Alternative methods to improve data collection in IOTC coastal fisheries: progress, pitfalls and priorities

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Background

The Indian Ocean supports the second largest tuna fishery in the world, with over 1 million tonnes caught annually. Here, coastal fisheries (operated by vessels < 24 m LoA exclusively fishing in the EEZ of their flag state[1]) are of significant economic, social, and cultural importance to many states and account for an estimated 50 % of all landings, while using only ~25 % of the fuel and sustaining 25 times the number of livelihoods compared with industrial vessels.

However, a focus on advancements in data collection, science and policy for the industrial sector has largely overshadowed the impacts of coastal fisheries while the importance of developments in this sector is increasingly being realised. Coastal fisheries catches are often dominated by neritic tunas, however, data for these species is inaccurate, incomplete and not provided in timely fashion, resulting in large uncertainty over the status of many of these species and associated catches. There is no substitute for good data collection (Giron-Nava et al., 2020), and the lack of accurate catch and effort data has been identified as one of the greatest challenges facing the Indian Ocean Tuna Commission (IOTC) Scientific Committee.

The IOTC requires that all fisheries are subject to an onboard data recording system (logbook), with specific data requirements outlined in Resolution 15/01. While coastal fisheries from developing CPCs were originally exempt from this measure, in recognition of the challenges faced, the Resolution states that data collection should *"be implemented progressively from 1 July 2016".* Yet this has still only been achieved by fraction of coastal states.

The IOTC has also established a Regional Observer Scheme (ROS) with the objective of collecting and verifying catch data and other scientific information through independent scientific observers (Resolution 22/04). As this is considered unrealistic for small coastal vessels, due to the general attributes of the fisheries which include large numbers of vessels, highly dispersed and remote landing sites and small sized vessels with insufficient space to host an observer (DFAR, 2021), they are exempt from this measure. However, all small vessels (< 24 m) that fish outside the EEZ are required to have observers onboard. Electronic Monitoring Systems (EMS) which uses onboard cameras has been used as a method to overcome the challenges of deploying human observers on vessels and the IOTC recently adopted standards for EMS[2] so that observer coverage may be complemented, or substituted, with

[1] As defined in IOTC Resolution 15/02

[2] Resolution 23/08

EMS[3]. But these standards were adopted for industrial fisheries whereas establishing EMS for the large number of small vessels on the high seas is more challenging. For small coastal vessels, Resolution 22/04 instead makes provisions for catches to be monitored at landing sites by independent field samplers (minimum 5 % of effort).

The resulting problem is that requirements are not being met as they are not considered feasible.

- 100% logbook coverage is still highly challenging for small vessels and
- deploying observers is still highly challenging for small vessels operating on the high seas

The result is that despite these resolutions being in place for over 13 years, data collection systems are still based primarily on sampling at landing sites, which is not capturing discarding (including non-target species interactions) or operational level data such as spatial information or gear configurations.

Given these challenges, there is an increasing need to evaluate data collection mechanisms that may supplement current information through other means. Recently there has been a welcome increase in the attention to the needs of coastal fisheries. Innovative methods and tools have been developed to yield new information and in turn strengthen traceability, governance and sustainability in this globally important sector. There are now numerous pilots underway across the Indian Ocean, trialling a range of new initiatives in different coastal fisheries. Because many of the trials are small-scale, findings are often not reported or otherwise communicated, which can prevent lessons being learned more widely. A lack of synthesis and cohesive strategy is lacking and limiting these schemes from learning from each other and hindering progress.

Objectives

This report aims to catalogue the initiatives that are currently being trialled or in place across the Indian Ocean and review these in terms of their successes as well as the challenges encountered. Specifically, what were considered enabling conditions for initiatives to be effective, as well as reviewing the main challenges and how these were overcome to derive some learning points to guide future initiatives.

The WPDCS has termed these new initiatives 'alternative' data collection methods. In this report, this is defined as data collection methods other than the standard requirements (i.e., onboard observers or field samplers as described in Resolution 22/04, EMS as described in Resolution 23/08 or logbooks as described in Resolution 15/01). As there are a limited number of completely new methods, the approach has been to be as inclusive as possible, so new electronic data collection tools (e.g. e-logbooks or mobile apps for catch sampling at landing sites) have also been reviewed.

Lack of formal recognition by the IOTC has also prevented progress in accepting data from 'alternative' data collection schemes and so this report also aims to review the validity of these alternatives wherever possible with the overall aim of improving the quality, coverage and diversity of information collected and reported by coastal fisheries.

The specific objectives of this study were to:

(i) identify and assess the current data collection systems in place, being trialled or being developed in coastal IO fisheries
(ii) assess the validity of these initiatives and the feasibility of implementing these as alternatives

[3] Resolution 22/04

(iii) synthesis findings and lessons learned

Approach

The approach used comprised a literature review followed by semi-structured questionnaires to gather information about the various initiatives taking place across IOTC contracting and non-contracting cooperating parties (CPCs) with coastal fisheries. Semi-structured interviews were used due to the flexibility they allowed to cover the range of different schemes and as previous attempts to email questionnaires had resulted in very low response rates[4]. A list of the questions included are provided in Appendix I.

Representatives from coastal CPCs were sent emails to introduce the project aims and invite them to take part in online meetings. Respondents were also requested to provide a list of datafields collected by the initiative (summarised in Appendix II) and to complete a budget summary (insufficient information was obtained).

A list of people who responded to the request and agreed to an interview is provided in Appendix III. This includes a range of stakeholders, including government representatives, NGOs and technology providers to obtain a variety of perspectives. As only one respondent was interviewed about each programme, there may be some associated biases based on the interviewee, their professional and personal perspectives, be they representatives from NGO, government or commercial entities. Nevertheless, the conclusions drawn attempted to draw together the key conclusions across a range of initiatives rather than relying on any single scheme.

Given the time and resource constraints of this study, interviews were all conducted online. The relatively high proportion of NGOs included was due to the large number of new initiatives that are being led by NGOs, as well as a lack of response from some government departments. For instances where no response was provided from any contacts whatsoever, a literature review was used instead.

The interviews were used to develop a series of practice-based case studies. These are studies that report from a real-life practice setting, providing a systematic narrative of the development and outcomes emerging from the experiential knowledge of stakeholders (Hardoon et al., 2021). This is a useful tool for disseminating transferable learning from the implementation of local programmes and summarising success, challenges and learning as well as any unexpected consequences. Reviewing a collection of case studies like this is beneficial because it demonstrates how similar activities work in different contexts, or how different activities can achieve similar outcomes to determine how activities can be rolled out, or adapted to different contexts (Hardoon et al., 2021).

Data collection systems

There are a variety of different approaches that are currently used to monitor fishing activities globally, depending on the fisheries, resources available and the objectives. These include:

- catch sampling at landing sites
- paper or electronic logbooks for documenting catches
- at-sea observers for assessing discards and biological sampling
- electronic monitoring systems
- fisher interviews

[4] The recent survey on Electronic Data Collection Tools which was sent out to all CPCs with coastal fisheries received only one response.

- spatial monitoring, including VMS (Vessel Monitoring System) and AIS (Automatic Identification System) [Not included in this report which focusses on Resolution 15/01 and Resolution 22/04]

Independent on-board observer programmes have generally been regarded as the most reliable means to assess discards and has been a mandatory requirement for IOTC industrial fisheries for over 12 years (IOTC Resolution 10/04).

Alternative data collection methods

The alternative data collection methods that were identified in this study fell under the categories identified by the Scientific Committee:

- skipper/crew reporting (with or without new e-technologies)
- simplified EM (cost-effective camera systems)
- sampling at landing sites (using new e-technologies)

Further technology developments included the use of handheld digital cameras for image capturing and emerging technologies such as machine learning and artificial intelligence to identify species or the most effective sampling strategies (Razzaque et al., 2021).

A brief description of the alternative data collection approaches that have been piloted or implemented in IOTC coastal fisheries is provided below including a summary of the main challenges faced and, if applicable, how these were overcome. This is based on the literature review and interviews with respondents so is not exhaustive. A summary is provided in Appendix II which can be updated following the WPDCS meeting. This section aims to review best practices and enabling conditions leading to successful implementation of data collection methods and lessons learned that can be applied more widely. It does not intend to provide a definition description of the data collection systems, as has already been provided by Feary et al. (2018), but instead focuses on evaluating the success of alternative initiatives and new e-tools. Cross-cutting issues have been drawn together so that key insights can be drawn from the range of experiences and used to expedite progress elsewhere.

Simplified EM

Mozambique

In 2022 WWF initiated a project to monitor catches of artisanal vessels in Mozambique with the aim of collecting data on ETP species interactions. Camera trials were carried out using technology developed by Shellcatch Inc.[5] on two artisanal gillnet vessels. Boats were very small (5 – 6 m in length) without sufficient places for camera attachment, so a local welder constructed a personalised stand for the camera. Technical issues resulted in a lack of footage available from the initial pilot trips, followed by further issues with data transfer, preventing further progress. The project ran for two months (April – May 2022) until project funding expired, however, the technical issues have not yet been fully resolved and so no data were available for review. The remoteness of the selected landing sites and lack of internet access were identified as key issues.

Fisher cooperation was a challenge as many were suspicious of the project intentions, suspecting information may be used for compliance purposes. This led to a lack of volunteers willing to have cameras fixed to their vessels. Another issue that had not been budgeted for was the request for financial compensation for participation in the programme. Previous development projects in the region

[5] http://www.shellcatch.com

have led to expectations of payment for participation, so financial incentives were necessary; cool boxes, project t-shirts and caps were provided. Nevertheless, there remained a general lack of trust from fishers which hindered all aspects of the project. While the MoF provided a licence for the activities, they had no other involvement in project, although it is intended that they will be was confirmed that they will be the ultimate beneficiaries of data. The project is currently on hold pending further funding, while plans are being prepared for future trials in a less remote region where there is a fishing community that is more receptive to the scheme.

Pakistan

In 2018, WWF-Pakistan began camera trials onboard vessels as an independent means of verifying data reported by fishers. Initially, two CCTV cameras were positioned onboard vessels and used to collect data, but this was not pursued any further due to a range of implementation issues including issues with power supply and the need to manually download data. There were also software issues which hindered data processing such as not being able to rewind and review footage and no established ongoing maintenance support for the systems.

Following these unsuccessful trials, the Shellcatch technology was piloted. This involved a single camera trial on one boat, focussed on the operational side of the deck and included user-friendly image processing software and ongoing support. Technical issues related to the very low light levels onboard at dawn during hauling resulted in poor quality footage so cameras were returned for customisation to include infrared technology to cope with the low light levels. These have now been developed and trialled but are yet to be piloted in Pakistan as the project has paused until further funding becomes available. The Shellcatch technology was preferred over CCTV due to its purpose-built set-up for small-scale fisheries including solar-powered batteries, WiFi capabilities, secure data sharing mechanisms and built-in AI technology, as well as the maintenance and support provisions (Sfeir et al., 2023). There were no data to review yet, and image quality has not yet been evaluated, however, it is expected to be good as species identification was possible from the initial CCTV footage.

Fishers were initially reluctant to have cameras onboard and did not want to maintain them due to privacy concerns, but access to the data monitoring screen and data visualisations proved to be of interest and incentivised participation. Other fisher incentives that have been linked to the ShellCatch monitoring systems include the price premiums gained through traceability initiatives. This has proved successful in Belize where fishers are linked to restaurants where consumers can scan a QR code to learn about the fish on their plate and the fisher who caught it. These incentives are important for fisheries which supply markets that are too small-scale to consider MSC certification. The technology is substantially less expensive than human observer programmes, with savings estimates ranging from 50% (Bartholomew et al., 2018), to 75-95%, depending on the fishery operations and country of implementation (Sfeir et al., 2023).

La Réunion (EU,France)

A camera solution for small vessels was piloted in La Réunion's coastal longline fleet between 2018 and 2019. This was developed as an attempt to overcome the ongoing issues with the deployment of observers onboard small vessels and to provide an opportunity to validate the skipper self-reporting programme[6]. Cameras were trialled onboard two longline vessels of 16 m and 21 m LOA as part of a large EU framework project to strengthen regional cooperation in fisheries data collection (RECOLAPE).

[6] It should be noted that as these vessels are < 24 m operating exclusively within the EEZ there is no mandate from the IOTC to deploy onboard observers; this is an internal EU requirement. Nonetheless, the experiences and lessons learned may prove useful for other coastal fleets.

The commercial developers, Marine Instruments[7], equipped vessels with the Electronic Eye (eEYE™) v6.2, a system which comprises three cameras recording images at a frequency of 0.5 frame per second, a V6 antenna with GPS connection and a network attached storage (NAS) installed into the wheelhouse to speed up image retrieval (Bach et al., 2019). Cameras were pointed at the working deck, the stern where the fishing line Is deployed and starboard side where for the line is hauled. Recording was triggered by a rotation sensor monitoring drum activity so both setting and hauling were monitored. Data were stored locally and then transferred offline at the end of the trip for dry observation.

The Beluga software developed by Marine Instruments was used by two desk-based scientists from the Institut de Recherche pour le Developpement (IRD) to review footage and process the images. Data have not been fully integrated into the ObServe database as not all datafields included in the ROS standards were collected, however, it was established that missing fields (eg, mainline material and diameter, branchline material etc) could generally be collected through alternative means, such as monitoring at landing sites (Bach et al., 2019).

Marine Instruments were responsible for technical maintenance of the equipment while crew were responsible for basic upkeep such as cleaning the lens and ensuring the view remained unobstructed. Data collected via cameras were compared with observer data (15 operations) (Bach et al., 2019). Total captures were very similar (r = 0.99), however, the camera footage resulted in a large proportion of unidentified individuals. For target species, estimates based on camera footage were only a little lower than estimates made by human onboard observers (<10%). But sharks were underestimated by 155 % as they were mostly unidentified (Bach et al., 2019).

Comparison of 26 sets with data self-reported by skippers showed the same trends, with high similarities in total catches and target species, but underestimation of discarded sharks and other finfish by the cameras. This is likely due to the fact that sharks were not generally hauled onto the deck for safety reasons. Interactions which took place in the water were therefore outside the field of view and unrecorded. An additional camera with a wide underwater lens installed next to the hauling door of the freeboard deck might be a potential solution to this issue, but identifying species under the water could still be challenging. Notably interactions with ETP species were well recorded by both schemes: both fishers and the cameras were able to document the occurrence of a single mammal and turtle interaction (Bach et al., 2019).

Calibration issues prevented the collection of length frequency data during the pilot, however this was rectified through proper installation on one vessel, highlighting that this could be possible in future. Results from this pilot indicated that for longline fishing, cameras need to be able to capture images at a frequency of 4 frames per second or higher during setting and hauling for image analysis. The camera system reduced the amount of time taken to monitor fishing operations by 67% so represents a saving in terms of number of hours compared with onboard observers, but also requires 3 or potentially 4 cameras per vessel. While the pilot was considered successful, no funding has been designated for ongoing implementation of the scheme.

Collaboration with fishers was also identified as an important consideration: "*This pilot study learnt us that the implementation of an electronic monitoring program (EMP) is not only the deployment of cameras on a fishing vessel. Before its implementation the coordinator of the program must to present properly the requirements of the program to the fishing industry and the crew of vessels involved. Afterwards, the implementation is going to be effective through a Memorandum of Understanding*

[7] www.marineinstruments.es/

(MoU). To be effective the EMP will need a collaboration of the crew to enhance the quality of the data collection, particularly to control the dirt of the lens of cameras".

Thailand

A Fishery Improvement Project[8] (FIP) for longtail tuna caught by the purse seine fleet was initiated by the Thai Tuna Industry Association in 2019. The main objective was to achieve the standards necessary for MSC certification by the end of 2024[9] for which a key challenge was obtaining independent bycatch information. A pilot project using cameras was initiated to address this but never materialised due to the high costs and problems with skippers willingness to volunteer vessels for inclusion in the scheme. Although outside the IOTC Area of Competence, this project provides an example where a market incentive might facilitate the implementation of a camera initiative. The FIP became inactive in 2022.

Sri Lanka

Cameras were piloted on Sri Lankan vessels as part of a project aiming to assist Sri Lanka in meeting its regional obligations to IOTC in terms of monitoring fisheries activities at-sea through scientific data collection and reporting (DFAR, 2021). The EM manufacturer Marine Instruments[10] worked in collaboration with SG Holdings Lanka Pvt Ltd, a local Sri Lankan technical service provider, on the equipment specifications and development. Four longline vessels (12 – 15 m LOA) were included in the trials. Three cameras were placed on each vessel with the aim of comprehensively recording all fishing operations (setting, hauling and processing). Calibration marks were drawn during installation to allow measurement of fish. Two hard discs (2TB) were supplied per vessel to provide data storage for several months of imagery, to be returned to Marine Instruments at the end of each trip.

Skippers and boat owners reported interference with vessel communication systems (jammed communications and unidentified noise) as well as noting unexpected battery drainage of the vessels (DFAR, 2021). This resulted in the devices being switched off by fishers so no complete set was recorded during the trials. Amendments to the equipment have been made to reduce noise and interference with other vessel communication devices and to reduce power consumption as the vessel battery capacity was not as large as expected. However, these were not trialled again as COVID-19 related travel restrictions prevented technicians providing the equipment to fix the installed units (DFAR, 2021). Dry observers were trained in the Beluga and Medusa software systems to process the video footage. Training was however virtual and incomplete, again due to travel restrictions at the time and more training has been identified as a need for dry observers.

Fisher cooperation was identified as a big challenge and prevented the piloting of any cameras on gillnet vessels. This is due to poor government relationships with fishers following gear restrictions, raised taxes and pressure to switch to pole and line methods. Fishers are sceptical that motives are solely scientific and so are highly resistant to cameras being placed onboard vessels, even as part of a pilot. Gillnet vessels also pose further challenges in terms of the lack of a suitable structure to attach a camera.

Despite the issues arising, the small amount of data obtained indicates that the scheme could be successful to complete several of the IOTC ROS data fields. Following completion of the IOTC project, DFAR has started working with a local technology firm, Zhindhu Holdings (Pvt) Ltd. They are located within the fisheries department, as they are the current VMS service providers so already have a good working relationship with fisheries officials and detailed knowledge of the vessels and their

[8] Fishery Improvement Projects (FIPs) are a market-based interventions which aim to facilitate transitions to more sustainable fisheries, however, success is mixed. (19) Fishery Improvement Projects (FIPs): A global analysis of status and performance | Request PDF (researchgate.net)
[9] INACTIVE Thailand longtail tuna - purse seine | Fishery Progress
[10] https://www.marineinstruments.es/

communications systems. A simpler method is currently being developed, based on the local knowledge of the vessels, structure and other electronic devices used onboard and needs of the fishery, including portability.

While equipment prices are similar, the more local company can offer much lower shipping costs with faster delivery, iterations are much easier to perform, vessels can be visited regularly, there is better knowledge of vessels and in-country support and maintenance. DFAR have stated "*The need of permanent local partner or trained someone from the DFAR is important for the technical support for installation and address technical issues*". One further pilot trip has taken place with a camera system set up onboard a longline vessel but was not successful due to GPS installation issues. Currently, DFAR and Zindhu Holdings are working together to install equipment on two vessels with oversight and remote assistance from Marine Instruments and IOTC.

While fishers were not happy about being filmed, boat owners see benefits in being able to monitor activities onboard their vessels, so while no market incentives have been identified, this may be sufficient motivation. The cost of cameras is substantial, however, and still too much for vessel owners so alternative solutions are being explored. To achieve 5% coverage of a fleet of ~1,200 vessels, 60 vessels require cameras at any one time so a shared camera ownership scheme is being discussed, whereby cameras would be jointly owned and rotated among vessels. Efforts are underway to develop portable equipment as a more affordable method of distributing the costs.

Discussion of simplified EM

Camera solutions or simplified Electronic Monitoring (EM) has been increasingly used in fisheries monitoring as an alternative method to obtain reliable information on bycatch and discards. One of the advantages of EM is that it can provide spatial information, from which main fishing grounds and effort can be estimated. Additional benefits include improved traceability, potentially resulting in price premiums, and incentivising better compliance and discard reduction (Rogers & Graff Zivin, 2022; van Helmond et al., 2020a).

In Indonesia, an onboard Crew Operated Data Recording System (CODRS) has been used to monitor catches from demersal vessels. This is a modified form of EM whereby crew operated hand-held cameras with GPS trackers to simultaneously record catch, time, and location. Although it was successful in meeting its objectives (length-based species information for stock assessment purposes, it was still highly resource intensive in terms of data analysis, equipment costs and remuneration of skippers (Wibisono et al., 2022).

In Peru, a pilot trial of cameras on small-scale vessels in the elasmobranch gillnet fishery provided proof of concept that EM can be highly effective at recording total catches as well as the genera of target catches (sharks and rays), however detection rates were lower for turtles and cetaceans (Bartholomew et al., 2018). One issue encountered that is specific to mixed species net fisheries was the difficulty with identifying and quantifying catches when large numbers of individuals (> 15) were hauled together and became piled up on deck (Bartholomew et al., 2018).

In Denmark, camera trials in the small-scale gillnet fishery were used successfully to monitor interactions with seabirds. Bycatch was identified to the species level in 98.9% of cases and bycatch rates could be estimated (Glemarec et al., 2020).

Of all the camera pilots that are underway in coastal Indian Ocean tuna fisheries, only the trials that have taken place for the La Réunion fleet are sufficiently long established to have data available for evaluation. Results showed good corroboration of observer and camera data for total catches, target species and ETP interactions, including turtles and cetaceans but shark bycatch was underestimated (Bach et al., 2019).

One of the greatest challenges of EM in industrial as well as small-scale fisheries is fisher uptake due to concerns over loss of privacy and mistrust of data usage (Mangi et al., 2015). Hence, stakeholder engagement, outreach and communication is the first pre-requisite listed for EM in tRFMOs (Pew, 2020). Collaboration with fishers has been described as a fundamental requirement (Ruiz 2018) to both improve understanding of fishers' concerns, but to also explore potential benefits, such as increased traceability, sustainability claims and market access which may enhance implementation on a larger scale (van Helmond et al., 2020a). Rigorous rules are required regarding use of the data and data protection, and placement needs to be mutually agreed, particularly in small vessels where lack of privacy is an even greater issue due to the more limited space **(SADC & WWF, 2022)**.

There is already a vast literature on the use of EMS for fisheries monitoring, focussed on industrial fleets (Fujita et al., 2018; Gilman et al., 2019; Michelin et al., 2020; van Helmond et al., 2020b), and standards have recently been adopted for IOTC fisheries. Even in industrial fleets, implementing EMS is never a "one size fits all" process (Fujita et al., 2018) and trials are key to testing proof of concept. This takes time and must be undertaken through an iterative and collaborative process to refine EMS to meet specific requirements (Ruiz et al., 2018). The challenges are even greater in small-scale, multi-species fisheries that span different gear types where an overly complex and expensive system has limited applicability (Wibisono et al., 2022). For coastal fleets, the challenge is balancing scientific rigour with limited resources so lower cost, simpler alternatives are being trialled. Holding coastal fleets to the same standards as industrial fleets would be disproportionately restrictive and could undermine efforts to monitor small-scale coastal fisheries.

Despite cost-cutting relative to industrial fisheries and some successful pilots, EM programmes have not been implemented widely in small-scale fisheries as comprehensive deployment has been hindered by the high price of equipment relative to revenues, the high number of vessels involved and the capacity of fisheries institutions to process and manage large quantities of image data (Bartholomew et al., 2018). While 100 % coverage of the fleet is usually a desired target, for coastal fisheries where fleets often comprise thousands of vessels, this is unrealistic. Sharing simple, more portable low-cost EM systems across several vessels may be more achievable (Michelin et al., 2020).

Fisher self-reporting

Various stakeholder groups have developed self-reporting systems for a range of purposes, with differing objectives and degrees of rigour. The following summaries provide an overview of the main pilots or programmes underway in the Indian Ocean describing key successes and challenges to develop lessons learned for other fleets planning to implement similar programmes **(Hartill & Thompson, 2016).**

La Réunion

The coastal longline fishery of La Réunion is dominated by small vessels[11] with insufficient space for onboard observers. In 2011, an alternative method of monitoring via self-reporting was developed as part of a collaboration between IRD and CAP RUN (Centre technique d'Appui à la Pêche RéUNionnaise, CITEB), within the EU Data Collection Framework. Fishers collect information and submit this to CAP RUN, receiving financial remuneration and a summary report of their activities in return (Bach et al., 2013). Through self-reporting, the small vessels achieve ~15 % sampling coverage. The contractors,

[11] In 2021, there were 19 active coastal longline vessels ≥12m and 21 <12m (IOTC-2022-SC25-NR06FE_EU.pdf)

CITEB, are responsible for managing the programme and ongoing support to fishers, data entry and compilation as well as developing the sampling strategy.

Fishers use paper forms to record information which is manually entered into a centralised database, ObServe, which also hosts the observer data and data recorded from scientific surveys, so the datasets are fully integrated. A debriefing process with the skipper is used to verify information and check for errors. Datafields collected are very similar to observer data, although no length-frequency sampling is conducted through self-reporting. Data are used primarily for analysing discarding, not for total catch estimation which is based on landings and logbooks. Data are submitted annually to the national and regional bodies. Prior to this formal submission, validation is undertaken using various scripts to check for outliers, bias and potential errors. As a further form of validation, a pilot camera trial was used to verify fisher reporting (described above).

Species identification is a key challenge so skippers are given training, particularly for bycatch species where their taxonomic knowledge is typically lower. Some species are aggregated into groups for reporting (e.g. mako sharks), species identification guides are also provided and photographic verification is an option, although this is not commonly used. The majority of errors are thought to be identified as part of the debriefing process.

Self-reporting forms have been designed to be easy to record and compatible with the workload of fishermen during fishing operations but nevertheless include a wider diversity and more detailed information than is required in logbooks, primarily regarding interactions with bycatch and depredation. The final selection of datafields is a compromise between observer data collection requirements, fisher knowledge and incentives for data reporting as well as national and international legislation (Bach et al., 2013). The result is a set of datafields that are very similar to observer requirements, but recorded at a lower taxonomic resolution and with the exception of biological information (Chevallier et al., 2015).

Engaging all fishers equally is also a challenge so there may therefore be some selection bias due to lack of involvement from certain skippers. Younger skippers who are more environmentally aware and engaged with sustainability issues and the science processes show greater involvement in the scheme. This creates some self-selection bias, although the relatively high remuneration for every reported operation aims to combat this bias. Despite this renumeration, self-reporting is much more cost effective than having scientific observers onboard which is 5.5 times more expensive for each set sampled. Another potential source of bias is the very small vessels (< 10 m) that may be under-represented in some years. This is due to the limited numbers of Time-Depth-Recorders used to track the depth of line setting as part of the self-sampling process, presenting logistical challenges.

Perhaps the largest caveat of fisher self-reporting is the non-independence of the data and so verifying the accuracy is seen as a key priority. Skipper training is seen as crucially important to success of the scheme, and so they are treated similarly to observers in terms of the regularity of training and rigour of debriefing to ensure the quality of the data. Studies comparing self-reporting data with simplified EM showed very good congruence between overall catch estimates and for retained target species and fisher self-reporting performed better than simplified EM at estimating discards of finfish and sharks due to a higher proportion of species identification catches (Bach et al., 2019).

Studies comparing the species composition of catches of observer data with self-reporting data highlighted the poor identification by both observers and fishers at the beginning of the scheme (2011 - 2012) as most billfish catches were unidentified. Increased training and distribution of species identification guides reduced the proportion of unidentified catch and resulted in fairly similar species composition in later years. There were still some discrepancies in species identification between fishers and observers which may have been due to low observer coverage or poor identification by fishers, however, poor fisher identification was considered to be the most plausible option (Chevallier et al., 2015). It was suggested that to reduce these types of error, expanding the training to include crew as well as skippers may be beneficial, in conjunction with using species identification posters onboard (Chevallier et al., 2015).

In terms of wider benefits of the programme, fishers have shown a greater awareness and appreciation of interactions with bycatch species which has improved logbook reporting. Fishers have also become more interested and involved in the monitoring, particularly through the use of TDRs which enable them to know at what depths they are fishing, and to adjust their fishing technique accordingly, creating another incentive for fishers to participate in the programme.

This programme covers the coastal longline fleet, while the smaller handline and troll lines (129 vessels <12m in 2021) are monitored through a combination of port sampling and logbooks.

Pakistan

In response to substantial gaps in Pakistan's fishery statistics, a "Crew-Based Observer Programme" was piloted between 2012 and 2019 by WWF-Pakistan for gillnet vessels ranging from 15 – 24 m LOA which fish in areas including the high seas. The aim was to provide information on bycatch species, including incidences of entanglement and mortality of cetaceans and other endangered, threatened and protected (ETP) species as well as to improve estimates of tuna and tuna-like species.

The idea originated from a skipper workshop held in 2011 where their excellent taxonomic knowledge of target species was noted and discussions that followed resulted in a recommendation from the workshop for self-reporting trials. These were established with the support of the ABNJ tuna project to help generate some of the information about the tuna fisheries of Pakistan required under IOTC Resolution 11/04 (Moazzam et al., 2021). The scheme enrolled 4 vessels in 2012, expanding to 100 by 2017, but came to an end in 2020 with the end of project funding. It is anticipated that it will restart under the upcoming ABNJ tuna project phase II (WGEMS02, 2022).

Data forms were designed by WWF-Pakistan in close collaboration with fishers who trialled them and provided feedback throughout in an iterative process. After each trip, crew members collecting data were interviewed by WWF-Pakistan in debriefing sessions in which trip details were reviewed. As part of this process, numerous questions were asked to confirm the reliability of data, identifying any potentially spurious figures, repetitions, omissions, outliers, and also checking against the fishers' own personal diaries/logbooks. As the scheme expanded it became integrated with the routine port sampling of fisheries officers from the Government of Pakistan, whereby WWF paid officials to also monitor the boats that were self-reporting as a form of debriefing and validation, however, this sampling was fairly limited. This combination of checking forms against photographs taken, post trip interviews and port sampling was used as part of a triangulation method of validation.

Issues identified during debriefing included instances such as changing gears or practices mid-trip, e.g., setting demersal rather than surface nets and not recording the change. These errors were generally identified based on the species composition of catches. Other errors included accidentally repeated figures, but intentional misreporting did not appear to be an issue. This was evident as a substantial amount of information that might be considered sensitive was reported and even documented on film, such as whale entanglements. In a technical review provided by a visit to Pakistan by the IOTC Secretariat, it was concluded that, given the lack of access to alternative data to validate the reconstructed catches, such as from logbooks or port sampling "verification of the trend and revised catch estimates is difficult to independently assess" (IOTC, 2019). No conclusions were made regarding the validity of the information. This has led to the development of a simplified EM programme as an attempt to validate crew reported data (see previous section).

Information was stored in the WWF office in both hard copy and electronic format (Moazzam and Khan, 2018), however, only a subset of information has been digitised due to a backlog in the cleaning and digitisation of data from paper forms which was further delayed by a system failure combined with a lack of back-up. Nevertheless, digitisation is continuing with the support of Duke University.

Wider benefits from the scheme were realised including the implementation of safe handling and release practices for ETP species. These practices, such as diving into the water to untangle a whale shark, were filmed and footage was often uploaded onto social media, attracting attention from local news outlets. This resulted in a large spill-over effect whereby best practices were taken up by other fishers not involved in the scheme who also started to film and report their releases. This created a social uplift within the previously marginalised immigrant fishing communities, with skippers regularly featuring in the news in positive stories which resulted in them achieving minor celebrity status and feelings of acceptance and integration within society. The government also took pride in the efforts and regularly promoted the work that was taking place. However, there were still tensions in place due to the government ban on large-scale gillnets (> 2.5 km) operating in the high seas and corresponding legal challenge by the fishing community.

While this initial publicity was very positive in terms of generating momentum and enthusiasm for the programme, the longer-term impacts are unclear. While fishers still sometimes upload images of good practices onto social media, this has declined over time and so it is unclear as to how widely these practices are still being used at sea. While these wider benefits are very positive for reducing ecosystem impacts of the fishery, the effect on data collection may be less positive. Given that vessels were essentially a self-selected sample, it is unclear how representative they were of the entire fleet and as best practices were promoted to those same vessels in conjunction with the launch of the data collection programme, this may have introduced further bias.

Social challenges included the amount of time taken to complete the forms, especially collecting length frequency data. Fishers were generally willing to measure target species, but not bycatch. Forms were under regular review by skippers and kept as simple as possible to reduce the number of additional requirements from crew as this would increase the expected payments from skippers. Fishers were given no compensation for cutting nets to release animals which they frequently undertook on a voluntary basis despite the high cost of nets. These costs had not been considered during the development stage so compensation had not been budgeted. While they were generally offset by the initial good social media coverage, the practices may not continue if the financial burden becomes too great.

Skippers undertook the data collection activities on a voluntary basis, but as an incentive, a financial reward was given to the fisher who had provided the most complete data. Initially there was a great deal of suspicion from fishers but multiple training activities and engagement workshops helped to build trust. This has gradually improved over time and now there is better mutual understanding about balancing the objectives of the scheme with fisher needs and priorities which has led to improved cooperation. Yet this has taken time and the information has not been used for compliance purposes. It is important to maintain transparency so that trust continues even if management measures are implemented based on the results.

South Africa

While there is a national logbook system in place for the small-scale sector as well as catch monitoring at landing sites, uptake is low and there is a substantial time lag in electronic data capture (Ngqongwa, 2022). In response to the poor data situation and marginalised fishing communities, a new initiative was established by 'ABALOBI' (which means "fisher" in the isiXhosa language), a public benefit organisation and social enterprise working with artisanal fishers with the combined aims of connecting fishers to markets and improving data collecting processes to strengthen governance (Wanless et al., 2021). It was established in 2014 and is based around a framework of electronic tools for mobile data collection and management including a 'FISHER' app for fishers to collect self-reported logbook type data, and a 'MARKETPLACE' app used to connect buyers with fishers who have reported catches using the 'FISHER' app.

It was co-designed with fishers and data enumerators to ensure intuitive, easy-to-use interfaces requiring minimal training to achieve proficiency (Wanless et al 2021). A substantial amount of training has taken place over a long time period in some communities to establish ABALOBI as the norm. Training workshops that involve learning about the experiences of fishers from other communities firsthand have proved very successful in terms of sharing learning, improving trust and inspiring other fishers to join the scheme. New ABALOBI support staff have been recruited from fishing communities to further increase the level of trust and respect among project staff and fishers.

Incentives for fisher cooperation are a key challenge, but the main mechanism is through improving market access. Fishers are charged a logistics fee to sell their fish via the platform which covers the cost of transporting the fish efficiently from landing site to restaurant. This is crucial for the long-term viability of implementing the platform so the benefits to fishers need to outweigh the financial cost as well as the time cost (ABALOBI, 2019). Another incentive may be the price premiums evoked from establishment of a Fishery Improvement Project (FIP), and the South African east coast rock lobster fishery provides an example of ABALOBI data collection systems contributing to the evidence base of impacts required for a FIP (ABALOBI, 2019). However, whether fisher self-reporting or landing site monitoring would be considered good enough evidence of impacts for a fishery which is known to have more bycatch or ETP interactions is yet to be established. For subsistence fishers in very remote locations, incentives for engagement are more limited. Reporting project outputs back to fishers has been very well received though and is another incentive for involvement as fishers have shown a keen interest in results and data visualisation of fisheries information as well as financial summaries to make more informed business decisions.

A major challenge is that the government has yet to formally adopted the scheme. Collaboration is increasing and government staff are now using the MONITOR app system for monitoring catches at landings sites. Although progress is being made in terms of collaborative efforts, formal recognition is only the first step and another hurdle will be aligning data systems so that data can easily be transferred from the data collection apps to a centralised national database. The ABALOBI platform uses standardised approaches where possible following the standards of the Global Dialogue on Seafood Traceability (GDST) to ensure interoperability between ABALOBI MONITOR and other platforms, allowing data exports to other databases. This is particularly valuable for meeting CPCs reporting obligations to the IOTC (Wanless, 2021). Some communities are still collecting data onboard vessels, while others have moved to a landing site monitoring approach. While the scheme has been bottom-up to date, government adoption of the system may be critical for longer term sustainability, using regulatory mechanisms as well as market incentives to maintain progress.

Limited smartphone ownership poses a challenge to the scheme as only 38 % of fishers own one, lower than the national average in South Africa. Data packages can also prove to be prohibitively expensive and in addition, some fishers still struggle to use the app successfully, especially those who are older with limited previous exposure to technology. ABALOBI attempts to overcome this by contributing to data costs, providing access to WiFi in the ABALOBI community centres/offices and providing in-person support in person from Community Engagement Officers based in the communities. While the ABALOBI support team provide all ongoing IT technical support and training, this is restricted based on the length of project funding available.

Wider benefits introduced by the scheme include the positive market incentive that has been created for the harvest of WWF-SASSI green-listed species. This is likely the result of active work by the ABALOBI restaurant engagement team to encourage chefs to support small-scale fishers by preferentially procuring what were previously considered 'low-value' species, the majority of which are WWF-SASSI green-listed (ABALOBI, 2019).

Seychelles

A Seychelles Conservation and Climate Trust (SeyCCAT) funded project was developed with a local company, Lansiv, and the commercial South African data application ABALOBI to support fisher livelihoods in Seychelles by improved value chain transparency through onboard self-reporting. Project inception began in 2017 and the pilot phase is now close to completion. The project is a large collaboration involving multiple partners including SFA, Lansiv, ABALOBI, the Fishing Boat Owners Association and CLS Telemetry contributing GPS tracking devices ('NEMO') that collect spatial data from participating vessels. The ABALOBI 'FISHER' and 'MARKETPLACE' mobile applications were customised for the Seychelles artisanal fleet through a series of workshops with fisher associations to streamline the questions and ensure relevancy for the fisheries. These were tested by the FBOA Chairperson as well as several fishers and further revised during fisher workshops. There are ~30 vessels involved in the scheme. Some basic validation takes place during fisher interviews, however, once the data are analysed, wider validation will take place as part of a project wrap-up workshop.

The CLS trackers should enhance the fishers' safety-at-sea by providing the ability to conduct live tracking of the vessels, an aspect strongly supported by the Seychellois fishers (ABALOBI, 2019). While the project was formally approved by SFA, lack of involvement thereafter has created issues with data ownership and use. There have been some difficulties integrating data for vessels using both the SFA vessel tracking system and ABALOBI data though an agreement has now been established and the project has been granted access to the vessels it is monitoring, while maintaining confidentiality of the remaining vessels. It remains unclear how ABALOBI daily catch logs will be integrated into the current data system for artisanal landings.

Fisher smartphone ownership is low and there was resistance to the monitoring of fishing and financial activities. The complexity of logging catches on the FISHER app was also raised by fishers. While IT support is available from ABALOBI, fishes were unlikely to try to access this. Direct data collection was eventually abandoned by the majority and the system has now moved to daily logs by Lansiv representatives based on phone interviews for all but four fishers.

The biggest overall challenge facing the scheme in Seychelles is the very high consumption of fish per capita and the destination of the majority of fish directly to the public rather than to hotels and restaurants. Given these very different market arrangements, the restaurant-supported fishery model developed in South Africa has not proved successful (ABALOBI, 2019). Seychelles has also recently implemented public health protocols and quality control measures for fish such that permits are now required to transfer fish from landing sites to purchasers. This combination of issues resulted in the value chain project component being abandoned, requiring amendment to fit the specific Seychellois context. This has undermined fisher incentives and so voluntary completion of catch logs was low as the complexity of selling fish on the app versus traditional method of roadside sale or directly to clients was not financially worthwhile.

Nevertheless, Seychellois are used to spending a considerable amount of time driving to different landing sites in search of fish, so ABALOBI are considering using the MARKETPLACE app to reduce this search time by enabling consumers to see exactly where and when fish has been landed. Modification of the mobile application could allow fishers to record their catch and use a digital platform to announce the presence of fish at a landing site, much like the traditional call of the lansiv shell horn, potentially benefitting both fishers and local buyers. A challenge with this approach is the very high variability in fish prices over short periods of time, meaning that fixing high fish prices for fishers is unlikely to work and these would still need to be negotiated on the spot with potentially increased competition (ABALOBI, 2019).

There has been interest from fishers in the expense tracking options offered by the platform which enables them to keep track of their business' expenses and transactions and monitor their annual performance as records for potentially accessing finances from banking institutions. Introductory talks have been held with national banks to establish whether the sales information contained in the FISHER logs might constitute evidence of income to support credit applications. Increased access to credit could enable fishers to sell to large tourism establishments which only buy on credit. This is to be explored further once a full year of data is available in the hope that it may provide the incentive crucially needed for increased fisher uptake. There are still many challenges to the development of a working model so to develop these areas further, the project is currently seeking funding to extend beyond 2024.

Thailand

In Thailand, all vessels are required to inform authorities of fishing trips prior to departure by completing a form in the Port-In, Port-Out (E-PIPO) mobile application. Arrivals are similarly self-reported through the app so that the trip length can be monitored for management purposes to ensure vessels do not exceed their annual allowances. These effort data are verified through random spot-checks at ports by inspectors from the Department of Fisheries to ensure that the submitted information is correct and to check data on vessel licences, reported gears onboard, vessel labourers and permits. This was established in 2015 due to the yellow card imposed by the EU, intended to crack down on and prevent IUU and labour rights violations. A mandatory logbook system is also in place for vessels 10 m - 24 m LOA to collect operational level information, including bycatch interactions. Verification of retained catch is carried out at landing sites by port samplers. A proposal has been developed for a transition to an e-logbook system, however, funding has yet to be obtained.

Indonesia

Logbooks were introduced to the coastal fisheries in Indonesia in 2012, however uptake has been very low. To help overcome this, in 2018, the Department of Fisheries developed an e-logbook solution, e-Logbook Penagkapan Ikan KKP, to assist data collection in the field. This comprises a dedicated mobile application that can be installed on fishers' smartphones. The electronic interface has been designed to be user-friendly and simplified with a reduced number of datafields compared with the reporting requirements for industrial fleets. Completion of electronic or paper-based logbooks is mandatory for all vessels > 5 GT, but implementation is low (Abdi et al., 2022). The logbooks are currently voluntary for smaller vessels (< 5 GT), while a simplified logbook is developed for them. This is integrated into a Fishing Logbook Information System incorporating data analysis and reporting. Data are stored offline and transferred when a signal is present.

The application was developed by IT technicians in Indonesia based on the original logbook requirements. Academics, industrial fishers and Department of Fisheries officials were all involved in product development, and trials further informed the refining of the system. This is an ongoing, iterative process with developments still taking place to align the system with different needs, including current work to update it with information required by the IOTC. A small number of smartphones were provided for fishers using USAID funding for trials during the development stages of the project, but now fishers are expected to use their own devices. 'Socialisation' sessions took place where fishers were introduced to the technology, training was provided and feedback was sought. A comprehensive data validation process is in place which includes comparison with different data sources where available (VMS data for vessels > 30 GT and port sampling data).

The main challenge is the low level of implementation due to a number of contributing factors. Many landing sites are very remote and lacking infrastructure such as laptops, internet connection and support staff. There has been insufficient fisher awareness raising or 'socialisation' which includes training and feedback on the systems with some ports having received nothing except a set of manuals. Species identification is also poor for most species other than the target catch. For very small-scale fishers using vessels (< 5 GT), smartphone ownership is also a problem, as well as limited fisher IT knowledge. For fishers unused to technology, the application has been reported as very stressful to use. As such, small vessels remain underrepresented and most data are collected by vessels 20 - 30 GT.

Fisher appreciation of the importance of data collection and cooperation have been increasingly recognised as essential for success of the data collection initiative. However there are limited incentives for fishers. Ecolabelling is one area in which fishers may realise tangible benefits from the data collection systems and MSC certification and FIPs have been implemented in some areas, although under the jurisdiction of the WCPFC (Anhalzer et al., 2020). Onboard observers are usually only deployed on large vessels, but can be deployed on small boats in case of issues with logbook data that require investigation or to encourage fishers to collect data. This has been supported by a local NGO, Masyarakat Dan Perikanan Indonesia (MDPI), who have been deploying observers on small boats to collect data on ETP species. However, numbers are extremely limited (Abdi et al., 2022). Financial challenges include limited budget for the ongoing updates necessary for the logbook system to continue functioning well and technical capacity to analyse the increasing amount of data being collected.

Sri Lanka

In Sri Lanka, electronic data reporting via e-logbooks is currently being implemented onboard gillnet and longline vessels < 18 m LOA which, combined with existing port sampling, is contributing to improvements in the timeliness and accuracy of catch estimates for small-scale vessels. This has been initiated as part of a scheme to collect observer data in high seas fisheries for vessels < 24m in length (Gunawardane & Phil, 2016). The system was introduced in 2012, then transitioned to an e-system in 2016 and by 2019 2,400 tablets had been distributed to fishers in support of the programme (Weerasekera et al., 2019). In 2018 DFAR introduced a 'local observer programme' on its vessels as an alternative to onboard observers for its substantial (> 1,200) fleet of vessels < 24 m registered to fish on the high seas (Weerasekera et al., 2019). Under this programme, fishers collect logbook data as usual but are also provided with tablets or digital cameras to collect images of each fish and also record the length and weight of each fish caught. At the end of each trip, these images are reviewed during debriefing sessions between skippers and data are manually recorded by DFAR officers in a local observer data collection book. Images and the associated information that is captured electronically (e.g. year, month, day, time, geo location) are extracted in excel format and submitted to DFAR with the local observer data collection books and set information is manually linked to the images. This scheme records approximately 120 trips per year.

Discussion of fisher self-reporting

While fisher-self reporting does not provide such detailed information as observer data and is not considered independent (IOTC-ROS2, 2019), it has substantial benefits, particularly for small-scale fisheries where fisher-led reporting on discards may enable more comprehensive, cost-effective sampling coverage (Mendo et al., 2022). Fishers often keep records of their catch for their own interest or for competition purposes (Moazzam pers comm.), but the utility of these data is often unknown or overlooked by fisheries managers. The development of self-reporting systems and regular reporting back to fishers can also lead to greater fisher engagement in the data collection process and better understanding of the scientific process (Hartill & Thompson, 2016).

Self-sampling by fishers has been shown to provide high quality, robust data, comparable with observer sampling, with improved coverage, accuracy and precision (Hoare et al., 2011; Mion et al., 2015; Prescott et al., 2016; Roman et al., 2011; Starr & Vignaux, 1998), even in an illegal fishing context (Mendo et al., 2022). In turn, collaboration between scientists and fishers can lead to a common knowledge base, leading to increasing agreement on management approaches (Mion et al., 2015). As Hoare et al. (2011) concluded *"it is the greater involvement of fishers in the assessment process that is the ultimate benefit of self-sampling programmes".* Nevertheless, self-reporting is unlikely to work well if there is an economic or regulatory disincentive to report, which may be the case when monitoring contentious, rare or protected species (Mangi 2015). In some cases, penalties for mis-reporting may be successful (Hartill & Thompson, 2016), but finding a common goal among fishers and managers is likely to be the best approach (Bradley et al., 2019). An example of this was where fishers wanted to assess the level of their impact as a way of evidencing their sustainability and legitimising their fishery (Mendo et al., 2022). With voluntary schemes, there is also uncertainty around representativeness suggesting that this information should be used to augment rather than replace existing data sources (Hartill & Thompson, 2016).

In addition to data quality, one of the biggest challenges facing self-reporting is motivating fisher involvement. While programmes can have good initial uptake, they often subsequently suffer from participation fatigue. Although initial participation may be high, data collected during this period is also usually unusable as it is collected during a training period so is therefore also associated with errors and missing data (Hoare et al., 2011). Mendo et al. (2022) observed that there may be methods to overcome fisher fatigue *"we believe that constant review of their submission data and frequent communication with them might have improved fisher engagement in reporting".* To maintain momentum, there clearly needs to be active and regular support for fishers for this kind of cooperative work to be successful. Sometimes financial and/or quota benefits create stronger incentives to participate, such as being provided with smartphones and data packages (Hoare et al., 2011). However, other important considerations include keeping processes simple and quick by using a mobile application with a user-friendly interface, only collecting essential information and collaborative design and testing (Mendo et al., 2022).

There are also issues with species identification, particularly for bycatch. In Pakistan this was overcome using smartphones to take photos for identification later, however, in La Réunion, although this was an option, fishers rarely took photographs. Photographic documentation would provide a good form of verification and ongoing learning for fishers but takes more time and a problem with any optional feature is, again, incentives.

Advances in sampling at landing sites: e-tools

Sampling at landing sites is the most widely implemented method of data collection in IOTC coastal fisheries. Surveys are conducted by field samplers with the purpose of collecting sample data on total catch and species composition, gear type and associated effort, and other secondary data such as fish size (FAO, 2002). To support sampling at landing sites (and self-reporting), there has been a recent proliferation of applications developed for mobile devices including smartphones and tablets (Calderwood, 2022). Mobile applications combine features such as GPS sensors, cameras, data transfer using wireless networks or offline data storage (Meyer et al., 2022). These offer benefits of increased usability in terms of being simpler to complete than paper-based forms, increasing efficiencies by saving time that would have been spent digitising records, allowing near real-time analysis of data and reducing errors. A summary of some of the new e-tools used for sampling at landings sites in IOTC coastal fisheries is provided below, based on CPCs responding to the information request.

South Africa

The ABALOBI-MONITOR app can be used by independent data enumerators at landing sites. The tool has is described above and in more detail by Wanless et al (Wanless et al., 2021). Enumerators using the ABALOBI-MONITOR app are paid government staff who can collect size frequency information as well as biological samples. These data can be used to validate information collected by self-reporting fishers.

Tanzania

A Fisheries and Aquaculture Information System (FAIMS) is used in Tanzania which has modules for Catch Assessment Surveys (CAS), Frame Surveys, economic impact assessments and fish marketing module, research module and potential fishing zone module. The eCAS System was developed by local developers from TAFIRI with funding from The Nature Conservancy (TNC) and WWF with the aim of improving the efficiency of data collection, particularly reducing the costs associated with travel of data enumerators from TAFIRI and MoF to landing sites to collect data in person. It is available in both web and mobile application forms which have been used since 2017. Participatory management takes place through legally established Beach Management Units (BMUs) and Village Fisheries Committee (VFCs) which enables fishers to be fully involved in the management process (Werema, 2022). Data are collected by fishers (BMU representatives) at landing sites on a voluntary basis. The Fisheries Ministry has recently issued smartphones to Collaborative Fisheries Management Areas to enhance data collection activities in selected regions, providing more of an incentive for involvement (Werema, 2022). Data are collected at ~106 landing sites out of a total of ~250, providing a high level of coverage.

Technical challenges include poor internet connectivity in some locations, undermining potential efficiencies by necessitating travel by enumerators. There are also a number of new landing sites that have evolved following changes in weather and fishing opportunities which so not have an established monitoring infrastructure. Some are large and potentially important, so there are concerns regarding the lack of monitoring in these locations. Interactions with ETP species and bycatch are reported, but only at landings sites, so the reliability of this information is unclear.

The success of the monitoring programme to date has been attributed to high involvement of fishing communities through local BMUs and VMCs during project inception which generated ownership of the project and its outcomes. The focus on capacity building rather than financial payments was also considered to have been a good strategy with a focus on encouraging participation through other mechanisms, such as joint ownership. The Ministry has been highly involved at all stages, coordinating work among partners so that it can be transferred entirely to the government on completion of the project by external partners, thereby ensuring sustainability. Fishers working with BMUs do so on a voluntary basis so introducing payments by the private sector would have undermined the feasibility of transferring oversight to the Ministry. Despite the lack of funding for BMUs, they are still perceived to be useful by fishers and the project has benefitted from the collaborative infrastructure that was already in place (Robertson et al., 2018).

Another key feature to which success is attributed is the high level of communication and feedback of results reported to BMUs. Reports and data analysis are produced by the Ministry of Fisheries on a regular basis specifically for BMUs, enabling them to take responsibility and use the information in a timely manner. This creates incentives to not only collect data but to collect good quality data. As tuna fishers migrate along the coastline to different management areas, they can compare catches and use this knowledge to validate and verify results. Nevertheless, as enumerators are volunteers, involvement is based on the time they have available. Sometimes this is taken up by fishing activities while at other times they divert their time to other projects which do involve financial compensation for time. This results in periods of inactivity in monitoring, causing patchy and incomplete data in some places.

Financial challenges include insufficient funding for smartphones to reach the new landing sites as well as replacement or maintenance of smartphones in currently reporting areas. Additional funding for fisher collaborative workshops is also needed.

Kenya

A mobile Catch Assessment Survey (eCAS) pilot project funded by WWF was implemented by the Kenya Fisheries Service (KFS) between June 2018 and May 2019 with the aim of strengthening tuna catch monitoring in the artisanal fisheries while reducing costs through minimising time spent entering, cleaning and analysing data. Vessels in the artisanal fisheries are 8 m LOA on average (Feary et al., 2018) using artisanal longline hooks, gillnets, monofilament nets and troll lines (Ndegwa et al., 2022). The eCAS app was developed by Fisheries Officers and IT technicians from KFS based on the open source ODK system and adapted to meet the needs of the CAS. The pilot scheme took place across four counties and 11 landing sites, representing a variety of gear-vessel fishery types. Data enumerators were trained and two were assigned to each landing site, equipped with android mobile phones, measuring boards and weighing scales (Mueni et al., 2019). The smartphones were used to take photos of any species that could not be identified and data were captured and submitted in real time via WiFi. The scheme ended on completion of the pilot following challenges with the high costs of data packages and the use of these for purposes other than data transfer, however, data collection via the eCAS resumed in 2020, supported by The Kenya Marine Fisheries and Socio-Economic Development (KEMFSED) project, implemented by the Government of Kenya, through the State Department for Blue Economy and Fisheries with support from the World Bank. this project is due to run until 2025. This has been further expanded to include training in mobile data collection for seven BMUs.

Mozambique

Mozambique has developed a Fisheries Statistics Master Plan with support from SWIOFish1 (2018-2021) with the objectives of meeting national and international reporting obligations. The plan involves the development of a more integrated information system that can support multiple data types for different purposes, piloting of the FAO OPEN ARTFISH data collection framework for artisanal fisheries (de Graaf et al., 2017) as a replacement for the PESCART database and capacity building of national staff in sample-based fisheries data collection following FAO guidelines (WorldBank, 2023). Fisheries sampling at landing sites now achieves 1 – 5 % coverage across all artisanal gear types (beach seine, handline, gillnets, purse seine and longlines) used on small vessels (< 10 m) (Mutombene et al., 2022). An onboard observer system also exists for slightly larger rod and reel and handline vessels (10 – 23 m), as well as longliners (often 23 m), reaching 4 - 5 % coverage. A logbook system is mandatory for all commercial vessels over 10 m length and recreational boats (< 8 m), however catch information provided by the recreational fishery is very limited (5%) (Mutombene et al., 2022). Operators report that tourists conducting sport fishing either refuse or forget to complete fishing catch cards despite it being a legal requirement, making it the least monitored fishery.

A new pilot data collection scheme has recently been initiated by WWF as part of the Management Oriented Monitoring System (MOMS). This is used to manage data collected using the opensource KoboCollect mobile application. MOMS agents collect data from fishers at landing sites through interviews and are paid by WWF for their time. These agents are from the fishing community and so have established good relationships with the fishers and built up a high level of trust. The accuracy of reported tuna and target species catches is thought to be good, whereas for bycatch and ETP interactions accuracy is considered low. Initial assessments have indicted a dramatic decline in the number of reported ETP species interactions which does not align with observations made during field visits to landing sites, where ETP species are regularly landed, and is indicative of growing levels of mistrust and misreporting. This is despite the sourcing of local agents from these communities who are trusted more than external researchers or enumerators.

Conversations with fishers have highlighted very different attitudes towards ETP species which do not align with government regulations for protection. The project is currently focussing on raising awareness of the objectives of government protection measures and working closely with Fisher Associations (CCPs) to share results. Nevertheless, given that ETP species are landed in this fishery and not seen as problematic, establishing common goals for both monitoring and management is a challenge. The government has not been involved in the programme so far other than to permit the activities, and while the ultimate aim is to submit data to the government, appropriate verification through community workshops is planned first.

Bangladesh

The coastal fisheries sector in Bangladesh is highly challenging, comprising 30,000 vessels under 12 m, with the majority < 6 m LOA. The fishery is dominated by gillnet vessels targeting hilsa during short (3-4 day) trips, while tuna are caught as bycatch. The 'Sustainable Coastal and Marine Fisheries Project' funded by the World Bank began 2018 with the objective of improving fisheries data collection for stock assessment (Feary et al., 2018). Through this, the Marine Fisheries Survey Management Unit (MFSMU) has trained 195 data enumerators to collect data across the 212 coastal landing sites, reaching close to 100 % coverage. In 2021, the Calipseo integrated fisheries data management system was introduced as a pilot scheme (FAO, 2023; Laurent, 2021) whereby data are collected using the opensource KoboToolbox system by enumerators at landing sites using tablets.

A further project aim was to extend Monitoring Control and Surveillance activities. To date, 1,500 Automatic Information System (AIS) devices and 8,500 Global System for Mobile Communications (GSM) devices have been installed on vessels. Enumerators use tablets to transmit data via WiFi to the MFSMU which stores and processes the data. This data includes the location of landing sites and coordinates from fishing activities from the vessels installed with tracking systems. Catch data covers all species caught, including interactions with ETP, however, as this takes place at landing sites based on fisher interviews, accuracy of this information will depend on fisher reporting. Biological sampling including length-frequency measurements are taken as well as socioeconomic information. Subdistrict fisheries officers perform initial data checking/verification before data are transmitted to a central database where they are further cleaned and validated.

The transition from paper to a fully digitised system been challenging for enumerators who have needed extensive training to familiarise them with the IT systems and data entry processes. The very high number of staff (195) to fully train in these items has been challenging, and the amount of work to clean, process and analyse the data is extensive while there is a shortage of technical knowledge.

Species identification has also been identified as a particular issue for enumerators. Another technical challenge is poor internet connectivity at some landing sites requiring offline storage and travel to the central office.

The main social challenge that has been experienced is the lack of fisher cooperation. Given the time taken for enumerators to sample catches and interview fishers about their activities, fisher cooperation is critical. Fishers were not involved in development of the programme and only engaged at the point of implementation. A number of initiatives have now been rolled out to raise awareness of fishers and local leaders and to clarify the programme objectives. In addition to these awareness raising initiatives which aim to promote fish cooperation, new legislation has been implemented making it legally binding for fishers to allow access to catch data for reporting and to cooperate with interviewers. As this is still relatively newly established, the success of these measures is not yet apparent.

The project will be ongoing until June 2025 after which the Department of Fisheries plans to integrate the data monitoring activities into its core programme of work, with the MFSMU taking on responsibility for monitoring at the end of the project. While this approach should provide a robust snapshot of information for this period in time, it will be financially challenging to continue with this level of near-total enumeration once the project has finished. It is envisaged that a sampling approach will be taken subsequently, using employees of the sub-district offices. A 10-year plan for action for the future of the artisanal fisheries data collection systems is currently being developed to address these concerns.

Comoros

In Comoros, fishing is entirely artisanal with the majority of fishers using traditional wooden canoes, while small, motorized, fibreglass vessels have been introduced over the last 20 years. The majority of boats are 3 – 9 m in length and mainly exploit pelagic species using trolling, longlines and handlines (DGRH, 2022). A project to improve coordination of the exploitation of the region's fisheries resources and to reduce annual economic losses was implemented under the SWIOfish1 World Bank initiative. This involved a tailored installation of OpenARTFISH linked to a mobile phone application based on the Open Data Kit (ODK) which is used by the Ministry of Fisheries (FAO, 2021). Tablets or smartphones have been used for data collection at landing sites by trained data enumerators employed by the Direction Générale de Ressources Halieutiques (DGRH) since 2017. Trip level, operation level and catch information are collected. Data are stored locally on the device or transferred via a mobile/WiFi internet connection when network coverage is available and the systems are maintained locally by Le Responsable du Système d'information Pêche. Notebook records are also kept by enumerators which are used to verify data entered into the application and database modules which detect logical errors are used to validate information. Limited connectivity at remote landing sites is a challenge. Fishers are generally willing to be involved in the monitoring process, although concerns about data privacy have been raised. The improved infrastructure that has been provided by the project and training on safety at sea has helped build trust and improved communication with fishers. Further awareness raising with fishers is planned to allow enumerators to better integrate into the fishing community.

In a separate initiative, the Comorian NGO 'Dahari' has partnered with ABALOBI and Blue Ventures to develop a project in Comoros using the MONITOR mobile platform (ABALOBI, 2020). It was introduced to community enumerators who found it easy to use, convenient and more efficient than paper-based systems. Workshops with fishers were held to find out what type of data analysis and visualisations they would be most interested in. This has provided the developers with more context as to what is needed from the application and established strong team working relationships among partner organisations and fishers. The project aimed to facilitate full transition to the ABALOBI MONITOR app in 2021, however it is uncertain as to whether this has yet been achieved, and government involvement is unclear (ABALOBI, 2020).

Thailand

In Thailand two types of port sampling take place for catch monitoring purposes. Total catches are collected through the Thai Flagged Catch Certification Scheme, a data collection and management system designed to improve market traceability and combat IUU. This system records 100% of catches by species group and weight, however, the species resolution is fairly poor due to the low capacity of port officials to identify catches to species level. Alongside the total catch enumeration is a science programme conducted by Department of Fisheries staff which involves sampling 10 % of catches from landing sites monthly. The species resolution of this dataset is high and is currently being used to improve national catch statistics by extrapolating species composition to total catches. Biological sampling and length-frequency data are also collected by scientists at port for national research programmes.

Madagascar

In Madagascar a range of applications for data collection at landing sites have been developed by different organisations. A key challenge with this is that they have each developed a different set of data collection procedures and systems and there is little coordination among them, resulting in limited overall use of the datasets.

The Ministry of Fishery Resources and Fisheries (MFRF) uses a tailored installation of OpenARTFISH linked to a mobile phone application. Data are collected at landing sites either digitally using smartphones or on paper forms (Fanazava & Rakotonjanahary, 2022). Fisheries officers from MFRF undertake monthly sampling from a limited number of landing sites. While these are trained staff who are competent in data recording and monitoring, there are a wide range of fisheries and ecosystems to monitor and they are not always aware of local contexts and do not have close working relationships with fishers. Due to limited funding, the MFRF is only able to sample 2 – 3 % of landing sites across 25 % of all marine districts (Feary et al., 2018).

Another mobile application for recording landings data was developed by WWF in 2018 based on the opensource Survey123 software for mobile applications. The scheme covers 25 landings sites where data collectors from the fishing community are provided with smartphones and paid a salary. Data are also still collected using paper forms, and these are collected periodically, collated and analysed with results that are provided as feedback to communities within Locally Managed Marine Areas. Fishers can query and validate results based on their local ecological knowledge and participate in the decision-making process for local fisheries management. Good trust has been established through these mechanisms as well as other income generating initiatives such as support seaweed farming and activities to reduce post-harvest losses. This is important as one of the main barriers to collecting size frequency data in Madagascar had been identified as the refusal of access to landings by fishers (Feary et al., 2018). Technical challenges include the inability to capture images within the application which hinders species identification, which is a key issue given that many species have multiple common names in Malagasy. Although the application is free, the server requires a licence fee to operate and this has now expired pending further funding.

A further mobile application was introduced by Blue Ventures using the ABALOBI system of e-tools with the aim of monitoring shark landings. However, as the development and support team are not based locally in Madagascar, any technical issues arising had to be resolved remotely which proved challenging. To overcome these issues, another data collection system was developed based on the open access Open Data Kit (ODK) software (FAO, 2021). Data collectors from the fishing community were provided with smartphones, paid a salary, and extra for every shark recorded as financial incentives for involvement, and data was collected multiple times a week. Notably, fishers were also paid for their time as they waited for data to be collected after landing (Jeffers et al., 2019).

An agreement has recently been signed between MFRF and other organisations supporting data collection initiatives (including WWF, Blue Ventures and WCS) to harmonise data collection approaches so that it is all digitised, centrally stored and validated together (Fanazava & Rakotonjanahary, 2022). While it may be challenging to establish common protocols and agree on a single IT system, this agreement should lead to numerous benefits, improving the comprehensiveness of data, as well as validity and accuracy. Ongoing challenge across all initiatives include expenses; the smartphones, solar chargers, data packages, payment for enumerators and sometimes fishers. In addition, unreliable mobile phone coverage can prevent landings data from being uploaded remotely and so regular data collection visits are often still required (Jeffers et al., 2019).

Pakistan

A mobile application, 'WWF PAK MARINE', was developed in 2021 by WWF for data collection by enumerators at landing sites and by fishers onboard. This is currently being introduced to fishers to adopt on a voluntary scheme to foster support for the initiative. Smartphones have been provided as part of a cost-sharing scheme whereby fishers contribute 25% of the total to incentivise data collection. While there is currently enthusiasm and support for the initiative, this momentum may wane with time and so the Government of Pakistan are now involved and may potentially adopt this as a national data collection tool in future (Razzaque et al., 2021). In addition to this e-log, WWF-Pakistan is collaborating with researchers from the University of Oxford to further develop AI/machine learning technology for species identification, focussing on CITES species (Razzaque et al., 2021).

Discussion of sampling at landing sites

Catch monitoring at landing sites is still by far the most universally implemented form of data monitoring and collection that takes place in IOTC coastal fisheries. The focus is on data priorities which are fundamental to stock assessment including total landings, species composition and length. Sampling at landing sites offers the most convenient and cost-effective method to obtain high levels of coverage (Brogan, 2002). Monitoring at landing sites includes a combination of sampling observed catches and fisher interviews through which more detailed information can be obtained regarding operational characteristics such as the number of gear deployed or the nature and extent of ETP interactions. The case studies provide examples of both of these methods of data collection at landing sites.

Direct sampling is considered independent, given that it takes place by independent data enumerators, but a major concern with this method of monitoring is the lack of information on discarded bycatch and ETP interactions. It is widely acknowledged that small-scale fisheries have low discard rates (~4%) (Kelleher, 2005), but despite this, there are growing efforts to quantify the discarding that is taking place as it is increasingly recognised that although the impact of an individual vessel may be low, the magnitude of their impact on the ecosystem can still be high given the vast quantities of vessels in the fleet. Fisher interviews are frequently used as a research survey method for estimating bycatch interactions (Kusuma Mustika et al., 2021), though they are not independent and subject to memory recall bias (Daw et al., 2011). Nevertheless, in the absence of alternative information, fisher interviews may provide the best data available.

Sampling at landing sites is a data collection approach that has been around for a longer period of time than many other types of monitoring, requires little input from fishers (although time can be precious at the critical moment of landing) and has often been mandated by government. Therefore, acceptance by fishers is relatively high compared with other methods of data collection. Key challenges include levels of sampling coverage which do not always meet 5 % due to the limited number of data enumerators and remoteness of some landing sites. While e-tools should ultimately provide costs savings in terms of improved efficiency, sufficient capital is required for upfront costs including the development of mobile applications, the provision of smartphones/tablets for data enumerators, ongoing updates to the application, data packages and cloud storage. Waterproof/rugged casing has also been identified as a need for onboard use (Meyer et al., 2022).

Evaluation of approaches

The Organization for Economic Cooperation and Development (OECD) Evaluation Framework was used to evaluate how appropriate the different tools are for IOTC coastal fisheries. These criteria constitute a cornerstone of evaluation practice, encouraging analysis of effectiveness and results rather than solely monitoring inputs and activities. The six evaluation criteria – relevance, coherence, effectiveness, efficiency, impact and sustainability - provide a framework to assess the approaches (Table 1).

Table 1. Benefits and limitations of alternative data collection methods

	Simplified EM	Self-reporting	Sampling at landing sites
Relevance	With clear objectives, the intervention can respond to national and regional needs and priorities for independently verified catch data. There is often a trade-off between national objectives which can prioritise target catches compared with funding partners who are often more focussed on bycatch or discards. This type of monitoring is therefore likely to be more relevant for organisations interested in bycatch. The system is particularly responsive to changes in data collection requirements as it includes comprehensive monitoring that can potentially be viewed historically to extract data for a difference purpose.	With clear objectives, the intervention can respond to national and regional needs and priorities for catch data. The system is somewhat responsive to changes in in data collection requirements as fishers can be trained and requested to collect different types of information and data collection systems can be altered, though this will take time.	With clear objectives, the intervention can respond to national and regional needs and priorities for independently verified catch data, including sampling. There is often a trade-off between national objectives which can prioritise target catches compared with funding partners who can be more focussed on bycatch or discards. This type of monitoring is therefore likely to be more relevant for national/regional management than some NGOs. There are a limited number of adaptations that can be made to the system as it is only landings that are monitored, however, fisher interviews can be incorporated if needed.
Coherence	As they are a relatively new development and information is stored and processed in a very different way (images), substantial effort is needed to integrate camera systems to achieve internal coherence with other data collection initiatives and databases within the ministry of fisheries. Achieving coherence externally with other CPCs may be easier if the same technology providers or software are used.	Logbooks are generally well established for industrial fisheries, but adapting the data collection processes, requirements and databases to meet the needs of coastal fisheries can require some modification to achieve internal coherence. Achieving external coherence can also be somewhat challenging given the huge range of different fisheries and metiers used by the coastal fisheries.	As most data collection systems are established based on port sampling, this is generally the most compatible with other data collection interventions in the fisheries sector. It is generally also the easiest to achieve external coherence among CPCs at the regional level as the data are usually coarser and already aggregated.
Effectiveness	Independence: Simplified EM is considered to be one of the most independent forms of data collection.	Independence: Fisher collected, so non-independent.	Independence: Involves direct sampling of landings by independent data enumerators.

	Data fields: Fairly comprehensive. Most bycatch interactions are recorded, though some may be missed. Generally needs to be combined with monitoring at landing to document vessel and gear information.	Data fields: Self-sampling can be the most comprehensive source of information of all as most information is possible for the fisher to collect. The main constraints are time, space and multi-tasking during fishing operations.	Data fields: Discards and ETP interactions are missed and operational level information is lacking. This is the only approach that includes biological sampling.
Efficiency	While lower cost than full EMS, these methods are still more expensive than other approaches. Time taken to review footage is shorter than for an onboard observer but can still be a very time-consuming process.	This is one of the most cost-effective methods of data collection, however, remuneration or other benefits should not be underestimated as fisher motivation is key to its success. Debriefing processes and data cleaning can take time but if electronic data collection tools are used then information should be transferred more rapidly.	This is fairly cost effective depending on the number of fisheries staff required and their remuneration levels. It can be very cost effective in cases where enumerators are volunteers. If electronic data collection tools are used then information should be transferred in a very timely way.
Impact	Overall impacts are low to-date due to the very limited implementation (not yet fully operational in any CPC) Once trialled successfully in more CPCS, the impact in terms of verification of other methods should be high.	Overall data collection impacts were relatively low to-date (fully operational with data reported to the IOTC by few CPCs) Once implemented more fully, it is likely to provide one of the most comprehensive sources of information in terms of both datafields and vessel coverage.	Sampling at landing sites has had the most impact to-date, being implemented more widely than any other type of schemes and so providing the most data. This is widely implemented and good for verified landings data well as providing broad coverage of the fishery.
Sustainability	For a scheme to be self-sustaining, it needs to be mandatory, enforceable and affordable or must benefit fishers sufficiently for them to opt in voluntarily. Ideally, systems would have both to guarantee sustainability. No pilots have achieved this yet.	Lack of fisher incentives has been the most critical factor in preventing pilots from continuing longer-term. This is crucial to ensure sustainability of schemes, and while work on this is progressing, there have been no successful examples fully established yet.	Sampling at landing sites has had the greatest longevity of all approaches. This is likely to be because they were introduced earlier than other data collection methods and typically have long-term government support. Community-led monitoring schemes encounter the same issues as other approaches in terms of incentives and sustainability.

Validity of approaches

The most robust means of evaluating a data source is to compare it with independent data that has been collected concurrently over a certain period of time, using a method specifically designed for that purpose, and analysed statistically. This kind of comparative testing is fairly common when assessing the objectivity of fisheries information. For Indian Ocean coastal fisheries, most projects are still at a very early stage of development so there is little data to assess the validity. The notable exception is the self-reporting scheme and EM trials that have been carried out for the small-scale longline fisheries of La Réunion (Bach et al., 2019; Chevallier et al., 2015). A triangulation of approaches using sampling at landing sites, self-reporting and cameras is also being carried out in Pakistan, Sri Lanka and in some parts of Indonesia with onboard observers, but the validation exercises are yet to be completed. Although the validity of self-reporting is often questioned, in practice monitoring at landing sites often involves fisher interviews which are subject to the same uncertainties (eg Iran, Table 3, Appendix II). Similarly, while cameras are generally considered the best practice for monitoring bycatch and ETP species, results from trials in La Réunion showed that fisher estimates of bycatch were more accurate than cameras (Bach et al., 2019). Ideally all initiatives will incorporate this type of objective comparative approach to assess the reliability of data collected.

Synthesis and lessons learned

No one-size fits all data collection approach

This review has highlighted the huge variety of data collection methods and tools that are already in place for the IOTC coastal fisheries with no single standardised system used in any two fisheries. By having a purely standards-based approach, this has encouraged innovation and cost-effectiveness by removing many barriers to new developments (Wanless, 2022). Commercial products developed specifically for artisanal fisheries now exist with demonstrated successes in small-sale fisheries. Even where tried and tested tools and methods in one fishery have been transferred to another fishery (e.g. successful camera monitoring using ShellCatch technology in the Peruvian gillnet fishery trialled in Pakistan and Mozambique, ABALOBI FISHER applied successfully in South Africa trialled in Seychelles or Marine Instruments successfully piloted in La Réunion and trialled in Sri Lanka), experiences have shown that substantial tailoring has still been needed to suit the situation and its specific needs. This is due to the huge diversity of fisheries in terms of the gear types and vessels, data collection methods, ecosystems they operate within, institutional structures, information systems, level of infrastructure, regulatory frameworks, market structures, languages, cultures and relationships among those within the fisheries sector. As such, there is no 'off-the-shelf' solution and some form of customisation is inevitably required.

While camera approaches are more cost effective than onboard observers, they are still more costly than self-reporting and sampling at landing sites and expense is the primary reason that no camera monitoring is currently underway in IOTC coastal fisheries. Nevertheless, the EM trials in La Réunion and Sri Lanka which incorporated three camera per vessel and collected most of the ROS datafields were not necessarily 'low cost' or 'simplified' EM, so further savings for these systems could be considered (albeit at the expense of some of the data). Comparing the cost of the alternative data collection methods any further is, however, problematic due to the high variability in approaches to renumeration that have been taken. The costs of the self-reporting programme in La Réunion where fishers are paid per operation is much higher than in Pakistan where it is undertaken on a voluntary basis with a few incentives of cash prizes included. In Sri Lanka and Thailand it is lower cost again, based on mandatory legislation. Similarly sampling programmes at landing sites may be resource intensive if carried out by paid government staff and if coverage is high (e.g. Bangladesh) compared with voluntary schemes with small bonuses included (e.g. Tanzania).

Wanless (2022) proposed that countries should *"establish standards for submissions and remain agnostic about the tools users choose",* advice that is even more pertinent to a regional body like the IOTC. This view is supported by Mendo et al. (2022) who observed that establishing the appropriate framework and conditions for data collection approaches to work successfully is more important than the exact nature of the underpinning technology. This is not to suggest that all new initiatives should start completely from scratch. Using established technologies developed specifically for small-scale fisheries and tailoring them is still likely to create greater efficiencies as well as leading to greater interoperability among systems. These may be commercial technologies such as ABALOBI, ShellCatch and Marine Instruments, or open-source software such as ODK or the Kobo ToolBox, or shared resources among CPCs with similar fleets, such as the logbook scheme established in Pakistan based on the data collection forms for gillnet fisheries operating in Sri Lanka (Moazzam, 2019). If the data collection forms and description/name of the technologies used are submitted to the IOTC Secretariat, as they are for the industrial fleets, and are hosted on the website, this will give other CPCs the opportunity to utilise these and share resources.

Iterative process

It is important to take an iterative approach and seek to continuously monitor the effectiveness of monitoring programmes and adapt as necessary based on feedback from all stakeholders (data analysts as well as data collectors). The most successful schemes are also the longest running, where methods have been adapted and refined over time based on lessons learned, indicating that time is also key to success.

Interoperability of systems

A common failure in many of the initiatives included in this report is the lack of interoperability of data collection systems. One specific example was the instance of camera interference with the vessel communications systems in Sri Lanka which undermined the whole effort as it ultimately led to the cameras being switched off. A more commonly encountered problem was data not being transferred to a coherent fisheries information system, sometimes where these were not compatible but at other times due to lack of coordination among organisations involved in data collection.

Government involvement

A number of the initiatives that have been established involve the government only to a limited extent, if at all. This is limiting the potential impact of these schemes by restricting the wider use of information beyond the scope of the project and reducing the overall impact it might have on management. Indeed, a workshop on low-cost data collection methods that involved governments and NGOs from the western Indian Ocean observed that *"national administrations are reticent to accept data from third parties without a comprehensive system in place to manage rights, access, etc."* (SADC & WWF, 2022).

Establishing initiatives in isolation with government support also makes duplication of efforts more likely as similar, competing schemes may be developed in parallel, thereby reducing efficiencies and lessening the potential for mutual learning. This has been taking place in Madagascar, but is now being addressed through an agreement which should lead to collaboration and harmonisation of approaches. But if government institutes and fishers are involved from the outset their priorities can be incorporated into the development stage. Projects that involve governments also have better prospects of long-term sustainability as government support is usually needed to maintain and update systems once project funding has expired (Hartill & Thompson, 2016). Even if governments are involved, they also *"require a "champion" decision-maker within the civil service to be successful "* (SADC & WWF, 2022). Governments also have the ability to implement legislation to support data collection initiatives, complementing incentives for data collection with regulatory backing. But token participation or just the granting of permissions for a project to be undertaken is not sufficient, as evidenced by the examples in this report. For new data collection initiatives to be successful, government priorities need to be addressed and projects need to have a clear goal or particular purpose to inform specific monitoring goals; reviews have shown that the establishment of clear objectives is a prerequisite for success (Michelin et al., 2020).

Locally developed solutions

Locally driven, developed, implemented and maintained projects are likely to be the most successful in the long term. A number of the case studies reported problems with the use of externally provided technologies, even when these have been developed specifically for small-scale fisheries. In Sri Lanka, delays in dealing with technical issues due to support teams being based remotely[12] and the high costs of shipping faulty equipment has led to collaborations with a local technology provider. Benefits include ease of communication, previous collaborations, good contextual knowledge and lower shipping costs. In Madagascar the ABALOBI app was trialled but abandoned due to the lack of local expertise and support. In-country solutions which include national technology providers and IT support services and lead or co-developers, ideally within the fisheries department, are more likely to progress quickly, be maintained, updated and sustainable in the longer-term.

Fisher involvement

The main challenges encountered across all case studies regardless of country, fishery, type of data collection initiative or technology used were social, based on overcoming issues of trust and lack of buy-in from the fishing community. This was so prevalent an outcome that it is clear that fisher engagement and support is not just a bonus or positive- side-effect of an initiative, it is the most fundamental pre-requisite or enabling condition for any project to have the potential for successful. Even for industrial fisheries in developed nations where vessels are large and limited in number and enforcement is good fisher involvement has still been described as vital for the successful implementation of EM systems (Fujita et al., 2018) and is the number one key element in the Pew guide to designing an EM programme (Pew, 2020). For coastal fisheries in the Indian Ocean, the challenges are much greater and schemes cannot rely on government enforcement alone. Fishers need to be fully engaged and supportive of any initiative for it to possibly succeed. A key conclusion of the western Indian Ocean workshop on low-cost data collection methods was that *"projects with national governments will have a higher probability of success if participatory and/or co-management approaches to fisheries management are meaningfully woven into pilots*" but also that "*fishers are often/usually excluded from decision-making"* (SADC & WWF, 2022).

Transdisciplinary approach

While it has been increasingly recognised that fisher involvement is crucial to any data collection initiative, this has often remained implementation focussed. Emphasis was placed on fisher awareness raising, capacity building and training which are required due to low educational levels of many members of the fishing community and incentivising fishers was also a key challenge discussed. Rather than tackling these issues separately, a transdisciplinary approach to management is adopted that is

[12] Enhanced by COVID-19-related travel restrictions at the time

centred on collaborative problem-solving among fishers, managers and other stakeholders could overcome these simultaneously (Bradley et al., 2019). Transdisciplinary management is initiated by establishing shared goals among stakeholders. Specific concerns and needs may vary across stakeholders, eg, for fishers bycatch creates inefficiencies by reducing target catch and may result in fines, for managers it creates a regulatory problem if ETP species are involved, for traders it may undermine traceability efforts to market products as sustainable (see Figure 1). But underlying all of these concerns is a common goal, and if this can be established, then it can then be acted on (Bradley et al., 2019).

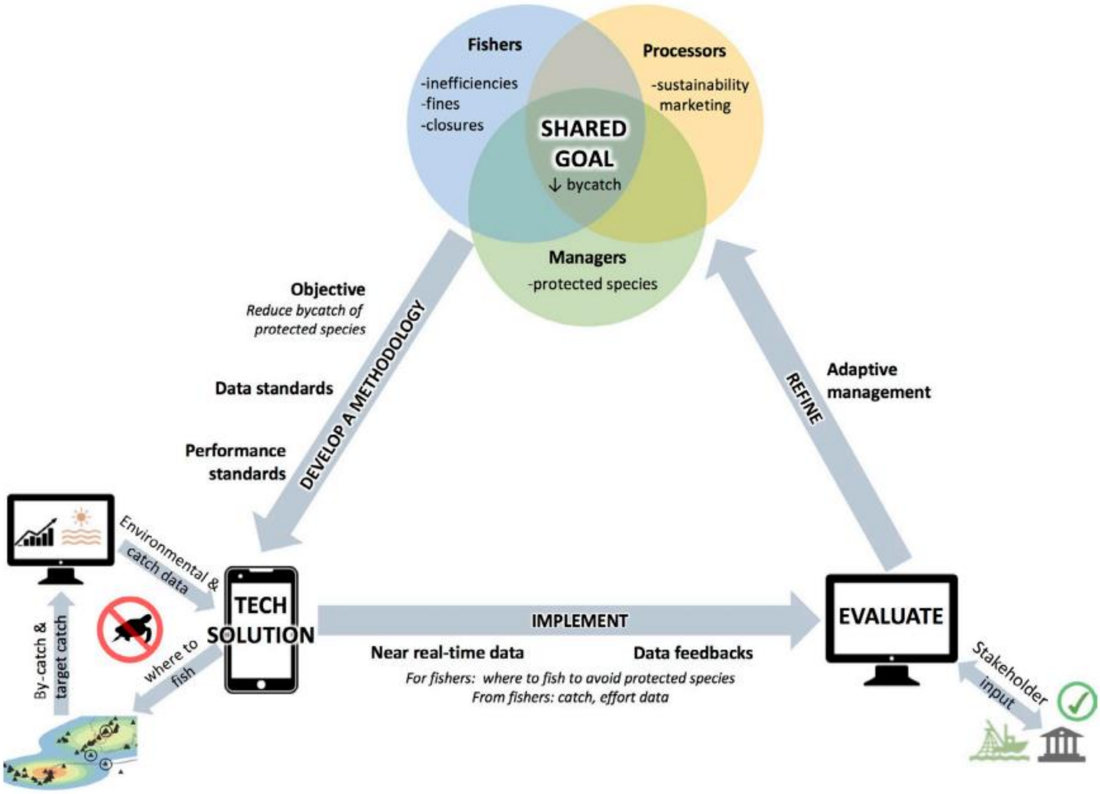

Figure 1. A conceptual figure showing the process of transdisciplinary fisheries management as a pathway to the adoption of new high-tech fishery-dependent data collection systems (with the shared goal of bycatch reduction used as an illustrative example) (from Bradley et al., 2019)

This is followed by defining specific objectives and developing a method to address these, with agreed actions and steps to follow for mutual review, feedback and action towards a shared solution (Mangi et al., 2015). Inclusion of all stakeholders from the outset, on an equal basis, is what distinguishes this as a transdisciplinary approach (Bradley et al., 2019). This is based around trust which takes time to build but is essential for schemes to work. Where relationships between fishers and managers are poor, intermediaries such as NGOs may play a useful role in bridging communications gaps. The collaborative process, shared decision-making and collaborative design of initiatives aim to create transparency and a sense of fairness, which may increase the likelihood of engagement, activity and compliance, eg, fishers are more likely to use a self-reporting tool if they have been involved in its design and testing as they should then find it more intuitive and easy to use (Hartill & Thompson, 2016).

Experienced researchers who are familiar with national and regional reporting requirements should also be involved in the collaborations and design of the data collection scheme from the outset. This will help to ensure that the data collected are scientifically rigorous and fit for purpose while communicating the reasons for tasks which may otherwise appear needlessly onerous, reducing the motivation for participation (Hartill & Thompson, 2016). The SADC workshop (2022) recommended that projects should ideally include a variety of expertise through contributions from multiple national departments, CSOs, donors and multilateral organisations such as SADC and IOTC.

Effective and transparent communication are also key, helping to build trust (Mendo et al., 2022). Maintaining transparency and managing expectations is also important, particularly if contributions are voluntary. There can often be a mismatch between the short-term expectations of fishers and the more medium-term delivery from the scientific process as well as fisher expectations that participation will lead to positive outcomes in the form of increased fishing opportunities, which may not necessarily transpire (Hoare et al., 2011). This is why mutually agreed goals, transparent approaches and mutually agreed upon standards for information use are so important. This includes feedback of data and results to all stakeholders as an essential part of the collaborative process (Bradley et al., 2019).

From the experiences described in this report, it is clear that data collection systems are very likely to fail if there are no perceived benefit to fishers. Key successes have been observed in cases where a transdisciplinary approach has been taken, which has prioritised fishers and livelihood improvements from the project outset and fishers have been involved continuously throughout development and implementation (e.g. projects in Tanzania, South Africa and Madagascar). These initiatives have taken time but have built strong levels of trust. Incentives may include improved safety due to electronic devices with GPS and communications (e.g. Seychelles), weather forecasting capabilities, direct financial benefits (e.g. Madagascar), increased effort allocations (Hoare et al., 2011) better fishery knowledge which can be utilised to improve operations or for local management (e.g. Tanzania) or market-based motivations (e.g. Indonesia). These have worked best when they are defined as part of the objective setting stage, rather than being considered later.

A well-established framework for leveraging fisher benefits from improved data recording is through the development of Fishery Improvement Projects (FIPs) that works towards obtaining Marine Stewardship Council (MSC) certification. These work in fisheries which have clear markets where demand for sustainable products is high but are less effective for fisheries with smaller-scale marketing arrangements. In these instances, schemes (including ABALOBI and ShellCatch) aim to connect buyers with fishers directly, increasing fisher remuneration by cutting out middle-men and focussing on high-end outputs such as restaurants where consumers will be willing to pay a price premium for knowing that the product is sustainable and local (Wanless, 2022). These have worked well in some cases, such as certain projects in South Africa and Belize, but due to the very different market conditions among different fisheries, specific approaches need to be developed to suit the specific circumstances.

Fisher needs and benefits need to be considered from the outset. Benefits need to be concrete and sufficient to ensure sustainability. If the data and the data collection process have no value to fishers, then participation in data collection programmes and data technologies are likely to be met with resistance (Bradley et al., 2019).

Capacity building and training

A common pattern observed during implementation of projects was the greater level of resistance from older fishers than those from younger generations, who were generally both more environmentally aware as well as more technology literate. Where older fishers predominate within a fishery, schemes need to consider this and adapt programmes accordingly. Insufficient training was widely cited as an issue across programmes, with the amount of time taken frequently underestimated, or considered to be something undertaken at a fixed point in time, rather than an ongoing process. The most effective schemes did not implement one-way training, but instead had a series of ongoing workshops which were two-way in terms of providing support where needed as well as taking on feedback regarding problems and suggested improvements, such as in Pakistan. Cases where this was combined with feedback of data for discussions proved the most effective of all as results were reviewed, considered, validated, adapted as necessary, and served as motivational drivers to continue with the data collection.

Supporting national infrastructure

Improving critical national data infrastructure has also been listed as essential to ensuring success of incorporating new data collection technologies (SADC & WWF, 2022). National information systems need to establish comprehensive Fisheries Information Systems which can handle multiple data types from different sources in a coherent and cohesive way. Smaller-scale support to infrastructure at landing sites is also needed including providing an internet connection where this is needed for data transfer and access to electronic devices such as laptops, tablets or smartphones.

Species identification

Problems with species identification was a cross-cutting issue recognised across almost every initiative. Incorporating images of species within data collection applications to facilitate better identification was recommended in some cases (Abdi et al., 2022), as well as allowing fishers to take photos when verification was needed, improving the resources available to support identification onboard as well as increasing training activities. Ultimately automated catch identification through AI and machine learning techniques are likely to be able to improve this substantially, but this has not yet been implemented successfully in any fishery reviewed (Razzaque et al., 2021).

A combination of approaches

The best approach and most appropriate technology to be used for data collection will depend on the specific objectives for each fishery. Results from the case studies and literature review indicate that each type of data collection approach has its own particular drawbacks. Even within a single approach (e.g. low-cost cameras), outcomes can be very different depending on the fishery, gear and target species. Cameras used to monitor the La Réunion longline fishery estimated turtles and cetacean interactions well but underestimated shark catches (Bach et al., 2019) while camera systems used in the Peruvian gillnet fishery estimated sharks with good accuracy but underestimated turtle and cetacean interactions (Bartholomew et al., 2018). No method is 100 % accurate, precise and independent while providing comprehensive coverage. As the specific limitations vary depending on the approach used, the most appropriate strategy may be to use a combination of complementary approaches and tools (Mangi et al., 2015). Once there is a collective understanding of the monitoring objectives and limitations within a specific context, the best fitting approach or combination of approaches can be adopted to obtain more comprehensive and reliable data.

Tables 3 - 5 in Appendix II show the range of datafields that are currently collected using the various approaches. However, for the adoption of multiple approaches to work, fully integrated Fishery Information Systems are needed. The implementation of new fully integrated Fishery Information Systems that assimilate multiple layers of fishery data may be more efficient than trying to improve inefficiencies in older systems. An example of this being used in tuna fisheries by members of the Parties to the Nauru Agreement (PNA) is a Fisheries Information Management System (FIMS[13]) which can

[13] FIMS — Fisheries Information Management System (ifims.com)

combine observer data with port sampling information and electronic logbook entries among others. While these are generally being used in data-rich contexts, these are ideal for the complex needs of small-scale fisheries, particularly where data infrastructure is currently lacking (Bradley et al., 2019).

Possible approaches moving forwards

This review highlights the huge variety of fisheries, contexts and approaches and tools that are currently being trialled, tested and implemented across the Indian Ocean. While this is challenging for regional data aggregation, science and management processes, it has emerged out of necessity as it is clear there is no one-size-fits-all approach to fisheries data collection.

Supporting and enabling legislation alongside specific capacity building initiatives is needed to encourage progress in data collection in coastal fisheries, and the Scientific Committee has requested the WPDSC to evaluate the validity of alternative data collection tools as potential alternatives to onboard human observers, in recognition that this is more appropriate than restricting progress by maintaining requirements that are simply not feasible. The IOTC has stressed the important of accurate catch data (Resolution 22/04[14]) and effort data[15] (Resolution 23/08). Given these are the priorities for data collection initiatives, some suggestions for the consideration of the WPDSC are outlined below.

Finer distinction among coastal vessels

The examples described in this report indicate that even within a single fleet, different approaches to data collection are being implemented for vessels of different sizes. For example, in La Réunion and Sri Lanka, cameras were trialled on vessels > 15 m and > 12 m respectively, logbook reporting in Indonesia is only mandatory for vessels > 5GT and in Thailand fisher self-reporting only takes place on vessels > 10 m. This demonstrates that even within the coastal fisheries there are finer-scale distinctions among vessels that further determine the feasibility of data collection methods.

The newly adopted vessel definitions (Table 1) create a finer characterisation of coastal vessels, based on size, purpose and area of operation, with less ambiguity (IOTC, 2022). In particular, vessels 15 - 24 m operating on the high seas are now classified as semi-industrial rather than industrial in recognition of the importance of the size difference. Following these changes, it is proposed that data collection requirements follow suit by using this finer distinction among vessel types. Several IOTC resolutions are applicable to authorised vessels only, many of which are related to the collection and provision of fisheries statistics to the IOTC (including Resolution 15/01 and Resolution 22/04). This fairly coarse distinction has resulted in requirements which are not practical for many coastal fisheries and so it is proposed that the newly adopted vessel categorisations are used as the basis for developing more specific data collection requirements. Minimum datafields are also proposed which is essential for the standardisation of data that are to be aggregated regionally, while not being overly prescriptive to the point of limiting activities.

[14] *: "to collect verified catch data and other scientific data related to the fisheries for tuna and tuna-like species in the IOTC area of competence"*

[15] *"the importance of collecting sufficient verified catch data and effort and other scientific data related to the fisheries for tuna and tuna-like species in the IOTC area of competence to enable the Scientific Committee (SC) to provide the Commission with scientific assessments, advice and recommendations"*

Table 2. Definitions of IOTC fishery types. EEZ = Exclusive Economic Zone. AFSs = Authorised Fishing Vessels (IOTC, 2022).

Purpose	Vessel size	Area of operation	Type	AFVs
Recreational	< 24 m*	Flag state EEZ only*	Recreational	NO
Subsistence	< 15 m*	Flag state EEZ only*	Subsistence	NO
Commercial	< 15 m	Flag state EEZ only	Small-scale	NO
Commercial	15 – 24 m	Flag state EEZ only	Semi-industrial	NO
Commercial	< 24 m	Includes other EEZs and / or high seas	Semi-industrial (ABNJ)	YES
Commercial	≥ 24 m	Anywhere	Industrial	YES
Scientific	≥ 24 m*	Anywhere*	Exploratory	YES

Industrial vessels

Industrial vessels are defined as commercial vessels ≥ 24 m fishing anywhere in the IOTC Area of Competence (IOTC, 2022). It is proposed that only these vessels are required to have onboard observer coverage as set out in Resolution 22/04.

Proposed amendment: vessels < 24 m would not be required to have onboard observer coverage or full EMS.

Proposed datafield requirements: Current IOTC data collection requirements

Semi-industrial and recreational vessels

For semi-industrial vessels (< 24 m operating beyond the EEZ or 15 – 24 m within the EEZ) and recreational fisheries, a combination of alternative data collection methods (low-cost cameras, self-reporting and sampling at landing sites) has been demonstrated to be more feasible.

Proposed amendment: a combination of simplified EM with sampling at landing sites (necessary for obtaining gear and vessel information) and self-reporting with sampling at landing sites (for verification). i.e.

(simplified EM with sampling at landing sites) + (self-reporting with sampling at landing sites) = 5 %

Proposed datafield requirements: simplified EM and self-reporting to follow logbook requirements in Resolution 15/01 as a minimum, while sampling at landing sites follows requirements in Resolution 22/04[16].

This proposition allows flexibility for each CPC to determine the most appropriate form of monitoring in the form of simplified EM or self-reporting. Sampling at landing sites is necessary alongside simplified EM to provide missing information, while also providing verification.

For the long-term sustainability of these measures, fisher or fisher organisation incentives are a fundamental requirement. Most of those that are self-sufficient (eg ABALOBI MARKETPLACE app and ShellCatch Fresca Pesca/Fish Right to East Right schemes) are targeted at commercial fishers who sell catches, so this would be unlikely to work for very small-scale, subsistence fishers at the most remote landing sites.

[16] *"Field samplers shall monitor catches at the landing place with a view to estimating catch-at-size by type of boat, gear and species, or carry out such scientific work as may be requested by the IOTC Scientific Committee".*

Small-scale commercial and subsistence vessels

For vessels smaller than 15 m fishing within the EEZ, even these approaches have generally been considered too challenging and in reality, almost no fleets are achieving this for small vessels. Most schemes that have attempted them have resorted to monitoring at landing sites. The requirement for these vessels is that *"Field samplers shall monitor catches at the landing place with a view to estimating catch-at-size by type of boat, gear and species, or carry out such scientific work as may be requested by the IOTC Scientific Committee"* (Resolution 22/04).

Snapshot surveys at a point in time

For particularly important fleets, e.g. where catches are known to be substantial but the level of reporting is particularly poor for the size of the fleet and its impacts, the IOTC may want to consider a different approach. Given that most projects have funding for a limited timeframe, which has been a key challenge when initiating new data collection initiatives, and the main identified cause of long-term failure, an approach that works based on short time frames may sometimes be a pragmatic alternative. This may comprise a data collection effort that comprises a concerted effort to achieve near 100 % coverage through sampling at landing sites, self-sampling or low-cost cameras onboard vessels for a short period of time such as for a year. Given resource constraints, this may be a more practical and attainable goal, while still resulting in more accurate information to be used in stock assessments for a number of years. This type of survey is currently being implemented in Bangladesh through comprehensive sampling at landing sites to achieve good quality data for a snap-shot in time. This type of data has also proved useful in informing stock assessments as the IOTC Secretariat will often use historic data that are considered reliable and extrapolate it forwards in time, in preference to more recently reported data that are dubious in quality based on poor coverage or lack of independence (e.g. IOTC, 2019).

Conclusions

The alternative data collection approaches considered here can all be utilised as valid methods for obtaining fisheries information, depending on the context and framework in which they are applied. It is important that the most appropriate methods can be selected according to the specific project objectives depending on the fishery system and its needs. Nevertheless, it is also crucial that appropriate validation of methods is undertaken and included in pilot programmes to evaluate the quality of data. Inadequate training was considered a greater concern than lack of independence in most cases, particularly in terms of species identification which was a ubiquitous issue.

Compliance-led approaches are very difficult to enforce and have not been very successful. Instead, obtaining fisher buy-in and cooperation has been identified as the most fundamental prerequisite to the development of a successful programme. In-country approaches need to be harmonised and involve all stakeholders from the outset of a programme; it is vital that fishers and fisheries ministries are collaborators and a transdisciplinary approach is recommended. Fisher priorities and motivations for involvement are likely to vary according to the context, but a unanimous finding across all data collection approaches and projects was the interest fishers have in the data visualisations and analysis of their fishery. All of the successful approaches reviewed have undergone an iterative approach to development and have taken a very long time to establish. Locally developed solutions were generally the most sustainable.

Lastly, some proposals for the acceptance of alternative data collection approaches in IOTC coastal fisheries have been put forward for discussion by WPDCS. These are based on the new finer-scale vessel categorisations and seek to simplify rather than add complexity.

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Appendix I - Semi-structured interview questions

General

1. CPC
2. Institution
3. Department
4. Contact (name and role)

Project

5. Project title/product name
6. Funding organization
7. Background of project (eg was it developed in response to mandatory requirements from RFMOs?)
8. Project aims
    a. Science, knowledge and data gathering
    b. Information provision to fishers
    c. Employment, legislation and safety
    d. Value chains and post-harvest

(more broadly: what are the national organisational aims and funder objectives- do these align closely with IOTC data requirements/priorities? Are there any trade-offs between national/regional/funder objectives?)

9. Project time frame

Fishery

10. Artisanal gear type/s
11. Length of vessels
12. Fishing location
13. Total number of vessels included in study (if EMS, also include the total % of footage reviewed)

Method

14. What is the current level of development of the method (development not yet started, development ongoing, development completed, feasibility study, identified as feasible and now awaiting funding for rollout)
15. How flexible/responsive to change is the method? (eg responsiveness to changes in IOTC requirements for data/safety/confidentiality etc)
16. Who are the developers? (were/are industry involved in design)
17. Is the product open-source, commercial or not available externally?
18. What is the current level of implementation of the method and expected rollout? (including number of vessels currently involved in project)
19. Can you describe the new/alternative method of data collection?
    - EMS?
    - Port sampling?
    - Combination of EMS and port sampling?
    - Fisher self-sampling? (logbooks?)
    - Other?

(Detailed description)

20. Where does data collection take place:
    - At the landing site by enumerators from the fisheries administration
    - Onboard by fishers (eg logbooks)
    - Onboard by independent operators (eg scientific observers)
    - Onboard with no human interactions (eg EMS)

21. Are electronic devices used and, if so, what type? (eg mobile phones, Portable Digital Assistants (PDAs), smartphones, tablets, laptops, dedicated equipment (eg EMS), other)

IF yes, answer Qs 22- 24

22. Is cellular / data connectivity required for the entire data collection operation to work successfully? (examples below)
    - (No, all data are stored locally on the device and then transferred off-line (e.g., USB connection, HDD transfer, etc.) at the end of the trip,
    - No, all data are stored locally on the device and then transferred via mobile / WiFi Internet connection when network coverage is available
    - Yes, a mobile / WiFi Internet connection is always required for the EDCTs to work properly during the fishing trip / at the landing site (depending on the case)

23. Is the tool equipped with GPS? If so, how is it used?

24. Is the tool equipped with a digital camera or other imaging device? (if so, how is it used?)

25. How well does the initiative fit within the established routine data collection system within the fisheries ministry/organisation responsible for data collection and management? Is there coherence with other data collection systems (eg logbooks/port samplers) and verification/management processes (eg a unified database)? Does it introduce any duplication of effort (eg withVMS) or are the systems fully complementary?

26. Who is responsible for ongoing maintenance or the systems?

27. Beyond the intended purposes, have there been any wider benefits of the initiative? (eg the camera effect, assessment of mitigation or best practice release methods, greater fisher engagement?)

Data

28. Data items collected (complete table)
    - Is trip/vessel/crew information collected?
    - Is operational level information collected?
    - Is catch level information collected?

    (please provide a list of all data fields that are collected)

    - Are all species recorded or just select species?

29. When are data submitted to the national authorities? (in realtime, at the end of each trip, after a given number of trips or samples, at regular intervals, eg weekly or monthly)

30. Describe any data verification and validation systems that are in place prior to submission to national authorities (eg debriefing from skipper, automatic, land-based monitoring or images, geospatial information checked against VMS/AIS, etc) For self-reporting schemes – has there been any review of the reliability of self-reporting such as a comparison with EMS or onboard observer?/ any form of validation of the method itself?)

31. Is the information used to support the compilation of aggregated statistics?
    - Information is used for catch-assessment survey purposes,
    - Information represents a known sample of all trips / fishing operations at a given spatio-temporal scale (day, week, month, quarter, landing site, province, etc.) and is processed accordingly by national institutions,
    - Information is used by national institutions to correct (e.g., species composition) national statistics collected by other means
    - Information already corresponds to total enumeration and therefore does not need further processing and is simply collated together to produce total figures

Technical challenges

32. What kind of technical challenges have you experienced during the project? Describe these in detail and how they may be overcome (eg, voluntary vessels taking part in the scheme creates bias, limited connectivity issues, lack of technical support, lack of validation, complexity of data requirements, limited scale of project relative to fleet size)

33. Are all the intended data fields collected in practice or have there been problems encountered with any particular fields? Is data completeness a problem?

34. How effective has the initiative been in practice? Is it achieving the intended outcomes or are there any unexpected occurrences, eg, in certain data fields, geographical locations, stages of data reporting and processing? (or 'The camera effect' resulting in more accurate logbook reporting across the fishery?)

35. How independent is the data collection process and what measures have been put in place to ensure transparency?

Social challenges

36. What kind of social challenges have you experienced during the project?
    - Is there willingness for uptake of the scheme?
    - What are the main concerns expressed by fishers? (e.g., intrusion of privacy, liability, costs, time and space)
    - Have you discovered any features that increase the attractiveness of the project to fishers which could incentivise them to be more accepting? (eg, safety benefits, sustainability and traceability evidence leading to increased market access or price premiums? reduction in IUU fishing? Weather data? Vessel security?)

Financial challenges

37. What were the main financial challenges experienced? To understand the resource requirements of data collection systems, please provide a breakdown of the financial costs involved, including additional unexpected costs that have arisen during the project lifetime.

Item	Unit	Quantity	Timeframe (eg one-off, monthly, annually etc)
Programme start-up costs (fixed costs that remain constant whatever the scale of the initiative)			
Equipment	US$		
Training	US$		
Staffing	Person hours		
Other (please list all)			
Ongoing running costs			
Ongoing maintenance	US$		
IT support	US$		
Land observer/data entry	Person hours		
Data storage and back-up	US$		
Insurance	US$		
Other (please list all)			
Variable costs (costs per additional vessel)			
Equipment	US$		
Ongoing maintenance	US$		
IT support	US$		
Land observer/data entry	Person hours		
Data storage and back-up	US$		
Insurance	US$		
Other (please list all)			
Total			

Appendix II - Data comparison

Table 3. Low-cost cameras

CPC	Developer	Gear	Retained catch	Effort	Data level (trip/operation)	Retained bycatch	Discards	Fate of discards	ETP species interactions	Spatial data	Length	Biological sampling
EU, La Réunion	Marine Instruments	Longline	Y	Y	Operation	Y	Y	N	Y (less accurate for sharks)	Y	Y	N
Mozambique	ShellCatch[17]	Gillnet	Y	Y[18]	Operation	Y	Y	N	Y (less accurate for turtles and mammals)	Y	Y	N
Pakistan	CCTV/ShellCatch	Gillnet	Y	Y	Operation			N	Y	Y	Y	N
Sri Lanka	Marine Instruments	Longline	Y	Y	Operation	Y	Y	N	Y	Y	Y	N

Table 4. Self-reporting

CPC	Name of scheme/e-tool	Gear	Retained catch	Effort	Data level (trip/operation)	Retained bycatch	Discards	Fate of discards	ETP species interactions	Spatial data	Length	Biological sampling
EU, La Réunion	Paper forms + ObServe database	Longline	Y	Y	Operation	Y	Y	Y	Y	Y	N	N
Pakistan	Crew observer scheme	Gillnet	Y	Y	Operation	Y	Y	Y	Y	Y	Y (target species only)	N
South Africa[19]	ABALOBI FISHER	Mixed	Y	Y	Trip	Y	N	N	N	Y	N	N
Seychelles	ABALOBI FISHER	Handline/traps	Y	Y	Trip	Y	N	N	N	Y	N	N
Thailand	E-PIPO Self-reporting (paper)	Small purse seine	N Y	Y Y	Trip Operation	N Y	N UNK	N UNK	N UNK	N Y	N N	N N
Indonesia	e-Logbook Penagkapan Ikan KKP with SILOPI	Mixed	Y		Operation	Y	Y	N	Y	Y	N	N

[17] Due to lack of data from Shellcatch trials, information from Bartholomew et al. (2018) was used to assess Mozambique and Pakistan. Due to a lack of catch from Sri Lankan trials, results from trials in Reunion were used.
[18] Length of net could not be estimated by Bartholomew et al. (2018) but developers were sure this could be overcome (A. Sfeir pers comm.)
[19] Based on data provided from Lansiv-ABALOBI so may not fully reflect all datafields in the S. Africa version

Sri Lanka[20]	e-logbook	Longline/gillnet	Y	Y	Operation	Y	To be added	To be added	To be added	Y	N	N

Table 5. Landing site monitoring e-tools

CPC	Name of scheme/e-tool	Gear	Retained catch	Effort	Data level (trip/operation)	Retained bycatch	Discards	Fate of discards	ETP species interactions	Spatial data	Length	Biological sampling
Bangladesh	Calipseo with KoBoToolBox	Mixed (mostly gillnet)	Y	Y	Trip	Y	Y	N	Y	Landing site only	Y	N
Comoros	OpenARTFISH under SWIOfish1 project	Mixed (trolling, longline and light hand line)	Y	Y	Trip	Y	Y	UNK	UNK	Landing site only	Y	UNK
I.R. Iran	Artisanal Vessel Fishing Catch Questionnaire (paper)	Mixed (artisanal long line hooks, gillnets, monofilament nets and troll lines)	Y	Y	Trip	Y	N	N	N	Landing site only	N	UNK
Kenya	eCAS	Mixed	Y	Y	Trip	Y	N	N	N	Landing site	Y	UNK
Madagascar	Survey123	Mixed	Y	Y	Trip	Y	N	N	N	Fishing area	Y	UNK
Malaysia	eSistem Maklumat Perangkaan Perikanan (ESMPP) database (with paper forms)	Mixed (gillnet, small purse seine trawl troll lines)	Y	Y	Trip	Y	N	N	N	N	UNK	UNK
Mozambique	(MOMS) and KoboCollect	Mixed	Y	Y	Trip	Y	Y	Y	Y	UNK	UNK	UNK
Seychelles	System Information Halieutique	Handline/trap	Y	Y	Trip	Y	N	N	N	Fishing area	N	N

[20] IOTC-2016-WPDCS12-14

Sri Lanka[21]	Android based application	Mixed (longline, gillnets, surrounding nets, traps)	Y	Y	Trip	Y	Y	N	N	Fishing area	Y	N
Tanzania	eCAS	Mixed	Y	Y	Trip	Y	Y	N	N	Landing site	N	UNK
Thailand	Thai Flagged Catch Certification Scheme	Small purse seine	Y	N	Trip	Y	N	N	N	Landing site	N	N

[21] IOTC-2021-WPDCS17-16_Rev1

Appendix III - Interviewees

Country	Contact	Affiliation
Bangladesh	Shoukot Chowdhury	Department of Fisheries
Comoros	Abderremane Maaloumi	Directorate-General of Fisheries Resources (by correspondence)
European Union (Réunion)	Philippe Sabbarros	Institut Recherche Pour Le Développement
Indonesia	Putuh Suadela	Directorate of Fisheries Resources Management
	Aris Budiarto	Directorate of Fisheries Resources Management
Iran, Islamic Republic of	Sabah Khorshidi	Iran Fisheries Organisation
Kenya	Edward Kimani	KMFRI
	Johnson Omukoto	KMFRI
	Elizabeth Mueni	KMFRI
Madagascar	Lalaina Rakotonaivo	WWF
Malaysia	Nor Azlin	*Department of Fisheries Malaysia*
	Mohamad Ariff	*Department of Fisheries Malaysia*
Mozambique	Vanessa Muteria	WWF
	Vincente Cossa	WWF
Pakistan	Umair Shahid	WWF
	Shoaib Abdul Razzaque	WWF
Seychelles	Betty Mondon	Lansiv
Sri Lanka	Suraj chandrakuamara	Department of Fisheries and Aquatic Resources
South Africa	Craig Smith	WWF
Tanzania	Zephania Arnold	WWF
Thailand	Pavarot Noranarttragoon	Department of Fisheries