From bottom to up: effects of fishery improvement projects on the stock status of multi-specific small-scale fisheries from Mexico

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**Abstract**

Small-scale fisheries are socioeconomically important in data poor areas as a source of income, food, and employment. However, most fisheries lack information (e.g., catch and effort) needed to evaluate their status, and are poorly managed. Fishery Improvement Projects (FIP) have emerged as a community-drived option to enhance management since they require to evaluate the status of harvested stocks. We assessed the stock status of ten species involved in FIPs in Mexico, using data-poor methods based on catches. Due to the historical inconsistencies of landing reports in the country, data reconstructions have to be made for most of the stocks evaluated. Data generated by communities involved in FIPs were used to refine these reconstructions and to inform assessment models. Results showed that most of the stocks are fished at unsustainable levels which may be related to increases in landings for the last ten years. Models including abundances indexes, estimated from FIPs data, produced better estimations. Stock status indicate that management actions area needed along with improvements in data collection. Improvement projects represent an opportunity to fill information gaps and inform assessment models in data-poor areas when official data is not available, which will help to secure the sustainability of small-scale fisheries.



## 1. Introduction

Small-scale fisheries contribute to about half of the global fish catches and represent two-thirds of the yields directed to human consumption (FAO, 2015). However, the information on their operations and catch is only sometimes available. This data scarcity leads to small-scale fisheries being often overlooked and unassessed. Around 80% of global fish catches come from unassessed fisheries, including most small-scale fisheries (Costello et al. 2012). Furthermore, recent analysis suggests that marine fish stocks, with an assessment of their status, are in better shape and with effective management systems (Hilborn et al. 2020), highlighting the need to evaluate the stocks exploited by small-scale fisheries to improve their management. In 2019, 64.6% of assessed stocks by FAO were within biologically sustainable levels, while 35.4% were at biologically unsustainable levels (FAO, 2022).

In Mexico, coastal finfish fisheries (locally known as "escama") have a significant socioeconomic impact on many coastal communities as a source of income, food, and employment (Cavieses Nuñez et al., 2018; Ojeda-Ruiz et al., 2019; Galindo-Cortes et al., 2019). Finfishes are caught by small-scale vessels (<10 m) using hooks, gillnets (bottom and surface set), longlines (bottom and surface set), and traps (Ojeda Ruiz et al., 2019; DOF, 2012; DOF 2020). These fisheries are multi-specific; their catches include more than 440 bony fishes categorized in 17 groups (Cavieses Nuñez et al., 2018; DOF 2012; 2018).

Finfish fisheries in Mexico are managed by the National Commission of Fisheries and Aquaculture (CONAPESCA) and the National Institute of Fisheries and Aquaculture (INAPESCA) which oversees the collection and publication of landings in the Fisheries Statistics Yearbooks, the publication of the National Fisheries Charter (NFC), which is one of the leading management tools where fisheries management reference points and recommendations are published (Sosa-Nishizaki et al., 2020), and the developing the Fisheries Management Plans for each fishery. Despite the fishing importance of these species, the deficiencies in the official catch records (lack of catches time series by species and null reports of fishing effort) and the scarce data on their biology make their populations assessments and sustainable management extremely difficult (Saldaña-Ruiz et al., 2017; Perez-Jimenez et al., 2022).

Since the 2000s, several small-scale fisheries worldwide began to record more specific own information with stakeholders' support, favoring their fisheries' co-management and promoting cooperative research (Kaplan and McCay, 2004). At the same time, the development of environmentally responsible fishing standards has been highlighted through the certification of fisheries and recommendations for the consumption of seafood (Kirby et al., 2014; Ward and Phillips, 2008) and gave rise to the Fishery Improvement Projects (FIPs) in 2002 (Cannon et al. 2018).

FIPs aim to develop sustainable fishing practices and represent a great opportunity and frame of reference for improving resource management in developing countries like Mexico. In this country, 97% of the total fishing effort (total = 76,880 fishing vessels) is operated by small-scale fisheries that are poorly managed (CONAPESCA, 2019). Further, FIPs represent an opportunity to produce robust species-specific information to aid in assessing and managing exploited stocks. Currently, 37 FIPs are implemented in Mexico (15 % of all FIPs worldwide) (Fishery progress, 2023 ). Nine FIPs in Mexico focus on finfish fishery species, representing a significant collaborative effort between stakeholders and citizen science toward the sustainability of these data-limited small-scale fisheries (Perez-Jimenez et al., 2022).

During stage one of the FIP development, the assessment of the fish stock status of the fishery is needed to be associated with an accurate indicator of its level (CASS, 2015). Stock assessments aim to understand how many fish can be sustainably caught by fitting population dynamics models to fisheries monitoring data. While comparing with biological reference points, they allow for assessing whether the stock is in an overfishing state or overfished (Punt et al. 2020) and guide operational fisheries management actions. Depending on the available data, several quantitative approaches have been developed to assess fisheries stocks using data-limited to rich and intensive data and costly methodologies (Ditchmond et al., 2021). For most small-scale fisheries, the need for more data-rich information to perform robust stock assessments is common (Salas et al., 2007; Rosenberg et al., 2014). Therefore, data-limited stock assessment methods have been developed to fill these gaps (Costello et al., 2012; Martell & Froese, 2012; Anderson et al., 2017).

Within the data-limited stock assessments methods, catch-only methods provide a simple approach to produce estimates for stock biomass status (B/Bmsy) and other reference points based primarily on the trends of catch or landings time series and life history traits (Thorson et al., 2013; Free et al., 2020; Ovando et al., 2022). Among these methods, Catch-MSY (CMSY) is a mechanistic method developed by Martell and Froese (2013) and improved by Froese et al. (2017) that has been used widely to determine the stock status of global (Costello et al., 2016; Palomares et al., 2020) and regional fisheries (Winker et al., 2017; Froese et al., 2018). This method has been used in Mexico to evaluate the stock status of the Pacific angel shark (*Squatina californica*; Flores-Guzmán, 2018) and the barred sand bass (*Paralabrax nebulifer*), which later led to the implementation of a fishery management plan (DOF, 2021). Due to the deficiencies in the fishing report system in Mexico described above, these methods pose an opportunity to give insights into the stock status of fished species and to develop proper management actions that secure the sustainable use of fishing resources.

In this study, we used the information produced, up to date, from selected cases of small-scale finfish fisheries associated with five FIPs to estimate the stock status of nine fish stocks from Northwestern Mexico and one in the Gulf of Mexico using the CMSY method. Then, we discuss the challenges that the development of FIPs confronts under the Mexican fisheries management systems and their potential to improve this system from the bottom up.

## 2. Methods

### 2.1. Study cases

We assessed the status of ten finfish stocks in coastal areas from the Mexican Pacific Northwest and the Gulf of Mexico (Fig. 1). The studied cases included the Ocean whitefish (*Caulolatilus princeps*), California sheephead (*Semicossyphus pulcher)*, barred sand bass (*Paralabrax nebulifer*), vermilion rockfish (*Sebastes miniatus*), starry rockfish (*S. constellatus*), yellowtail (*Seriola lalandi*), rooster hind (*Hyporthodus acanthistius*), goldspotted sand bass (*Paralabrax auroguttatus*), Pacific red snapper (*Lutjanus peru*), and the northern red snapper (*Lutjanus campechanus*) (Table 1). These coastal fishes have a variety of life-history traits, with maximum ages ranging between 20 to 61 years (Shanks et al. 2005, Allen et al. 2006; SEDAR24, 2010) and age at maturity ranging from 2 to 6 years (Love et al., 1990; Allen et al., 2006; Froehlich et al., 2021). Most of the species are broadcast spawners, except for the *Sebastes* species, in which the fertilization and embryo development occur internally (Love et al., 1990). In addition, *S. pulcher* is a protogynous hermaphrodite species that can transition from a reproductively functional female to a male (Allen et al. 2006; Shanks et al., 2005).

## 2.1. Data sources

Details of data sources used for landing reconstructions and assessment of stock status are reported in Table 2. The baseline for this analysis was the official landing statistics reported in the CONAPESCA's Fisheries Statistics Yearbook. Formerly, other agencies have produced these statistics, causing differences in the amount and quality of the information reported. Yearbooks contain landings by common name (that could include multiple species), by Fishing Office and State when most detailed. Landings reported from 1970 to 1999 were used. Since 2000, more detailed landing statistics have been made available through the National Transparency Platform. From 2000 to 2019 (last year with official landings records), landings from this source were used. All landings used for these analysis were "landed weight," as fishers reported this information directly.

Even if it has been proposed to differentiate stock between the west coast of the Baja California peninsula and the Gulf of California, none of the evidence is conclusive. For these analyses, all species were evaluated as a single stock from the Northwestern Mexican Pacific, including landings from the states of Baja California (BC), Baja California Sur (BCS), Sonora (SON), and Sinaloa (SIN). The red snapper in the Gulf of Mexico, a single stock for the Mexican part, was also considered for the analysis.

## 2.2. Landing reconstructions

Because official landings in Mexico are not reported at the species level, landing reconstructions must be made for some stocks. Reconstructions were done based on the methods described in Saldaña-Ruiz et al. (2017). For the California sheephead, the barred sand bass, the goldspotted sand bass, and the rooster hind, all landings reported in official statistics were considered to belong to the species evaluated because no other species are reported under any of their names (Table S1).

The Pacific red snapper is included in the "huachinangos and pargos" group along other nine species (Table S1). Most of these species are commonly reported under the "pargo" category, which is differentiated in official statistics from "huachinango", which includes *L. argentrivetris*, *L. jordani* and *L. peru*. Based on the monitoring developed by the Guaymas FIP, *L. peru* contributes 92.5 % of the total catch of the "huachinango" group, so this percentage was applied to the reported official landings to estimate the reconstructed landings for this species. As with the Pacific red snapper, the yellowtail is reported along with another eight species (Table S1) under the common name "jurel" (DOF 2010). The yellowtail has a distribution limited to the west coast of the Baja California peninsula and the Gulf of California. Other species are distributed in southern areas (Baxter 1960, Ulloa-Ramírez et al. 2008), so "jurel" landings from BC, BCS, SON and SIN were assumed to belong to *S. lalandi*.

The ocean whitefish is reported with two other species in the group "pierna y conejo." On BC and BCS, *C. princeps* is named "pierna" or "blanco/blanquillo," while *C. affinis* is reported as "conejo" (Manriquez-Ledezma 2008). From 1980 to 1999, all "pierna" landings were assumed to belong to ocean whitefish, while from 2000 to 2019, landings of "pierna" and "blanquillo" were considered to belong to this species. The starry and vermillion rockfish are reported under the category "rocote". To estimate the specific landings for each species, the information produced in the monitoring implemented by El Rosario's FIP was used. The percentage for *S. miniatus* (97.31%) and *S. constellatus* (1.06%) in total "rocote" landings was applied to the entire landing for the group.

The northern red snapper is aggregated with other two species (Table S1) under the common name of "huachinango". Based on the monitoring made by the Nuevo Campechito's FIP, the northern red snapper contributes 81.3% of total "huachinangos" landings, so this factor was applied to all landings reported in official statistics from 1977 to 2019.

### 2.3. Stock status assessment

Due to the lack of species-specific landings and abundance indexes (CPUE) for all the evaluated species, none of the stock could be assessed with traditional stock assessments, so we used a data-poor approach to estimate stock status. Despite the limitations previously described for landing data in Mexico, this information is the most reliable fishing data in the country and has been collected for more than 50 years.

The model chosen was the $C_{MSY}$ (Froese et al., 2017) which fits a Schafer model and applies Monte Carlo simulations to produce estimations for reference points like stock size ($B/B_{MSY}$) and exploitation rate ($F/F_{MSY}$) based on a catch time series and measurements of the resilience of the stock (Martell & Froese, 2013). It also produces proxies for MSY, the biomass level producing the MSY ($B_{MSY}$), and the fishing pressure related to the MSY level (FMSY). When an abundance or biomass index (i.e., CPUE) is available (even if temporal gaps exist), $C_{MSY}$ could apply a Bayesian state-space Schaefer surplus production model to refine the estimations related to stock status (Froese et al., 2017). The detailed framework of the model is described in Froese et al. (2017). Briefly, the essential biomass dynamics used for the estimation are estimated using the equation:

$$\mathbf{B_{t+1} = B_t + r\,(1-B_t/k)\,B_t - C_t}$$

$B_{t+1}$ is the biomass in the following year $t+1$, $B_t$ is the current biomass, $r$ is the rate of population increase, $k$ is the population's carrying capacity, and $C_t$ is the catch in year $t$. This model requires information on the catch, priors for $r$, and biomass depletion ($B/k$) at the time series' beginning and end. Catch time series were described in the previous section. For the prior ranges for $r$, values from resilience levels reported in FishBase (Froese & Pauly 2019) were used to match categories reported by Froese et al. (2018). Specific values were available for the yellowtail and the Pacific red snapper (Table 3). For the priors of biomass at the beginning and the end of the time series, initial value ranges proposed by Froese et al. (2017) were used based on existing information for the species (Table 4). All the analyzed stocks were assumed to be minimally exploited at the beginning of the time series (*low depletion*) . For the end of the time series, the status reported in the National Fishing Chart was used, even if this status was not reported at species-level (see previous section). The current stock status in that document could be described as “overfished” or “harvested at the maximum limit,” which was considered analogous to *medium depletion.*

The fishing cooperatives involved in the FIPs have developed monitoring programs for the species evaluated. This monitoring is a recent effort (<five years), so the information on abundance indexes could not be used to improve the estimations of the $C_{MSY}$. However, for the yellowtail and the Pacific red snapper, CPUE produced by other FIP in the region (Table 1) were used to include them in the assessment. In addition, Kobe plots were constructed to have a better visualization of stock status. All analyses were performed in R software.

## 3. **Results**

### 3.1. Reconstructed landing time series

Between 1974-1988, yellowtail landings fluctuated between 773 t and 1,989 t (Fig. 2). After that, catches declined to less than 500 t in 1992, followed by a steady increase until reaching a maximum peak between 2010-2014 (~2,800 t). First, most of landings were reported in BC, but in the eighties, landings from BCS surpassed them, contributing between 75–85% of total landings for the stock in the last ten years (Fig. S1). Guaymas, where the FIP is based, was the fishing office that contributed more to the state landings of SIN between 2000-2019, with an average of 69% (Fig. S2). The FIP contributed less than 1% of total landings for the stock in 2019 (Table 5).

For the Pacific red snapper, reported landings were below 2,000 t until 1980 (Fig. 2), with a higher contribution of SON landings (Fig S3). From 1980 to 2014, landings ranged between 425 and volumes slightly above 1,000 t (Fig. 2), with the majority coming from BCS (Fig. S3). An increase above 2,000 t occurred in 2015, and since then, landings have triplet to reach a maximum peak in 2017 (4,067 t). Most landings were reported in BCS (~55% in 2019, Fig. S1). Between 2000-2019, most landings in SON came from Huatabampo (almost 80% of total state landings), with Guaymas contributing less than 10% (Fig. S4). In 2019, the FIP contributed 0.16% of total landings from the stock (Table 5).

From 1980 to 1985, landings of the ocean whitefish were <1,410 t (Fig. 2). Between 1986 and 1996, landings for this species were absent in official statistics. Since 1997, landings increased constantly to a maximum peak in 2017 (2,736 t) with landings averaging 2,100 t in the last five years (Fig. 2). During all the time series, most landings (>90%) were reported in BCS (Fig. S5). From 2000-2019, <2% of total landings of BCS came from the Fishing office where the FIP of Natividad Island reports their landings (Bahía Tortugas, Fig. S6). In the last six years, landings from Guaymas had the highest contribution to SON total landings (Fig. S7). Among the three FIPs catching this species, the one from El Rosario contributed 1.65% of total landings from the stock in 2019, followed by Natividad Island (0.07 %) and Guaymas (<0.01%, Table 5).

For the barred sand bass, reported landings were low until 1982 (<440 t) and then disappeared from official statistics until 1997. In that year, the highest peak of landings was reported (6,073 t), followed by fluctuating landings (2,544-5,600 t) until 2019 (Fig. 2). Most landings were reported in BCS (>90% of total landings), with minimal contribution from SIN and SON (Fig. S8). In the latest five years, the office of El Rosario, where the FIP is located, recorded the highest landings within BC (Fig. S9), contributing 0.21% of total landings for the stock in 2019.

Landings for the California sheephead appeared in yearbooks from 1972 to 1974 and disappeared from official statistics until 2000. Since that year, landings have ranged between 58 t and a maximum peak of 270 t in 2011 (Fig. 2). Most landings came from the west coast of BC and BCS (Fig. S10). In BC, the highest landings came from the Fishing office of El Rosario from 2000-2019, contributing up to 70% of total state landings (Fig. S11). The contribution to total landings from El Rosario's FIP for this species was meager in 2019 (0.46%, Table 5).

For the vermillion rockfish and starry rockfish, landings trends follow the same pattern because both species are reported under the same common name, "rocot" (Fig. 2). Landings for "rocot" were sparse until 1999. Since 2000, landings for the vermillion rockfish have increased until reaching a first peak in 2007 (658 t) followed by a decrease until 2015. In the last three years, landings increased to a maximum peak (717 t). For the starry rockfish, the highest estimated landings were found in the last year of the time series (8 t). Between 2000-2019, most landings (58-90%) were reported in BC (Fig. S12), with some years representing >90% of total landings for the stock. From 2000-2009, El Rosario was the office with the highest landings for both species in BC (45%) and since then it has contributed between 30-46% of total state landings (Fig. S13). In 2019, the FIP from El Rosario contributed 24.18% and 24.01% of total landings for the stock of *S. miniatus* and *S. constellatus*, respectively (Table 5).

Landings for the golspotted sand bass were available since 2000 (Table 2). Until 2012, catches fluctuated below 700 t (Fig. 2). Since then, landings increased until reaching a maximum peak in 2019 (1,297 t). Most landings were reported in SON, representing between 30-50% of total landings with the contribution of BC and BCS increasing in the later years (Fig. S14). Later, landings from BC and BCS increased to levels like those from SON (approximately 30%), but in the last year, landings from SON contributed 50% of total landings from the stock. From 2000-2002, most landings in SON came from the fishing office of Guaymas (Fig. S15), which contributed between 4-12% of total state landings in the last five years (Fig. S15). In 2019, the landings from the Guaymas FIP represented 2.14% of total stock landings (Table 5).

The rooster hind had the highest peak of landing at the beginning of the time series (2,981 t), followed by a decrease until 1988 (741 t, Fig. 2). Between 1989 and 1993, reports of landings in the yearbooks were absent. From 1994 to 1999, reported landings ranged between 1,100-1,650 t, followed by a decrease until 2011, with landings below 500 t. Since 2012, a steady increase in landings started until the end of the time series, reaching 2,200 t (Fig. 2). Landings were reported mainly in SON (Fig. S16). Between 2000-2019, landings reported in Guaymas ranged between 7 and 113 t, representing up to 75% of the state total in the first three years and currently contributing 11% (Fig. S17). The contribution of the Guaymas FIP to total landings in 2019 was 0.21% (Table 5).

Landings from the northern red snapper increased since the beginning of the time series until a maximum peak in the early nineties (7,200 t; Fig. 2). Until 1999, landings were reported in a higher proportion in Yucatán, followed by Veracruz and Tamaulipas (Fig. S18). Following that year, landings decreased to a minimum catch in 2003 (Fig. 2). Between 2004 and 2015, landings were constant at around 2,000 t, with most landings reported in Tabasco (Fig. S18). Since 2015 a slight increase was detected, surpassing 3,000 t in 2019, with most landings reported in Campeche (Fig. 2, S18). The Atasta office, where the FIP reports their landings, contributed between 0.69% and 14.76% of total state landings between 2000 and 2019 (Fig. S19). In 2019, the landings from the FIP of Nuevo Campechito represented 1.99% of total landings from the stock (Table 5).

### 3.2. Stock status assessment

From the ten stocks evaluated, the relative biomass in the last year of the time series is above the level producing MSY ($B/B_{MSY}$ <1) in four stocks (Fig 3, Table 5). In another three, relative biomass is below MSY but around the reference point used by the MSC (0.9 MSY). In the remaining three, the stock biomass is below the reference point but above the point where the recruitment would be impaired (0.5 $B_{MSY}$, Fig. 3). The biomass of the rooster hind stock has been below MSY the whole time series.

Regarding the fishing pressure, all stocks are currently at levels above the reference point ($F/F_{MSY}$ >1), except for the northern red snapper ($F/F_{MSY}$ = 0.80) and have been at this level for the past three years (Fig. 4, Table 5). In almost all stocks, the fishing pressure was at levels below MSY ($B/B_{MSY}$ <1) for most of the time series (Fig. 4). However, this reference point was surpassed in the last ten years because of the increases in catches described in the previous section. Estimations from *r* and *k* were under the limits set as a prior (Fig. S20).

According to the Kobe plots, there is a high probability that six of the stocks are currently overfished with overfishing occurring (Fig. 6). For the other three stocks, overfishing is happening, and only the stock of the northern red snapper is in optimal conditions. As well as with the biomass and fishing pressure trends, the stock status of these species changed drastically in the last ten years of the time series due to increases in landings (Fig. 2).

## 4. Discussion

### 4.1 Stock status of case studies and reconstructed landing trends

Our estimations showed that most stocks are fished at unsustainable levels, with overfishing occurring in almost all the stocks and some under overfished conditions. Except for two stocks (rooster hind and northern red snapper), this status is related to increases in landings (triplicated for some species) for the past ten years. Despite the limitations of catch-only models for stock assessments, trends in stock biomass and fishing pressure are evident: management actions are urgently needed for all species analyzed. Even if results must be taken with care due to the intrinsic limitations of this kind of model (Vasconcellos and Cochrane, 2005; Ovando et al., 2021), they can be used as a baseline to asess the stock status of these fisheries.

Catch-based models, such as $C_{MSY}$, have proven to help evaluate the stock status of marine resources (Palomares et al., 2020; Sharma et al., 2021). When these models are implemented with informative priors, their performance in estimating the stock status improves, making them a helpful tool for evaluating fisheries in areas where robust stock assessments are unavailable (Sharma et al., 2021). Some cautions need to be considered when using this model type. Pons et al. (2020) found that catch-based model performance highly depends on life-history parameters (i.e., *r*, *K*), depletion levels, and fishing intensity. Nevertheless, catch-only models can give good results for referent points like MSY when long catch-time series are used (Ovando et al., 2021). For this reason, through the reconstruction process of the catches in this study, we tried to have the most extended landing time series for all the stocks analyzed.

Increases in landings for the yellowtail in BCS were reported previously (Cisnero-Soberanis, 2018), which could be related to increases in fishing effort between 2005-2011 (Cota-Nieto et al., 2018). The historical fishing importance of the Pacific red snapper in the Gulf of California has increased over the years, gaining significant relevance in the 1990s and 2000s (Sala et al., 2004). Our time series includes landings since 1977 but older records indicate high economic relevance and local consumption of snappers in the Gulf of California since the 1940s (Linder, 1947), which were not found in Official Fishing Statistics nor included in the analyses. Sand bass fishing has been highlighted for the Gulf of California since the 1940s and the mid-1990s (Linder, 1947; Cudney-Bueno and Boyer, 1998), but official statistics only reported landings since 2000, when an increase in catches was previously reported (Aburto-Oropeza et al., 2008).

The ocean whitefish fishery in the Northwest Mexican Pacific can be traced back to the 1940s (Linder, 1947), and until the 1980s, it was considered a low-importance species (Sala et al., 2004), which may explain their absence from official landings between 1986-1996. As our catch reconstruction shows, its importance in landings increased in the late nineties (Sala et al., 2004). In the Gulf of California, an intense fishing effort for the roster hind was reported in coastal SON and BC during the seventies (Cudney-Bueno and Boyer, 1998). In the eighties, rooster hind catches decreased due to the rising demand for shark meat in Mexico until it resurfaced in the nineties (Cudney-Bueno and Boyer, 1998; Aburto-Oropeza et al., 2008), followed by a decrease until 2010, as our data shows. For the California sheephead, official landings were found in the early seventies and then disappeared from official statistics until 2000, around the time when its fishing importance in Baja California, Mexico, and Southern California, US, was reported (Rosales-Casian, 2011; Rosales-Casian et al., 2003; Hamilton et al., 2007). Like our catch reconstruction, the fishery of the barred sand bass on the Pacific coast of BC and BCS became important in 2001 (Domínguez-Contreras et al., 2018), which could explain its presence in official fishing statistics until late 1990s (CONAPESCA, 1997). The vermillion and starry rockfishes have been commercially fished in California since the nineteenth century (Love et al., 1998; Rodríguez-Santiago et al., 2020), but in the Baja California peninsula has been reported as important since the 2000s (Rosales-Casian et al., 2003) due to the lack of studies on the history of the fishery in the region.

The catch of the northern red snapper can be traced to the late 1890s in Campeche Bank, being this region one of the most important between 1950-1970 (Carpenter 1965). Estimated landings decrease trends of this species in the southern Gulf of Mexico during the nineties have also been reported by Perez-Jimenez et al. (2022). As our results show, FIPs and the promoted citizen science can be valuable tool to improve catch reconstructions that provide insights into the fishery trends of the species and allows us to step further in future population assessments and the development of management strategies.

Biomass from most of the evaluated stocks was above the reference point in most time series, except for the rooster hind and the northern red snapper. In the last years, the stock biomass started to decline to levels around and below the reference point. These declines are related to an increase in landings in the past ten years that has also been reported for other fishing resources in Mexico (CONAPESCA 2019, Sosa-Nishizaki et al. 2020, Fajardo-Yamamoto et al. 2022). Due to deficiencies in the fishing report system in the country, it is impossible to identify if this increase is related to changes in fishing effort. Even in stocks that were assessed with shorter time series (e.g., barred sand bass) these declines in biomass have occurred in the last five years. For the roster hind, the largest catches were identified at the beginning of the time series producing stock sizes below MSY and continuing at a constant level for the rest of the time series. Besides the decrease in landings for this species, another reason the stock biomass did not decrease at lower levels could be that this species has a larger stock size (the largest *K* estimated among all stocks). The northern red snapper's stock biomass decreased below MSY in the early nineties. This stock was reported as overexploited in Mexico (DOF 2018), with a population reduction of around 58% (Anderson et al. 2015). In our estimations, the stock exceeded the reference point in the last three years after overexploiting. Like the stock biomass, the increase in landings for the past ten years has produced unsustainable fishing pressure for all the stocks except for the northern red snapper.

The lack of data in Mexican fisheries is a common feature preventing the development of formal stock assessments needed to implement management strategies (Salas et al., 2007; Arreguín-Sánchez and Arcos-Huitrón, 2011). An alternative data source is the logbooks filled out by fishing cooperatives or fishing permit owners, even if this source data still has some limitations (e.g., Russo et al., 2016; Mendoza-Carranza et al., 2018). Fulton et al. (2019) recommended the institutionalization and adoption of citizen science by fisheries management agencies and researchers to help create national data collection networks. Therefore, to improve the stock status of Mexican fisheries and in line with recommendations from other studies (Cisneros-Mata 2016; Saldaña-Ruíz et al. 2017), we propose some considerations: 1) although landings reconstruction methods have proven to diminish uncertainty on species-specific catch records in data-poor areas and this could be improved by citizen science, these methods do not exclude the need to have official catch records at the species level; 2) efforts should be made to estimate updated life-history parameters for exploited stocks to increase dynamic population knowledge (i.e., size at first maturity, growth parameters, estimate natural, and fishing mortality), and 3) detailed information of fishing effort (i.e., fishing gears including type and sizes, soaking times) associated with catches should be collected so index of abundances (e.g., CPUE) could be estimated. Addressing these topics will allow the implementation of more robust stock assessment. Control rules to regulate fishing efforts and landings need to be established and published in specific

Fishing Management Plans to secure that stock biomass and fishing pressure fluctuate around the reference point.

## 4.2 Management implications and recommendations

In the latest version of the National Fishing Chart that included finfish fisheries, the central management recommendation was to maintain the current level of captures, as the fishery is exploited at its maximum sustainability level (CNP, 2012). Among the finfish species considered in this work, only the management fishery plan for the barred sand bass in the Baja California peninsula has been published (DOF, 2021). Other finfish species need management plans, harvest strategies, and stock assessments, making their fisheries management weak. Based on the NFC, two general management actions are possible: 1) Fishers need to own a finfish fishing permit ("permiso de escama"), which encompasses ~70 fish species, and 2) if landing volumes fall from a specific threshold, more management actions need to be enforced for the *S. lalandi*, *P. auroguttatus*, *P. nebulifer*, *C. princeps*, *H. acanthistius*, *L. peru* (DOF, 2010), *S. miniatus* and *S. pulcher* (DOF, 2012). However, the NFC make these recommendations for categories that include multiple species, preventing that management action can be defined at the species level (for example, the Carangidae complex group "jureles" and "medregales" contains nine species, and the Serranidae complex group includes 18 species) (DOF, 2010). The California sheephead is considered a bycatch in the Serranidae complex group; therefore, the NFC only established the use of a finfish permit for its harvest as a management action.

Although the northern red snapper is one of the leading fishing resources in the Gulf of Mexico (Erisman et al., 2020), the NFC established that the Fishing Management Plan needs to be elaborated and implemented (DOF, 2018), which until this date, has not been done. As stated above , the barred sand bass is the only assessed species in this study with a Fishing Management Plan (DOF, 2021). Based on its stock status, it suggests that biomass should be maintained below $B_{MSY}$ and established the formulation of harvest control rates, minimum catch size, and regulation of fishing gears. This plan was published very recently, so it is unknown if and how these actions have been implemented.

All the stocks evaluated are part of Comprehensive FIPs, except the ocean whitefish targeted in Natividad Island, meaning an evaluation applying the MSC standard should be made as part of the reporting. Based on the estimated stock status and the lack of specific harvest strategies and control rules for most stocks, all stocks (except the northern red snapper) will fail to achieve the highest score for most of the indicators of Principle 1 and 3. All the stocks, except the rooster hind and barred sand bass, could achieve the highest score (≥80) for the indicators related to stock status because stock sizes are around the reference points. Only the barred sand bass has a Fishing Management Plan with harvest strategies and control rules (even if those are not very clear), reaching a medium score for those two indicators. The rest of the stocks lack these management strategies, achieving the lowest score possible. This lack of harvest strategies is critical because fishing pressure in all the stocks is above the reference point, so control rules need to be established to ensure that stock sizes stay above MSY. Some finfish FIPs have set internal measures such as minimum catch size or fishing effort in Mexico but at a fishing community level. This effort must be implemented at the species distribution level to influence population status.

The catch for all the stocks in this work is monitored periodically only by the logbooks that fishers submit to the Fishing Offices. However, this information is not always reported at a specific level and has no information on fishing effort. Under the current context, the monitoring indicator under the FIP will achieve a medium score. As part of the FIPs implementation, communities have developed monitoring programs for fishing and biological information. This monitoring will produce information regarding relative abundances by fishing gear (CPUE) and specific landings that, in the short term, will aid in improving the current stock assessment to get a more accurate estimation of stock status, like with the yellowtail and the Pacific red snapper. However, this monitoring should be extended to other areas where the stocks are caught, especially where the highest landings are reported.

FIPs can help facilitate the organization and management of fisheries at local level. Involving more communities and fishing cooperatives in the FIPs is critical to gathered the amount of data needed to strengthen stock status estimations needed to produce proper management actions that secure the sustainable use of fishing resources. This joint work will help to have a systematized information exchange between them to meet the standards and key indicators on a larger scale and reach the objectives of the FIPs. However, monitoring capacity is limited, and it is equally crucial that stakeholders take responsibility for obtaining this data with more extensive coverage. Therefore, data collection should not be considered complementary or only performed to meet MSC standards. Still, FIPs can support and reinforce this critical task to seek the sustainability of the fishery (Crona et al., 2019). Initiatives raised from the bottom of the fishing system may be the key to internally establishing effective management strategies, even if Fishing Authorities do not produce them.

It is essential to mention that the catch from FIPs contributes less than 5% to the total yield of the stock, except for the rockfish species, which has implications for fishery management, as it largely depends on the population status and its assessment due to data collection and quality. It is necessary to have information on a representative percentage of the total population stock for a more robust evaluation. To comply the principle 1 of the MSC, sustainability of the stock, the cooperatives that participate in FIPs play an essential role in generating this information to fill existing gaps and contribute to the improvement of practical management actions. There are examples of how fishers have provided information to detect shifting fishing seasons and catch compositions, allowing them to inform management decisions quickly and efficiently (Fulton et al., 2019). Citizen science-based information can be used to develop strategic management plans and comprehensive models despite the scarcity of data (Zetina Rejón et al., 2022).

To improve fishery practices toward sustainability, implementation of FIPs has been increasing worldwide over the last few years (Samy-Kamal, 2021). Even Samy-Kamal (2021) suggests that only half of the implemented FIPs have improved. The FIPs we analyzed have implemented systematic monitoring of their fishing operations that, in the future, will allow having catch and fishing effort time series with species compositions. Moreover, combined with the necessary biological knowledge of the assessed species, it will permit the application of more robust stock assessment models, either for single or multiple species (Dichmont et al., 2021; Johnson and Cox, 2021). For the case of Mexico, this tool sounds very promising for a bottom-up reconciliation route for a gain of regional multi-specific artisanal fisheries management. Nevertheless, deepening other aspects considering the fisher's operations to understand the dynamics of the fishing effort (Saldaña et al. 2017) and social, economic, and human constraints (Barr et al. 2019; Thomas Travaille et al. 2019) might also need to strengthen regional sustainable fisheries practices in Mexico.

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Table 1. Study species from five different Fishery Improvement Projects (FIP) in Mexico. The geographic locations of the FIPs are shown in Fig. 1.

| FIP | Species | Fishing gear | Start of the FIP | Number of vessels |
|---|---|---|---|---|
| Guaymas | *S. lalandi, L. peru, C. princeps, P. auroguttatus, H. acanthistius* | Handline | 2018 | 16 |
| El Rosario | *C. princeps, P. nebulifer, S. pulcher, S. miniatus, S. constellatus* | Handline and trap | 2018 | 20 |

| | | | | |
|---|---|---|---|---|
| Natividad Island | *C. princeps* | Handline and trap | 2017 | 18 |
| San Cosme-Punta Coyote Corridor | *L. peru, S. lalandi* | Handline | 2019 | 29 |
| Nuevo Campechito | *L. campechanus* | Bottom and vertical longlines | 2018 | 6 |



Table 2. Data sources available for the assessment of ten stocks in Mexico.

| **Species** | **Catch period** | **Abundance indexes** | **Catch reconstructed** | **Base for the reconstruction** |
|---|---|---|---|---|
| *S. lalandi* | 1970-2019 | CPUE (2011-2019)* | Yes | Limit of distribution (Baxter 1960, Ulloa-Ramírez et al. 2008) |
| *L. peru* | 1970-2019 | CPUE (2011-2019)* | Yes | FIP monitoring in Guaymas |
| *C. princeps* | 1980-2019 | | Yes | Common names reported by Manriquez-Ledezma 2008 |
| *P. nebulifer* | 1997-2019 | | No | - |
| *S. pulcher* | 2000-2019 | | No | - |
| *S. miniatus* | 2000-2019 | | Yes | FIP monitoring in El Rosario |
| *S. constellatus* | 2000-2019 | | Yes | FIP monitoring in El Rosario |

| | | | |
|---|---|---|---|
| *P. auroguttatus* | 2000-2019 | No | - |
| *H. acanthistius* | 1973-2019 | No | - |
| *L. campechanus* | 1977-2019 | Yes | FIP monitoring in Nuevo Campechito |

* CPUE was estimated from the fishing monitoring developed by the communities at the beginning of the San Cosme-Punta Coyote Corridor FIP.

Table 3. Prior ranges for population growth rate (r) were used to assess ten stocks in Mexico based on the classification of resilience according to Froese et al. (2017). Ranges in bold are species-specific.

| **Resilience (*r*)** | **Prior range** | **Stocks** |
|---|---|---|
| High | 0.6 – 1.5 | |
| Medium | 0.2 – 0.8 | *S. lalandi* (**0.16-0-49),** *L. peru, P. nebulifer, L. campechanus* ***(0.28-0.81****)* |
| Low | 0.05-0.5 | *P. auroguttatus, C. princeps, S. constellatus, S. miniatus* |
| Very low | 0.015-0.1 | *S. pulcher, H. acanthistius* |

Table 4. Prior relative biomass (B/k) ranges used for assessing ten stocks in Mexico based on the depletion status suggested by Froese et al. (2017).

| **Depletion** | **Prior range** | **Stocks at beginning** | **Stocks at the end** |
|---|---|---|---|
| Very low | 0.6-1 | | |

| | | | |
|---|---|---|---|
| Low | 0.4-0.8 | *S. lalandi, L. peru, C. princeps, P. nebulifer, S. pulcher, S. miniatus, S. constellatus, P. auroguttatus, H. acanthistius, L. campechanus* | *S. constellatus* |
| Medium | 0.2-0.6 | | *S. lalandi, L. peru, C. princeps, P. nebulifer, S. pulcher, S. miniatus, P. auroguttatus, H. acanthistius, L. campechanus* |
| Strong | 0.01-0.4 | | |
| Very strong | 0.01-0.2 | | |



Table 5. Total landings and landings reported by the communities involved in the Fishery Improvement Projects for ten stocks in Mexico in the last year of the time series (2019). Percentages of landings relative to the total stock landings are shown in parentheses. NI = Natividad Island, ROS = El Rosario, GUY = Guaymas, NCAM = Nuevo Campechito.

| **Species** | **Total catch (t)** | **NI (t)** | **ROS (t)** | **GUY (t)** | **NCAM (t)** |
|---|---|---|---|---|---|
| *S. lalandi* | 2,084.4 | - | - | 14.6 (0.70%) | - |
| *L. peru* | 2,920.7 | - | - | 4.66 (0.16%) | - |
| *C. princeps* | 1,998.7 | 1.43 (0.07%) | 32.98 (1.65%) | 0.03 (<0.01%) | - |
| *P. nebulifer* | 4,139.7 | - | 8.70 (0.21%) | - | - |

| | | | | | |
|---|---|---|---|---|---|
| *S. pulcher* | 223.8 | - | 1.04 (0.46%) | - | - |
| *S. miniatus* | 717.1 | - | 173.38 (24.18%) | - | - |
| *S. constellatus* | 7.8 | - | 1.88 (24.01%) | - | - |
| *P. auroguttatus* | 1,107.7 | - | - | 23.73 (2.14%) | - |
| *H. acanthistius* | 2,216.0 | - | - | 4.6 (0.21%) | - |
| *L. campechanus* | 3,109.71 | - | - | - | 61.92 (1.99%) |

Table 6. Estimates of biological parameters and reference points for ten stocks in Mexico. Reference points presented are biomass in the reference point ($B_{MSY}$), relative biomass in the last year ($B/B_{MSY}$), fishing mortality in the reference point ($F_{MSY}$), and fishing pressure in the previous year ($F/F_{MSY}$). Values in parentheses belong to the estimates without incorporating the CPUE index.

| **Species** | **r** | **K ($10^3$ t)** | **$B_{MSY}$ ($10^3$ t)** | **$B/B_{MSY}$** | **$F_{MSY}$** | **$F/F_{MSY}$** |
|---|---|---|---|---|---|---|
| *S. lalandi* | 0.32 (0.33) | 24.94 (23.46) | 12.47 (11.73) | 0.95 (0.70) | 0.16 (0.16) | 1.21 (1.77) |
| *L. peru* | 0.40 (0.46) | 26.75 (25.26) | 13.37 (12.63) | 1.08 (0.94) | 0.20 (0.23) | 1.53 (1.42) |
| *C. princeps* | 0.22 | 24.65 | 12.32 | 0.73 | 0.11 | 1.95 |
| *P. nebulifer* | 0.60 | 26.52 | 13.26 | 0.71 | 0.30 | 1.44 |
| *S. pulcher* | 0.05 | 11.35 | 5.67 | 1.06 | 0.03 | 1.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *S. miniatus* | 0.23 | 6.85 | 3.43 | 0.98 | 0.12 | 1.84 |
| *S. constellatus* | 0.22 | 0.08 | 0.04 | 1.27 | 0.11 | 1.24 |
| *P. auroguttatus* | 0.22 | 10.43 | 5.21 | 0.96 | 0.11 | 1.95 |
| *H. acanthistius* | 0.03 | 127.10 | 63.55 | 0.79 | 0.01 | 2.22 |
| *L. campechanus* | 0.38 | 37.88 | 18.94 | 1.07 | 0.19 | 0.80 |


Figure 1. Location of the communities where the Fishery Improvement Projects are being implemented in northwestern Mexico and the Gulf of Mexico.

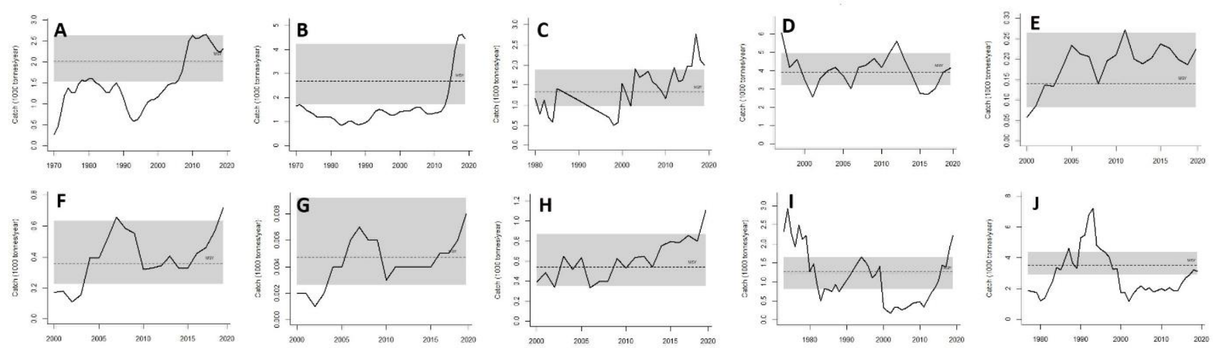


Figure 2. Catch trends for ten stocks in Mexico. The solid line indicates catches, the discontinued line indicates the catch in the reference point ($C_{MSY}$), and the gray area is the CI 95%. A = *S. lalandi*. B = *L. peru.* C = *C. princeps*. D = *P. nebulifer*. E = *S. pulcher.* F = *S. miniatus*. G = *S. constellatus*. H = *P. auroguttatus.* I = *H. acanthistius.* J = *L. campechanus.*

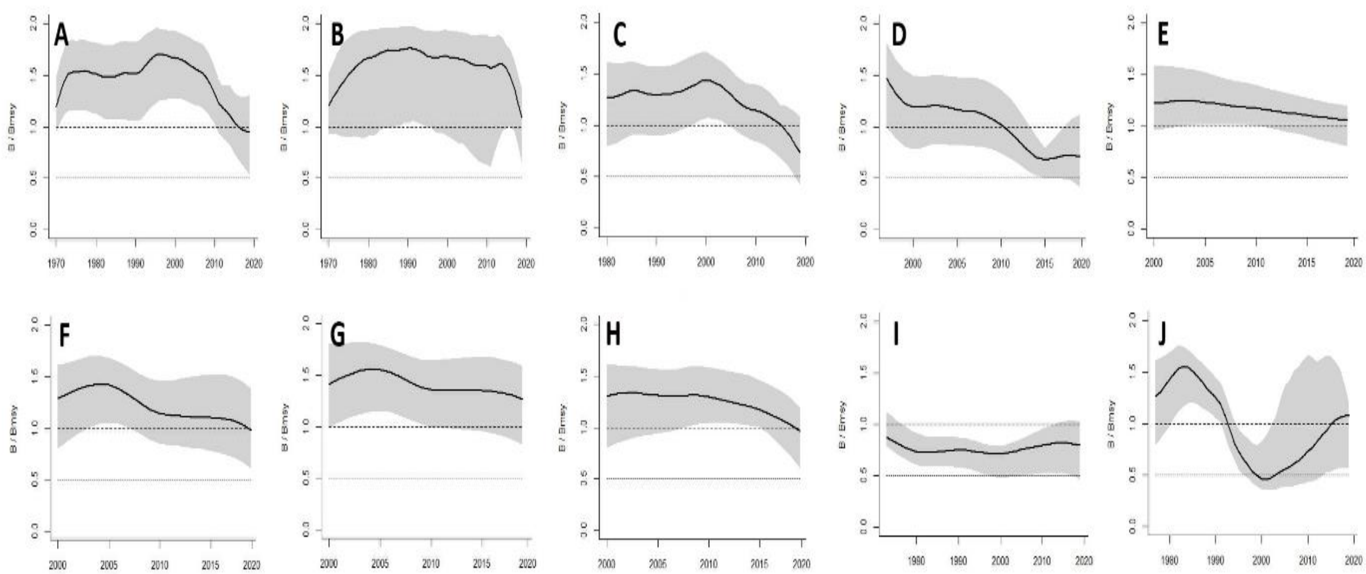


Figure 3. Relative biomass trends ($B/B_{MSY}$) for ten stocks in Mexico. The discontinued line indicates the biomass in the reference point ($B_{MSY}$), the pointed line indicates the level where the recruitment could be impaired (0.5 $B_{MSY}$), and the gray area is the uncertainty. A = *S. lalandi*. B = *L. peru.* C = *C. princeps*. D = *P. nebulifer*. E = *S. pulcher.* F = *S. miniatus*. G = *S. constellatus*. H = *P. auroguttatus.* I = *H. acanthistius.* J = *L. campechanus.*

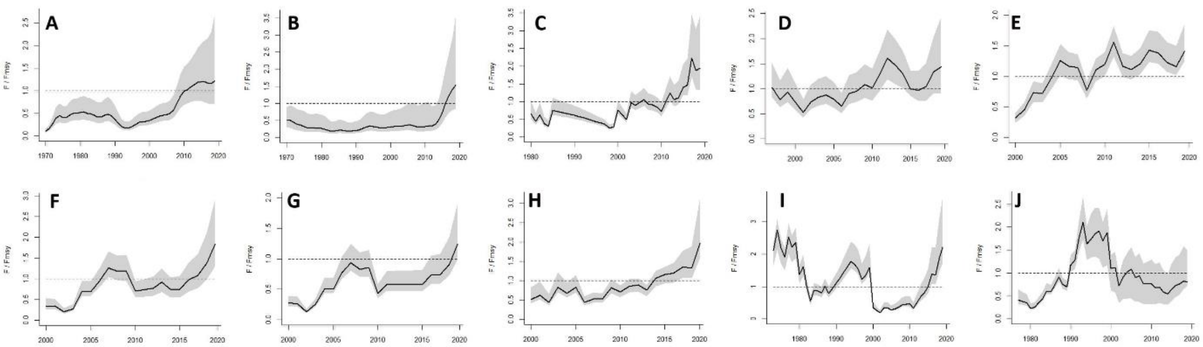


Figure 4. Relative fishing pressure trends ($F/F_{MSY}$) for ten stocks in Mexico. The discontinued line indicates the fishing mortality in the reference point ($B_{MSY}$), and the gray area is the uncertainty. A = *S. lalandi*. B = *L. peru.* C = *C. princeps*. D = *P. nebulifer*. E = *S. pulcher*. F = *S. miniatus*. G = *S. constellatus*. H = *P. auroguttatus.* I = *H. acanthistius.* J = *L. campechanus.*

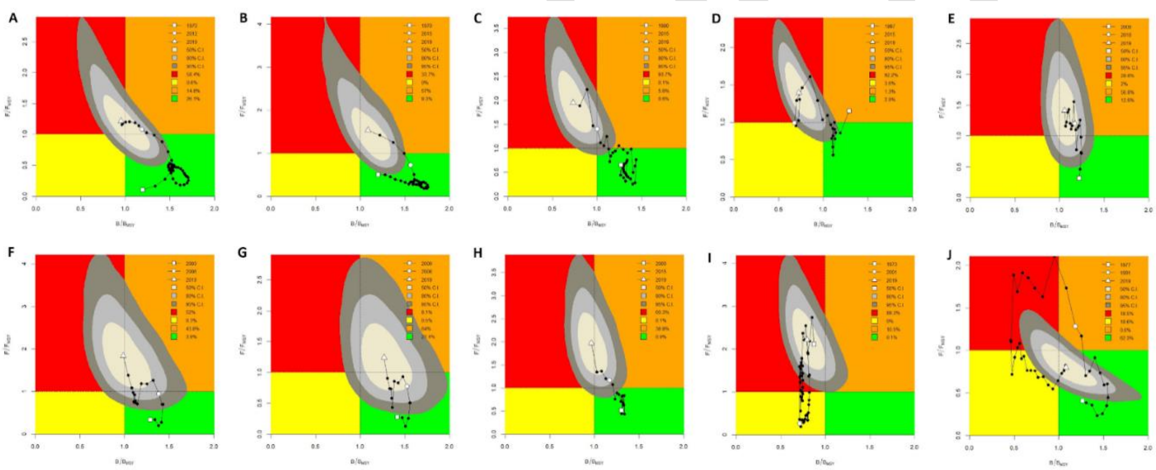


Figure 5. Kobe plots with the stock status trend for ten stocks in Mexico. The gray area around the triangle indicates uncertainty related to the final year (yellow for 50%, grey for 80%, and dark grey for 95% confidence levels). Legend indicates the probability of the stock status being of each of the plot quadrants. A = *S. lalandi*. B = *L. peru.* C = *C. princeps*. D = *P. nebulifer*. E = *S. pulcher.* F = *S. miniatus*. G = *S. constellatus*. H = *P. auroguttatus.* I = *H. acanthistius.* J = *L. campechanus.*

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