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A Risk-Based Assessment to Advise the Responsible Consumption of Invertebrates, Elasmobranch, and Fishes of Commercial Interest in Mexico

Luz Erandi Saldaña-Ruiz[1]*, *Alesa Flores-Guzmán*[2], *Frida Cisneros-Soberanis*[1], *Gabriela Alejandra Cuevas-Gómez*[2], *Ernesto Gastélum-Nava*[3], *Lorena Rocha-Tejeda*[2], *Jose Francisco Chavez*[4], *Raziel Elihu Hernandez-Pimienta*[2] *and Francisco Javier Fernández-Rivera Melo*[2]

[1] *Laboratorio de Ecología Pesquera, Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico, Departamento de Oceanografía Biológica, Ensenada, Mexico,* [2] *Comunidad y Biodiversidad A.C., Guaymas, Mexico,* [3] *Centro Regional de Investigación Acuicola y Pesquera, Instituto Nacional de Pesca, Guaymas, Mexico,* [4] *Restauración de Ecosistemas A.C., Los Mochis, Mexico*

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***Correspondence:**
Luz Erandi Saldaña-Ruiz
lsaldana@cicese.mx

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The main key drivers of vulnerability for marine species are anthropogenic stressors, ranging from pollution and fishing to climate change. The widely documented impacts of fishing activities on marine species, the growing concern about the population status of many marine species, and the increase in per capita consumption of marine products worldwide have led to the development of environmentally responsible fishing standards and initiatives to inform consumers about the health status of the species. In Mexico, fishing is a vital source of jobs and food security for many coastal communities, but the population status of many species of commercial importance has not been evaluated. Management efforts and fisheries certification procedures and standards to achieve the sustainability of many Mexican fisheries are hindered by a lack of biological and fishery data for many species. In this study, a risk assessment methodology for data-limited fisheries, a Productivity, and Susceptibility Analysis was used to estimate the relative vulnerability of marine invertebrates and fishes commercially important in Mexico to fishing. Ninety-eight invertebrates, 66 elasmobranchs, and 367 bony fish were analyzed. The vulnerability among the 531 evaluated species is high for 115 (22%), moderate for 113 (21%), and low for 303 (57%). The most vulnerable species are the Mexican geoduck (*Panopea globosa*) and the Black Sea Cucumber (*Holothuria atra*) for invertebrates, the Spiny butterfly ray (*Gymnura altavela*) among elasmobranches, and the Black-and-yellow rockfish (*Sebastes chrysomelas*) for bony fishes. This study provides a first screening of the many species potentially affected by fisheries, prioritizes marine species for future research and management efforts, identifies the main data gaps, and sets the baseline for future research efforts and management. Furthermore, the results could improve market-based approaches like eco-labeling initiatives and the Responsible Seafood

Consumption Guide, developed by Mexican authorities in collaboration with Comunidad and Biodiversidad (COBI, a civil society organization), to inform consumers about the origin and sustainability of fishery products.

Keywords: vulnerability, data-limited fisheries, eco-labeling, fisheries sustainability, productivity and susceptibility analysis (PSA)

INTRODUCTION

Worldwide, the population depletion of many marine species by overfishing threatens the sources of jobs and food security of many regions where fishing is one of the main economic activities (FAO, 2020). In Mexico, fishing is an important activity that generates direct and indirect jobs and is a source of protein for more than 11 000 coastal communities (SAGARPA, 2017). In 2018, fishing production in Mexico reached 2,159,650 tons and an average national consumption per capita in the last five years of 18.24 kg (SAGARPA, 2020), which places Mexico among the 15 leading fish producers in the world (FAO, 2020). In Mexico, a total of 551 marine invertebrates and fishes are recorded that are relevant for small-scale and industrial fisheries for consumption or ornament purposes (DOF, 2000). The main key species are abalones, clams, squids, octopus, scallops, shrimps, lobsters, conchs, sea urchins, elasmobranchs, small pelagic fishes, coastal and demersal fishes, and tunids (DOF, 2018). The Mexican fishing fleet includes 2,020 larger vessels and 74,286 small (coastal) vessels, and a record of more than 238,000 people in the fishing sector (DOF, 2020). Fishing is carried out with a wide variety of fishing gear, including purse seines, gillnets (bottom and surface set), longlines (bottom and surface set), handlines, trawl lines, pots, traps, diving, and manual gathering (DOF, 2012; DOF, 2018). Invertebrates and fishes are sold fresh, frozen, or live (filleted or whole) or processed (e.g., dried, salt dried, canned, cooked, smoked) (DOF, 2010a; DOF, 2012; SAGARPA, 2021). The fishery products are sold in the domestic markets (with high national consumption) and international markets, with more than 350,000 t exported in 2019, mainly to the United States of America, Hong Kong, Japan, Spain, and China (SAGARPA, 2021).

Fisheries management in Mexico is administered by the General Law of Sustainable Aquaculture and Fisheries (LGPAS, by its Spanish acronym) (DOF, 2007). The LGPAS establishes the national policy for regulating the fisheries *via* the Official Fisheries Mexican Standards (NOM-PESC), which describe the specific management measures by species or group of species. The National Fisheries Charter (CNP) is another legally binding instrument used in Mexico to manage all the fisheries in Mexico with yearly updates (DOF, 2007). Developed by the National Fisheries and Aquaculture Institute (INAPESCA), the CNP indicates the strategies and actions that must be fulfilled to regulate fishing in Mexico, including information related to the fishing sites and gears, the status of the stocks, and fishing effort (DOF, 2007; DOF, 2018). In addition, researchers from INAPESCA elaborate and update the fisheries management plans (FMP) approved by CONAPESCA. The fisheries management plans include actions aimed at developing the fishing activity sustainable and are based on biological, ecological fishing, environmental, economic, cultural, and social knowledge. Of a total of 36 main fisheries, 27 (75%) of these fisheries are at the level of maximum sustainable yield, seven are in deterioration, two with development potential, and only 13 (36%) have a management plan (DOF, 2018).

Given the growing concern about invertebrate and fish populations' status and the increased demand for marine products, initiatives have been developed to inform consumers about the production processes (Roheim, 2003; FAO, 2010). The development of environmentally responsible fishing standards has been highlighted through the certification of fisheries and recommendations for the consumption of seafood (Ward and Phillips, 2008; Kirby et al., 2014). These standards have been recognized by the Committee on Trade and Environment of the World Trade Organization as environmental policy instruments (Maneiro Jurjo and Burguillo Cuesta, 2007) and represent a great opportunity and frame of reference towards the development of sustainable fisheries in Mexico. There are different eco-labels or programs based on sustainability schemes, among which some stand out on a global scale for incorporating rigorous aspects of social, political, economic, and ecological issues. The Marine Stewardship Council (MSC), Seafood Watch (SFW), and Fair-Trade USA (FT) are three of the organizations that have boomed in the last decade because they show robust and sustainable principles (CEA, 2020).

However, organizations such as the MSC have recognized that certification procedures and standards are more challenging for fisheries in developing countries, especially small-scale fisheries with poor and limited data. For the above, the MSC developed a methodology to evaluate data-deficient fisheries following the ecological risk assessments framework to generate critical information for fisheries (Ponte, 2012). Ecological risk assessments have been developed in recent years as an alternative to conventional stock assessments, which require a large amount of information (Carruthers et al., 2014). Within the framework of ecological risk assessments, there is the semi-quantitative Productivity and Susceptibility Analysis (PSA), in which the relative vulnerability of a particular stock to fishing is estimated by analyzing the interaction of fishing with the stock (susceptibility) and the capacity of the species to face the impacts of fishing through its biological characteristics (productivity) (Hobday et al., 2011; Cortés et al., 2015).

The National Commission for the Knowledge and Use of Biodiversity (CONABIO) developed the Responsible Seafood Consumption Guide (RSCG) in Mexico. This RSCG includes advice and recommendations for a total of 615 species of fish and invertebrates in a colored guide system (Green = Recommended, Yellow = Not recommended or in moderation, and Red =

Avoid) to create awareness of sustainably managed fisheries and encourage the consumers about the sustainable seafood consumption and behavioral changes that could reduce fishing pressure on vulnerable species (Gulbrandsen, 2009; Vázquez-Rowe et al., 2013; Fernández-Rivera Melo et al., 2018). The RSCG considers the following criteria to issue a seafood purchase recommendation: a) fishing origin (e.g., domestic or imported), b) status of the populations based on the official information on current fisheries published in the National fisheries charter ((DOF, 2010a; DOF, 2012; DOF, 2018), c) species at risk based on the Official Mexican Standards for Species at Risk (NOM-059-SEMARNAT-2010) and the Red List of the International Union for Conservation of Nature (IUCN), d) type of ban available, and e) the catch selectivity. However, there is no information on the population status of many species due to the lack of biological and fishing information necessary to assess the populations using traditional quantitative methods. Hence, the impact of extractive activities on many species is unknown (Arreguín-Sánchez and Arcos-Huitrón, 2011; Saldaña-ruiz et al., 2017), and it is not possible to issue a seafood purchase advice or recommendation. In this study, we estimate the relative vulnerability of invertebrates, elasmobranchs, and bony fish of commercial importance to fishing activities in Mexico, using the MSC's version of the productivity and susceptibility analysis (MSC, 2014) for data-limited fisheries.

MATERIALS AND METHODS

Study Area

Mexico is located in an intertropical geographical position and has a large oceanic extension that includes a region in the Pacific Ocean and the Atlantic, with an exclusive economic zone of 2,715,012 km^2 and a coastline of 11,122 km (Lara-Lara et al., 2008: **Figure 1**). Mexico has a wide variety of oceanic and coastal ecosystems, home to an enormous marine fauna diversity that supports the country's fisheries (De la Lanza-Espino, 2004). Marine fishing activities in Mexico are divided into three regions within the Exclusive Economic Zone (EEZ) based on official management and policies: 1) the North Pacific, 2) the South Pacific, and 3) the Gulf of Mexico and the Caribbean Sea (**Figure 1**). These fishing regions have their own physical and socio-economic characteristics with different levels of fisheries development (DOF, 2020). The North Pacific region has two zones with unique physical characteristics. The west coast of the Baja California peninsula is characterized by a mixture of cold and nutrient-rich waters from the California Current and warm waters from the south (Durazo et al., 2007). Moreover, the Gulf of California, located between the Baja peninsula and the mainland, with variable high sea surface temperatures and high primary productivity during winter and spring (Álvarez-Romero et al., 2013). In the North Pacific region, a wide range of subpolar, cold-temperate waters, and subtropical species are distributed with a high diversity of fishes and invertebrates (Brusca et al., 2005; Lara-Lara et al., 2008). The South Pacific includes a transitional zone of temperatures influenced by the southern end of the California Current, the surface current from the Gulf of California, and the North Equatorial Countercurrent (De la Lanza, 1991; Badan, 1997; Filonov et al., 2000); as well as a tropical zone of high seasonal variability in productivity due to variations in upwelling and nutrient inputs from river outflow in coastal areas (Trasviña et al., 1995; Gallegos-García and Barberán-Falcón, 1998). Species of tropical and subtropical distribution can be found in this region. The Gulf of Mexico and the Caribbean Sea is a semi-enclosed basin located in the Atlantic Ocean connected to the Caribbean Sea through the Yucatan Channel (Candela et al., 2019). This region is characterized by a transition zone between tropical and subtropical climates. Their physical and oceanographic features include the Loop Current, which brings oceanic water into the Gulf, entering through the Yucatan Channel and exiting through the Straits of Florida, continental shelf wind-driven upwellings, and cold fronts known as "nortes" during autumn, winter, and spring (atlas). This region has a great variety of marine ecosystems (e.g., lagoon systems, mangrove forests, seagrass meadows, and coral reefs) and high biodiversity of marine invertebrates and fishes (Felder and Camp, 2009).

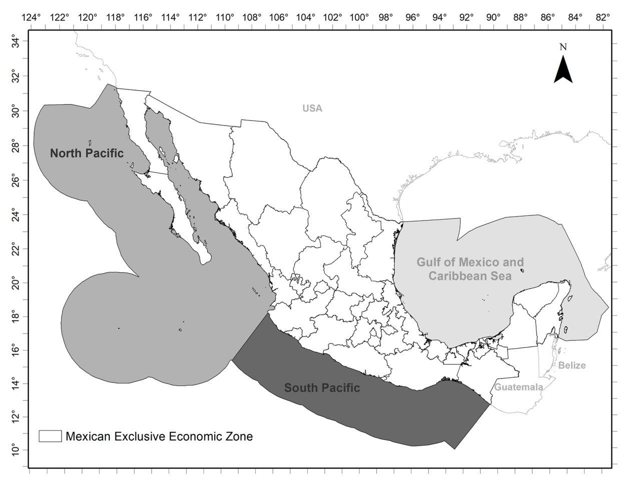

FIGURE 1 | The main fishing regions in Mexico based on official management and policies (DOF, 2020). In grayscale are the North and South Pacific, the Gulf of Mexico, and the Caribbean Sea regions, and the black outline indicates the Exclusive Economic Zone of Mexico.

Vulnerability Analysis

The relative vulnerability (RV) of invertebrates, elasmobranchs and bony fish species of commercial importance to becoming overfished was evaluated using a PSA version modified by the MSC as part of the requirements for data-poor fisheries certification (Patrick et al., 2010; Hobday et al., 2011; MSC, 2014). The biological productivity was evaluated through a set of attributes related to the life history traits of the evaluated species (**Supplementary Table S1**) (MSC, 2014). The species life history data were obtained from the scientific and grey literature (thesis and technical reports) and online databases (FishBase, www.fishbase.org; SeaLifeBase, www.sealifebase.org, MolluscaBase, www.molluscabase.org). A total of seven attributes were used to evaluate productivity in bony fishes and elasmobranches (**Supplementary Table S1**) (MSC, 2014). For invertebrates, a total of six attributes were used, and the attribute "Density-dependence" was used instead of the attributes "Average maximum size" and "Average size at maturity" to consider the depensatory effects on the resilience of marine invertebrates to fishing mortality, as shown in some crabs and lobsters, and often also sedentary bivalves (**Supplementary Table S1**) (MSC, 2020).

The susceptibility of the species was determined with four attributes related to aspects like area overlap (availability), encounter ability, selectivity, and post-capture mortality of species (See **Supplementary Table S2** for a detailed list of the susceptibility attributes; MSC, 2020). The information about the main catch systems used by various fisheries for each of the species was obtained from the scientific literature and Mexican official sources like the National fisheries Charter, which contains data from all the fisheries in Mexico, including the current management tools, actions, and strategies (DOF, 2000; DOF, 2010a; DOF, 2012; DOF, 2018).

Productivity and susceptibility attributes were independently scored on a three-point scale, from high (1) to low (3) productivity and from low (1) to high (3) susceptibility. When information was not available for one species, data from other genera, family, or related species was used or was assigned an intermediate score following the MSC precautionary principle (Hobday et al., 2011; MSC, 2014). The productivity (P) and susceptibility (S) scores were calculated with the average across all scored attributes and displayed on a scatter plot x-y (PSA-Plot). The relative vulnerability (RV) was estimated by calculating the Euclidean distance from the origin (X_0-Y_0) of the PSA-Plot to P and S total scores through the following formula (MSC, 2020):

$$RV = \sqrt{\left[\left(P - X_0\right)^2 + \left(S - Y_0\right)^2\right]}$$

The PSA plot was divided into three equal thirds, representing categories of low (RV <= 2.64), moderate (2.64 < RV < 3.18), and high (RV >= 3.18) relative vulnerability to help with the general interpretation of vulnerability (Hobday et al., 2011; MSC, 2020). The MSC risk-based framework Worksheets templates v2.01 were used (MSC, 2014). The species with the largest RV were the ones with the highest productivity and susceptibility scores (Hobday et al., 2011; MSC, 2020).

Data-Quality Evaluation

The information used to evaluate the productivity and susceptibility attributes was scored based on the data-quality-score and criteria developed by Patrick et al. (2010) to provide details on the uncertainty of the vulnerability results, identify data gaps, and help with the interpretation of the overall vulnerability results (**Table 1**). The information was scored based on five criteria ranging from best to no data available. Data-quality (DQ) scores were divided into three data-quality categories: poor (>3.5), moderate (2.0-3.5), and good (<2.0) for display purposes.

RESULTS

Productivity and Susceptibility Analysis

A total of 531 species of commercial interest in Mexico were evaluated, 98 invertebrates, 66 elasmobranchs, and 367 bony fishes. The highest productivity scores were for invertebrates and bony fish species and the lowest for elasmobranch species. In the invertebrate group, 27 species (28%) had high productivity, including several shrimps, abalone, sea cucumber, clams, mussels, octopus, lobster, and oysters; only one invertebrate resulted with low productivity (P-score of 2.5), the giant horse conch (*Triplofusus giganteus*). Between bony fishes, the species with the highest biological productivity were the scrawled cowfish (*Acanthostracion quadricornis*), the Irish pompano (*Diapterus auratus*), the striped mojarra (*Eugerres plumieri*), the southern puffer (*Sphoeroides nephelus*), and the hospe and flathead grey mullets (*Mugil cephalus* and *M. hospes*), and only three rockfish species with low productivity (P-score of 2.4), blackgill rockfish (*Sebastes melanostomus*), the Mexican rockfish (*S. macdonaldi*), and the cowcod (*S. levi*). Among the elasmobranch species, the most productive (P-score of 2) were the spotted round ray (*Urobatis maculatus*) and the haller's round ray (*Urobatis halleri*); and the species with the lowest productivity (P-score of 3) were the dusky shark (*Carcharhinus obscurus*), the bull shark (*C. leucas*), and the shortfin mako shark (*Isurus oxyrinchus*), these last three shark species resulted with the lowest biological productivity among all the analyzed species, including invertebrates and bony fishes (see **Supplementary Table S3** for detailed scores for all the 531 evaluated species).

The susceptibility among all the evaluated species (531) was high for 47 invertebrates (9%), 37 bony fishes (7%), and seven elasmobranches (1%). The highest susceptibility was for several species of shrimps, abalone, sea cucumbers, clams, mussels, lobsters, oysters, rockfishes, sand flounders, lizardfishes, croakers fishes, scorpionfishes, weakfishes, surgeonfishes, stingrays, butterfly rays, round rays, guitar fishes, and only one shark species, the gray smoothhound (*Mustelus californicus*). The vulnerability among the 531 evaluated species was high for 115 (22%), moderate for 113 (21%), and low for 303 (57%; **Table 2**).

TABLE 1 | The overall vulnerability of the 531 evaluated species.

VC	Invertebrates	Elasmobranchs	Bony fishes	All the species
High	47	29	39	115
Moderate	14	36	63	113
Low	37	1	265	303

The number of species in the relative vulnerability category (VC) of High, Moderate, and Low by taxonomic group.

The species with the highest vulnerability values were the spiny butterfly ray (*Gymnura altavela*; RV=3.85), the black-and-yellow rockfish (*Sebastes chrysomelas*; RV=3.68), and the Mexican geoduck and the black sea cucumber (*Panopea globosa* and *Holothuria atra* respectively; RV=3.51). Among invertebrates, the vulnerability resulted high for 47 species (48%), moderate for 14 (14%), and low for 36 (37%). For the elasmobranch group, the vulnerability scores were high for 29 species (44%), moderate for 36 (55%), and low for 1 (2%). Finally, among the bony fishes, it was high for 39 species (11%), moderate for 63 (17%), and low for 265 (72%).

Species of High Commercial Importance

A total of 208 species (75 invertebrates, 38 elasmobranchs, and 95 bony fishes) were identified as species of high commercial importance, based on the information established in the National fisheries charter (DOF, 2018). The vulnerability among these species was high for 57 species (27%), moderate for 68 (33%), and low for 83 (40%). The most vulnerable species are the Mexican geoduck (*P. globosa*), the black sea cucumber (*H. atra*), the black-and-yellow rockfish (*S. chrysomelas*), and the gray smoothhound (*M. californicus*; **Table 3** and **Figure 2**). A total of 35 (47% among invertebrates) invertebrate species resulted with high vulnerability, including sea cucumbers (1), clams (9), abalones (3), lobsters (7), crabs (1), shrimps (10), mussels (2), oysters (1), and one jellyfish (1; **Figure 2**). As for the vulnerability among the elasmobranchs, most of the species resulted with moderate (66% among elasmobranchs), 12 species (32%) with high, and only one with low vulnerability. In the bony fish group, more than half of the species (56%) resulted low vulnerable, only 10 (11% among bony fishes) species resulted with high vulnerability, including several scorpionfishes (*Sebastes* sp.; 5), weakfishes of the *Cynoscion* genus (2), the gafftopsail catfish (*Bagre marinus*) the Atlantic thread herrin (*Opisthonema oglinum*) and the shoal flounder (*Syacium gunteri*; **Figure 2**). The most vulnerable elasmobranch species were several requiem sharks of the *Carcharhinus* genus (3), two angel sharks (*Squatina* sp.), the gray smoothhound (*M. californicus*), the tiger shark (*Galeocerdo cuvier*), the shortfin mako (*I. oxyrinchus*), the great hammerhead (*Sphyrna mokarran*), and three rays, the smooth butterfly ray (*Gymnura micrura*), the brazilian electric ray (*Narcine brasiliensis*), and the cownose ray (*Rhinoptera bonasus;* **Figure 2**). Seventeen species of high commercial importance are fished in the Mexican EEZ exclusive zone in the three regions (the North Pacific, the South Pacific, and the Gulf of Mexico and the Caribbean Sea; **Supplementary Figure S4**). Among these species, the majority (65%) resulted with high RV. For 56 species being fished in the North Pacific region, 23 species resulted with moderate RV, followed by 17 species with low RV and 16 with high RV (**Supplementary Figure S5**). In the Mexican Pacific, including both the North and South Pacific, 51 species are fished, of which the RV was low for 19, moderate for 15, and high for 17 (**Supplementary Figure S6**). Of a total of 84 species fished in the Gulf of Mexico, 43 species (51%) resulted with low RV, 23 (27%) with moderate RV, and 18 (21%) with high RV (**Supplementary Figure S7**).

TABLE 2 | Description of scores used in data quality evaluation (Modified from Patrick et al., 2010).

Data-quality score	Description
1	Best data. Information is based on collected data for the species in Mexican waters (e.g., Data-rich stock assessment; scientific literature)
2	Adequate data. Information is based on limited coverage and corroboration, or for some other reason, is not as reliable as score 1
3	Limited data. Estimates with high variation and limited confidence or based on studies of similar taxa or life-history strategies (e.g., similar genus or family)
4	Very limited data. Information based on expert opinion or on general literature reviews from a wide range of species, or outside of Mexican waters
5	No data. When there are no data available

Data-Quality

The data quality scores ranged from 1 for the Scalloped hammerhead (*S. lewini*) to 5 for two puffer species, the white-spotted and the guineafow (*Arothron hispidus* and *A. Meleagris*; See **Supplementary Table S3**). Most of the species (471; 89%) had moderate data quality, 47 (9%) had poor data quality, and only 13 (2%) had good data. Within three groups of species analyzed in this study, it was found that the best data available is for species with high commercial or conservation importance, with many research efforts directed towards those species. The data quality was mostly moderate, with a very small proportion of species with good data. The species with good data quality (data quality score < 2.0) were seven elasmobranchs and six bony fishes. The elasmobranchs with the best data are the blacknose shark (*Carcharhinus acronotus*), the blue shark (*Prionace glauca*), the shovelnose guitarfish (*Pseudobatos productus*), pacific sharpnose shark (*Rhizoprionodon longurio*), the shortfin mako (*I. oxyrinchus*), and two hammerhead sharks (*S. lewini* and *S. tiburo*). The bony fishes with the best information available were the wahoo (Acanthocybium solandri), white weakfish (*Atractoscion nobilis*), the red grouper (*Epinephelus morio*), the southern red snapper (*Lutjanus peru*) and marlin (*Makaira nigricans* and *Kajikia audax*). A total of 47 species have poor data quality, of which 38 are invertebrates. Among the 531 evaluated species, the lowest quality of data was for the information used to assess susceptibility attributes ranging from "very limited" to "no data" data category for many species. The best quality of data was for the information used to evaluate the attributes of reproductive strategy and average max size (**Supplementary Figure S8**). The lowest quality of data was for the information used to assess the attributes of density dependence (only for invertebrates), availability, selectivity, and post-capture mortality (**Supplementary Figure S9**).The main data gaps identified among the 531 evaluated species were the trophic level, fishing selectivity, and post-catch mortality (**Supplementary Figure S8**, **S9**). Information about the overlap of species spatial

TABLE 3 | Overall scores and results of the productivity and susceptibility analysis (PSA) for species of high commercial importance species only (n = 208).

Taxonomic group	PL	Species	P	S	V	VC	DQ
Invertebrates	IN1	*Penaeus stylirostris, Rimapenaeus similis*	1.2	1.9	2.2	Low	M, M
	IN2	*Melongena melongena*	2.0	1.2	2.3	Low	M
	IN3	*Fasciolaria tulipa*	2.2	1.0	2.4	Low	M
	IN4	*Triplofusus giganteus*	2.5	1.0	2.7	Moderate	M
	IN5	*Codakia orbicularis, Penaeus brasiliensis, P. brevirostris, P. californiensis, P. duorarum, Megapitaria aurantiaca, M. squalida, Mytilus californianus, Rangia flexuosa, Rimapenaeus faoe, R. pacificus*	1.2	3.0	3.2	High	P, M, M, M, M, M, M, M, P, P, P
	IN6	*Argopecten irradians, Callinectes arcuatus, C. bellicosus, C. danae, C. ornatus, C. rathbunae C. sapidus, C. similis, C. toxotes, Cardisoma guanhumi, Larkinia multicostata, Penaeus aztecus, P. vannamei, Xiphopenaeus kroyeri, X. riveti*	1.2	2.3	2.6	Low	M, P, P, P, P, P, M, M, P, P, M, M, M, M, M
	IN7	*Chione californiensis, Crassostrea rhizophorae, C. virginica, Anadara tuberculosa, Atrina maura, A. tuerculosa, Macrobrachium carcinus*	1.3	2.3	2.7	Moderate	M, P, M, M, P, M, P
	IN8	*Chione undatella, Crassostrea corteziensis, Macrobrachium americanum, M. heterochirus, M. tenellum, Mercenaria campechiensis, Pteria sterna, Rangia cuneata, Sicyonia brevirostris, Stomolophus meleagris*	1.3	3.0	3.3	High	M, M, P, P, P, M, P, M, P, M
	IN9	*Doryteuthis opalescens, Haliotis fulgens, H. rufescens*	1.5	2.3	2.8	Moderate	M, P, P
	IN10	*Haliotis corrugata, H. cracherodii, Panopea generosa, Ucides cordatus*	1.5	3.0	3.4	High	P, M, M, M
	IN11	*Dosidicus gigas, Octopus bimaculatus, O. bimaculoides, O. hubbsorum, Strombus pugilis*	1.7	1.2	2.1	Low	M, M, M, M, M
	IN12	*Haliotis sorenseni, Panulirus argus, P. gracilis, P. guttatus, P. inflatus, P. interruptus, P. laevicauda, P. penicillatus*	1.7	3.0	3.4	High	M, M, M, M, M, M, M, M
	IN13	*Octopus maya, O. vulgaris*	1.7	1.4	2.2	Low	M, M
	IN14	*Holothuria atra, Panopea globosa*	1.8	3.0	3.5	High	P, P
	IN15	*Megastraea turbanica, M. undosa, Melongena corona*	1.8	1.2	2.2	Low	M, M, M
Bony fishes	BF1	*Ariopsis felis*	1.3	1.7	2.1	Low	M
	BF2	*Bagre marinus*	1.9	3.0	3.5	High	M
	BF3	*Caulolatilus princeps*	1.7	1.9	2.5	Low	M
	BF4	*Epinephelus drummondhayi*	1.4	1.4	2.0	Low	M
	BF5	*Istiophorus platypterus*	1.7	2.3	2.9	Moderate	M
	BF6	*Kajikia audax*	1.6	1.1	1.9	Low	G
	BF7	*Lutjanus analis*	1.4	1.3	1.9	Low	M
	BF8	*Lutjanus campechanus*	1.3	1.6	2.0	Low	M
	BF9	*Makaira mazara*	2.0	2.3	3.1	Moderate	M
	BF10	*Makaira nigricans*	2.0	1.1	2.3	Low	G
	BF11	*Mugil cephalus*	1.0	1.4	1.7	Low	M
	BF12	*Mugil curema*	1.1	1.4	1.8	Low	M
	BF13	*Mycteroperca microlepis*	1.9	1.7	2.5	Low	M
	BF14	*Pontinus vaughani*	1.6	1.4	2.1	Low	M
	BF15	*Sebastes chrysomelas*	2.1	3.0	3.7	High	M
	BF16	*Sebastes mystinus*	2.3	1.7	2.8	Moderate	M
	BF17	*Tetrapturus angustirostris*	1.7	1.1	2.0	Low	M
	BF18	*Thunnus orientalis*	1.7	1.2	2.1	Low	M
	BF19	*Brevoortia patronus, Cetengraulis mysticetus, Lutjanus vivanus*	1.1	1.9	2.2	Low	M, M, M
	BF20	*Caranx latus, Engraulis mordax, Harengula clupeola, H. jaguana, Lutjanus cyanopterus, Oligoplites refulgens*	1.3	1.4	1.9	Low	M, M, M, M, M, P
	BF21	*Epinephelus adscensionis, Leiostomus xanthurus, Lutjanus apodus, L. bucanella, L. griseus, L. guttatus, L. peru, Neomerinthe hemingwayi, Opisthonema bulleri, O. libertate*	1.3	1.9	2.3	Low	M, M, M, M, M, M, G, P, M, M
	BF22	*Cynoscion nothus, Lutjanus synagris*	1.3	2.3	2.7	Moderate	M, M
	BF23	*Cynoscion arenarius, C. othonopterus*	1.3	3.0	3.3	High	M, M
	BF24	*Cephalopholis fulva, Euthynnus lineatus, Merluccius productus, Paralabrax nebulifer*	1.4	1.4	2.0	Low	M, M, M, M
	BF25	*Etelis oculatus, Lutjanus purpureus, Opisthonema medirastre, Rhomboplites aurorubens, Scomberomorus regalis*	1.4	1.9	2.4	Low	M, M, M, M, M
	BF26	*Caranx crysos, Sarda chilensis, Scomberomorus cavalla, S. maculatus*	1.4	2.3	2.7	Moderate	M, M, M, M
	BF27	*Opisthonema oglinum, Syacium gunteri*	1w.4	3.0	3.3	High	M, M

(Continue)

TABLE 3 | Continued

Taxonomic group	PL	Species	P	S	V	VC	DQ
	BF28	*Scomber japonicus, Trachurus symmetricus*	1.6	1.2	2.0	Low	M, M
	BF29	*Centropomus parallelus, Mycteroperca venenosa*	1.6	1.7	2.3	Low	M, M
	BF30	*Caranx hippos, Sardinops sagax*	1.6	1.9	2.4	Low	M, M
	BF31	*Lutjanus jocu, Mycteroperca interstitialis, Scomberomorus concolor, Sebastes paucispinis*	1.6	2.3	2.8	Moderate	M, M, M, M
	BF32	*Caranx lugubris, Centropomus undecimalis*	1.7	1.4	2.2	Low	M, M
	BF33	*Mycteroperca bonaci, Xiphias gladius*	1.9	1.9	2.6	Low	M, M
	BF34	*Centropomus poeyi, Sebastes constellatus*	1.9	2.3	3.0	Moderate	M, M
	BF35	*Anoplopoma fimbria, Epinephelus guttatus, E. itajara, E. morio, E. striatus, Thunnus albacares*	2.0	1.9	2.7	Moderate	M, M, M, G, M, M
	BF36	*Sebastes atrovirens, S. rastrelliger*	2.0	3.0	3.6	High	M, M
	BF37	*Sebastes caurinus, S. chlorostictus*	2.1	1.4	2.6	Low	M, M
	BF38	*Sebastes ensifer, S. entomelas, S. goodei, S. rubrivinctus*	2.1	1.7	2.7	Moderate	M, M, M, M
	BF39	*Sebastes elongatus, S. hopkinsi, S. melanosema, S. rosaceus*	2.1	2.3	3.2	Moderate	M, M, M, M
	BF40	*Sebastes miniatus, S.rufus*	2.3	2.3	3.3	High	M, M
	BF41	*Sebastes levis, S. macdonaldi, and S. melanostomus*	2.4	1.7	2.9	Moderate	M, M, M
Elasmobranches	EL1	*Mustelus californicus*	2.1	3.0	3.7	High	M
	EL2	*Mustelus canis*	2.1	1.9	2.8	Moderate	M
	EL3	*Sphyrna tiburo*	2.1	1.4	2.6	Low	G
	EL4	*Carcharhinus acronotus*	2.4	1.4	2.8	Moderate	G
	EL5	*Carcharhinus limbatus*	2.4	1.7	2.9	Moderate	M
	EL6	*Carcharhinus porosus*	2.4	2.3	3.4	High	M
	EL7	*Carcharhinus brevipinna*	2.6	1.4	2.9	High	M
	EL8	*Carcharhinus longimanus*	2.6	1.2	2.8	Moderate	M
	EL9	*Gymnura micrura*	2.6	2.3	3.5	High	M
	EL10	*Prionace glauca*	2.7	1.1	2.9	Moderate	G
	EL11	*Carcharhinus falciformis*	2.9	1.2	3.1	Moderate	M
	EL12	*Carcharhinus leucas*	3.0	1.7	3.4	High	M
	EL13	*Carcharhinus obscurus*	3.0	1.4	3.3	High	M
	EL14	*Isurus oxyrinchus*	3.0	1.1	3.2	High	G
	EL15	*Galeocerdo cuvier, Sphyrna mokarran*	2.9	1.4	3.2	High	M, M
	EL16	*Gymnura marmorata, Mustelus henlei, Rhizoprionodon longurio, Narcine entemedor, Rhinoptera steindachneri, Sphyrna corona*	2.3	1.9	3.0	Moderate	M, M, G, M, M, M
	EL17	*Narcine brasiliensis, Rhinoptera bonasus*	2.3	2.3	3.3	Moderate	M, M
	EL18	*Mustelus lunulatus, Rhizoprionodon terraenovae, Sphyrna lewini, Nasolamia velox, Pseudobatos productus*	2.4	1.9	3.1	Moderate	M, M, G, M, G
	EL19	*Squatina californica, S. dumeril*	2.6	1.9	3.2	High	M, M
	EL20	*Negaprion brevirostris, Sphyrna zygaena*	2.7	1.4	3.1	Moderate	M, M
	EL21	*Alopias pelagicus, A. superciliosus, Aetobatus narinari, Carcharhinus plumbeus, Ginglymostoma cirratum*	2.7	1.2	3.0	Moderate	M, M, M, M, M

PL, point labels (species with equal RV values are grouped); P, productivity score; S, susceptibility score; RV, relative vulnerability; and VC, vulnerability category as follows: low, RV < 2.64; moderate, 2.64 < RV < 3.18; and high, RV > 3.18; DQ = DQ, Data quality as follows; G, good; M, moderate; P, poor data.

distribution range with fishery was also scarce for many species, mostly invertebrates and bony fishes. In the invertebrate group, no information was found on the depensatory effects on the resilience of marine invertebrates to fishing mortality. Among the species of high commercial importance (n= 208), the data quality was moderate for 169 species (81%), poor for 28 (13%), and good for 11 (5%). The scalloped hammerhead (*S. lewini*) is the species with the best data available (DQ= 1), and the shortjaw leatherjacket (*Oligoplites refulgens*) has the least amount of data available (DQ = 3.82).The quality of the information used to evaluate the susceptibility of the species was low to moderate. The impact and interaction of the fishing gear on many species are unknown, especially for invertebrates and to a lesser extent for bony fish. For the elasmobranch species, the susceptibility data quality was mostly moderate. The quality of the data used to evaluate the productivity was mostly good for elasmobranchs, from good to moderate for bony fish and moderate for invertebrates. The attributes to evaluate productivity with scarcer information were "density dependence" and "trophic level."

DISCUSSION

In the present study, more invertebrates were highly vulnerable, followed by elasmobranchs and bony fishes. Although in the elasmobranch group, we identified the species with the lowest biological productivity (*I. oxyrinchus*) among all the evaluated species and the highest proportion of species with high and moderate vulnerability. The high vulnerability of the invertebrates is associated with the life traits of some species such as clams, abalones, and sea cucumbers (e.g., *P. generosa*, *P. globosa*, *Haliotis corrugata*, *H. cracherodii*, *H. sorenseni*, and *Holothuria casoae*) that are relatively long-lived (Andrews et al., 2013; Suárez-Moo et al., 2013). Three of the sea cucumbers species are listed

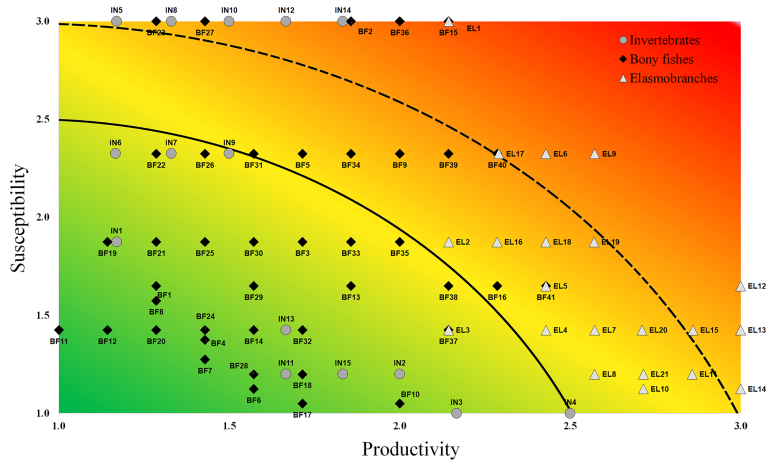

FIGURE 2 | Productivity and Susceptibility Analysis plot for species of high commercial importance in Mexican fisheries. Isopleths delimit areas of equal relative vulnerability, species with the highest vulnerability above the dotted line (V > 3.18), those with medium vulnerability above the solid line (2.64 < V < 3.18), and those with the lowest vulnerability below the solid line. See **Table 3** for the point labels to identify the species in the plot.

as critically in danger and one species as Data Deficient by the IUCN red list (Samyn, 2013; Peters and Rogers-Bennett, 2021a; Peters and Rogers-Bennett, 2021b; Peters and Rogers-Bennett, 2021c). Furthermore, these and other lobster, clams, and shrimp species (e.g., *Panulirus* sp., *Rangia* sp., *Rimapenaeus* sp., *Sicyonia* sp., and *Penaeus* sp.) have a high fisheries susceptibility due to their narrow habitat range, low mobility and high gear selectivity of the fisheries that catch them (Briones Fourzán, 1995; Ramírez-Rodríguez et al., 2000; Wakida-Kusunoki and MacKenzie, 2004; Hendrickx, 2016). Many invertebrate species are manually harvested through diving, resulting in a high selectivity (Melchor-Aragón et al., 2002). Sessile or slow-moving invertebrates have a limited capacity to flee or seek refuge from divers and active fishing gears (Menge and Lubchenco, 1981; Levitan and Genovese, 1989; Hunt et al., 2020); thus, a high proportion of species (82%) caught by dive fisheries resulted with high vulnerability. Furthermore, the tendency of several sessile marine invertebrate species to assemblage (Osman, 2015) increases the possibility of the fishing gear encountering a higher density of organisms. Nevertheless, this grouping feature and the proximity of the invertebrate species with the fishing communities has made possible the establishment of adequate and effective measures for their management through functional management units (e.g., marine protected areas, areas of repopulation, monitoring, and surveillance by fishers), and abundance estimations as a baseline for harvest strategies (Defeo and Castilla, 2005; López-Rocha et al., 2021).

More than half of the evaluated elasmobranch species resulted with moderate vulnerability to fishing activities despite the widely documented low biological productivity for this group (Stevens et al., 2000). The above is because elasmobranch species with low productivity have low susceptibility and, high susceptible species have moderate productivity. In our analysis, we identified elasmobranchs that, unlike invertebrates, have wider geographic distribution, significant mobility through the water column, and are highly migratory species (e.g., *Alopias* sp., *Carcharhinus falciformis*, *C. longimanus*, *P. glauca*, and *Aetobatus narinari*), thus, a reduced overlap with fishing activities (Camhi et al., 1998). Furthermore, among the 17 species (including both elasmobranchs and bony fishes) that are fished in all the regions of the Mexican EEZ, only four resulted in high RV to fishing. These are highly migratory pelagic sharks and bony fishes (e.g., *Alopias* sp., *C. falciformis*, *C. longimanus*, *C. leucas*, *Galeocerdo cuvier*, *I. oxyrinchus*, *P. glauca*, *Sphyrna* sp., *Thunnus albacares*, *Istiophorus platypterus*, and *Xiphias gladius*). Nevertheless, it is essential to acknowledge that the distribution of these highly migratory pelagic shark and bony fishes (e.g., tunas and billfishes) overlaps with fishing fleets from other countries in both the Pacific and the Atlantic (Calich et al., 2018; White et al., 2019). This study focuses on evaluating the RV only for Mexican fisheries. Thus, for highly migratory species management and conservation measures, besides the negotiations among jurisdictions, should consider a better understanding of their distribution, habitat use over large spatial scales, overlap patterns between species distribution and fishing fleets across borders, and the effect of these fisheries on the species (Pons et al., 2018; White et al., 2019). On the other hand, several elasmobranch species resulted highly susceptible to fishing activities (e.g., *Mustelus canis*, *M. henlei*, *M. lunulatus*, *Nasolamia velox*, *Negaprion brevirostris*, *Squatina cubensis*, *S. californica*, *S. dumeril*, *Gymnura marmorata*, *Myliobatis goodei*, *Pseudobatos productos*, and *Beringraja inornata*); however, their biological productivity is moderate. The bonnethead shark (*Sphyrna tiburo*) was the only one with low vulnerability among elasmobranchs, mostly due to their high biological productivity (Parsons, 1993; Ebert et al., 2013; Frazier et al., 2014). Other PSA analyses in Mexico reported low vulnerability for the bonnethead shark, however, is classified as Critically Endangered by the IUCN red list (Furlong-Estrada et al., 2014; Pollom et al., 2020). In the Mexican Pacific, this species is reported as possibly extirpated (Pérez-Jiménez, 2014; Saldaña-ruiz et al., 2017). For the above, studies are needed to clarify the population status of the bonnethead shark in the Pacific and identify the cause of its possible absence. Most of the elasmobranchs in this analysis resulted with moderate RV to fishing activities in Mexico. However, future analysis should consider that species may be subject to other sources of pressure (e.g., overlapping with fishing fleets from other countries, oil spills, climate change, and habitat loss) (Calich et al., 2018; Osgood et al., 2021; Yan et al., 2021; Romo-Curiel et al., 2022). Moreover, half of the evaluated elasmobranchs in this study belong to extinction risk categories of the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN) of Critically Endangered, Endangered, and Vulnerable (**Supplementary Table S3**). For all the above, elasmobranch's research and management efforts should consider the complexities of the factors influencing their overall vulnerability.

In our study, more than half of the evaluated species (57%) had low vulnerability to fisheries, mostly bony fishes with high biological productivity. Most bony fish are called "r" strategists due to their high biological productivity and large interannual variation in recruitment related to climate-oceanic changes (Musick, 1999; King and McFarlane, 2003). These characteristics allow this group to recover their populations from fishing extraction rapidly; however, it is not an intrinsic characteristic of all bony fish species, and proper management tools are necessary to maintain healthy populations. For example, scorpionfishes of the *Sebastes* genus resulted with moderate to low productivity due to their reproductive strategy and great longevity (Echeverria, 1987; Reilly et al., 1994; Cailliet et al., 2001; Munk, 2001; Love, 2012; Berkel and Cacan, 2021). Also, we identified several species (e.g., *Hypsopsetta guttulata*, *Kyphosus azureus*, *Mycteroperca jordani*, *Sebastes atrovirens*, *S. chrysomelas*, *S. miniatus*, *S. rastrelliger*, *S. rosenblatti*, *S. rufus*, *S. semicinctus*, *S. serranoides*, *S. serriceps*, *S. simulator*, *S. umbrosus*, and *Semicossyphus pulcher)* with limited geographic distribution, increasing their encounterability with the fishing activities (Eschmeyer et al., 1983; Williams and Ralston, 2002; Fricke et al., 2021). There are endemic invertebrate and fish species in Mexico with significantly restricted distribution to the Northern Gulf of California, like the sandy clamp (*Chione cortezi*), the gulf croaker (*Micropogonias megalops*), and the gulf corvina (*Cynoscion othonopterus*) (Villarreal-Chávez et al., 1999; Garcés-Rodríguez et al., 2018). Another critical issue for these species is the habitat loss due to the disruption of the Colorado River that once flowed into the Northern Gulf of California (Rowell et al., 2005; Rodríguez-Quiroz et al., 2010). In this study, these species resulted with high RV, and the data quality was poor for the sandy clamp and the gulf croaker. For all the above, its prioritization for future evaluations to identify the status of the populations is highlighted.

This vulnerability analysis was specific to a particular fishery and fishing gear type in this study. However, it is important to consider the multi-species and multi-gear character of the fisheries in Mexico (Arce-Acosta et al., 2018). Evaluating the cumulative effects of multiple fisheries affecting one species was beyond our scope. However, further evaluations focused on evaluating the impacts that multiple fisheries may have on individual species should be considered. The most vulnerable species identified in this study could provide the basis for prioritizing future research along these lines. In Mexico, there are 21 fisheries management plans, nine in the Mexican Pacific (Region 1 and 2) and 12 in the Gulf of Mexico and the Caribbean Sea (Region 3) (Peña-Puch et al., 2020). Among the evaluated species in this study, only 33 have a fisheries management plan (e.g., *Octopus bimaculatus, O. Maya y O. Vulgaris, O. hubbsorum, Megapitaria squalida, Centropomus viridis, Lutjanus colorado, Thunnus orientalis, T. albacares, Paralabrax nebulife, Dosidicus gigas, Xiphopenaeus kroyeri, Penaeus brasiliensis, P. aztecus, P. setiferus, P. duorarum, Sicyonia brevirostris, Fasciolaria tulipa, Strombus costatus, S. pugilis, Melongena melongena, M. corona, Cynoscion othonopterus, Callinectes* spp.*, Panulirus argus, Mugil cephalus, M. curema, E. morio, Entropomus undecimalis*, and several sardines, anchovies, and mackerel species). Despite having management plans, there is no robust assessment of the population status for many of these species. Through this study, future research efforts can be prioritized to evaluate the populations of the species and to review the established management tools. Regarding the main information gaps detected, there are very few studies focused on evaluating selectivity and post-capture mortality, and there are mainly focused on incidentally caught elasmobranch species (Poisson et al., 2014; Hutchinson et al., 2015; Eddy et al., 2016). The complexity of many Mexican fisheries, in which various species are caught using various gear-types, makes it difficult to evaluate the selectivity and post-capture mortality of the species (Castillo-Géniz et al., 1998; Pérez-Jiménez et al., 2005). This study identifies data gaps about the area overlap between the species and the fisheries for many species. Knowing the degree of area overlap of the species distribution with the fishery is essential to determine the species' susceptibility to the fisheries; a greater overlap indicates highest susceptibility (Patrick et al., 2010; Hobday et al., 2011). Understanding the spatial dimensions of fishing activities in relation to the distribution of the species is critical to improve the management of complex multi-gear and multi-species Mexican fisheries (Salas et al., 2007; Moreno-Báez et al., 2010). For most of the invertebrate species, there is no data about the depensatory effects on the resilience of marine invertebrates to fishing mortality Various studies indicate that abiotic factors mainly influence fluctuations in invertebrate species abundance (e.g., temperature and precipitation); Villalejo-Fuerte et al., 2000; Houlahan et al., 2007; Gonzalez and Loreau, 2009). Trophic ecology studies were also very scarce for many species, especially invertebrates; thus, data on the trophic level were obtained mainly from Fishbase. In Fishbase, the trophic position is calculated with diet and food information based on prey lists or stomach content studies, which gives high uncertainty to the value of trophic level used. In this data-limited context, the PSA in this study is an effective risk-based approach to estimate the potential vulnerability of the species to fishing. Nevertheless, we acknowledge the subjectivity of elements of the PSA analysis (Hordyk and Carruthers, 2018). For example, this analysis calculates the relative vulnerability for each species based on productivity and susceptibility attributes scores (1, 2, or 3) derived from source data that range from highly precise (e.g., age determination study using otoliths) to imprecise data (e.g., adopting age from a species in the same genus or family). However, having the quality scores of the data used for the analysis allows us to identify the reliability of the RV results and help us with the interpretation (Patrick et al., 2009). The PSA also has limitations in assessing a cumulative vulnerability of a species to multiple fisheries (Griffiths et al., 2019), which would be especially useful in the specific case of the multi-species Mexican fisheries. However, the PSA is useful to prioritize species needing research and management attention despite data limitations. Although the PSA does not replace a robust population assessment, is a valuable tool to identify priority species for future research, biological and fishery data gaps, and set the baseline for future research efforts toward the sustainability of fisheries.

Implications of the Productivity and Susceptibility Analysis results in the responsible seafood consumption

Fisheries certification and eco-labeling have been promoted in the past three decades as a useful market-based instrument to encourage sustainable fisheries operations worldwide (Ward and Phillips, 2008). Within fishery certification schemes such as the Marine Stewardship Council, the Seafood Watch, and Fairtrade USA (fisheries), PSA analysis is used in cases where there is no quantitative stock assessment available to determine species vulnerability to fishing pressure (USA, 2017; MSC, 2020; Watch, 2020). The MSC has become the most influential fisheries certification entity globally (Le Manach et al., 2020). Nevertheless, the MSC certification process is not suitable for fisheries in developing countries (Pérez-Ramírez et al., 2016), including those located in Latin America and the Caribbean like Argentina (Pérez-Ramírez et al., 2012a), Chile (MSC, 2019), and several fisheries in Mexico (Pérez-Ramírez et al., 2012b). This high underrepresentation of the MSC in developing countries is due to the lack of reliable scientific data to address the state of their fisheries and species populations, necessary for the certification process (Gulbrandsen, 2009). Due to the above, the MSC developed a risk-based framework (RBF), the PSA, to assess the vulnerability of species impacted by fishing activities in small-scale and data-deficient fisheries to inform the certification process (Howes, 2008; Ponte, 2012). This RBF is used to address deficiencies in the ecological principles for sustainable fisheries (i.e., Principle 1: stock status and Principle 2: minimizing environmental impacts) in the preliminary review of the MSC to identify if the fishery is ready to enter full assessment (Mohamed et al., 2018; MSC, 2020). However, the effectiveness of the MSC's risk-based framework to increase the number of certified fisheries in developing countries will need to be evaluated, and actions are still needed to improve the capacity to initiate, develop and sustain the certification processes (Ponte, 2012; Stratoudakis et al., 2016). Furthermore, the limitations and uncertainty associated with the PSA should be further explored and evaluated to improve the analysis (McCully Phillips et al., 2015). Like other risk-based approaches, this analysis does not replace standard stock assessments but rather evaluates the relative vulnerability to becoming overfished (Patrick et al., 2010; Hobday et al., 2011). Moreover, these vulnerability results do not indicate levels of sustainability since this analysis does not consider inputs from the management and socio-economic aspects of the analyzed fisheries (Hilborn et al., 2015; Astles and Cormier, 2018). It is important to consider that the results of this analysis cannot be used directly in future pre-assessments of the MSC since specific characteristics of the fishery to be evaluated must be looked upon (e.g., evaluation of susceptibility to different fishing gear types to those evaluated in this study). However, this is a straightforward approach that can be used in a data-poor environment that provides a preliminary screening of the many species of commercial importance potentially affected by fisheries. As a result, it represents a potential means to advance progress towards reducing some barriers to certification of fisheries in developing countries. The market-based approaches within the eco-labeling initiatives, like the RSCG, use a seafood-ranking guides system to inform consumers on the purchasing choices providing information about the origin and sustainability of fishery products (Kaiser and Edwards-Jones, 2006; Gulbrandsen, 2009). The RSCG include information about certified fisheries (e.g., the MSC and FT), fisheries that follow responsible fishing practices (e.g., Seafood Watch and the Fishery Improvement Project), the status of the species populations, according to Mexican regulations (e.g., the National fishery charter and the normative instrument that defines the risk categories for the Mexico flora and fauna species; DOF, 2010b; DOF, 2018), and the global conservation status of species of the Red List of Threatened Species by the International Union for Conservation of Nature. The eco-labeling implementation and success of approaches like the RSCG to promote sustainable fisheries will depend on many factors, including the level of concern for sustainable fisheries by the consumers, the evaluation of the economic benefits for the fishers, and the effective monitoring of the certified fisheries (Kaiser and Edwards-Jones, 2006). However, these results set the baseline for future research efforts to improve the biology data and the interaction of the species with the fisheries. Also, the vulnerability results can be incorporated in the RSCG to improve the guidance and recommendations to help consumers choose seafood from sustainably Mexican fisheries, which is critical in a country where fisheries play a key role in livelihoods and food security and well-being of many coastal communities.

CONCLUSIONS

The relative vulnerability results prioritize invertebrate, elasmobranch, and bony fish species of commercial interest for either research efforts or management attention. Furthermore, the vulnerability results could be incorporated in market-based approaches within the eco-labeling initiatives, like the RSCG, to strengthen the criteria to issue recommendations to consumers while formal evaluations of the species populations are in progress. In this study, biological and fishery data gaps by species can be rapidly identified, which could guide data collection and monitoring efforts. Like other risk-based approaches, this analysis can only assess the relative vulnerability. Nevertheless, this is an accessible approach for data-deficient fisheries that provides a first screening of the many species potentially affected by fisheries. This work may provide a reference for the more than 400 species in Mexico that do not have a population evaluation, or their status is unknown. Moreover, this study can serve as the foundation for future research efforts to evaluate the species in data-limited settings and facilitate certification processes involving these species.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

LE-SR, A-FG, GA-CG, and FJ-FRM conceived and designed the study. LE-SR, A-FG, and JF-C created databases, wrote the original draft, and prepared figures. All authors contributed equally to data collection, manuscript revisions, and approved the final draft.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.866135/full#supplementary-material

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