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DEVELOPMENT OF OPTIONS FOR A SHARK DATA COLLECTION PROGRAM FOR IATTC FISHERIES: LESSONS AND OPPORTUNITIES

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EXECUTIVE SUMMARY

Sharks are a common target and bycatch of pelagic fisheries in the eastern Pacific Ocean (EPO) to which the IATTC has been increasing efforts towards their conservation and management through the development of resolutions and sampling programs specific to sharks. However, a lack of reliable catch, effort and species and size composition data, particularly from small scale coastal ('artisanal') fisheries, have hindered attempts to develop stock assessments for the most common species (e.g., silky shark). In an effort to collect reliable relevant information on sharks impacted by IATTC fisheries, the IATTC implemented Resolution C-23-07, which, among other things, requires the implementation of a data collection program for sharks by 2024. This document provides an overview of existing data collection

programs for sharks in the EPO, a review of survey methods that can be applied to large scale fisheries, and descriptions of recent and ongoing experiences from pilot sampling programs for sharks in small scale coastal fisheries in the EPO. These experiences highlight the enormous challenges of monitoring shark catches in small scale coastal fisheries distributed across hundreds to thousands of access points that can vary dramatically in their importance as landing sites for the catches of particular species (e.g., silky shark) across various times scales. While recent and ongoing projects have improved our understanding of the order of magnitude of shark catches (SAC-14 INF-L), future surveys must ensure that sampling is designed around the ultimate survey objective. ABNJ-"Tuna 1" and ABNJ-"Tuna 2" were largely designed with a goal of estimating the order of magnitude of shark catches in small scale coastal fisheries in the IATTC Convention Area. Maintained over time, these estimates of total catches can be used as stand-alone indicators or as additional components in stock assessment models. However, the objectives of the shark sampling program are currently uncertain given the current absence of a prescribed list of shark species under the purview of the IATTC (see SAC-15-09) and may evolve over time, and so, methods must adapt as needed. For example, future IATTC efforts to assess the status of shark species will likely emphasize tools such as close-kin mark-recapture (CKMR) over conventional stock assessment models that depend on catch-per-unit-effort as an abundance index. CKMR uses information on the rate at which "close kin" (e.g. half-siblings or parent-offspring pairs) are found within samples taken from a population to attempt to estimate parameters of interest such as total abundance and potentially total mortality without the need for catch or catch-per-unit-effort (CPUE) data. However, it does require collection of sufficiently high-quality genetic samples and associated metadata (e.g., length and sex of sampled individuals). A successful CKMR model requires a carefully designed sampling protocol, and it is unclear whether the sampling design that might provide the best estimates of total catch would also be the best for use in CKMR. In this regard, the IATTC staff is currently conducting a feasibility study that will help shape, design and plan future cost-effective CKMR efforts in the area. Similarly, any assessment effort, including integrated stock assessments, CKMR, or any form of vulnerability assessment (e.g., EASI-Fish), require accurate biological and ecological information (e.g., length-weight relationships or length-at-age keys), which rely on the on-site collection of data. Therefore, ongoing sampling efforts for sharks in the IATTC Convention Area need to consider these diverse objectives in their design to ensure that collected data are able to fulfil their ultimate purpose. Although some options are provided as to potential designs for a shark data collection program that focuses either on priority species identified from management or vulnerability analyses or all species under the purview of the IATTC, the staff suggests that completion of the ongoing ABNJ-"Tuna 2" project is critical to better understand the sampling requirements for a program for all coastal states in the IATTC Convention Area before final implementation.

1. BACKGROUND

The primary responsibility of the IATTC is stated under Article II of the Antigua Convention—entering into force in 2010—as "…to ensure the long-term conservation and sustainable use of the fish stocks covered by this Convention, in accordance with the relevant rules of international law." However, the spatial and temporal scope of IATTC tuna fisheries is extensive, extending spatially from the coast of the Americas to far offshore waters to 150˚W and operating for the majority of the year. The gear deployed by the industrial fisheries is also diverse. Longline fisheries deploy many kilometers of mainline supporting thousands of hooks that fish from the surface to hundreds of meters depth (Griffiths and Duffy, 2017), while large purse-seine vessels employ a variety of fishing modes, including setting on dolphins with the objective of extracting co-occurring large yellowfin tuna (Ballance et al., 2021). They also set upon free-swimming tuna schools and fish aggregating devices (FADs), which attract many species of tuna and tuna-like species, as well as several other non-target species (Hall and Roman, 2013). Many species of pelagic and neritic sharks commonly associate with tuna and tuna-like species, or at least share similar habitats, prey or environmental conditions. As a result, sharks are a common bycatch in IATTC fisheries (Duffy et al., 2019; Diaz-Delgado et al., 2021).

In recent years, the sustainability of sharks caught by tuna fisheries has become of increasing concern to the IATTC, and other tuna regional fisheries management organizations (t-RFMOs) globally, as current exploitation levels may not be sustainable for many shark populations, especially those exhibiting slow growth, long life spans, and limited reproductive capacity (Clarke et al., 2014). This has resulted in the IATTC implementing a range of conservations measures in the EPO in the form of binding resolutions on several species of sharks (e.g., C-11-10, C-19-05, C-19-06, C-23-07), whilst incrementally improving data collection to support stock assessment of species such as silky shark (IATTC, 2014; Clarke et al., 2018) and vulnerability assessments of all shark species documented to interact with IATTC pelagic fisheries EPO (SAC-13-11). Together, these assessments of shark species in the EPO have identified that small scale coastal, or 'artisanal', fleets may contribute to a significant proportion of the total catch of sharks in the IATTC Convention Area. Recent work by the IATTC staff has included data from preliminary surveys in Central America to produce order-of-magnitude catch estimates for silky and hammerhead sharks. These estimates indicate that the catches by these fleets may exceed those of the industrial longline and purse-seine fleets that fish far offshore (SAC-14 INF-L).

Therefore, the Commission has acknowledged the importance of data collection for these small scale coastal fleets in coastal states for the purposes of providing reliable information to assess species listed under the purview of the IATTC (see SAC-15-09). In 2023, the IATTC adopted Resolution C-23-07 "*Conservation measures for the protection and sustainable management of sharks*" to consolidate existing measures pertaining to sharks and to strengthen shark conservation and management measures in the EPO. In addition, the resolution sets forth various recommendations and mandates regarding research and data collection pertaining to sharks in order for the IATTC to comply with the provisions and measures of C-23-07, other relevant IATTC resolutions, and relevant items under the Antigua Convention. In particular, Article 14 of the resolution requires "*In 2024, the IATTC scientific staff, in consultation with the IATTC SAC and EBWG shall implement a data collection program for sharks associated with fisheries managed by the Commission, making use of existing research and data collection mechanisms and programs where possible. The program will include the monitoring of shark catches by small scale fisheries in coastal countries and the establishment, maintenance and strengthening of standardized data management databases, considering appropriate assistance to those CPCs*".

This paper summarizes previous and ongoing staff research and recommendations pertaining to data collection, catch and effort monitoring, and assessment of shark species that interact with IATTC pelagic fisheries and makes recommendations to improve efforts to fulfill mandates under C-23-07 and the Antigua Convention more broadly. A review of potential survey options is presented in the context of small scale coastal fisheries followed by a proposal that builds upon this review coupled with previous and ongoing work in the ABNJ-"Tuna 1" and ABNJ-"Tuna 2" projects, for a preliminary sampling design that may improve coverage and/or cost-effectiveness of surveys that are required to be representative of the thousands of access points that extend across thousands of kilometers of coastline from which these small scale coastal fishing fleets operate.

2. SHARK DATA COLLECTION AND IMPROVEMENTS NEEDED

2.1. Purse seine (Class 6)

Catch and effort data pertaining to sharks in the large purse-seine fishery (i.e., vessels with a carrying capacity >363 t) in the EPO is of very high quality since the onboard observer program of the Agreement on the International Dolphin Conservation Program (AIDCP) and National Programs covers 100% of the trips. These vessels employ three primary types of fishing sets where the net is deployed: i) in association with natural or artificial floating objects (OBJ), ii) in association with dolphins (DEL), or iii) on schools of tuna that are neither associated with dolphins or floating objects (NOA). Observers onboard these vessels undergo specific training on the identification and recording of shark species typically caught by these vessels. Since 2004, observers began collecting species-specific data on sharks, with the implementation of the dedicated shark record, and at a minimum categorize each individual by size (i.e., small, medium, large); where possible, they record actual lengths, sex and other biological information and disposition prior to release (Fuller et al., 2022).

With regards to challenges in data collection, time constraints can limit an observer's ability to identify each specimen to species. As a result, the IATTC databases contain many instances where a shark was identified to genus or a higher taxonomic aggregation such as "*Alopias*, nei", particularly prior to 2004, and these taxonomic groupings have very limited value, if any, for scientific purposes, especially for vulnerability or stock assessments. However, with the implementation of electronic monitoring systems (EMS) being developed by the IATTC over recent years the quality and quantity of data pertaining to sharks species may improve as observers will not require to split time between taxonomic identification of shark bycatch and their core compliance tasks (SAC-15 INF-Q).

2.2. Purse seine (Classes 1–5)

Smaller purse-seine vessels (i.e., vessels with a carrying capacity ≤ 363 t) also operate in the EPO. These vessels range from 'artisanal' vessels (Classes 1–2) that are generally confined to coastal areas, to larger commercial vessels (Classes 3–5) that frequently fish at a great distance from the coast. The AIDCP does not require these smaller vessels to carry an observer, except in specific situations, and so the primary data source for this fleet is fisher-completed daily logbooks and FAD forms—regardless of the number of sets made—where sharks are not often recorded or identified. However, the Tuna Conservation Group (TUNACONS) has deployed observers on primarily Ecuadorian vessels since 2018, with coverage being 34% of the total number of trips reported for all Class 1–5 vessels in the EPO in 2023 (EB-02-01). However, it is unknown whether TUNACONS observer data is representative of the Class 1-5 fleet. The staff intend to investigate these data, but also seeks to provide the Commission with recommendations for increasing observer coverage to a minimum of 20%, either human or electronic, for each CPC (SAC-15-13, SAC-15 INF-Q), and updating the data provision resolution (C-03-05) and its corresponding technical data specifications to include catch and effort data for bycatch species through a series of planned workshops organized by gear type (e.g., small purse seine as well as the artisanal fisheries described below).

2.3. Industrial longline

The longline fishery in the EPO can be difficult to clearly define as they operate both within and outside the Exclusive Economic Zones (EEZs) of coastal States, include a wide variety of vessel sizes, gear configurations, and target species. Vessel range from large sophisticated purpose-built longlining vessels of up to 91.5 m length overall (LOA) with hydraulic line haulers and large refrigerated fish holds (SAC-08-07b), to much smaller 'artisanal' vessels of less than 12 m LOA (often termed "pangas") that are fiberglass hulls equipped with outboard motors and hand-hauled gear that generally fish in the neritic waters within the EEZs of coastal States (Andraka et al., 2013; Martínez-Ortiz et al., 2015; Aires-da-Silva et al., 2016; Siu and Aires-da-Silva, 2016). Larger vessels (>12 m LOA), are generally included referred to as 'industrial' vessels, although the number of categories, their names and size thresholds, vary among countries, as do the criteria for allocating vessels to categories.

However, IATTC Resolution C-03-07 classifies longline vessels over >24 m LOA as "large-scale tuna longline fishing vessels" (LSTLFVs) and are required to be included in the IATTC Regional Vessel Register to be authorized to fish for tuna and tuna-like species in the EPO. For simplicity, the fishery conducted by LSTLFVs is hereafter referred to as the "industrial longline fishery", whereas other smaller longline vessels are described in section 2.4 as small scale coastal fishing vessels.

Data for the industrial longline fishery is collected from vessel logbooks or collected by on-board scientific observers from national observer programs and submitted to the IATTC by its Members under Resolutions C-03-05 and C-19-08, respectively (see detailed description in SAC-08-07b). Specifically, the industrial longline fishery logbook data pertains to vessels >24 m LOA included in the IATTC Regional Vessel Register that are authorized to fish for tuna and tuna-like species. These data exist as highly agregated monthly reports of catch and fishing effort at a resolution of at least 5° x 5°—although a few CPCs submit data at 1° x 1°—primarily for the main tuna and tuna-like species. Also some commercially important shark species (e.g., blue and shortfin mako sharks) are sometimes recorded, other incidentally caught species are poorly recorded, if at all.

Resolution C-19-08 requires that each CPC to provide a minimum of 5% observer coverage of the effort (defined as either number of hooks or days fishing) by their LSTLFVs over 20 m LOA carry a scientific observer from a national scientific observer program. Since 2019, CPCs have been required to submit detailed operational-level data for all species interactions with some CPCs submitting data back to at least 2013 (SAC-15 INF-B REV). Despite improvements in the quality and quantity of data reported, obstacles remain for IATTC scientists to undertake detailed scientific analyses using these data. IATTC staff have maintained a recommendation that the minimum observer coverage rate should be at least 20%, and problems associated with only 5% coverage are often compounded because the data that is collected are often not representative of the activities of the fleet in space or time (BYC-10 INF-D). Consequently, catch and effort data from both logbook and observer data are insufficient for the IATTC scientific staff to undertake reliable vulnerability or stock assessments for sharks and other bycatch species.

Therefore, the staff have requested improved high resolution species-specific data reporting for bycatch species and fishing effort and to improve the utility of catch data for the longline fishery. For several years the IATTC staff has recommended observer coverage be increased to at least 20% (see Resolution C-19-08; Griffiths et al., 2021), which is likely to help significantly improve the assessment of sharks in future but also for routine catch monitoring and reporting. Several of the main longlining nations face the problem of retaining observers on their trips that can last for many months, even years, and so EMS are being considered as a supplementary method that could collect data on shark interactions by this fishery (SAC-15 INF-Q). In 2023, the staff undertook a workshop to seek the input by Members to improve data provision for the industrial longline fishery (WSDAT-01), and made the pertinent recommendations to improve these (SAC-14 INF-Q). Similar workshops are planned for other fisheries, including the artisanal (smale scale) longline fleets.

2.4. Small scale coastal fisheries

In contrast to the industrial longline fishery, there are a broad range of smaller longline vessels that primarily operate within the EEZs of coastal nations that target a broader complex of large pelagic species—mainly sharks, tunas, billfish and dorado (*Coryphaena hippurus*)—but their spatial distribution can extend beyond coastal waters and their respective national jurisdictions (see Aires-da-Silva *et al.*, 2016; Siu and Aires-da-Silva, 2016). For example, there is a growing "oceanic-artisanal" fleet that fish offshore waters in small vessels, using the assistance from motherships, targeting tuna, billfish, and sharks at least as far as 100°W (Andraka et al., 2013; Martínez-Ortiz et al., 2015).

These smaller longline vessels can be broadly divided by size into two categories: smaller 'artisanal' vessels, generally called 'pangas', which are typically less than 12 meters length overall (LOA), and larger longline vessels (<20m) that are often considered in some regions as 'industrial', although the number of vessel categories, their names and size thresholds, vary among countries, as do the criteria for allocating vessels to categories (Siu and Aires-da-Silva, 2016). In the EPO these 'industrial' vessels may best be described as 'domestic commercial longliners vessels' that are usually issued a license to fish by their respective fishing authority—but often do not appear on the IATTC LSTLFV List (>24m) as being authorized to fish for tuna and tuna-like species in the EPO—and in some countries they are required to collect and submit some type of catch and effort information, either through a logbook system, or by vessel inspections at ports by fishing authority staff (e.g., Costa Rica). There are two main size classes of domestic commercial longliners vessels: medium-size or range ("Mediana") vessels and advanced-size or advanced-range ("Avanzada") vessels that operate within 40 nm of the coast and from 40–100+ nm from the coast, respectively (Siu and Aires-da-Silva, 2016; Oliveros-Ramos *et* al., 2020). These vessels usually land their catch at commercial unloading ports and are quite accessible in terms of catch sampling, although representatively sampling the catches from these vessels has additional considerations, for example if catches are unloaded by size, species or by differing equipment (Oliveros-Ramos *et* al., 2020 Lennert-Cody et al. 2022).

Resolution C-19-08 requires vessels above 20 m LOA carry a scientific observer to document the activities of at least 5% of the total effort, but as discussed above, 5% coverage levels and problems with the observer coverage being representative of fleet activity hinder that data's usefulness. For vessels smaller than 20 m, the amount of quality, reliable data is even more sparse. Monitoring domestic commercial longline vessels is easier compared to small scale coastal fleets, and it is the latter that can present a challenge to national fisheries agencies (Salas et al., 2007). However, despite the small size of these vessels, the cumulative spatial 'footprint' of these fleets can be large and their impacts on sharks, and other non-target species, have been shown to be significant (Alfaro-Shigueto et al., 2010; Cartamil et al., 2011; Martínez-Ortiz et al., 2015; Sosa-Nishizaki et al., 2020), heightening the importance of compliance with the obligation to report to the IATTC the catch and effort of these vessels as stipulated in Resolution C-03-05.

3. A REVIEW OF POTENTIAL SURVEY APPROACHES FOR SMALL SCALE COASTAL FISHERIES

Fisheries scientists in many parts of the world often face the common problem of having to obtain representative data from fisheries, such as the multispecies small scale coastal fleets in the Americas, where effort is highly diffuse in space and/or time for the purposes of informing assessments and management. One of the most problematic fisheries worldwide has been marine recreational fisheries where fishing effort can be highly dispersed across thousands of kilometers of coastline where fishers participate in their activity from a diversity of locations, or "access points", such as boat launching ramps, marinas, moorings, beaches, and estuaries (Lyle et al., 2002). Therefore, it is often cost-prohibitive and impractical to pursue a census of catch and effort by deploying survey staff to all access points—assuming they can all be reliably identified a priori—on each fishing day. Because sampling difficulties identified in IATTC projects of the small scale coastal multispecies/shark fisheries in Central America (see SAC-14_INF-P; Siu and Aires-da-Silva, 2016; Oliveros-Ramos et al., 2020) share many similarities with recreational fisheries, the widely established survey methods applied to recreational fisheries are herein presented as potential options to be applied directly to small scale coastal fisheries in the region to allow for a better understanding of the justifications for employing the survey designs for the pilot sampling program discussed in Section 4, and how these pilot surveys may be expanded to include additional species, if desired.

While several sampling methods are available to collect catch and effort data from large-scale coastal fisheries, they differ significantly in the type, quality and quantity of information they can gather, as well as their cost-effectiveness. For comprehensive reviews of these sampling methods and their possible biases see Pollock et al. (1994), NRC (2006) and Griffiths et al. (2010) as well as an overview of how these survey methods may be applicable to small scale coastal fisheries (Table 1). The fundamental problem is that list-sampling frames—complete lists from which individuals or vessels can be selected for sampling—are often not available for small scale coastal fisheries. Another challenge is characterizing effort in terms of number of vessels is that although licensing or permitting requirements are in place in countries in the region, evidence suggests that in some locations fishing without a license may be common. Therefore, list-frames based on licenses or permits are likely to be incomplete. By extension, the self-reporting of species-specific catch and effort data, where required as a condition of permitting is also problematic. The challenge with these data is not only vessels failing to obtain a license do not participate in self-reporting, but there are also quality and reliability concerns with the self-reported data itself, when available. As a result, researchers often need to conduct expensive large-scale on-site surveys (e.g., Pérez-Jiménez et al., 2005; Cartamil et al., 2011), where the list frame is developed during sampling, or they recruit a probability sample of individuals from multiple lists (see Andrews et al., 2013; Vølstad et al., 2020), such as fisher diaries or official data available from national authorities.

3.1. On-site surveys

On-site surveys provide the most precise information on effort and species and size composition of catches from individual trips. These surveys generally aim to sample all possible access points relevant to the species stock and/or fishery, usually using stratified random sampling (SRS). Field staff are stationed at each access point for an entire fishing day and intercept fishers as they enter or leave the access point. In situations where many access points are close to each other, a 'bus route' or 'roving' survey can be used where field staff visit several access points in a single day by spending a specified period at a site before moving to the next (McGlennon and Kinloch, 1997). However, these surveys can suffer from length-of-stay bias where the number of fishers intercepted is influenced by the length of time and time of day that the survey staff is at a particular access point. Such an approach is not recommended for rare or infrequently caught species as the probability of intercepting a fisher during the sampling period who has captured such as species is low.

One major sampling issue identified in previous IATTC surveys of the Central American artisanal fisheries (see SAC-14 INF-P) is the dynamic nature of species targeting by fishers. It was observed that fishers would sporadically move from their 'home' locations to other areas where desirable species (e.g., silky and hammerhead sharks) may be periodically locally abundant. Using SRS, productive trips away from home or 'in-scope' locations are often missed resulting in zero inflation, catch rates being underestimated, and inflated variances (Morton and Lyle, 2003). To address this common issue of short-term spatial shifts in the fishing effort by recreational fishers, particularly for infrequently encountered species such as thresher sharks (Gallucci and Hariharan, 2012; Hariharan et al., 2013), researchers have begun to explore the use of dynamic sampling such as stratified adaptive cluster sampling (ACS), which was originally developed to sample terrestrial animals that are rare and/or have highly clustered distributions (Thompson, 2012). This involves undertaking SRS of access points within a defined 'universe' of access points and sampling additional access points in the vicinity of those where the target species is encountered.

3.2. Off-site surveys

An alternative to on-site surveys are off-site surveys, such as telephone surveys, which are cheaper, more rapid to complete, and can reach many more participants than on-site surveys, but they often suffer from major biases that compromise the accuracy and precision of the data. For example, there is often high non-response and survey refusals in phone surveys due to call screening of unfamiliar phone numbers assumed to be unsolicited marketing and "robo" calls. Furthermore, if licensing is not in place researchers lack a complete list from which to draw a representative sample of fishers and in instances where licensing is in place, access to the complete list frame is sometimes not possible due to issues of confidentiality. Because off-site surveys rely on recalled fisher-reported information, data can be unreliable for several reasons; most commonly recall bias where fishers are unable to accurately recall the details of catch and effort from specific trips undertaken in the previous 2–3 months (Lyle, 1999; Andrews et al., 2018). This recall period becomes increasingly shorter with increasing frequency of fishing trips as it becomes more difficult for fishers to differentiate the specific details of 'routine' trips. An exception is where fishers have memorable trips, for example exceptionally large catches, or catch of a very unique species or large specimens. As such, surveys with long recall periods have been successful for recreational game fishing where a small number of memorable events occur. Another major problem is that the recalled information provided voluntarily by respondents cannot be directly verified by the researcher and therefore various inaccuracies and biases can arise with respect to species identification, rounding bias (e.g., round up number of fish from 7 to 10), prestige bias (i.e., exaggerating sizes of fish or catches), and intentional deception in situations where there may be distrust in research or regulatory authorities.

3.3. Complemented survey designs

3.3.1 Sampling fisher catch and effort

In recent years, various "complemented survey" designs using various combinations of on-site and off-site surveys have been developed—primarily for recreational fisheries for which some small scale coastal fisheries may be substituted—that capitalize on the benefits of one method to account for deficiencies of another method. In large scale surveys in Australia, the United States and many countries across Europe the telephone–diary approach has been by far the most effective method for collecting trip-specific catch and effort data from a representative sample of fishers that can allow for expansion to the total fishery effort (Hartill et al., 2012). In a traditional telephone–diary survey a telephone 'screening' survey of a stratified random sample of households or fishers from a list frame is used to recruit fishers to a longitudinal survey—often 12 months—where they are trained to record specific data fields (e.g., date, hours fished, gear, number of fish caught) in a hardcopy or electronic diary. For small scale coastal fleets, the list frame may be the license/permit of the fisher and or/vessel, should they exist and be accessible to the researcher. However, the time burden on the respondents to complete the diary for each trip that increases with fishing frequency, rates of incomplete data fields completeness, non-response, and 'drop-outs' tend to increase with survey duration. To combat this problem, a "telephone diary" is often used where survey staff call the respondent regularly to record the details of their fishing activity for an individual trip (West et al., 2015; Lyle and Tracey, 2016; Ryan et al., 2022). This approach also has the advantage of building rapport and mutual respect between the fishers and the researcher (Lyle et al., 2002). The use of incentives for participating diarists (e.g., discounted license fees) can also be effective for retaining respondents for the full survey period. The diary has a distinct advantage over other survey methods in highly dynamic fisheries where, for example, fishers may periodically move from 'home' locations to fish other areas where the relative abundance of target species (e.g., silky shark or dorado) or market prices may be higher. In typical on-site surveys these productive trips are likely to be missed by on-site survey staff who repeatedly visit the 'home' locations.

The diary approach can be very effective for recording effort and catch for the more common or distinct species, but without specific training identification issues may arise for less common species. Therefore, clear project objectives are required before considering the design of the survey as in many cases, these surveys are 'fit-for-purpose' and not easily modified without causing significant issues with respect to statistical analyses. Using the diary method, fishers can be trained to collect length data of individual fish caught (see Griffiths, 2012), but the time burden for fishers to measure large numbers of individuals is likely to reduce survey participation. If length information is important, diarists are likely capable of recording their catch by species and aggregated by size category (e.g., small, medium, large) as is performed by IATTC and AIDCP observers in the EPO (Fuller et al., 2022). However, if precise length data, or other biological samples (e.g., genetic samples for CKMR), are required, these would need to be collected by on-site surveys at access points relevant to the species of interest.

3.3.2 Estimating total fishing effort

Once catch and effort data are sampled from a representative sample of fishers, an ancillary survey is required to estimate the total effort of the fishery, to which the sample data can be expanded to. Effort surveys are often on-site surveys involving staff counting of vessels as they enter or leave the fishery (Pollock et al., 1994) or instantaneous counts during a pre-defined survey period (Pollock et al., 1997) when visiting sites by land, water, or air, depending on the access points and the distance between them. For example, Hartill and Edwards (2015) employed an aerial survey to estimate recreational fishing effort in New Zealand at 66% of the cost of a household telephone survey. Although aerial surveys of small scale coastal fishing effort may be possible across the Americas, they would likely need to be stratified by country given probable limitations of cross-jurisdictional flights. Furthermore, aerial surveys may not be feasible in regions where illicit activities may pose a safety risk to pilot staff.

As an alternative, frequently updated satellite imagery may be a cost-effective alternative to aerial surveys for obtaining instantaneous vessel counts to estimate effort, in which a similar approach was taken in ABNJ-"Tuna 1" to identify potential landing sites for small scale coastal fishing vessels. The use of near-real-time satellite imagery was proposed as a potential option to monitor recreational fishing effort in the vast offshore waters of Australia's Commonwealth fisheries (Griffiths et al., 2010), but the low resolution (200m) and high cost (up to AUD$7M per day) of satellite imagery at the time made it cost-prohibitive. More recently, however, satellite imagery has improved dramatically with resolution down to 15 cm (Maxar Technologies) and planned to reduce even further to 10 cm in 2025 (Albedo Space), which would allow for daily fishing vessel counts at sites open to view by satellite (see Figure 1). A complete census of fishing effort (i.e., the sum of daily vessel counts) could be achieved by using daily satellite imagery, although if daily imagery costs are significant, stratified random sampling of days could be undertaken to estimate total annual effort, in terms of fishing days.

4. LESSONS LEARNED FROM PILOT SAMPLING PROGRAMS FOR SMALL SCALE COASTAL FISHERIES

4.1. Pilot study in Central America (ABNJ-"Tuna 1")

The review of large-scale sampling methods in section 3 revealed the enormous logistical and financial difficulties in sampling fisheries that operate from a diversity of access points dispersed across thousands of kilometers of coastline. Consequently, it may be impractical and cost-prohibitive to attempt a census of fishing effort and shark catches by small scale coastal fisheries in the EPO, and therefore the only alternative is to sample a selection of access points with a view to expand catch rates from these sites to other sites within a known sampling universe of sites to estimate catch totals for shark species.

During the ABNJ-"Tuna 1" project that focused on Central America, hundreds of potential sites were identified, totaling 1,443 locations of interest (LOIs), of which 789 were verified as shark landing sites (SAC-11-13). The relative importance of each LOI as a shark landing site was determined through on-site intercept surveys of fishers at each site. This procedure was important for establishing a long-term program for the region to account for the frequently sudden changes in the fishing dynamics at each site (IATTC-98-02c). Monitoring all LOIs incurs prohibitive labor and operational costs, and so, sites were prioritized based on their perceived contribution to the total shark catch, particularly with respect to silky and hammerhead sharks, which have been identified by the IATTC Members (see C-16-05) and more recently in quantitative vulnerability assessments (SAC-13-11),as among the most vulnerable shark species caught by pelagic species in the EPO. Hence, the sampling design for this fleet must be fit for purpose to representatively sample the fleet and the catch of the species of interest. However, it must also be flexible enough to capture the spatio-temporal dynamics of the fishery and research priorities, such as particular shark species becoming potentially vulnerable. However, it was also determined during the pilot sampling program that the extent of spatial stratification within regions is critically important, not only for samples from access points to be sufficiently representative of regional catches, but to minimize travel and logistical costs between access points. This was done by prioritizing important sites for species of interest while minimizing the proximity to less significant sites that would be sampled less frequently. Furthermore, temporal variability in vessel numbers at access points was a consideration for obtaining representative samples from which minimally unbiased annual catch estimates could be derived.

In recognizing the paucity of shark data for these small scale coastal fisheries, collaborative research with OSPESCA and IATTC's Central American CPCs was conducted between 2015 and 2021, with a focus on establishing a long-term shark sampling program for fisheries in Central America. Throughout these efforts, practical experiences accumulated from previous work have proven to be instrumental in refining sampling methodologies for sharks, addressing major logistical challenges, and minimizing labor and operational costs. The insights gained from this collaborative effort are summarized below:

- Central America boasts thousands of landing sites (SAC-11-13), making it impractical and cost-prohibitive to regularly monitor each one (IATTC-98-02c). Therefore, selecting a representative subset of landing sites is the most feasible approach for routine monitoring of shark catch and effort.
- Small scale coastal ('artisanal') fisheries in the region are seasonal and exhibit strong spatio-temporal dynamics, with effort at the main landing sites for key species (e.g., silky shark) often fluctuation on short time scales as fishers move along the coastline to fish areas where their preferred target species are periodically abundant. Therefore, flexibility in sampling design is crucial to adapt to these fluctuations in effort (SAC-14 INF-P, IATTC-98-02c).
- The sampling design must account for longer-term temporal variability in effort as a result of seasonal and annual fluctuations in shark populations (SAC-14 INF-P, SAC-14-INF-L, IATTC-98-02c).
- Stratification by sampling area is essential to ensure that data that are representative of the regions, vessels and species are collected across this extensive fishing zone (SAC-14 INF-P, IATTC-98-02c, SAC-14 INF-L,).
- Incorporating opportunistic biological and ecological sampling enhances the depth and breadth of data collection efforts, capturing valuable insights beyond routine monitoring for catch and effort to support vulnerability, population (e.g., Close-kin mark recapture) and ecosystem assessments (SAC-14 INF-P, IATTC-98-02c, SAC-14 INF-L, SAC-14 INF-J).

These experiences highlight the importance of adaptive and collaborative approaches in addressing the unique challenges of shark sampling in small scale coastal fisheries in the region, ultimately contributing to the collection of more reliable data on which to base assessments leading to more effective conservation and management efforts.

4.2. ABNJ-"Tuna 2" (Mexico, Ecuador, Peru)

After the successful completion of ABNJ-"Tuna 1" in Central America, research efforts were expanded to Mexico, Ecuador, and Peru. Although differences exist between regions and countries, especially the spatial extent to be sampled, they are similar in that no harmonized or standardized data collection forms and processes exist between these countries, nor are fisheries and biological/ecological data collected in a standardized fashion. As in Central America, small scale coastal fishing fleets in Mexico, Peru and Ecuador are comprised of thousands of vessels that can be dynamic in their species targeting and operational characteristics. In addition, some fleets (e.g., Ecuador) operate from motherships ("nodrizas"), increasing the difficulties of monitoring specific vessels.

During the first year of the ABNJ-"Tuna 2" project (SAC-14 INF-M), a metadata review of 1,167 documents related to sharks and their fisheries identified hundreds of potential LOIs. To date, 1,622 LOIs were identified using satellite imagery (Google Earth), with 552 being exclusive shark landing sites. These findings are similar to the ABNJ-"Tuna 1" in Central America in that there are thousands of access points supporting a large number of small scale coastal fishing vessels. Although on-site surveys are planned for years 2 and 3 of the project, this preliminary information underscores the need to establish a consistent, harmonized and systematic sampling system for sharks in each country and across the EPO region to collect catch, effort, and biological data, which are lacking for most key species (e.g., SAC-05-11a) to support conventional stock assessment efforts.

5. PROPOSED SHARK SAMPLING PROGRAM FOR SMALL SCALE COASTAL FISHERIES

There is currently some ambiguity as to the definitive responsibilities of the IATTC and its Members pertaining to the conservation and management of sharks, which in some way limits the staff's ability to recommend a highly detailed shark monitoring program. The Commission has not yet agreed on a prescribed list of shark, and other, bycatch species under its purview, although document SAC-15-09 prepared by the IATTC staff this year, proposes an interim list of species that will need to first be endorsed by its Members before the scope of a monitoring program that can accommodate all species can be fully determined. Nonetheless, previous conservation and management measures pertaining to silky and hammerhead sharks (e.g. Resolutions C-16-06, C-19-05, C-21-06, C-23-08), their reference to as key shark species in Resolution C-23-07, and recent vulnerability assessments suggesting these species are among the most vulnerable species interacting with industrial and small scale coastal fisheries in the EPO (SAC-13-11, SAC-14-12), the staff has largely based the scope of shark monitoring efforts in ABNJ-"Tuna 1"and ABNJ-"Tuna 2" around these species with a goal of estimating the order of magnitude of shark catches in small scale coastal fisheries in the IATTC Convention Area. These ABNJ studies highlight the challenges of monitoring shark catches in small scale coastal fisheries distributed across hundreds to thousands of access points that can vary dramatically in their importance as landing sites for the catches of particular species (e.g., silky shark) across short (weeks) and long (season) times scales. While these projects have improved our understanding of the order of magnitude of shark catches (SAC-14 INF-L), future surveys must ensure that sampling is designed around the ultimate survey objective. Maintained over time, these estimates of total catches can be used as stand-alone indicators or as additional components in stock assessment models.

In order to develop a more definitive plan for a cost-effective shark sampling program that considers prioritized species or all species under the purview of the IATTC and all impacting fisheries in the region, it would be desirable to first complete the current ABNJ-"Tuna 2" project. Furthermore, the IATTC staff envision that, ultimately, the results from current and future planned activities can contribute to the development and implementation of an appropriate shark sampling program in the EPO that can provide reliable information for various types of population assessments undertaken by the IATTC staff in the short, medium, and long-term (see section 5 for details on assessments), including:

a) Short term (1–3 years): The recent development of EASI-Fish by the IATTC staff allows for the quantitative assessment of data-poor species using proxies for conventional biological reference points (BRPs). An EASI-Fish assessments for sharks in the EPO was presented in 2022 (SAC-13-

11) and will be iteratively improved as new data become available within 1–3 years. In addition, the development, implementation, and maintenance of sampling protocols implemented in ABNJ-"Tuna 1" and ABNJ-"Tuna 2" as well as new protocols required by specific assessment methods are expected in this phase, along with the completion of the initial phases of CKMR planning, including a feasibility study for prioritized species.

b) Medium term (3–5 years): The IATTC staff proposes using CKMR as a stock assessment tool for shark species in the EPO, such as silky and hammerhead sharks. Activities will include investigating the outcomes of the feasibility study and developing sampling designs for CKMR analysis, updating morphometric relationships, and collecting biological samples. Updating morphometric relationships and collecting biological samples for prioritized shark species is also important to support data-limited assessments (e.g., EASI-Fish). In addition, model-based estimates of catches (SAC-14 INF-L) could be conducted, as long as sufficient ongoing data collection is undertaken in the region.

c) Long-term (10–20 years): High-quality stock assessments that integrate conventional fisheries data with CKMR could be feasible as needed after sufficiently long time series of fishery data (catch, effort, species and size composition, and biology) are collected. This will be possible once a regional sampling program is implemented and maintained by EPO coastal states.

The success of a long-term shark sampling program in the region will depend on both adequate ongoing funding and the cooperation of local fisheries authorities and fishers. Therefore, it is crucial for CPCs in the region to assist the IATTC in implementing this program and fostering cooperation with local fisheries authorities and fishers. Given the scale and importance of the shark fisheries in Central America (SAC-14 INF-L, SAC-15-10) and the lack of fishery/biological sampling data from shark landings in that region (SAC-07-06b(iii)), establishing a regional IATTC office in Central America near the ports where the main shark landings occur (e.g., Costa Rica for silky shark) will enable more cost-effective data collection, improved capacity, improved coordination and enhance scientific collaboration between organizations, and therefore is desirable for the success of the program.

Given the current uncertainty over the shark species under the purview of the IATTC, but considering the aforementioned strategic approach to shark monitoring in the EPO, the potential design of shark monitoring programs is discussed in the following sections with respect to either a focus on prioritized shark species or including all species of sharks under the purview of the IATTC—possibly 19 or more species (see SAC-15-09).

5.1. Focused monitoring of prioritized species

Although the ABNJ-"Tuna 2" project is still underway, preliminary data coupled with the lessons learned from ABNJ-"Tuna 1" indicated that to adequately monitor even a small number of prioritized species, survey methods are required that can be feasibly implemented across the enormous spatial scale of small scale coastal fisheries, where it is believed the majority of the catches of these priority species occurs (SAC-14 INF-L), and the logistical complexities and significant resources required to sample the region. Therefore, an appropriate sampling program for prioritized shark species involves an on-site intercept survey where trained staff visit 'primary' sites regularly, where catches of priority species has been shown to be highest, supplemented with less frequent visits to 'secondary' and 'tertiary' sites to ensure that the spatio-temporal dynamics in fishing effort for these species is not significantly changing throughout the period for which data will be used to estimate total catch.

The advantage of an on-site survey approach is that fishers can be approached directly at the end of their trip and their catch physically inspected, as well as be able to collect biological information such as morphometric data, stomachs, gonads, and tissue for genetic analysis, which is envisioned to be of critical importance for CKMR. In this case, a sampling program will need to include technician training for species identification of processed catch (e.g., trunks), such as the training provided to project staff in ABNJ-"Tuna 1". However, given the difficulty of identifying highly processed carcasses, especially neonates unloaded in baskets, additional data needs to be collected to validate species identification, such as tissue samples for DNA analysis or smart species ID systems based on AI (Project B.1.a).

Although the on-site survey approach can collect data from the subset of fishers sampled on the designated sampling days, extrapolation and interpolation of these observations is required for unsampled sites in order to obtain order of magnitude catch estimates for these species, which can contain high variation (see SAC-14 INF-L). Therefore, future studies of fleet dynamics are important to support model-based estimation of fleet-level catches. The data collected in 2020–2021 on-site intercept survey identified possible differences in fisheries operational characteristics among countries, which could be exacerbated with the ultimate inclusion of Mexico, Ecuador and Peru (see ABNJ-"Tuna 2"). These future studies will allow staff to better understand fleet dynamics to allow for stratification of sampling by factors such as gear type, species targeting and/or vessel characteristics, which may lead to improved performance of model-based estimators of total catch by improving a model's ability to identify site characteristics related to catch size of the different shark species or groups.

A further consideration for improving total catch estimates is to obtain a more precise estimate of the total fleet size in each country to which catch rates can be expanded to. The optimal approach would be to have a census of fishing vessels, which may be obtained from regulatory authorities in each country where fishers are generally required to register their vessel. However, it would need to be determined whether there are confidentiality issues for authorities to provide these data. Furthermore, the IATTC staff would need to know if vessel registration data are in fact a complete census of vessels or whether they equate to an incomplete list frame of vessels due to any registration exemptions, for which separate ancillary surveys would need to be undertaken to determine whether exempted vessels have comparable characteristics to registered vessels, and thus can simply be included in fleet vessel totals.

It is important to note that the objectives of the shark sampling program may evolve over time, and methods must adapt as needed. For example, future IATTC efforts to assess the status of shark species will likely emphasize tools such as close-kin mark-recapture (CKMR) over conventional stock assessment models that depend on catch-per-unit-effort as an abundance index. CKMR requires collection of sufficiently high-quality genetic samples and associated metadata (e.g., length and sex of sampled individuals). A successful CKMR model requires a carefully designed sampling protocol, and it is unclear whether the sampling design that might provide the best estimates of total catch would also be the best for use in CKMR. In this regard, the IATTC staff is currently conducting a feasibility study that will help shape, design and plan future cost-effective CKMR efforts in the area. Similarly, any assessment effort, including integrated stock assessments, CKMR, or EASI-fish, require accurate biological and ecological information (e.g., length-weight relationships or length-at-age keys), which rely on the on-site collection of data. Therefore, ongoing sampling efforts for sharks in the IATTC Convention Area should consider these diverse objectives in their design to ensure that collected data are able to fulfil their ultimate purpose.

The success of a long-term shark sampling program in the region will depend on both adequate ongoing funding and the cooperation of local fisheries authorities and fishers. Therefore, it is crucial for CPCs in the region to assist the IATTC in implementing this program and fostering cooperation with local fisheries authorities and fishers. Given the scale and importance of the shark fisheries in Central America (SAC-14 INF-L) and the lack of fishery/biological sampling data from shark landings in that region (SAC-07-06b(iii)), establishing a regional IATTC office in Central America near the ports where the main shark landings occur (e.g., Costa Rica for silky shark) will enable more cost-effective data collection, improved capacity, improved coordination and enhance scientific collaboration between organizations, and therefore is desirable for the success of the program.

5.2. Monitoring all shark species under the purview of the IATTC

The extensive collaborative work undertaken by the IATTC staff with its CPCs leading up to this report has focused on designing sampling programs around specific prioritized species, namely silky and hammerhead sharks. However, it is possible that a larger number of species will eventually need to be considered. As the number of species to be monitored increases the more complex, and costly, a sampling program is likely to become due to the likely increase in the number of spatial and/or temporal sampling strata that will be needed to capture the inter-specific variability in catches of these species that are less frequently caught by fishers, and thus, encountered by field staff during sampling. Without undertaking further on-site sampling to collect data for all shark species, it is possible to glean some information from the existing data from ABNJ-“Tuna 1” and undertake further theoretical and simulation work to consider what sampling program might best stand to achieve desired levels of precision and accuracy around target metrics given a budget for a broad range of species of interest. However, it is important to note that developing a unified sampling program for monitoring a wide range of species outside of the established monitoring programs for industrial tuna fisheries, namely purse-seine and longline, will require substantial financial and personnel resources.

However, if such a unified sampling program for all species under the purview of the IATTC is desirable to the Members, the on-site survey methodology developed in ABNJ-“Tuna 1” is likely to be cost prohibitive for sampling a sufficient number of access points where all species under the purview of the IATTC—possibly 19 or more species (SAC-15-09)—are landed along the entire coastline of the Americas, and therefore alternative survey designs would need to be explored. For example, the on-site access point intercept survey component of ABNJ-“Tuna 1” that focused primarily on sampling ‘primary’ silky and hammerhead shark landing sites in five countries cost around USD$555,400 for the region (SAC-14 INF-P).

A cost-effective alternative to on-site surveys that is frequently used in large scale recreational fisheries that span thousands of kilometers of coastline and incorporate thousands of possible access points is a ‘complemented survey’ design that would ideally integrate three separate surveys to collect either catch data, effort data, or length data and biological samples for sharks. However, careful attention needs to be given to the potential sampling biases of each survey prior to implementation, which may need to be addressed in additional ancillary surveys, as well as the reality of obtaining list frames that will facilitate sampling.

The first component of a complemented survey would focus on estimating catch rates for each species whereby catch and effort data would be collected using a diary survey from a representative sample of fishers in specified spatial strata (e.g., region, country) who are recruited by interception at landing sites or by telephone using a list frame that sufficiently represents in-scope fishers (e.g., vessel registration database). Once recruited, these fishers would be contacted on a weekly basis—to minimize recall bias—by survey staff to record effort and species-specific catch information. This 'telephone diary' approach transfers the reporting burden to the survey staff and can greatly improve communication between researchers and fishers. The diary survey would ideally produce representative catch rate data for each spatial stratum that would then be expanded to the total annual number of fishing days/trips for each stratum and summed across all strata to produce an estimate of total catch by species.

The second component of the complemented design would collect data on the total effort by the fishery. Given the enormous number of access points across the Americas, it is cost-prohibitive to visit all sites to obtain daily or instantaneous vessel counts to estimate total annual effort. Cost-effective alternatives may be the use of daily satellite imagery whereby the number of vessels identified as active fishing vessels at each access point is recorded and annual effort estimated. Alternatively, annual total fishing effort may be estimated by obtaining vessel registration data in each country—as discussed for priority species—from which total fleet size may be determined and multiplied by the diary catch rates to estimate total catch by species.

The final component of a 'complemented survey' design would involve an on-site access point intercept survey, similar to that used in ABNJ-"Tuna 1", to collect length data or biological and genetic samples for population assessments, such as using length-based approaches or CKMR. Given that these data would require a lower frequency of collection to develop length-frequency distributions, morphometric relationships, or even singular collections of genetic tissue for CKMR, sampling may be more opportunistic and take place at predominant access points, such as the "primary" landing sites identified in ABNJ-"Tuna 1".

Despite a 'complemented survey' design for monitoring shark catches likely being substantially cheaper than conducting on-site surveys, given the spatial scale of the sampling region it is important to consider an indicative absolute cost for such a survey would be on the order of hundreds of thousands (USD) per country per survey year, which would likely cover only travel and operating expenses. Additional funding would be required for the analyses of biological or genetic materials, as well as ancillary surveys that may be required to assess the extent of particular sampling biases, such as non-response bias diary surveys or comparative characteristics of 'in-scope' versus 'out-of-scope' fishers from list frames (Lewin et al., 2021).

6. SHARK ASSESSMENTS

The fundamental reason for the need to explore deeply, and for the IATTC to invest resources, into the development of a shark sampling program in the EPO is to obtain reliable data needed for the assessment of species for which the IATTC has a mandate to ensure their long-term sustainability (see SAC-15-09). Demonstrating the substantiality of shark populations in which pelagic fisheries in the EPO interact is challenging as these species are generally an incidental catch (i.e., bycatch) in industrial longline and purse-seine fisheries as they are less frequently encountered and so reporting quality from conventional IATTC industrial fishery monitoring programs is not as complete or reliable as the targeted tuna and tuna-like species. The major confounding problem is that shark species caught by industrial tuna fleets in offshore waters are caught in significantly higher numbers by the thousands of domestic commercial and small scale coastal fishing vessels that operate in neritic waters mostly within the jurisdictions of coastal States (SAC-14 INF-L). Many of these countries do not have harmonized, systematic or even ongoing data collection programs in place, or undertake periodical surveys, that can generate reliable catch totals or undertake biological sampling for sharks in all fisheries. This lack of data hinders the ability of IATTC scientists to conduct scientifically defensible assessments of shark populations impacted by both tuna and non-tuna fisheries.

Accurate assessment of shark species requires representative data from across the population, which for some of these species will include data and removals from the industrial tuna fleet, industrial non-tuna fishing vessels, and small scale coastal fisheries, all of which may impact shark populations in some way. The IATTC staff realize that establishing a data collection program for sharks caught by small scale coastal fisheries is a necessary, yet a costly, and logistically and politically complex undertaking that will take several years to implement with the close cooperation of its CPCs. The ultimate goal of the monitoring program is to collect long time series of reliable data from these fleets for shark species, and ideally other species such as dorado, under the purview of the IATTC (see SAC-15-09; C-23-09). These data will facilitate the IATTC scientific staff's ability to develop assessment models with which to subsequently guide the development of conservation and management measures, if required.

Given the potential difficulties in collecting continuous, reliable, and representative conventional fisheries data (e.g., catch and effort) from these fisheries, the staff have begun to explore close-kin mark-recapture (CKMR) (Bravington et al., 2016) as an alternative to conventional stock assessment models that depend on catch-per-unit-effort as an abundance index. The distinct advantage of CKMR is that genetic material from a sample of individuals (alive or dead) can be used estimate absolute abundance with fewer assumptions than those required by conventional stock assessment models based on fishery-dependent CPUE data. CKMR has been successfully applied to elasmobranch populations in other regions (Delaval et al., 2023), so there is good reason to believe that it may be viable as a cost-effective solution to stock assessment of prioritized shark species for which collection of time series of accurate and representative catch and fishery-dependent CPUE may be untenable. CKMR requires collection of sufficiently high-quality genetic samples and associated metadata (e.g., length and sex of sampled individuals). In theory, one year of sample collection is generally sufficient for a CKMR model to estimate at least one year, and possibly more, of absolute abundance estimates, although it will take several years to develop and implement a sampling program for this purpose. Conversely, several years of catch and CPUE data is needed for a conventional assessment to estimate absolute abundance. However, the most basic versions of CKMR on its own will only provide an estimate of absolute abundance, and potentially total mortality. Having at least an order of magnitude estimate of shark catches will facilitate model fitting and potentially allow for more robust calculation of relevant management metrics such as fishing mortality rates. Therefore, implementing a program that can collect catch and genetic data in concert is the most ideal approach for facilitating any future stock assessment of sharks in the EPO.

In the intervening years of the IATTC developing conventional stock assessments or alternative population assessments using CKMR, the IATTC must continue to adhere to conservation policies enshrined in the Antigua Convention, namely the application of the precautionary approach (Article IV) whereby "…*the absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures*". The IATTC has proactively addressed this policy for data-limited shark, and other bycatch, species and their interacting fisheries by formalizing a research strategy in the 2018–2023 Strategic Science Plan (SSP) and to "*develop analytical tools to identify and prioritize species at risk*". The staff achieved this goal primarily through the development of a flexible spatially-explicit quantitative ecological risk assessment approach called the Ecological Assessment of Sustainable Impacts of Fisheries (EASI-Fish) (Griffiths et al., 2019). Since its development, EASI-Fish has been applied to various vulnerable bycatch species, such as the spinetail devil ray (Griffiths and Lezama-Ochoa, 2021) the Critically Endangered east Pacific stock of leatherback turtle (Griffiths et al., 2024), and 32 of the 49 shark species caught by industrial and small scale coastal pelagic fisheries in the EPO. In 2023, the staff used EASI-Fish in a prospective analysis to assess the potential efficacy of 43 hypothetical scenarios involving practical conservation and management measures (CMMs)—used in isolation and concert—to guide future research and management efforts on four of the most vulnerable shark species: silky shark (*Carcharhinus falciformis*), scalloped hammerhead (*Sphyrna lewini*), great hammerhead (*Sphyrna mokarran*), and smooth hammerhead (*Sphyrna zygaena*) (SAC-14-12). Although EASI-Fish is designed for application in data-limited settings, the method is highly dependent upon access to reliable spatially explicit locations for the presence of both species and fishing effort. Therefore, for the IATTC to continue its conservation and management efforts of sharks in the short and long term, it is imperative that appropriate data collection is undertaken for all mortality sources for sharks, which includes small-scale coastal fleets that are widely distributed along the coast of the Americas.

7. CONCLUSIONS

The IATTC has been proactive in meeting its responsibilities under the Antigua Convention and specific IATTC Resolutions pertaining to the conservation and management of sharks in the EPO. Although an *ad hoc* approach to the management of shark species in the absence of a prescriptive list of shark species under the purview of the IATTC (but see SAC-15-09), research and management efforts by the IATTC have focused on the most vulnerable species, especially silky and hammerhead sharks. Some of these species are the subject of specific IATTC Resolutions (e.g., C-11-10, C-19-05, C-19-06) and population monitoring (BYC-11 INF-B) in lieu of a reliable stock assessments in the EPO as attempts have been hampered by a lack of data for small scale coastal fleets (see SAC-05 INF-F). Major knowledge gaps for these priority, and other, shark species in these fisheries has begun to be bridged by the ABNJ-"Tuna 1" (completed) and ABNJ-"Tuna 2" (underway) projects conducted across 8 coastal states. This collaborative research has highlighted the enormous logistical and financial difficulties in sampling small scale coastal fisheries comprised of thousands of vessels operating from thousands of access points across the vast coastline of the Americas.

Although there are several potentially effective methods to support data collection for shark species, most are cost-prohibitive given the spatial scale of the region and the intensity of sampling required to obtain acceptable levels of precision of catch estimates to support stock assessment. The ABNJ projects indicate that a survey design must be fit for purpose whereby sampling only 'primary' access points may be possible for priority species—determined from quantitative vulnerability assessments—using an on-site intercept survey design that is capable of collecting catch, effort and biological information (e.g., genetics for CKMR). Conversely, if all species under the purview of the IATTC are to be monitored, the use of on-site surveys is likely to be cost-prohibitive. Therefore, off-site survey methods are likely to be required to achieve appropriate spatial and temporal coverage of catches for all species but can be prone to major sampling biases (e.g., non-response, intentional deception) that would require specific investigation in these fisheries before implementation of a final data collection program for sharks in the EPO. Although Resolution C-23-07 calls for the implementation of a data collection program in 2024, completion of ABNJ-"Tuna 2" is critical to better understand the sampling requirements for a program for all coastal states in the IATTC Convention Area before final implementation.

8. REFERENCES

Aires-Da-Silva, A., Siu, S., Lennert-Cody, C., Minte-Vera, C., Maunder, M.N., Pulvenis, J.-F., et al., 2016. Challenges to collecting shark fishery data in the Eastern Pacific Ocean, and recommendations for improvement. *7th Meeting of the Scientific Advisory Committee of the IATTC, 9-13 May 2016, La Jolla, California. Document SAC-07-06b(iii)*.

Alfaro-Shigueto, J., Mangel, J.C., Pajuelo, M., Dutton, P.H., Seminoff, J.A., Godley, B.J., 2010. Where small can have a large impact: Structure and characterization of small-scale fisheries in Peru. *Fisheries Research* **106**, 8-17.

Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M., et al., 2013. Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation* **160**, 214-224.

Andrews, R., Brick, J.M., Mathiowetz, W.N.A., 2013. *Continued development and testing of dual-frame surveys of fishing effort. Testing a dual-frame, mixed-mode survey design*. U.S. National Marine Fisheries Service, Silver Spring, MD

Andrews, W.R., Papacostas, K.J., Foster, J., 2018. A comparison of recall error in recreational fisheries surveys with one ‐ and two ‐ month reference periods. *North American Journal of Fisheries Management* **38**, 1284-1298.

Ballance, L.T., Gerrodette, T., Lennert-Cody, C., Pitman, R.L., Squires, D., 2021. A history of the tuna-dolphin problem: successes, failures, and lessons learned. *Frontiers in Marine Science*, 1700.

Bravington, M.V., Skaug, H.J., Anderson, E.C., 2016. Close-kin mark-recapture. *Statistical Science* **31**, 259–274.

Cartamil, D., Santana-Morales, O., Escobedo-Olvera, M., Kacev, D., Castillo-Geniz, L., Graham, J.B., et al., 2011. The artisanal elasmobranch fishery of the Pacific coast of Baja California, Mexico. *Fisheries Research* **108**, 393-403.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., Ochi, D., 2014. *Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures.* . FAO Fisheries and Aquaculture Technical Paper No. 588, Rome, Italy.

Clarke, S.C., Langley, A., Lennert-Cody, C., Aires-Da-Silva, A., Maunder, M., 2018. Pacific-wide silky shark (*Carcharhinus falciformis*) stock status assessment. *14th Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission, 8–16 August 2018, Busan, Republic of Korea. Document WCPFC-SC14-2018/SA-WP-08*.

Diaz-Delgado, E., Crespo-Neto, O., Martínez-Rincón, R.O., 2021. Environmental preferences of sharks bycaught by the tuna purse-seine fishery in the Eastern Pacific Ocean. *Fisheries Research* **243**, 106076.

Duffy, L.M., Lennert-Cody, C.E., Olson, R.J., Minte-Vera, C.V., Griffiths, S.P., 2019. Assessing vulnerability of bycatch species in the tuna purse-seine fisheries of the eastern Pacific Ocean. *Fisheries Research* **219**, 105316.

Fuller, L., Vogel, N., Griffiths, S., Román, M.H., Lennert-Cody, C., 2022. *History of the IATTC bycatch data collection and description of the 'bycatch database' for use in ecosystem and bycatch research*. Special Report 25. Inter-American Tropical Tuna Commission, La Jolla, California, USA.

Gallucci, V., Hariharan, A., 2012. *An adaptive sampling design for the estimation of thresher shark catch and effort in a recreational fishery in California*. University of Washington, Seattle, WA.

Griffiths, S.P., Pepperell, J., Tonks, M., Fay, G., Venables, W., Lyle, J., et al., 2010. *Developing innovative and cost effective tools for monitoring recreational fishing in Commonwealth fisheries*. Final report for FRDC project 2007/014, CSIRO, Cleveland, Qld.

Griffiths, S.P., 2012. Recreational catch composition, catch rates, effort and expenditure in a specialised land-based pelagic game fish fishery. *Fisheries Research* **127–128**, 40–44.

Griffiths, S.P., Duffy, L., 2017. A preliminary metadata analysis of large-scale tuna longline fishery data in the eastern Pacific Ocean: a precursor to Ecological Risk Assessment. *8th Meeting of the Scientific Advisory Committee of the IATTC, 8-12 May 2017, La Jolla, California, USA. Document SAC-08-07b.*, 1-34.

Griffiths, S.P., Kesner-Reyes, K., Garilao, C., Duffy, L.M., Román, M.H., 2019. Ecological Assessment of the Sustainable Impacts of Fisheries (EASI-Fish): a flexible vulnerability assessment approach to quantify the cumulative impacts of fishing in data-limited settings. *Marine Ecology Progress Series* **625**, 89-113.

Griffiths, S.P., Lennert-Cody, C., Wiley, B., Fuller, L., 2021. Update on operational longline observer data required under resolution C-19-08 and a preliminary assessment of data reliability for estimating total catch for bycatch species in the eastern Pacific Ocean. *10th Meeting of the IATTC Working Group on Bycatch, 5 May 2021, La Jolla, California, USA. Document BYC-10 INF-D*, 22.

Griffiths, S.P., Lezama-Ochoa, N., 2021. A 40-year chronology of spinetail devil ray (*Mobula mobular*) vulnerability to eastern Pacific tuna fisheries and options for future conservation and management. *Aquatic Conservation: Marine and Freshwater Ecosystems* **31**, 2910–2925.

Griffiths, S.P., Wallace, B.P., Cáceres, V., Helena Rodríguez, L., Lopez, J., Abrego, M., et al., 2024. Vulnerability of the Critically Endangered leatherback turtle to fisheries bycatch in the eastern Pacific Ocean. II. Assessment of mitigation measures. *Endangered Species Research* **53**, 295-326.

Hall, M., Roman, M., 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. *FAO fisheries and aquaculture technical paper* **568**, 249.

Hariharan, A., Gallucci, V., Heberer, C., 2013. Estimation of relative efficiency of adaptive cluster vs traditional sampling designs applied to arrival of sharks. *arXiv :1304.2460*, 24.

Hartill, B.W., Cryer, M., Lyle, J.M., Rees, E.B., Ryan, K.L., Steffe, A.S., et al., 2012. Scale- and context-dependent selection of recreational harvest estimation methods: the Australasian experience. *North American Journal of Fisheries Management* **32**, 109-123.

Hartill, B.W., Edwards, C.T.T., 2015. Comparison of recreational harvest estimates provided by onsite and offsite surveys: detecting bias and corroborating estimates. *Canadian Journal of Fisheries and Aquatic Sciences* **72**, 1379-1389.

Inter-American Tropical Tuna Commission (Iattc), 2014. A collaborative attempt to conduct a stock assessment for the silky shark in the eastern Pacific Ocean (1993-2010): update report. *5th Meeting of the Scientific Advisory Committee of the IATTC, 12-16 May 2014, La Jolla, California, USA. Document SAC-05 INF-F*.

Lewin, W.-C., Weltersbach, M.S., Haase, K., Riepe, C., Skov, C., Gundelund, C., et al., 2021. Comparing on-site and off-site survey data to investigate survey biases in recreational fisheries data. *ICES Journal of Marine Science* **78**, 2528-2546.

Lyle, J.M., 1999. Licensed recreational fishing and an evaluation of recall biases in the estimation of recreational catch and effort. *Final report to the Marine Recreational Fishing Council, Tasmanian Aquaculture and Fisheries Institute*.

Lyle, J.M., Coleman, A.P.M., West, L., Campbell, D., Henry, G.W., 2002. New large-scale methods for evaluating sport fisheries. In: Pitcher, T. J., Hollingworth, C. (Eds.), *Recreational fisheries: Ecological, economic and social evaluation. Fish and Aquatic Resources Series 8*. Blackwell Science, London, UK, pp. 207–226.

Lyle, J.M., Tracey, S.R., 2016. Catch, effort and fishing practices in a recreational gillnet fishery: assessing the impacts and response to management change. *Fisheries Research* **177**, 50-58.

Martínez-Ortiz, J., Aires-Da-Silva, A.M., Lennert-Cody, C.E., Maunder, M.N., 2015. The Ecuadorian artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. *PLoS One* **10**, e0135136.

Mcglennon, D., Kinloch, M.A., 1997. Evaluation of the bus-route creel survey method in a large Australian marine recreational fishery - II. Pilot surveys and optimal sampling allocation. *Fisheries Research* **33**, 89-99.

Morton, A.J., Lyle, J.M., 2003. Preliminary assessment of the recreational gamefish fishery in Tasmania, with particular reference to southern blue tuna. *Tasmanian Aquaculture and Fisheries Institute Technical report series* **21**, 30.

National Research Council (N.R.C.), 2006. *Review of recreational fisheries survey methods*. National Research Council, National Academy Press, Washington, D.C., USA.

Oliveros-Ramos, R., Lennert-Cody, C.E., Siu, S., Salaverria, S., Maunder, M., Aires-Dasilva, A., et al., 2020. Pilot study for a shark fishery sampling program in Central America. *11th Meeting of the Scientific Advisory Committee of the IATTC, 11-15 May 2020, La Jolla, California, USA. Document SAC-11-13*, 59.

Pérez-Jiménez, J.C., Sosa-Nishizaki, O., Furlong-Estrada, E., Corro-Espinosa, D., Venegas-Herrera, A., Barragán-Cuencas, O.V., 2005. Artisanal shark fishery at "Tres Marías" islands and Isabel island in the central Mexican Pacific. *Journal of Northwest Atlantic Fishery Science* **35**.

Pollock, K.H., Jones, C.M., Brown, T.L., 1994. Angler survey methods and their implications in fisheries management. *American Fisheries Society Special Publication 25*, 371.

Pollock, K.H., Hoenig, J.M., Jones, C.M., Robson, D.S., Greene, C.J., 1997. Catch rate estimation for roving and access point surveys. *North American Journal of Fisheries Management* **17**, 11-19.

Ryan, K.L., Lai, E.K.M., Smallwood, C.B., 2022. *Boat-based recreational fishing in Western Australia 2020/21. Fisheries Research Report No. 327* Department of Primary Industries and Regional Development, Perth, Western Australia.

Salas, S., Chuenpagdee, R., Seijo, J.C., Charles, A., 2007. Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fisheries Research* **87**, 5-16.

Siu, S., Aires-Da-Silva, A., 2016. An inventory of sources of data in central America on shark fisheries operating in the Eastern Pacific Ocean. Metadata report. *7th Meeting of the Scientific Advisory Committee of the IATTC, 9-13 May 2016, La Jolla, California. Document SAC-07-06b(ii)*.

Sosa-Nishizaki, O., García-Rodríguez, E., Morales-Portillo, C.D., Pérez-Jiménez, J.C., Rodríguez-Medrano, M.C., Bizzarro, J.J., et al., 2020. Fisheries interactions and the challenges for target and nontargeted take on shark conservation in the Mexican Pacific. *Advances in Marine Biology* **85**, 39-69.

Thompson, S.K., 2012. *Sampling. Second Edition*. John Wiley and Sons, New York, USA.

Vølstad, J.H., Christman, M., Ferter, K., Kleiven, A.R., Otterå, H., Aas, Ø., et al., 2020. Field surveying of marine recreational fisheries in Norway using a novel spatial sampling frame reveals striking under-coverage of alternative sampling frames. *ICES Journal of Marine Science* **77**, 2192-2205.

West, L.D., Stark, K., Murphy, J.J., Lyle, J., Ochwada-Doyle, F.A., 2015. *Survey of recreational fishing in New South Wales and the ACT, 2013/14*. University Of Tasmania, Hobart, TAS.

Table 1. Summary of data that can be collected from specific large-scale survey methods that can be applied to small scale coastal fisheries in the EPO with commentary on the advantages and disadvantages of each method. Complemented survey designs can be developed using two or more of these individual methods to compensate for specific weaknesses in each respective method. For comprehensive reviews of these, and other, sampling methods and their various biases see Pollock et al. (1994), NRC (2006) and Griffiths et al. (2010).

Survey method	Catch data	Effort data	Length data	Comments
Access point 'creel' survey	Precise trip-based catch rates for all species for inspected vessels	Precise fine-scale spatial and temporal effort data for inspected vessels	Precise fish length measurements possible for inspected vessels	Advantages - Highly precise measurements of catch, effort and fish lengths - Allows for collection of material for CKMR and biological studies Disadvantages - Estimates of total annual catch and effort requires expansion to total fleet from an ancillary survey or list frame (e.g., vessel register) - Length data cannot be extrapolated by effort by site or country - Extremely expensive to survey a representative sample of access points - Potentially dangerous to staff if a large proportion of vessels arrive at access points in the hours of darkness and/or at secluded locations Other considerations - Any unsampled vessels during the sampling day is assumed to have similar catch and effort as intercepted vessels
Access point survey (Roving or Bus Route)	Precise trip-based catch for all species for inspected vessels during a time block	Precise fine-scale spatial and temporal effort for inspected vessels during a time block	Precise trip-based fish length measurements possible for inspected vessels during a time block	Advantages - Highly precise measurements of catch, effort and fish lengths - Allows for collection of material for CKMR and biological studies Disadvantages - Catch and effort data collected from pre-defined sampling periods at each site assumed to be the same for unsampled time periods - Total annual catch and effort required to be expanded to total fleet from an ancillary survey or list frame (e.g., vessel register) - Length data cannot be extrapolated by effort by site or country - Extremely expensive to survey a representative sample of access points, at which only a fraction of each day is sampled - Highly prone to bias relating to length-of-stay of field staff at each location - It is assumed that the same number of vessels will be present at the site during each time block of the day and that any vessels present in blocks when staff absent will assumed to have similar catch, effort and fish lengths as intercepted vessels - Potentially dangerous to staff if a large proportion of vessels arrive at access points in the hours of darkness and/or at secluded locations Other considerations - Unlikely to be feasible if survey staff expected to use public transportation
Longitudinal diary survey	Precise trip-based catch rates for easily	Precise trip-based fine-scale spatial and	Fish length data unlikely to be recorded, but	Advantages - Low cost as access points do not need to be visited frequently (if at all) and fewer staff needed to maintain weekly telephone contact with each diarist.

Survey method	Catch data	Effort data	Length data	Comments
	identifiable species possible for all participating vessels, but dependent on level of training and frequency of contact with staff	temporal effort data participating vessels, but dependent on level of training and frequency of contact with staff	possible with training	- Precise measurements of catch and effort (and possibly fish lengths) with adequate fisher training - Very safe for staff since the majority of work is office-based. <u>Disadvantages</u> - Requires an initial on-site access point survey of representative sites to recruit diarists - Does not allow for independent collection of material for CKMR and biological studies, but possible with fisher training. - Estimates of total annual catch and effort requires total fleet estimates from ancillary studies or list frame (e.g., vessel register) - Length data unlikely to be recorded, needed from ancillary on-site surveys - Assume all diarists have similar fishing characteristics to unsampled fishers at each site, which may require small surveys to determine presence of 'volunteerism' bias. <u>Other considerations</u> - Possible refusal of fishers to participate if there is a strong perception the data will negatively impact their future fishing activities or if there is poor rapport with staff.
Retrospective recall survey	Total catch by fisher for the entire study period, but likely imprecise depending on recall period	Total effort by fisher for the entire study period, but likely imprecise depending on recall period	Fish length data unlikely to be recalled with reliable precision	<u>Advantages</u> - Very cheap to administer over large spatial scales (1000s of km) - Catch and effort data can be collected rapidly for long periods (e.g., 1 year) - Reasonably safe for staff as they only need to visit each site once <u>Disadvantages</u> - Studies will always be assessing fishing activity for the previous year(s) - Recall periods of >2 months result in imprecise estimates of catch, effort, fish lengths. - Using recall periods of <2 months requires more frequent on-site visitation, which dramatically increase costs - Estimates of total annual catch requires total fleet estimates from ancillary studies or list frame (e.g., vessel register) - Not possible to collect biological material for CKMR and biological studies - Length data unlikely to be recalled with reliable precision, unless recall period very short <u>Other considerations</u> - Possible refusal of fishers to participate if there is a strong perception the data will negatively impact their future fishing activities or if there is poor rapport with staff.
Aerial survey	Collection of catch data not possible	Precise instantaneous counts of vessels per site (or in situ) for a subset of days	Collection of fish length data not possible	<u>Advantages</u> - Can rapidly survey effort across very large spatial scales - Reasonably safe as pilots are trained. However, it may be dangerous in areas of known illicit activity. - Often highly cost effective given very few staff required <u>Disadvantages</u> - Only fishing effort data can be collected - Likely that total effort data can be collected, either at access points, or in situ - May be issues identifying fishing vessels from vessels undertaking other activities

Survey method	Catch data	Effort data	Length data	Comments
				- May be difficult to determine gear type being used - Not possible to collect biological material for CKMR and biological studies <u>Other considerations</u> - Continuous flights across jurisdictions likely not possible
Satellite imagery	Collection of catch data not possible	Precise daily count of total no. boats per site	Collection of fish length data not possible	<u>Advantages</u> - Can rapidly survey effort across very large spatial scales - Completely safe for staff as imagery is collected by satellite - Continuous surveys across multiple jurisdictions and potentially dangerous areas of criminal activity is possible - Generally low cost <u>Disadvantages</u> - Only fishing effort data can be collected - Likely that total effort data can be collected, either at access points, or in situ - May be issues identifying fishing vessels from vessels undertaking other activities - May be difficult to determine gear type being used - Not possible to collect biological material for CKMR and biological studies <u>Other considerations</u> - Level of precision of effort determination with be dictated by the available resolution of the satellite imagery
Vessel license frames	Collection of catch data not possible	Total no. vessels by jurisdiction	Collection of fish length data not possible	<u>Advantages</u> - Can rapidly enumerate total number of vessels across the entirety of each jurisdiction - Completely safe for staff to collect these data through formal contact with data custodians - Likely very low cost <u>Disadvantages</u> - Only total annual fishing effort data can be collected - Unlikely to determine the number of active fishing vessels - Not possible to determine gear type used by each registered vessel <u>Other considerations</u> - Access to data may be difficult if there are issues with data confidentiality - Ancillary surveys may be required if a reasonable proportion of vessels in the fishery are exempt from registration (e.g., for subsistence fishing)

FIGURE 1. An example of satellite imagery from Maxar Technologies showing a car parking lot at a resolution of 15 cm, demonstrating the potential for individual fishing vessels to be identified if used in the Americas. Source: https://blog.maxar.com/earth-intelligence/2020/introducing-15-cm-hd-the-highest-clarity-from-commercial-satellite-imagery

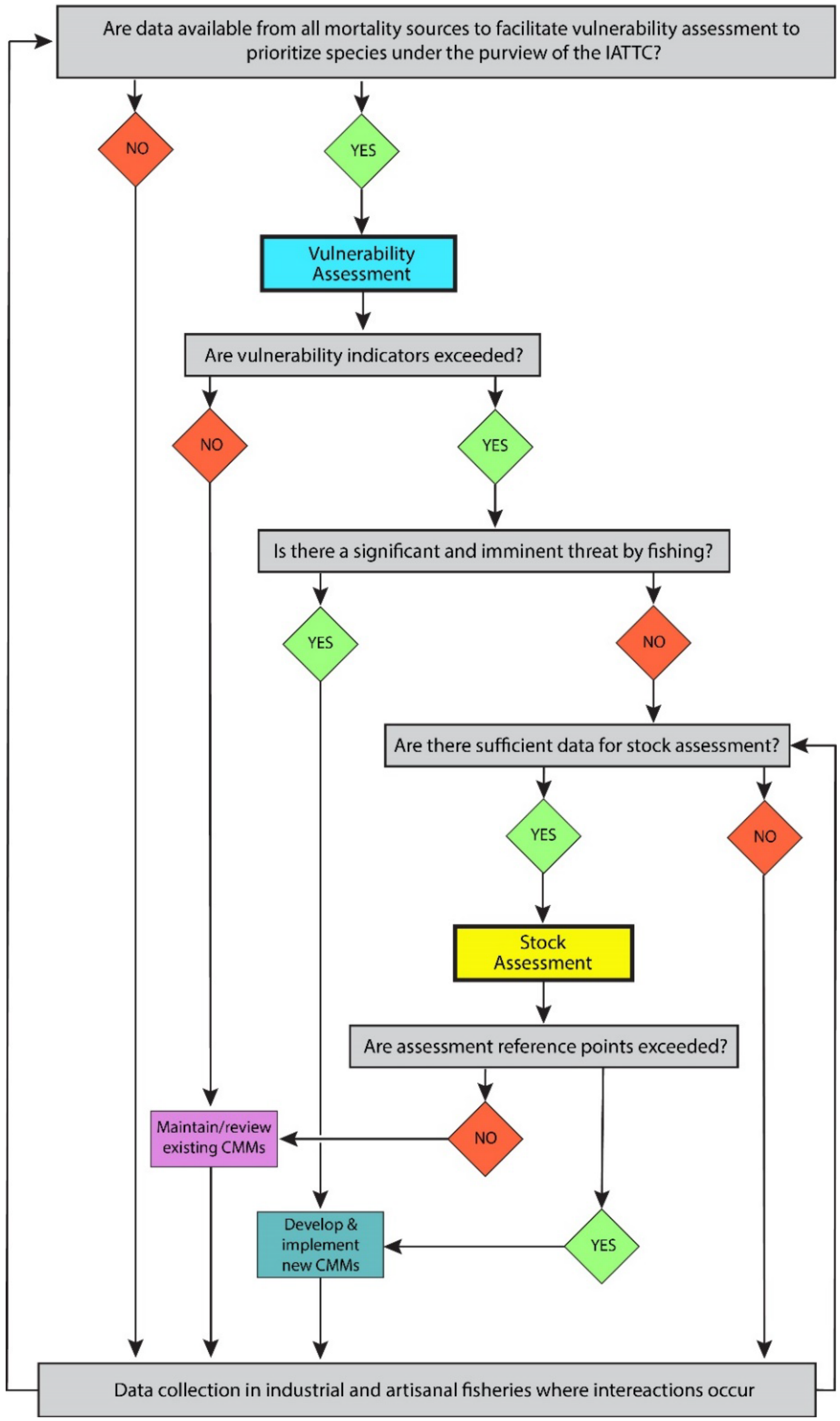

FIGURE 2. A proposed shark monitoring and assessment framework depicting a conceptual model of the integration of data collection with data-poor assessment models to prioritize shark species under the purview of the IATTC that are then subjected to conventional stock assessments, where required. The key to undertaking reliable assessments is the establishment of a data collection program for industrial and artisanal fisheries in the EPO.