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Fishing down the reef slope: Characteristics of the nearshore deepwater fisheries of MesoAmerica

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ABSTRACT

Deepwater fisheries in the Caribbean waters of Mexico, Belize, Guatemala, and Honduras are currently unmanaged, and there is very little monitoring of fishery landings. Increasing demand for high quality fish has led to the continued expansion of coastal fisheries into deeper waters in the region over several decades. The deepwater fisheries of the MesoAmerican Region are mostly small-scale, but they target species that are likely vulnerable to overexploitation due to conservative life history characteristics common to deepwater fish, including slow growth, late maturity, and low natural mortality. A total of 122 deepwater fishers from Mexico, Belize, Guatemala, and Honduras were interviewed to assess their perceptions on the status and future of deepwater fisheries, its history, current trends and prices. Deepwater fisheries in the region were mostly likely established in the 1970's, though outside of Belize fishers reported a longer perceived timeline. Fishers in Mexico, Belize, and Honduras mostly targeted snapper species, including silk (*Lutjanus vivanus*), blackfin (*L. buccanella*), wenchman/cardinal snapper (*Pristipomoides* spp.), queen (*Etelis oculatus*), vermillion (*Rhomboplites aurorubens*), and black (*Apsilus dentatus*) snappers while those in Guatemala targeted mainly sharks (mostly smoothhounds (*Mustelus* spp.), gulpers (*Centrophorus* spp.), sixgills (*Hexanchus* spp.), night sharks (*Carcharhinus signatus*), and dogfishes (*Squalus* spp.)) and groupers (mostly yellowedge (*Hyporthodus flavolimbatus*) and misty groupers (*H. mystacinus*)). Fishers largely sold directly to consumers, whether individuals, restaurants, or fish markets, and Honduras is currently the only country with a strong export market for deepwater fishes. As coastal fisheries continue to decline, and access to depth sounders and GPS becomes ubiquitous, fishing effort in these fisheries is expected to continue to increase.

1. Introduction

World-wide, deepwater fisheries are often well-established, and populations in decline before any biological, ecological, or economic surveys are conducted (Clark et al., 2001; Clarke et al., 2015; Devine et al., 2006; Foley et al., 2011; Haedrich et al., 2001). Deepwater fishes tend to have conservative life history strategies, and their slow growth, late maturity, low natural mortality, and long life expectancies make them especially vulnerable to overexploitation (Koslow, 2000; Large et al., 2013). This is especially true for deepwater shark species, which suffer from a general lack of data world-wide (Daley et al., 2015; Dulvy and Forrest, 2010; Frisk et al., 2005; Kjerstad et al., 1999; Stevens, 2000), and for slow-growing and long-lived grouper species (Sadovy de Mitcheson et al., 2013). With the exception of stocks in the United States' territorial waters in the Western North Atlantic Ocean, deepwater fish stocks are generally unmanaged and not assessed throughout the Caribbean Sea; however, even where stock assessments have been conducted, data limitations hinder useful analysis and conclusions (SEDAR, 2016; 2011a; 2011b).

The MesoAmerican Reef (MAR) extends along the Atlantic coastline of the countries of Mexico, Belize, Guatemala and Honduras in the western Caribbean Sea. Considered the second-longest barrier reef in the world and largest in the Northern Hemisphere, the reef plays an important role in food security and as income for fisheries and tourism (Fernandez et al., 2011; Perez, 2009). The monetary value of artisanal fishing surpasses industrial fisheries across the MAR countries (Canty et al., 2019). Small-scale fishing has had greater value in the Mexican Caribbean and Belize since the 1950's, and in Guatemala and Honduras

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since 2000 (Canty et al., 2019). Overall, catches from industrial fishing in the MAR countries has been decreasing for several decades, while those from small-scale fisheries is generally increasing (Canty et al., 2019). Ongoing management schemes, illegal, unreported, and unregulated fishing (IUU), and territorial disputes make these fisheries controversial and complex (Perez, 2009).

Contemporary shallow coastal fisheries along the MAR are generally overfished and under-managed, with habitat degradation also contributing to the decline of coastal fish stocks (Dunn et al., 2010; Graham et al, 2008, 2009; Heyman and Graham, 2000a, 2000b, 2000c; Heyman and Granados-Dieseldorff, 2012; Paddack et al., 2009). Spiny lobster is the most important single seafood product in the MAR (Zeller et al., 2011), and is sold both locally and exported, though recent assessments have indicated that stocks are fully-to over-exploited (OSPESCA/CLME, 2019). Deepwater fisheries (150–500 m) in the MAR's Caribbean Sea have been expanding in recent years, likely as a direct result of these declines (Baremore et al., 2016; Gobert et al., 2005a; Grant, 2019). The steep bathymetry of much of the Caribbean, transitioning from shallow waters to over 3000 m in depth within a few hundred meters of the barrier reef, enables deepwater access to small vessels. As observed in many fisheries around the world (Clark et al., 2001; Sadovy de Mitcheson et al., 2013; Bialek, 2003), there appears to be a general trend in 'fishing down' to deeper depths as shallow coastal resources become more scarce in the MAR.

Deepwater fisheries in the western Caribbean are mostly artisanal, and the majority of fishing effort consists of hand lines or hand-cranked reels. Both vertical and horizontal bottom-set longline gear is used throughout the region, though effort varies by country and region within each country (Canty et al., 2019; Gobert et al., 2005a; Grant, 2019; Hacohen-Domené et al., 2016). Little is known about historical or contemporary trends in effort and landings throughout the region, and there are currently no management schemes that directly address deepwater fisheries. In the Gulf of Honduras (encompassing southern Belize, Guatemala, and the Bay Islands of Honduras), the majority of fishing activity was concentrated in shallow coastal areas through the mid-1960's (Craig, 1966; Thompson, 1944), though there were earlier reports of fishers in Belize targeting deeper 'red snappers' in mid-summer when they came into shallower waters to spawn in summer months (Thompson, 1944).

There was a concerted effort by the United Nations Development Programme (UNDP) Caribbean Fisheries Project in the 1970's to develop demersal deep slope fisheries in many parts of the Caribbean (Brownell, 1972; Cifuentes Lemus, 1979; Giudicelli, 1979; Grant, 2019). Feasibility studies informed training programs, which were intended to offset overfishing of coastal finfish, lobster, and conch populations throughout the Caribbean. Most information on deepwater fisheries in Mexico is focused on the red grouper fishery in the southern Gulf of Mexico (Fernandez et al., 2011), and implications are that UNDP training concentrated on the Gulf of Mexico rather than the Caribbean (C. Meiners-Mandujano pers. comm.). Although listed as a participating country in the UNDP fisheries project, little historical information is available about deep slope fisheries in the MAR region of the state of Quintana Roo, Mexico, and modern landings are only reported to taxonomic family (CNAP, 2017; Fernandez et al., 2011). In Belize, a feasibility study lead to the creation of a deep slope finfish fishery in the 1970's, reaching peak production of 1 million pounds (~454,000 kg) in 1983 (Grant, 2019). A collapse in the foreign market led to the near complete decline of the fishery by 2005 (Grant, 2019). A second training workshop, promoted by the Government of Belize, was held in 2006 and convened by the government of Trinidad and Tobago and the Japan International Cooperation Agency (JICA). In 2010 a Cooperative was established in southern Belize for export to Jamaica; however, while production increased to a maximum of 525,880 lbs (~238,500 kg) in 2013, it subsequently declined to 100,000 lbs (~45,360 kg) in 2019 (Grant, 2019). Similar to Mexico, there is a lack of information about the Guatemalan Caribbean's small deepwater fishery, which operates out of El Quetzalito (Hacohen-Domené et al, 2016, 2020; Polanco-Vásquez et al., 2017). Gobert el al. (2005b) indicated that only a fraction of the artisanal fishery in the Bay Islands of Honduras directed effort toward deepwater snappers in the early 2000's, and demand for deepwater snappers was driven mainly by the export market during that time, especially in Utila (Box and Canty, 2011; Gobert et al., 2005a).

The most frequently targeted deepwater species throughout the wider Caribbean is the "deepwater red snapper," which is a species complex consisting of several reddish species including queen (*Etelis oculatus*), silk (*Lutjanus vivanus*), wenchman (*Pristipomoides aquilonaris*), cardinal (*P. macropthalmus*), blackfin (*L. buccanella*), and vermilion snappers (*Rhomboplites aurorubens*) (Baremore et al., 2016; Box and Canty, 2011; Fanning et al., 2011; Gobert et al., 2005b; Rosario et al., 2006; SEDAR, 2011a). In the MAR, deepwater snappers and groupers are the main targets of the fisheries (Baremore et al., 2016; Box and Canty, 2011; Gobert et al., 2005b), but sharks are also targeted and landed, mostly for the Guatemalan market (Baremore et al., 2019; Hacohen-Domené et al., 2020). Along with the red snappers listed above, targeted deepwater teleost species in the MAR include black snapper (*Apsilus dentatus*) and groupers, such as yellowedge (*Hyporthodus flavolimbatus*), Warsaw (*H. nigritus*), and misty (*H. mystacinus*) groupers. Carangids are also often captured incidentally, with the greater (*Seriola dumerili*) and lesser (*S. fasciata*) amberjacks, almaco (*S. riviolana*), and black (*Caranx lugubris*) jacks being captured most frequently. Captured elasmobranch species include smoothhounds (*Mustelus* spp.), gulper sharks (*Centrophorus* spp.), sixgills (*Hexanchus* spp.), dogfishes (*Squalus* spp.), night sharks (*Carcharhinus signatus*), and occasionally chimeras (Baremore et al., 2016; Hacohen-Domené et al., 2020; Polanco-Vásquez et al., 2017). Most of the snapper species targeted or captured as bycatch in the deepwater fisheries of the MAR are described as data deficient or least concern by the IUCN, while several groupers and some elasmobranchs range from near threatened to critically endangered (www.iucnredlist.org).

The long-term success of a management or conservation plan is largely dependent upon support from stakeholders - the direct and indirect users of resources - such as fishers and their communities (Alexander et al., 2020; Cisneros-Montemayor and Vincent, 2016; Drew, 2005; Heyman and Graham, 2000a, 2000b, 2000c; Johannes, 1982; King et al., 2001). International support and involvement can directly support data collection methods and scientific investigations, but often these gains in knowledge can be short-term when local capacities have not been established (Salas et al., 2007). Integrating local ecological knowledge (LEK) from fishers into research methods, and subsequently involving fishers in the process of research and management considerations can greatly improve the potential for success of conservation and management. Integrating LEK and research capacity can increase stakeholder buy-in and fostering relationships within the community (Bélisle et al., 2018; Cummings et al., 2015; Heyman and Granados-Dieseldorff, 2012; Johannes et al., 2000). Thus, there is a need for a more holistic approach to fisheries management in low- and middle-income countries. A practical and adaptive diagnostic approach, which takes into account ecological, economic, and societal needs is needed to improve management and conservation of these fisheries (Andrew et al., 2007; McElwee et al., 2020).

The aims of this research were to provide information on the deepwater fisheries of the MAR based on LEK derived from questionnaire surveys of fishers who participate in this fishery. This information will play an essential role in developing a future socio-ecological risk assessment for deepwater species and dependent communities. Specifically, the aims were to: 1) estimate the timeline of fishing effort in deepwater fisheries; 2) characterize the contemporary fishery by country; 3) provide semi-quantitative descriptions of effort, gear, and landings data; and 4) characterize fisher perceptions of the current status of the fishery and its future. As deepwater fisheries become more important in the region, and vulnerable species captured with little or management oversight, it is crucial to establish baselines of information for the fishery

and the species that are targeted and caught as bycatch.

2. Materials and methods

A questionnaire survey was developed to gather data on the demographics and perceptions of deepwater fishers as well as the characteristics of the fisheries in the MesoAmerican Barrier Reef countries of Mexico, Belize, Guatemala, and Honduras. For the purposes of this study, deepwater fishers are defined as those who spend at least part of their annual fishing effort bottom fishing at depths between 150 and 500 m. The survey was refined after a preliminary trial in San Pedro, Belize, with the final survey containing 37 questions (Appendix 1). Surveys were conducted in English in Belize and the Bay Islands of Honduras, and in Spanish for Honduras, Mexico, and Guatemala. Surveys were conducted in Belize (2015–2018), in Mexico and Guatemala (2019), and in Honduras (2018–2019). The first section of the survey consisted of questions about the fishers' personal fishing history and activities (n = 16 questions), the second focused on economics (n = 9 questions), the third on demographics (n = 5 questions), and the fourth section concerned fishers' perceptions of the deepwater fishery (n = 5 questions). Likert scales were used for perceptions and ranged from 1 (strongly disagree) to 5 (strongly agree) and were modified to include neutral skin-toned emojis to aid intuitive understanding (Appendix 1). If both captain and crew members from the same vessels were interviewed, answers that could be confounding, such as vessel size and economics were considered only from the captains' surveys. Prices were converted to US dollars ($) based on current exchange rates at the time of the interviews.

To assess fishers' knowledge of the history of the fishery and to ascertain the year when fishing effort in deeper waters was close to zero, deepwater fishers were asked when they thought the deepwater fishery began. For clarity, rather than the exact year, they often reported in terms of generations (e.g. 'the deepwater fishery began during my father's generation'). The age of the fisher was then used to estimate the decade that they indicated using 30 years as an approximate generation time.

All survey questions were grouped by country for comparison of answers within the MAR. Answers to questions with numerical values (weight, etc.) were summarized by calculating the mean value plus or minus the standard deviation, and discrete answers were summarized as counts. Answers to open-ended questions were grouped into categories based on responses. For example, for the question "Why did you start fishing in deep waters," answers such as "As an alternative to lobster" and "As alternative fishing grounds" were grouped into a common "Economic alternative" answer. Fishers were asked which fish they preferred to catch using photos when possible, otherwise local names and descriptions were used to ascertain species (Appendix 2). Participants were also encouraged to give anecdotes at the end of the survey, such as 'What is the most unusual fish you have caught,' and 'What is the best time to fish in the deep sea'. When possible, ambiguous or unclear answers were clarified through post-survey interviews with fishers and surveyors. To assess how seasonal conditions might affect fishing activity, average monthly wind speed for the region was gathered from weatherspark.com.

Deepwater fishes have species-specific depth preferences, which effectively limit the fishing area accessible to fishers. In order to estimate the area available within each country's Economic Exclusive Zone (EEZ) for deepwater fishing, the total sea surface area (km^2) was calculated over the depth ranges of target grouper and snapper species (between 100 and 550 m). Depths were estimated from the General Bathymetric Chart of the Oceans (GEBCO) gridded bathymetry data and plotted using QGIS (QGIS Development Team, 2020). Data preparation, descriptive statistics, and graphing were performed using the tidyverse package (Wickham, 2017) in R (R Core Team, 2019).

Questionnaire surveys were conducted by trained biologists and volunteers in Belize, Honduras, and Guatemala and by a fisher associate in Mexico. The goals of the research and the types of questions to be asked were explained to each fisher prior to the interview, and oral consent was obtained prior to the beginning of each interview. All data were anonymized, the identities of the fishers were safeguarded prior to data analysis, and this study followed the Ethical Principles in the Conduct of Research with Human Participants proposed by the American Psychological Association. Personal information about study participants are digitally stored offline and maintained separately to the participants responses, following the UK Guide to Data Protection (GPDR) guidelines and the Data Protection Act 2018 (UK).

3. Results

Of all fisher interviews conducted (n = 144), 122 self-identified as deepwater fishers in Mexico (n = 20, 16%), Belize (n = 30, 25%), Guatemala (n = 11, 9%), and Honduras (n = 61, 50%). There were none interviewed that were exclusively deepwater fishers, and there were differences in alternative fishing practices by country. In Mexico, only fishers from southern Quintana Roo were interviewed, and in Guatemala, fishers were interviewed in the main landing site of El Quetzalito (Fig. 1). In Belize, interviews took place in Belize City (n = 17; 57%), San Pedro (n = 5; 17%), and in southern Belize (n = 7; 23%), though some interviews were conducted opportunistically in the field or in other locations. In Honduras, deepwater fishers were interviewed in all three of the Bay Islands (n = 54; 88%), and in Puerto Cortes and Omoa on the mainland (n = 7; 12%) (Fig. 1). It is estimated that more than 80% of practicing deepwater fishers were interviewed in southern Quintana Roo, Mexico and in the Caribbean of Guatemala, but the total numbers of deepwater fishers in Belize and Honduras is unknown; therefore, we could not estimate the percentage of fishers covered by this survey. Vessels used for deepwater fishing ranged from small dories to semi-industrial ships (Fig. 1).

The total available deepwater fishing habitat in the MAR, from Cancun to the Bay Islands of Honduras is around 11,350 km^2 (Fig. 1). Guatemala's Caribbean EEZ is the smallest and contains the least amount of deepwater fishing grounds (~150 km^2), followed by Belize (2600 km^2), and the Mexican MAR (6000 km^2). Honduras has nearly 26,000 km^2 of deepwater fishing habitat available in its Caribbean EEZ; however, excluding the waters more than 50 km east of Guanaja, which are not part of the MAR, the total fishing area available to deepwater fishers in northwestern Honduras and the Bay Islands is similar to Belize at roughly 2600 km^2 (Fig. 1).

3.1. Fisher demographics, history, and activities

Interviewed deepwater fishers were all men and ranged in age from 18 to 78, with fishers in Belize and Mexico being older (mean age: 48 and 52 years, respectively) than those in Guatemala and Honduras (mean age: 42 and 44 years, respectively) (Fig. 2A). Most fishers in Belize had been fishing deep yet nearshore waters, for fewer than 10 years, while those in Mexico had been fishing these environments for between 5 and 30 years. Several fishers in Guatemala and Honduras reported fishing in deep waters for more than 40 years (Fig. 2B).

A commonality among fishers from all countries was the prevalence of individuals who, at least in part, fished in deep waters because of curiosity (Fig. 2C). Many expressed desires to discover or observe something new, and several made comments about mermaids and megalodon. After curiosity, the superior product and price were the most common motivations for deepwater fishing. Fishers in Honduras and Mexico expressed a lack of alternatives for income as their main incentive exploiting deepwater habitats (Fig. 2C). Some younger fishers (approximately 20 years old) in Guanaja, Bay Islands, Honduras responded, 'there's nothing else to do here.'

When asked about the history of the fishery in their region, fishers in Belize stated that the fishery was less than 20 years old, while many fishers in Mexico, Guatemala, and Honduras believed that deepwater

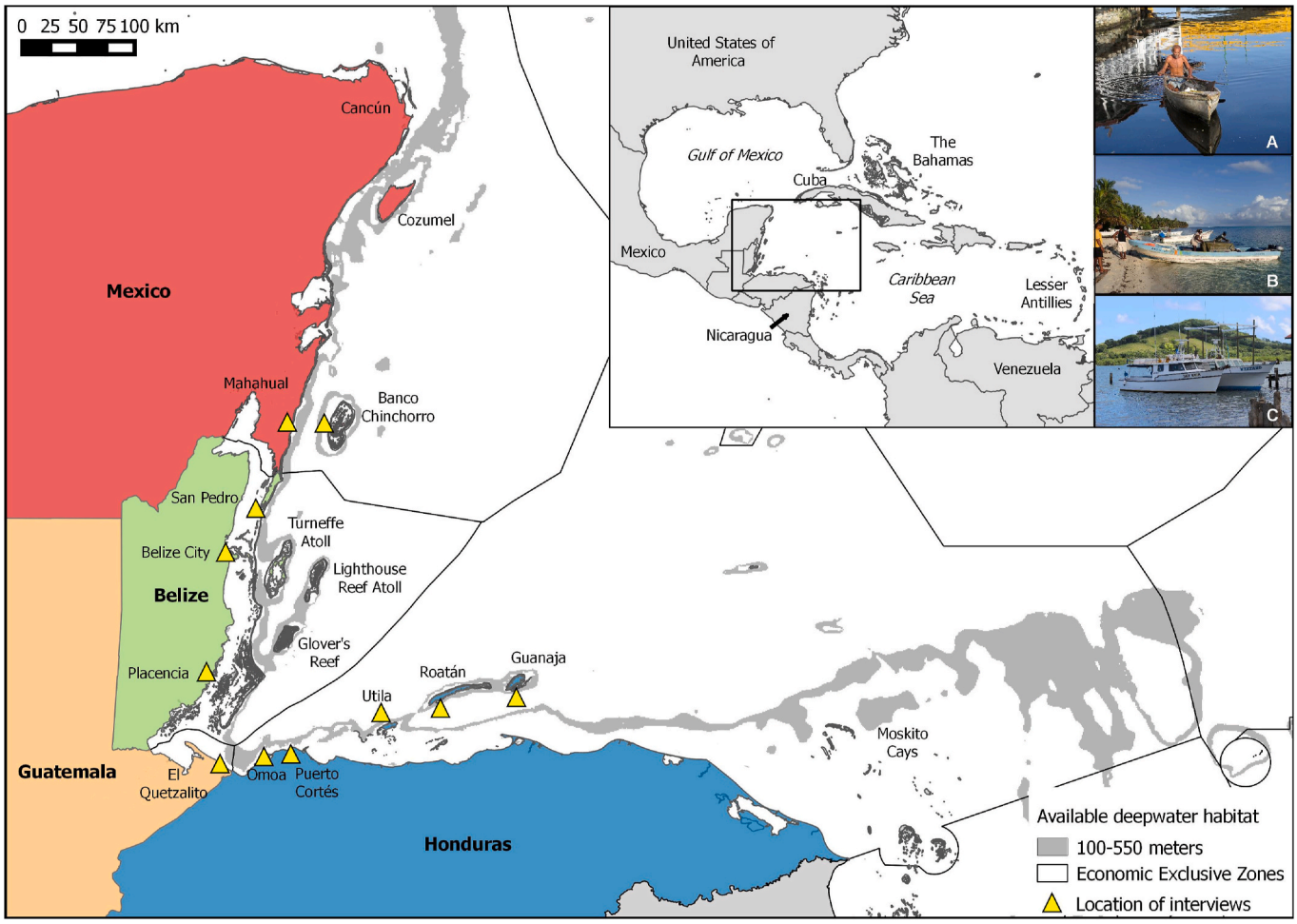

Fig. 1. MesoAmerican Reef countries coded by color and their exclusive economic zones, with the available deepwater fishing grounds (depths between 100 and 550 m) overlaid in grey. Yellow triangles indicate localities of interviews. Boat pictures represent the variety of vessel sizes participating in the fishery, (smallest to largest; A-C). Photo credit: A) Gabriela Ochoa; B) Rachel Graham; and C) Ivy Baremore. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

fishing had been established more than 100 years prior (Fig. 2D). Fishers in the Bay Islands (Honduras), and specifically Guanaja, associated the beginning of the deepwater fishery with the immigration of Cayman Islanders, who brought the fishing techniques and knowledge with them during their fathers' or grandfathers' generation (circa 1930). Fishers on Roatán and Utila (Honduras) were more likely to believe that the fishery was older (Fig. 2D), with some stating that the indigenous peoples of Honduras engaged in deepwater fishing and another responding that it had been around 'since the creation of the island'. Most fishers in Mexico believed that the fishery was at least 100 years old.

Boats used for deepwater fishing were of similar sizes in all four countries, with a mean boat size of 8.1 m (26 ft) (mean ± 2.5 SD) coinciding with the most readily available high bow pangas made in the region; however, in Honduras both smaller dories and larger semi-industrial size vessels were also common (Figs. 1 and 3A). Fishers reported a mean of 83.5 kg (184 lbs) ± 81.6 kg SD of fish were landed on a typical fishing trip (Fig. 3B), which was 2.5 days in duration (mean ± 4.0 days SD) (Fig. 3C). Honduras has an extensive EEZ (209,335 km^2, Fig. 1), and the larger vessels could undertake multi-week fishing trips, often to the offshore seamounts and 'banks' (25–50 km), the Moskito Cays (>400 km), and in some cases into transboundary waters (Fig. 3C). While semi-industrial boats are more common in the Bay Islands of Honduras than other countries, the mean trip duration in Honduras was 2.5 days (+5.0 days SD), which is indicative of the large number of subsistence and small-scale fishers in the country. Most deepwater fishers in Mexico (n = 14, 70%) spent more than 50% of their annual fishing effort in deep waters, while the majority in Guatemala (n = 10, 100%) and Belize (n = 14, 88%) reported spending less than 50% of their annual fishing effort in deep waters (Fig. 3D).

Many fishers in Belize and Mexico fished for lobster or conch (Belize, n = 18, 60%; Mexico n = 16, 80%), using the deepwater fishery as an alternative during lobster and conch closed seasons, while in Honduras, most of those interviewed were primarily deepwater fishers (Figs. 4 and 5; n = 52, 86%). Guatemalan fishers divided their fishing activities fairly evenly among shallow finfish (n = 9, 82%), shark (n = 11, 100%), and lobster (n = 9, 82%). Most fishers in Honduras fished in deep waters year-round when the weather conditions are favorable (Figs. 4 and 5), and identified the hurricane season (June to November) and winter months (December to February) as preferred (Fig. 4). Fishers from all countries also engaged in shallow finfish fisheries, while only fishers from Belize and Honduras also operated as tour guides (Fig. 5).

3.2. Economics

Prices (per lb) fishers sold their catch for were generally highest in Mexico and Belize, followed by Honduras, and then Guatemala (Fig. 6). Snapper and grouper in Mexico sold for US$3.00 and $3.25 per pound (lb) whole (mean ± $0.32 and $0.22 SD), respectively, while in Belize whole snapper was sold for US$2.50 (mean lb ± $1.20) and grouper was sold for US$3.00/lb (mean lb ± $1.30). In Belize, snapper and grouper

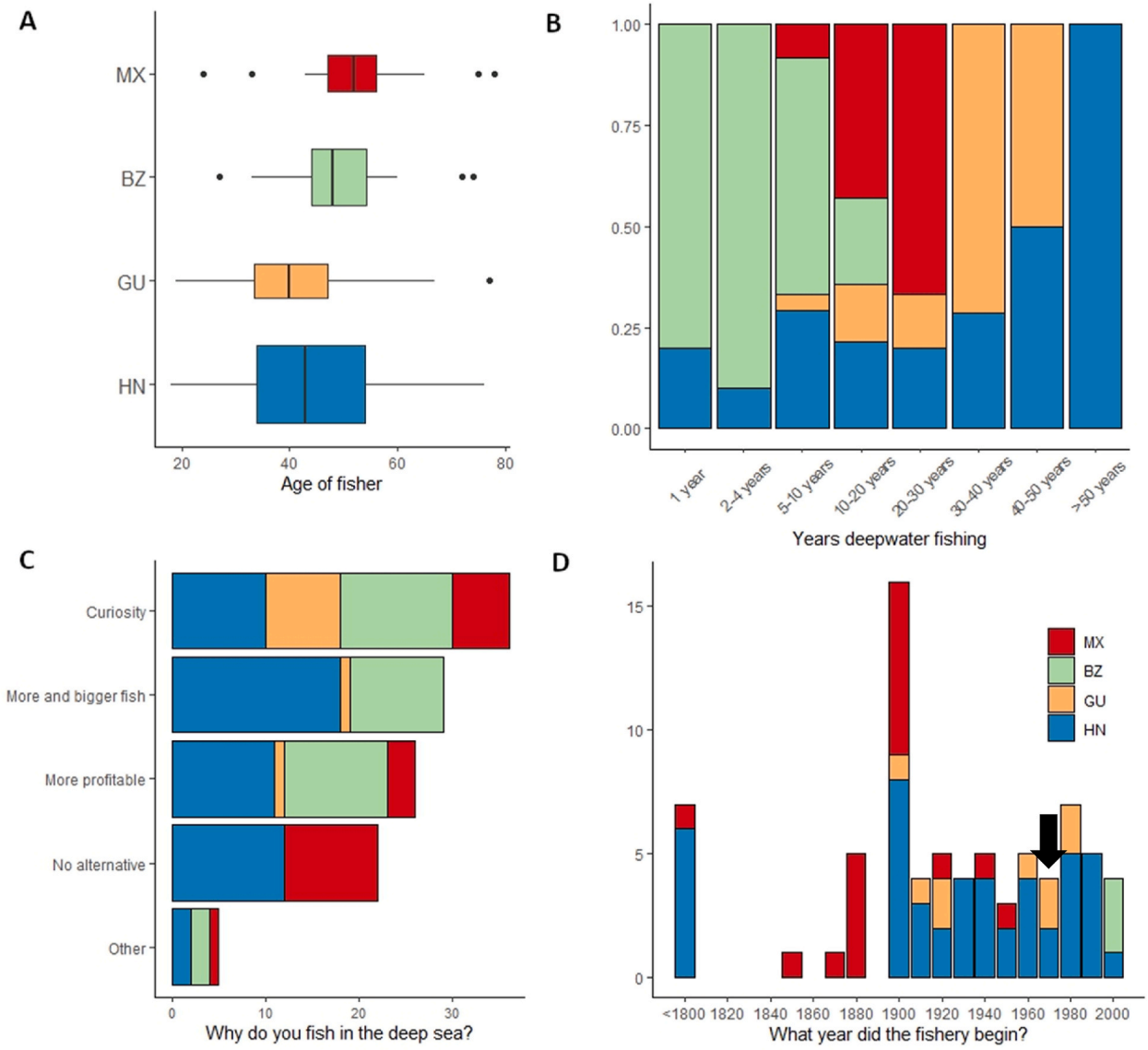

Fig. 2. Country variation in deepwater fishery characteristics in the MesoAmerican Reef countries. A) age of respondents; B) number of years respondents had been deep slope fishers; C) reason respondents gave for fishing in the deep sea; D) the decade respondents believed that the deep slope fishery began in their country/region, with the black arrow indicating when the UNDP conducted training initiatives in the Caribbean. Country abbreviations are as follows: MX = Mexico, BZ = Belize, GU = Guatemala, and HN = Honduras.

fillet sold for US$5.75 and US$7.00/lb, respectively (mean ± $1.40 and $1.35 SD). Prices in Honduras were approximately US$2.20/lb on average for whole snapper (mean ± $0.10), US$2.70/lb (mean ± $0.80) for snapper fillet, US$2.30/lb (mean ± $1.10) for grouper fillet, and US $2.10 (mean ± $0.20) for whole grouper. In Guatemala, grouper sold for US$1.30/lb whole (mean ± $0.60) and US$1.00/lb (mean ± $0.30) for fillet. Fishers in Guatemala reported that they do not encounter snappers often in the deeper waters. Sharks sold shark for an average of US$2.00/lb whole (mean ± $1.10) in Mexico and US$2.00/lb (mean ± $1.30) whole in Guatemala (US$2.40/lb ± $1.90 for shark fillet) (Fig. 6). Snappers were only sold whole (as opposed to fillet) in Mexico, and only Belize showed a consumer preference for fillet over whole fish.

Most respondents sold their catch directly to individuals, restaurants, or small neighborhood markets (Fig. 7), and 30% (n = 33) of fishers reported selling to multiple vendors depending on the price or convenience. Mexican fishers only sold deepwater fish to the local fisher cooperative, to restaurants, and/or individuals. Of the Belizean fishers, only those in the south of Belize sold to small fisher cooperatives (n = 5 of 7 fishers in southern Belize), as the larger cooperatives in Belize City generally did not buy finfish. Only in Honduras were sales reported to fabricas (fish processing factories), and fishers in Utila (n = 10) were the only respondents that sold exclusively to fabricas. Most (n = 43; 75%) Honduran fishers sold to individuals and restaurants, while owner/operators of the larger vessels were able to travel to the mainland or Roatán to sell their catch for export or for sale in local seafood markets, depending on the price (Fig. 7). All (100%) fishers in Guatemala sold their catch locally or to markets in the large port city of Puerto Barrios.

3.3. Fishery characteristics

Vertical and bottom longline, pulled and deployed by hand were the most common gear types used in all countries (n = 65; 48%) (Fig. 8). In Belize, vertical longlines were the most common gear type (n = 19; 53%), while in Mexico and Guatemala, bottom longlines were used most frequently (n = 17; 85% and n = 10; 91%, respectively). Single hook and line (n = 29; 47%) and vertical longline (n = 30; 49%) were most prevalent in Honduras. With the exception of a single fisher interviewed in Belize, gillnets were only used by Guatemalan fishers (n = 8 fishers)

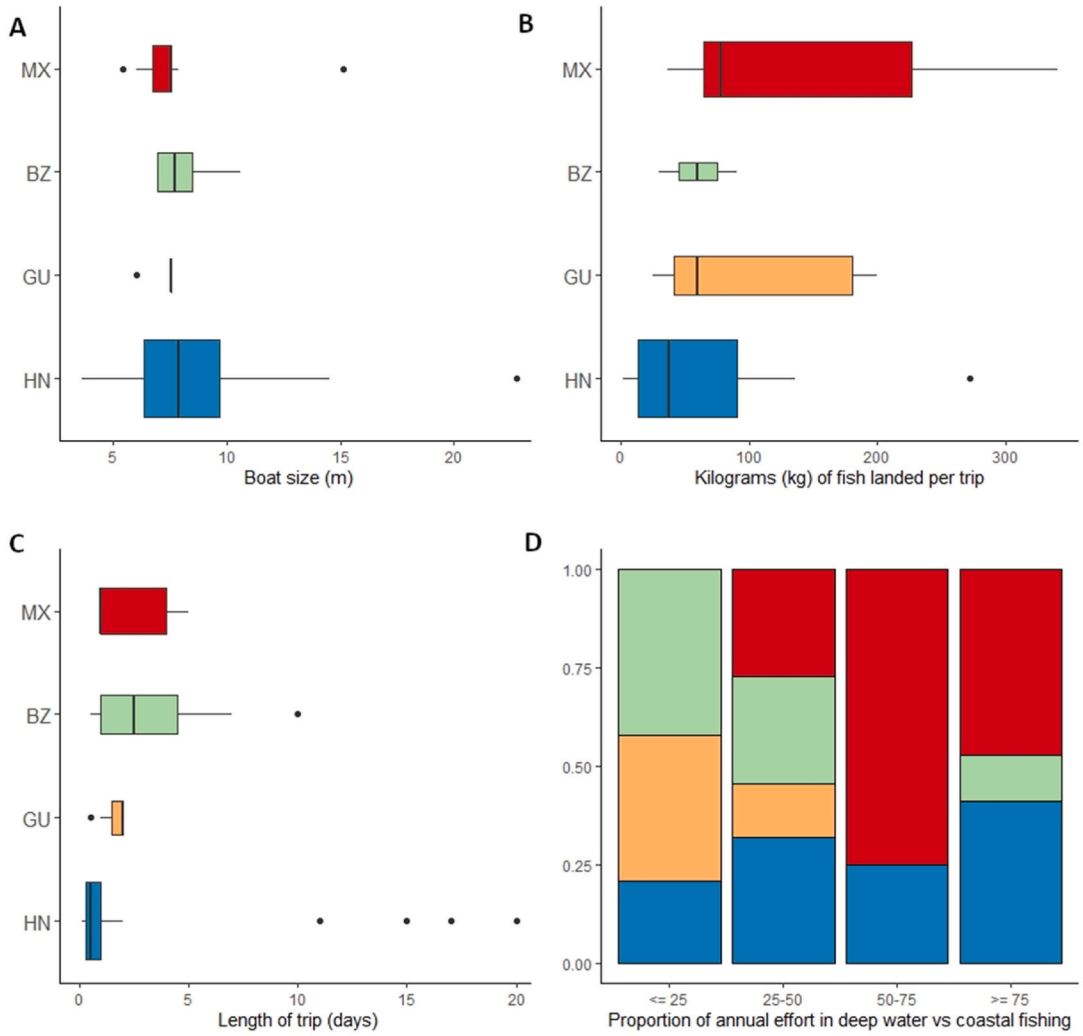

Fig. 3. Characteristics of the deepwater fishery of the MesoAmerican Reef countries: A) boat size; B) reported kilograms of fish landed per trip; C) length of typical fishing trip; D) proportion of annual effort. Country abbreviations are as follows: MX = Mexico, BZ = Belize, GU = Guatemala, and HN = Honduras.

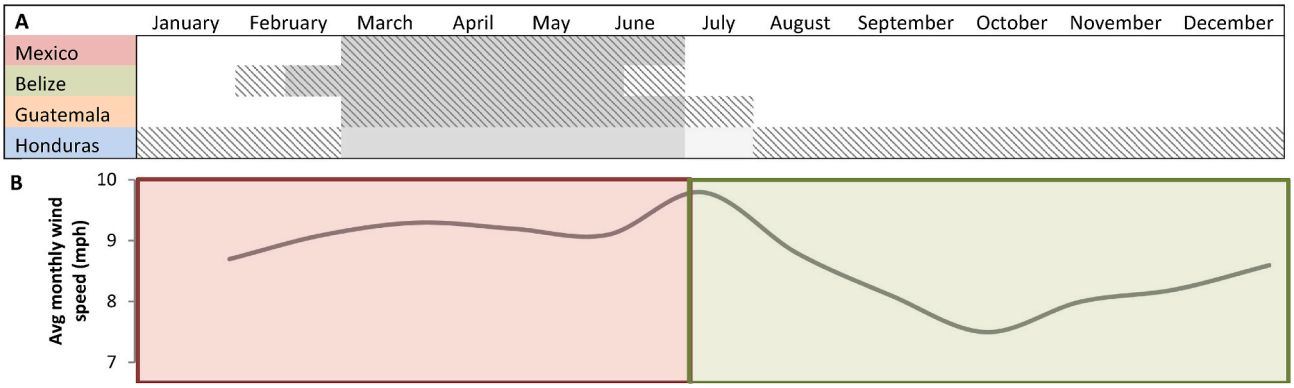

Fig. 4. A) Preferred months for deepwater fisheries in the MesoAmerican Reef countries highlighted with diagonal hatched bars, overlaid on country-specific closed seasons for lobster (filled grey boxes), which is economically the most important fishery in the region; B) Mean monthly wind speed in Belize, with higher monthly averages in the red box, and lower wind speeds in the green box. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Fig. 8). Electric reels for fishing rods were uncommon, and used mainly by tour operators in Belize (n = 5) and Honduras (n = 1).

3.4. Species composition

Among the most common snapper species (wenchman/cardinal, queen, silk, blackfin, and black), 100% of respondents in Mexico

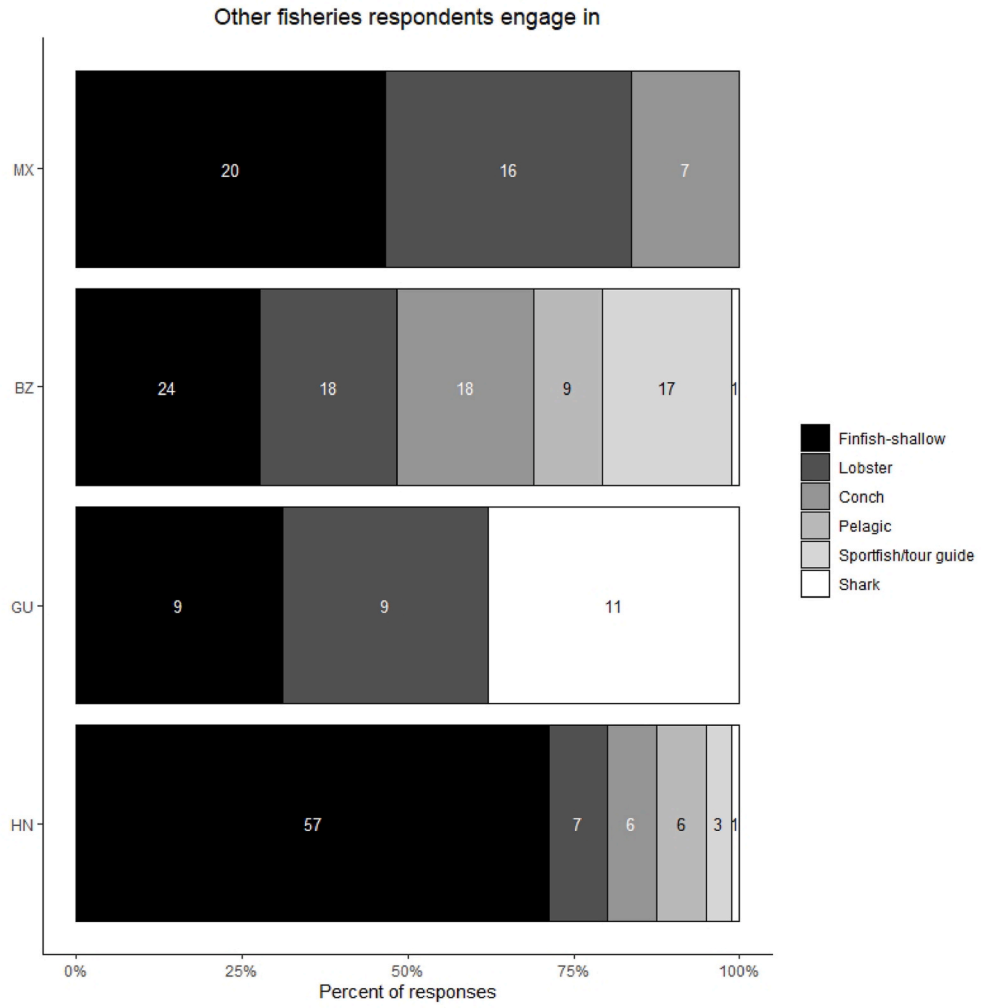

Fig. 5. Summary of other fisheries that deepwater fishers participate in across the MesoAmerican Reef countries. Country abbreviations are as follows: MX = Mexico, BZ = Belize, GU = Guatemala, and HN = Honduras.

reported catching all five species, while 79% of those in Belize and 81% of fishers in Honduras reported catching them. Queen snappers were the most preferred species, with 87% and 91% of Belizean and Honduran fishers reporting their preference, respectively, followed by silk (81% and 86%), black (86% and 75%), blackfin (77% and 72%), and wenchman/cardinal snappers (64% and 82%, in Belize and Honduras, respectively). Deepwater snappers were rarely captured by Guatemalan respondents, though they did report captures of mutton (*L. analis*) and other shallow water species. All respondents from Mexico and Guatemala stated that they targeted and preferred to catch groupers, while 59% and 68% of Belizean and Honduran fishers targeted deepwater groupers.

Most fishers in Guatemala (73%) stated that they preferred to catch sharks, followed by Mexico (10%). Only one fisher each in Belize and Honduras answered affirmatively. When asked what they did with sharks that were captured (incidentally or targeted), 100% of Guatemalan fishers reported that they landed them (as opposed to releasing them), followed by 60% of Mexican fishers, while 99% of Belizean fishers reported that they released all deepwater sharks. One fisher in Honduras reported keeping sharks for bait, while the rest reported that they released them (Honduras is a Shark Sanctuary). There is anecdotal evidence that deepwater fishers in Belize and Honduras view sharks as a nuisance and will occasionally kill them when captured (I. Baremore, pers. obs.).

3.5. Perceptions on abundance, profitability, and the future

Over all countries, 101 (Mexico = 19, Belize = 15, Guatemala = 11, Honduras = 56) fishers answered the perceptions portion of the survey, though not all respondents chose to answer every question. The majority of respondents (52%; n = 54) stated that they would be fishing more in deep waters in the future, with fishers in Honduras and Guatemala expressing the most stringent agreement (Fig. 9). Only 7% (n = 7) of respondents reported that they would not be fishing more in deep waters in the future. Mexican and Honduran fishers were the most likely to find the deepwater fishery to be more profitable than alternative/coastal fishing, while most Guatemalan fishers strongly disagreed (36%; n = 4) that deepwater fishing was more profitable. Fishers in Guatemala also largely found deepwater fishing to be more difficult than coastal fishing, likely because the fishing grounds are further offshore than in the other countries in the study, with fishers traveling 20–30 km offshore from El Quetzalito. Roughly half (51%; n = 52) of fishers across countries disagreed that there were more fish in deeper waters than when they first began fishing, while 27% (n = 27) agreed that there were more fish, and 17% (n = 17) thought it was roughly the same (Fig. 9). A little less than half of fishers (45%; n = 44) thought that some kind of management of the fishery was needed, with many expressing concerns about poaching and IUU.

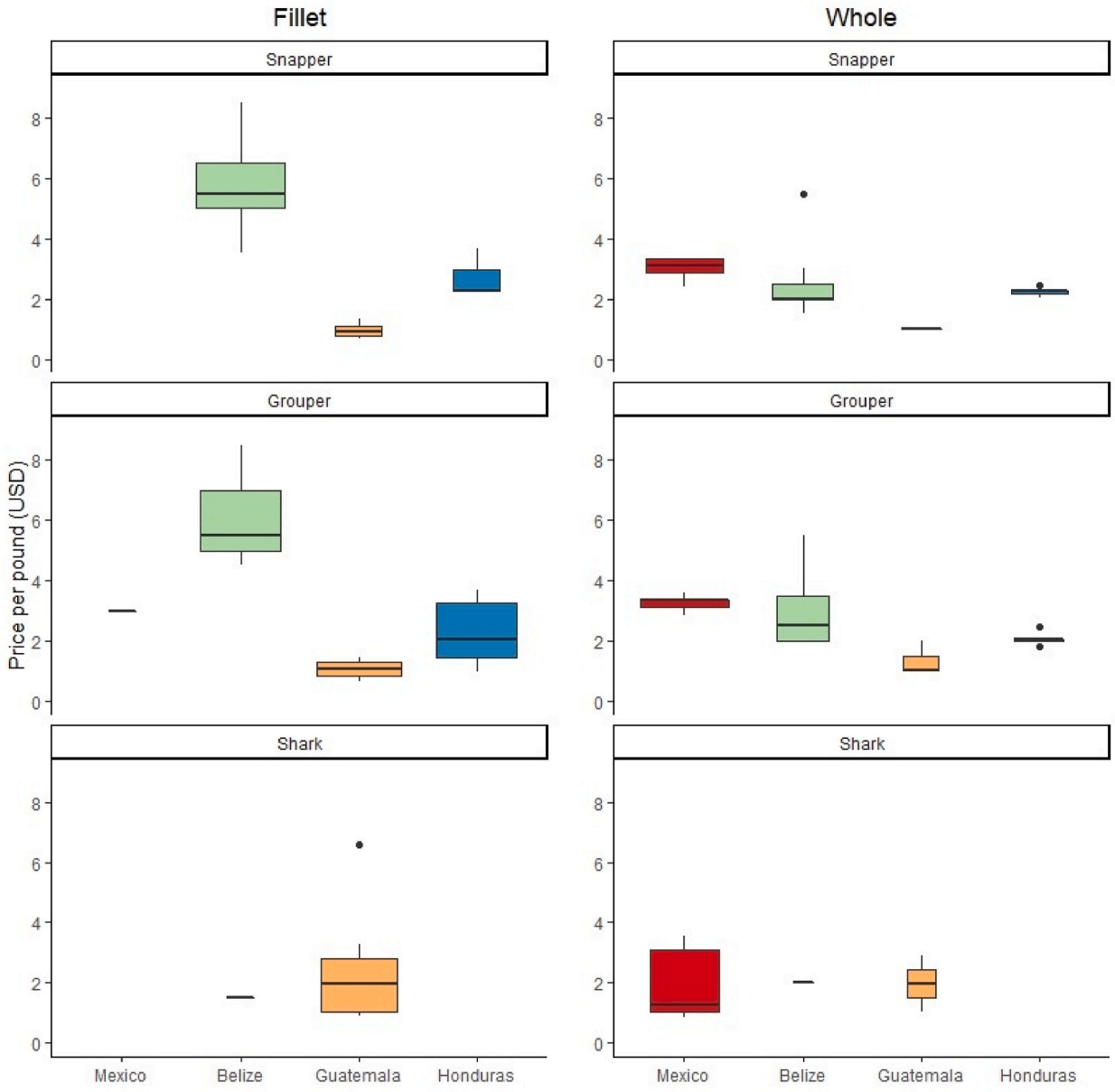

Fig. 6. Average prices per pound fishers in the MesoAmerican Reef countries reported for deepwater snappers, groupers, and sharks (Honduras is a Shark Sanctuary, no information given), and buyers of the product. Note that individual fishers often reported multiple buyers.

4. Discussion

Commercial exploitation of deepwater snappers was established in the Pacific Ocean before 1900 (Haight et al., 1993), and in Cuba vessels called 'viveros,' which became known as the deepwater fishing fleet, have been in use since at least the turn of the 20th Century (Caabro, 1957; Martinez, 1948; Tashiro and Coleman, 1977). Though capable of fishing in deeper waters, viveros primarily fished in waters less than 70 m, as the fish were kept in holds for live sale on land (Martinez, 1948). Fishers interviewed in the MAR countries of Mexico, Guatemala, and Honduras indicated a similar timeline in their countries; however, little evidence of the fishery can be found in the literature prior to the 1970's, when UNDP programs supported the development of the deep slope and other fisheries in the Caribbean (Ripley, 1970). The targeting of red snappers in Belize reported in the 1940's by Thompson (1944) appears to have been limited to June and July in the middle Cayes, when the snappers (most likely silk and blackfin) migrated to shallow waters to spawn; the fisheries at the time rarely extended past 45 m in depth. It is therefore likely that fishing effort in deep waters was minimal in the MAR prior to the 1950's, when coastal finfish, lobster, and conch were more prevalent throughout the region. While UNDP training programs were successful in parts of the wider Caribbean, it seems that export markets were too volatile to sustain the fisheries in the MAR until recent decades; therefore, concerted deepwater fishing effort in the MAR likely began around 1970, and increased throughout the 1970's and 1980's. Fishing techniques probably immigrated along with the fishing families as people in the Caribbean moved and settled throughout the 20th Century. In Belize, the export market collapsed in the early 2000's (Grant, 2019), while Honduras continued to export deepwater snappers through the market decline (Box and Canty, 2011) and is the only country with notable exports of deepwater snappers currently (Canty et al., 2019; Grant, 2019). This is reflected by the fishers' primary buyers, who are mostly local markets, restaurants, and individuals.

Demand for high quality fresh fish has continued to increase, both domestically within the MAR and internationally (Box and Canty, 2011; Canty et al., 2019; Grant, 2019). The number of deepwater fishers in

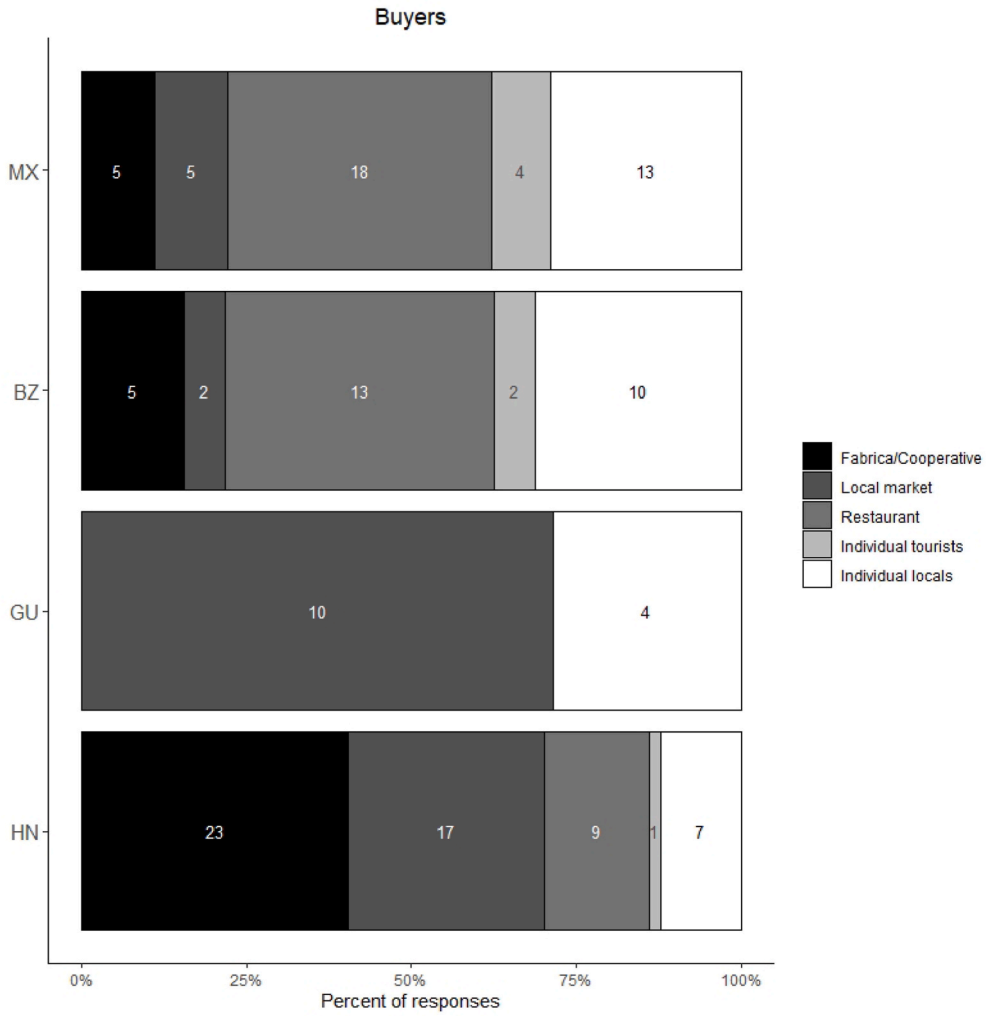

Fig. 7. Buyers of fish caught in MesoAmerican Region deepwater fisheries by country. Country abbreviations are as follows: MX = Mexico, BZ=Belize, GU = Guatemala, and HN=Honduras.

Belize increased during the course of this study, with reports of a 500% increase between 2011 and 2017 in requests for deep water gear made with the main fishing and tackle store in Belize City (Julian Quan, pers. comm). The government in Belize has again intervened to try to develop the deep slope fishery with the intention of reducing pressure on lobster and conch stocks and to provide economic diversification (Grant, 2019). In 2018, 20 fishers were outfitted with fishing gear, hand reels, and ice boxes so that they could remain at sea for longer periods of time while maintaining the quality of the fish. The outcome of the training is as yet unclear because the program is still underway, though the preliminary evidence is that fishers in the more remote south of the country are not faring as well as those closer to Belize City (S. Grant, pers. comm.). Cost is likely the most prohibitive factor to the expansion of the fishery in Belize due to high import taxes on goods, and some of the gear necessary (e.g. monofilament line of sufficient test and length) is only available in neighboring countries. Specialized equipment, such as high frequency depth sounders and GPS, is more readily available and cheaper in Mexico, Guatemala, and Honduras and thus is more often used in those countries. Along with a longer tradition and shared knowledge of continuous deepwater fishing, it is clear that the deepwater fisheries are much more developed in the two largest countries, while most Belizean fishers are relatively new to the fishery and likely face a steep learning curve and high startup costs.

The lobster fishery influences deepwater fishing effort in most countries, with at least a portion or a majority of fishers in Mexico, Belize, and Guatemala using the closed season for lobster, and to a lesser extent conch, as their primary deepwater fishing season. The closed season for lobster corresponds with some of the highest monthly wind speeds. Higher wind speeds can produce wave action outside the barrier reef and on the windward sides of islands/atolls, which makes fishing in deeper waters more difficult and dangerous. Only deepwater fishers in Honduras identified the calmer months of July–October as their main preferred time for fishing, and several said that the fish move into Honduran waters in the boreal autumn months (September to October) from the north. The lobster fishery in Honduras is mostly concentrated in the remote Moskito Cays, and most of the fishers interviewed from the Bay Islands were primarily local deepwater fishers.

Deepwater snappers and groupers have somewhat narrow and species-specific depth preferences, and the vertical distribution of the deepwater snapper-grouper complex is limited to depths between around 100 and 550 m. In much of the MAR, the bathymetry is very steep, and therefore much of the deepwater fishing grounds are within a few hundred meters of a barrier reef, atoll, or island. The available deepwater fishing grounds in the MAR varies by country, with Honduras having the most available depths, and Guatemala having the least; however, much of the available habitat in Honduras is accessible only by vessels capable of staying at sea for prolonged periods of time. In Belize and the southern MAR region of Mexico, access to deepwater fishing grounds is generally from villages or cayes close the barrier reef or offshore atolls.

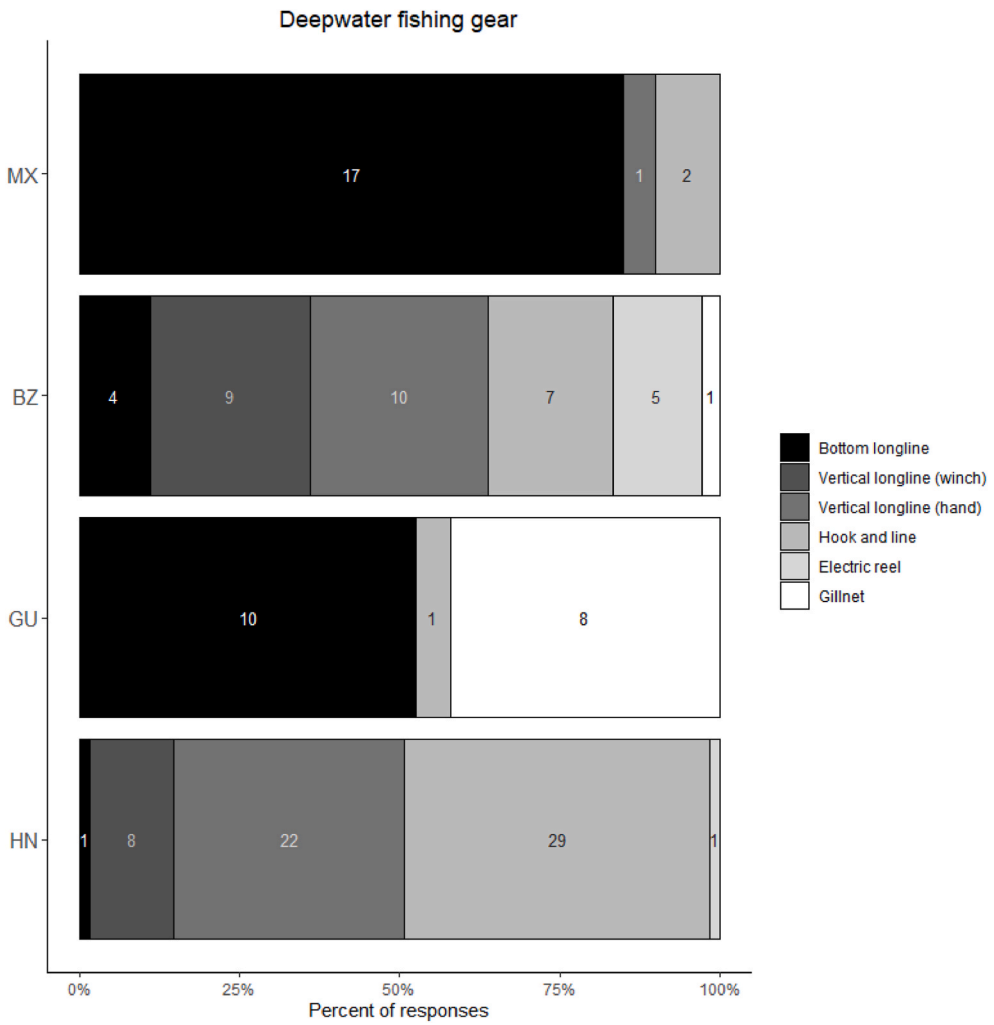

Fig. 8. Description of gear types used to catch deepwater fish and sharks in the MesoAmerican Region deepwater fishery by country. Bottom longlines were configured with multiple hooks deployed horizontally across the seafloor with two or more anchors, while vertical longlines were composed of multiple hooks suspended vertically above the seafloor, using one anchor. Hook and line and electric reels were generally one or two hooks deployed with light tackle and a sinker, and gillnets were deployed horizontally across the seafloor with two or more anchors. Country abbreviations are as follows: MX = Mexico, BZ=Belize, GU = Guatemala, and HN=Honduras.

Illegal fishing is prevalent in the MAR across all fishing sectors. Belize is beset by transboundary fishing from neighboring countries, while Honduran fishers reported illegal fishing from the Cayman Islands. Despite the small size of its Caribbean EEZ, and the small number of dedicated deepwater fishers (~12), Guatemala has an outsized influence on the MAR fisheries. This is due to a high levels of transboundary fishing and illegal imports of product, as demand for fish and shark products in the mainland of Guatemala continues to increase (Perez, 2009). Fishers in Guatemala all reported their fishing grounds to be exactly within their own EEZ; however, previous work has highlighted that many fishers regularly fish along the barrier reef of southern Belize (Graham, 2007). Fishers in Omoa and Puerto Cortes, Honduras, land deepwater snappers, but the bottom habitat offshore of these locations is muddy and flat, similar to that in Guatemala, and snappers are not common (Baremore, pers. obs.). A small vessel with an outboard engine can easily travel to the Belize Barrier Reef and Glover's Reef Atoll in a few hours, where deepwater snapper are more common, and Honduran vessels are regularly detained fishing in Belizean waters.

Fishers' perceptions about the deepwater fishery were somewhat pessimistic, many cited high costs, poaching, and diminishing returns, and saw little opportunity for improvement. Fishers in the Bay Islands of Honduras noted that the use of destructive fish traps was destroying the fishing grounds. Many fishers conceded that there were fewer fish in the deep waters than when they began fishing, but some said that this was not because there were fewer fish, but because the fish were learning to avoid hooks. Fishers in Belize and Honduras expressed a desire for enforcement of regulations, and especially increased patrols and monitoring by local Coastguard and fisheries management authorities. Many of the fishers interviewed in Mexico are part of a successful fisherman's cooperative, which largely self-manages its lobster and conch fisheries and regulates the supply chain for higher profits; it is therefore not surprising that most fishers answered that management of the fishery was unnecessary.

Deepwater snappers, especially Eteline snappers, are highly valued in the Pacific for their sushi-grade fillet, and are considered the most important component of deep slope fisheries in the Indo-Pacific (DeMartini, 2017; Haight et al., 1993). In the MAR, average prices for deepwater fish is comparable to their coastal counterparts, such as yellowtail (*Ocyurus chrysurus*) and mutton (*L. analis*) snappers, even though fishing effort is higher and the quality of the product greater for deepwater fishes. In Honduras, prices for deepwater snappers and groupers are only slightly higher than in Guatemala, but processing plants on the mainland and middlemen on Utila sell for double or triple the price (Box and Canty, 2011; Gill et al., 2019). There exists opportunity for independent deepwater fishers to market their product to high-end consumers, and therefore fetch greater prices, which could potentially reduce some pressure from deepwater resources; however, this effort would require specialized research and training to improve chances of success.

In early 2020, the COVID-19 pandemic profoundly affected the deepwater fisheries in the MAR. Initial lockdowns and restrictions on travel, fishing, and closure of national and international markets led to an abrupt cessation of fishing effort. Six months after the beginning of pandemic lockdowns in mid-March of 2020, deepwater fishing has

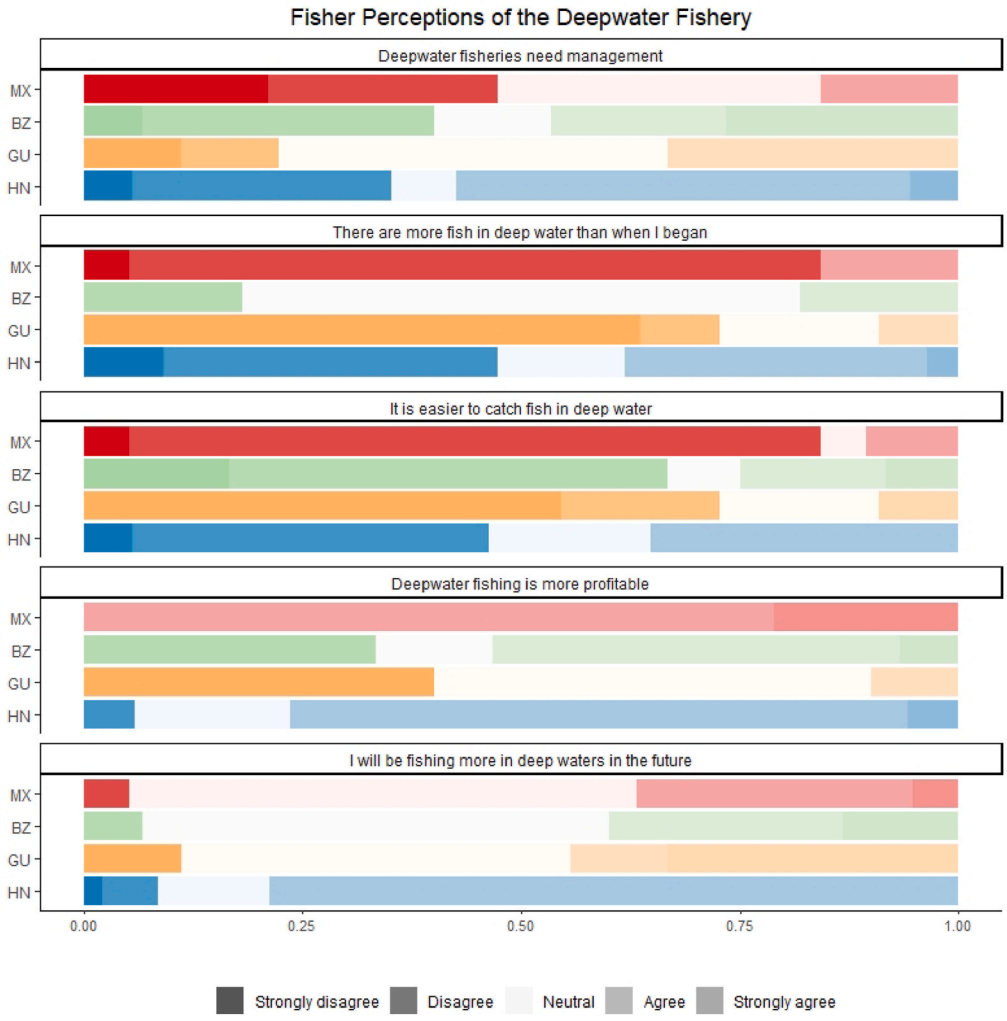

Fig. 9. Perceptions of deepwater fishers about the fishery of the MesoAmerican Region by country. Country abbreviations are as follows: MX = Mexico, BZ=Belize, GU = Guatemala, and HN=Honduras.

resumed, but mostly for local markets and at reduced prices. In Belize, the price of deepwater snapper fell by about 50%, while in Honduras prices decreased by 30–50%. In Mexico, landings in all fisheries were reduced by 30–80%, and prices for finfish fell by 50–60% (COBI, 2020). It is unclear what the long-term effects of the COVID-19 pandemic might be on deepwater fishers and the fishery, but the situation offers an opportunity for managers and fishers to work together toward a common goal for future sustainability as the fisheries begin to re-open.

5. Conclusions

Deepwater fishes are generally long-lived, slow-growing, and late to mature, which are life history characteristics that make them especially vulnerable to overexploitation. Although the deepwater fisheries in the MAR are mostly artisanal, small-scale fisheries provide more than half of the world's wild-caught seafood (Shester and Micheli, 2011) and have had lasting impacts on local fish populations (Salas et al., 2007). Successful management and conservation of these fisheries will require transparency and transfer of information among managers, researchers, conservation organizations, and stakeholders. Increasing access to technology, international and domestic demand for high quality fish, and loss of coastal fisheries are all factors that point to the continued expansion of the fishery in the region. Data on the biology and ecology of the species targeted and caught as bycatch in the deepwater fishery are needed to assess the vulnerability of these species to overexploitation and to inform management strategies. This study provides valuable knowledge about the history, characteristics, and fisher perceptions of the deepwater fishery of the MAR, and establishes a baseline of information for future fishery assessments.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105773.

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