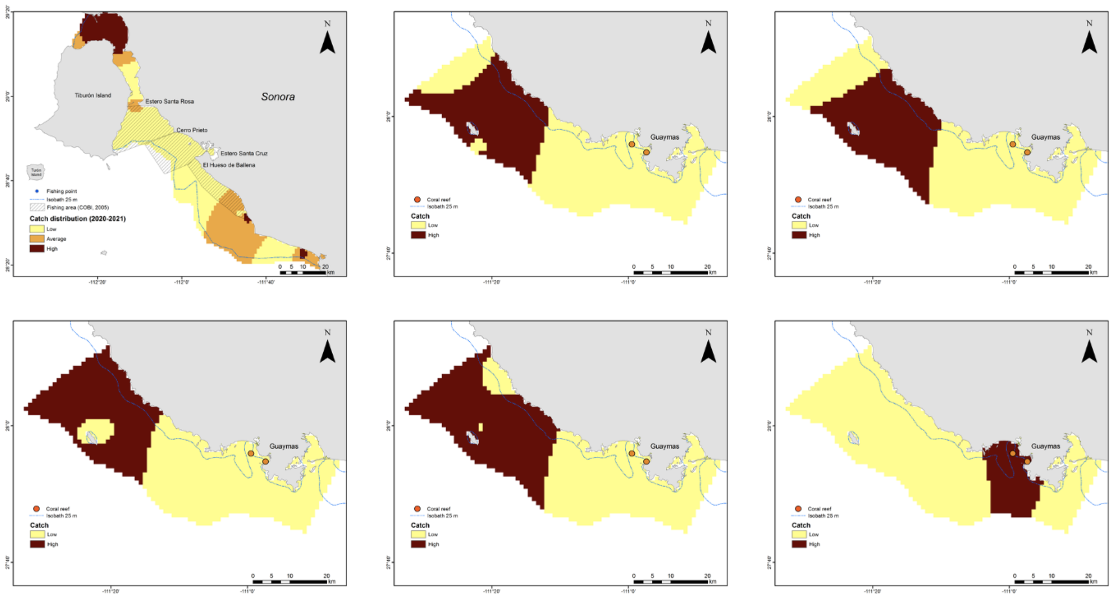

Fig. 4. Spatial distribution of the fishery catch of (1) penshell fishery in Bahía Kino; (2) (a) red snapper, (b) rooster hind, (c) gold spotted sand bass, (d) yellowtail, and (e) ocean whitefish in Guaymas.

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 located in the zone with the lowest (Fig. 5).

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 located in a high catch zone. 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; Annex 3).

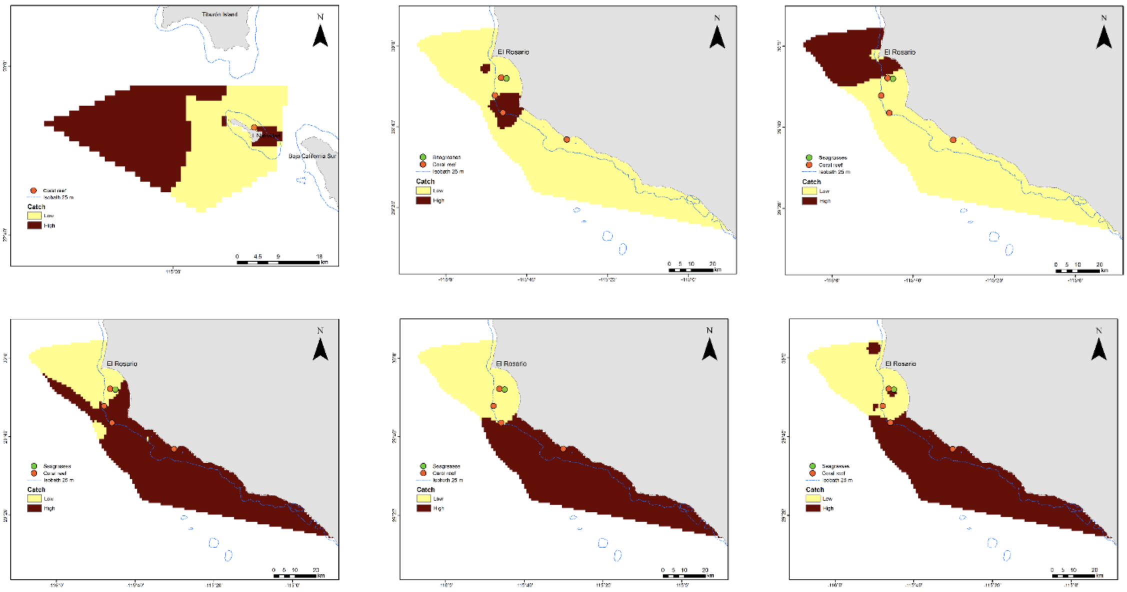

Fig. 5. Spatial distribution of the fishery catch of (1) ocean whitefish in Isla Natividad; (2) (a) ocean whitefish, (b) California sheephead, (c) barred sand bass, (d) starry rockfish and (e) vermillion rockfish in El Rosario.

4. Discussion

4.1 Species and size distribution

The hookah diving manual harvesting method is also highly selective, has minimal impact on the environment, and prevents bycatch of non-target species (AFMA, 2020). The catch of the target fishery in Bahía Kino represents less than 50% of the total catch but in the videos, it can be seen that the only resource that is captured is the penshell manually. However, other species are recorded in the logbooks. This may be due to the establishment of 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. Cinti et al., (2010) mentioned the Black murex snail is seasonal in their accessibility, and is rarely extracted because of their scarcity, low demand, and low price. 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. 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.

Despite the great diversity of species caugth 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 finish fisheries are multi-specific, as reported in the National Fishing Charter. For example, the rockfish and barred sea 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.

Our estimations showed that the fishing gears used for the catch of target species are selective to optimal sizes above their maturity size. Even for the ocean whitefish from Isla Natividad, fishing gears are catching sizes bigger than the estimated optimal sizes. These findings suggest that the fishing gears are selecting sizes that allow the juveniles to reach maturity size before being incorporated into the catch biomass.

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).

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). The selectivity analysis was not performed for all target species due to the fact that there was no detailed information on sizes and their relationship to the fishing gear used on logbooks fro 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.

4.2 CSA

The Spatial and Consequence Analysis for the fishing sites resulted in low risk. The analysis is based on six main characteristics: substrate, geomorphology, fauna, biome, subbiome and feature. Of which, for the characterization of the first three, the use of videos may be essential to have accurate information and complemented with interviews to fishers to verify what was observed in the videos.

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. 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 dregdes) (Auster et al., 2011). Although, there is some evidence that it can negatively impact sensitive marine organisms, such as corals and bryozoans due to sediment agitation (Medeiros et al., 2007). 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). In the videos, it was observed that the use of the bags, fins, and hooks causes agitation in the sediment, this is relevant because areas that overlap with coral reefs and grasses were recorded. 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 El Rosario, we observed that there are fishing sites associated with coral and hard bottom habitat, 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) 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, of which 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. 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. Also, it is seen in the videos that there are fishing sites that are dominated by macroalgae and mixed communities. In them, the traps use weights to sink, which when retrieved are dragged along the bottom for a few seconds, which can generate an impact on the substrate or the associated marine communities. Sometimes removal of biota and lifting of sediment is observed that can cause negative impacts on sensitive marine organisms, such as corals and bryozoans (Medeiros et al., 2007). However, a study 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.

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). The handline is considered a low-impact fishing gear (Chuenpagdee, 2003; FAO, 2005). However, the ocean whitefish fishery was found to have high catches in regions with corals. 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.

4.3 Catch spatial distribution

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). Regarding Isla Natividad, ocean whitefish is an associated specie with reefs, rocky, and sandy bottoms, and depths of 100 m (Humann and Deloach, 1993; Schneider and Krupp, 1995). It´s 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, it´s current management, and the selective fishing gear.

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.

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). Its complex topographic feature is also associated with hard substrates that are colonized by corals and sponges, contributing to the formation of coral reefs. Consequently, the use of trawling gear in slope areas has been limited (Hourigan, 2009). This type of fishing gear is not used in the fisheries of this study, which could contribute to the health status of the associated habitats in that region.

5. Implications for management and conclusions

The CSA and the catch spatial distribution show that the assessed fisheries have a low impact due to the fact that 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. There are many methods that have the potential to define and map habitats at finer spatial scales such as sonar mapping or physical or photographic sampling but they are expensive to collect over large areas and in shallow water (Kloser et al., 2007). In the absence of scientific mapping, quality-assured fishing data could possibly be used to produce useful fishery-scale maps. This inferential approach is less satisfactory, partly because some habitat types may remain unidentified, but it is feasible for data-poor situations and is precautionary since it contains habitat types that may be eliminated as additional data are incorporated. The distributions of finely detailed habitat types may be interpolated to larger spatial scales using surrogates (depth zones or features) as in the ERAEF, or simply be defined at a coarser surrogate scale in the first place (Auster and Shackell, 2000). In this case, local ecological knowledge (LEK) was essential to do the analyses. Fishers' knowledge provided many insights into species-habitat associations and the ecological roles of habitats. There is an incentive to provide such information because greater levels of understanding lead to reduced levels of precautionary management, and more accurate models (Auster, 2001).

One of the benefits of this analysis is that every time we have more information, it can be added and replicated to make it more robust. 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. In addition, we can evaluate which habitats are most vulnerable and identify those that improve the productivity of fishing species. The possibilities of achieving fisheries sustainability should be improving the space distribution and using gears that catch the largest individuals and have little overlap in gear selectivity.

Our results support the importance of Fishery Improvement Projects to secure the sustainability of small-scale fisheries in data-poor areas. In Mexico, the official monitoring of fishing activities has many limitations that prevent a better understanding of the state of the fisheries and their impacts. When FIPS are correctly executed, they may 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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