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WECAFC guide for improved monitoring of MFAD catches and improved assessment of MFAD impact on stocks

CONTENTS

Background ... 3

Overview of recent efforts to improve fishery data collection systems in WECAFC countries with significant MFAD fisheries ... 3

A current description of fishery data being collected across the region ... 4

Minimum data requirements: The CRFM logbook for FAD fisheries in the Eastern Caribbean ... 5

Alignment of the CRFM logbook with ICCAT data reporting and FAD management plan requirements ... 11

Moving forward: building on the CRFM logbook for minimum data requirements ... 11

A recommended additional data requirement ... 11

The challenge ... 11

The solution: Information and Communication Technology (ICT) to improve data collection and MFAD monitoring ... 13

Collection of biological data to supplement catch and effort data ... 16

Improving sampling and data collection ... 16

Implementation of a MFAD registration and monitoring system ... 16

Implementation of a licensing system ... 17

Data sharing and integration across the region 17
Improving assessment of fishing impact of MFADs on the ecosystem and stocks 20
MFADs as fishery-independent research tools 20
Addressing hyperstability on MFADs using fishery-independent data..23
References 24

BACKGROUND

Since the late 1960's, when Moored Fish Aggregating Device (MFAD) fisheries were first introduced in the Western Central Atlantic Fisheries Commission (WECAFC) region, there has been a steady increase in the number of WECAFC states (or their overseas territories) supporting MFAD fisheries, most of which are located in the insular Caribbean (Wilson et al. 2020). A recent survey has estimated there are currently about 3,500+ MFADs across the WECAFC region, exploited by 5,000+ small-scale fishers using 3,000+ small (<9 m long) fishing vessels and various highly selective fishing techniques (Valles, in prep).

The rapid development of this small-scale, but largely unregulated, fishery has led to increases in the exploitation of straddling stocks of large pelagics in the region and raised concerns about the impacts of the fishery on these stocks (CRFM 2015). Such concerns include the potential excessive exploitation of juveniles of tuna and other species (dolphinfish) that associate with MFADs (Morgan 2011; Dagorn et al. 2013; CRFM 2015), the targeting of species currently considered overfished such as blue marlin (FAO 2016; Bealey et al. 2019), potential increases in incidental by-catch (Morgan 2011; Dagorn et al. 2013; Leroy et al. 2013), the potential for MFADs to act as ecological traps (Hallier and Gaertner 2008; Dagorn et al. 2013), and the problem of how the fish aggregating properties of MFADs preclude a straightforward interpretation of catch-per-unit-effort MFAD data as an index of stock abundance (Ehrhardt et al. 2017b).

These are some of the concerns that contributed to prompt the establishment of the WECAFC FAD Working Group on the Development of Sustainable MFAD Fishing in the Lesser Antilles in 2001, which was later expanded to include the National Institute for Ocean Science (IFREMER), the Japan International Cooperation Agency (JICA) and Caribbean Regional Fisheries Mechanism (CRFM) as regional partners. They also led to the drafting of the Sub-regional MFAD fishery management plan for the Eastern Caribbean in 2015 (CRFM 2015). In 2019, the Regional WECAFC FAD WG obtained the endorsement of the Recommendation WECAFC/17/2019/21 "On the sustainability of fisheries using moored fish aggregating devices in the WECAFC area"1. This recommendation explicitly recognized "*… the need to improve data and information to reduce uncertainties to stock assessment methodologies currently used and to monitor long-term impacts of these fisheries on the stocks*…". In line with this recognition, one of the key activities of the pursuant EU-funded project GCP/SLC/217/EC "Support to the Secretariat of WECAFC in implementing targeted actions of the 2019-2020 Workplan on improved regional fisheries governance" is the development of a guide for improved monitoring of MFAD catches and improved assessment of MFAD impacts on stocks.

This guide is mainly aimed at national/local fishery authorities and researchers involved in developing and implementing fishery data collection systems. It first describes recent efforts in improving fishery data collection systems involving MFADs in the WECAFC region, with focus on the Eastern Caribbean. It then builds on such efforts to propose a way forward that hinges on the potentially transformative power of Information and Communication Technology (ICT) to address past and current data deficiencies.

OVERVIEW OF RECENT EFFORTS TO IMPROVE FISHERY DATA COLLECTION SYSTEMS IN WECAFC COUNTRIES WITH SIGNIFICANT MFAD FISHERIES

In 2008, the Secretariats of CRFM, CARICOM and JICA, signed the implementation of The Study on the Formulation of a Master Plan for Sustainable Use for Fisheries Resources for the Coastal Community Development in the Caribbean (CRFM/JICA 2012). This study, which covered 13 CARICOM countries, conducted baseline surveys to help characterize the fisheries of several of the participant countries and identify key issues that needed addressing. Among the issues identified were those surrounding the generation and handling of fisheries statistics. These included (1) insufficient data collection to inform decision making, (2) inadequate data management, (3) insufficient use of the Caribbean Fisheries Information System (CARIFIS), and (4) inadequate dissemination of information.

[1] http://www.fao.org/fi/static-media/MeetingDocuments/WECAFC/WECAFC2019/17/RecWECAFC%20XVII-2019-21.pdf

Moreover, this baseline study recognized that substantial differences existed among countries in the development of their fisheries statistical systems. This study also emphasized the importance of establishing a regional database for the countries of the Caribbean region but recognized that this would be a difficult undertaking given the differences in capabilities and policies among countries.

This study also led to the execution of a pilot project on the MFAD fishery in two countries, St Lucia and Dominica, with the aim of (1) improving the capacity of fisheries officers and fishers' organizations to manage pelagic resources exploited using MFADs and, (2) increasing the productivity of the MFAD fishery by developing skills and capacity to utilize pelagic resources. Based on the experience of the MFAD pilot project component of the Master Plan Study, the 5-year Caribbean Fisheries Co-Management (CARIFICO) Project followed up in 2013. It aimed to further develop a co-management approach to MFAD fisheries for each participating country. This project expanded to include five countries with MFAD fisheries, Antigua and Barbuda, St Kitts and Nevis, Dominica, St Lucia, St Vincent and the Grenadines and Grenada. A key co-management output of this project was the development of a data collection logbook system to be filled by fishers, as part of their responsibility to help monitor the MFAD fishery.

In parallel to these efforts, Barnwell (2014) conducted a review of fishery data collection systems in selected countries of CRFM with a view to assess the extent to which MFAD data was being integrated into these systems. Several considerations came out of this report and subsequent feedback from participating countries in relation to minimum data requirements (CRFM 2014). Notably, that data collected should be consistent with the requirements by ICCAT's 2011 Recommendation on a Multi-annual Conservation and Management Program for Bigeye and Yellowfin tunas and in relation to the Guidelines for Preparation of FAD management plans (Annex 2 of the same recommendation). Moreover, the report recognized efforts of several countries to integrate MFADs in their data collection systems, but further highlighted existing differences among these countries in the data collected as well as in data management tools. It thus recommended some degree of standardization among countries in data management tools, minimum data requirements, fishing effort measures, and data collection methods (census vs sampling). It also recommended the regular collection of biological data (at least length frequency data). Discussions on these findings also highlighted the importance of incorporating socio-economic data (fuel costs; unit price of fish; value of catch) into the data collection process (CRFM 2014).

The report also recognized the value of sharing a common computerized data management system across countries to integrate and help standardize datasets and so facilitate addressing research questions. However, it also recognized that past efforts in this regard had failed due to a lack of consistent technical assistance. Thus, the preferred approach for the different countries at the time was to maintain their respective data management systems, while continuing to work towards standardizing minimum data requirements for both catch effort and biological data.

A CURRENT DESCRIPTION OF FISHERY DATA BEING COLLECTED ACROSS THE REGION

The existence of considerable differences among countries in the implementation of fishery statistical systems is confirmed by the results of a recent survey of key informants across 20 territories/countries with significant MFAD fisheries. First, one quarter (25%) of the locations were not engaged in any type of systematic fishery data collection involving MFADs. The remainder of locations (75%) did have an active fishery data collection system facilitated by a standardized data collection form (Table 1); nearly all these locations explicitly distinguished landings from MFAD fishing from non-MFAD fishing.

A closer look into the data requirements of the locations with active data collection systems identified some pieces of information that were collected across most (>75%) locations. These included (1) time spent fishing, (2) number of fishers on boat, (3) fishing techniques used, (4) total weight landed, and (5) total weight landed by species (Table 1). In contrast, only 50% of these locations quantified the number of fishing lines actively fishing, a more refined measure of fishing effort. Even fewer locations recorded the location/identity of MFAD used and fuel consumption expenses (Table 1). These results support the need to implement a minimum set of standardized data requirements to facilitate regional data integration.

Table 1. Percentage of territories/countries (out of 15) that collect data on 12 variables from fishing trips to MFADs based on a recent survey of 20 locations. Five (out of 20) locations are not engaged in any systematic fishery data collection involving MFADs.

Variable	Yes	Some times	No
MFAD ID or location	38%	23%	38%
Time spent fishing	87%	13%	0%
Time spent travelling	43%	14%	43%
Number of fishers on boat	87%	7%	7%
Fishing techniques used	93%	7%	0%
Number of fishing lines in the water	50%	17%	33%
Total weight landed	93%	7%	0%
Weight landed by species	86%	14%	0%
Fuel consumption and other expenses	36%	29%	36%
Estimate of revenue from sale	64%	7%	29%
Number of fish landed	47%	27%	27%
Number of fish landed by species	47%	33%	20%

MINIMUM DATA REQUIREMENTS: THE CRFM LOGBOOK FOR FAD FISHERIES IN THE EASTERN CARIBBEAN

Between 2014 and 2015, the CRFM supported the CARIFICO project by helping further develop a logbook for the MFAD fishery with input from the five countries that were at the time part of the project (Mohammed and Masters 2014; Masters and Mohammed 2015; Mohammed 2015; Mohammed and Masters 2015). The process leading to a final log book is described in detail in (Mohammed 2015). This logbook effort, which followed up previous work (CRFM/JICA 2012; Barnwell 2014; CRFM 2014) and involved an additional review of fishery statistical systems implemented during the CARIFICO project, was expected to considerably strengthen existing fishery data systems by:

1. Supporting the standardization of MFAD data requirements and collection across countries to help consolidate these data for regional-level fisheries analysis,
2. Allowing the extraction of adequate performance indicators to assess the position of the fishery in relation to specific management socio-economic objectives typically associated with MFAD fishing,
3. Aligning data requirements with those of ICCAT recommendations for large tunas,
4. Allowing the quantification of the effects of MFAD fishing on key biological components of the ecosystem, namely the capture of juveniles of target species, target species undergoing overfishing, and non-target species.
5. Allowing assessing the effect of gear type, bait, and fishing depth on fishing yields and species composition.
6. Allowing assessing the effect of selected environmental factors on fishing yields and species composition.

The logbook contains four different sections, including (1) a general section that identifies the boat, boat owner, and landing site; (2) a section with the logsheets to enter the relevant information for each fishing trip; (3) a section with a map of fishing zones, MFAD locations, and landing and departure sites; (4) a section with guidelines for filling the logsheets, including drawings of key species to facilitate their identification and, (5) an example of dully filled log sheet. An example of logsheet is presented in Figure 1.

Of particular relevance, the data prescriptions contained in this final version reflect the outcome of an iterative participatory process with fishery officers of the five countries and a necessary compromise between keeping data requirements to a minimum to facilitate participation of fishers while maximizing information output to meaningfully guide MFAD fishery management. These data requirements thus represent a validated minimum standard for the MFAD fishery in the region. Table 2 shows the data requirements of the logsheets of the logbook.

Figure 2 illustrates the links between the different variables in the logbook with an example of data for a fictitious fishing trip. A boat with two fishers leaves port at 5 am and returns at 11 am. During that time, it visited two different FADs. In the first MFAD, it used both droplines and surface trolling and captured blue marlin, yellow fin tuna, and dolphinfish. In the second MFAD, it only used trolling and caught dolphinfish. The form explicitly requires linking a specific gear to the species caught, along with the provision of data on effort (number of hooks and fishing hours), fishing depth, time of day, and type of bait associated with the gear. These minimum data prescriptions are critical because the abundance and composition of the catch are known to be strongly influenced by changes in any of these parameters and by the location of the MFAD (e.g. distance from shore, mooring depth, level of exposure) (reviewed in CRFM 2015). These data can also be used to provide reasonably accurate estimates of CPUE and fishing efficiency. Moreover, the form requires informing about the presence of other boats fishing in the same MFAD, which is likely to affect yields by individual fishing boats (Sidman et al. 2014). It also seeks to tackle potential differences across locations in weight reporting due to the level of processing that fish might undergo while on-board, which should facilitate the process of data standardization and consolidation across locations. Although individual fish sizes (or weights) are not requested, the form does require stating the number of fish caught of each species with each specific gear. This piece of information can be combined with the total weight caught to derive the average individual fish weight for each species captured, a crude size-based metric that could nevertheless meaningfully inform management about spatiotemporal trends in sizes for individual species (Shin et al. 2005).

The form also requires the identification of non-target groups (e.g. turtles, sharks, mammals, sea birds) caught while fishing and their fate (kept, discarded alive or dead). Although in the form the capture of such groups is not directly linked to a specific gear or MFAD, which is useful information, the comment section in the form could be used to do so. The form also seeks to capture the potential effect of sea conditions on fishing yields by requesting simple information on sea state, water colour, and whether *Sargassum* rafts were present that day.

Importantly, the form also requests the input of financial data for the fishing trip. It captures the expenses endured during the fishing trip, namely on fuel, oil, food, ice, and lost gear as well as the revenue generated by the sale of the catch, acknowledging that not all fish caught might be sold.

The minimum data requirements proposed can be used to derive fairly precise performance indicators that can be contrasted with a range of broad management objectives typically associated in MFAD fishery in the region (Table 3).

Boat Name:	Boat registration number:	
Departure site (see map to identify site):	Departure date (day/month/year):	Departure time:
Landing site (see map to identify site):	Landing date (day/month/year):	Landing time:

FISHING EFFORT	Number of Fishers:		
Gear Types: TR: trolling; HL: Handline DL: Dropline; LL: Longline RR: Rod & Reel	*See map to identify FAD # or fishing area*		
	FAD # or fishing area:	FAD # or fishing area:	FAD # or fishing area:
Gear used (select from above) :			
Number of lines			
Number of hooks			
Number of hours fished:			
Day (D) or night (N) fishing:	D □ N □	D □ N □	D □ N □
Total number of boats fishing:			
Depth fished: □ feet □ metres (tick one)			

CATCH

Levels of processing – Gutted (GU); Gilled (GI); Headed (H); Finned (F); Whole (W)
Bait Type: Artificial Lure OR Natural Species – list species (list below)
Weights in □ lbs □ kg (tick one) - **Weights are** □ estimated □ measured on a scale (tick one)

FAD#/ fishing area	**Species**	**Level of Processing** (encircle which applies)	**Gear Type** (encircle which applies)	**Bait Type**	**Weight Caught**	**No. Caught**	**Weight Sold**	**Unit Price**
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					
		GU GI H F W	TR HL DL LL RR					

BY-CATCH	Turtles	Seabirds	Sharks	Whales	Dolphins	Porpoise	Manatee	Other
Number Kept								
Number discarded dead								
Number discarded alive								

FISHING COSTS	Indicate money spent in XCD for the following that are used for the fishing trip						
	Fuel:	Oil:	Ice:	Food:	Bait:	Gear:	Other (specify):
	Amount of oil used for the trip: Gallons □ Litres □ (tick one)				Amount of fuel used for the trip: Gallons □ Litres □ (tick one)		

SEA STATE (encircle one): see the Sea State Code Chart in the guidelines.	Calm (glassy)	Calm (rippled)	Smooth (wavelets)	Slight	Moderate	Rough	Very rough	High	Very high

WATER COLOUR (encircle one): see the Water Colour Description Chart in the guidelines.	Blue	Milky turquoise-purple	Blue-green	Green	Dark green	Light brown	Red/Reddish/ Red strikes	Pink	Purple	Seaweed present

COMMENTS & OBSERVATIONS: ……………………………………………………………………………………………………

………

SUBMISSION OF LOGSHEET: Name of fisher (in BLOCK letters)…………………………………………………………………

Signature of person filling in the log sheet: ……………………………………… Date of completion of log sheet (day/month/year): ………………………

FOR OFFICIAL USE

Received by:-	Signature:-	Date (day/month/year):
Verified by:-	Signature:-	Date (day/month/year):
Computerized by:-	Signature:-	Date (day/month/year):

Figure 1 – Logsheet of the CRFM MFAD logbook showing the data requirements for a fishing

Table 2 – Links between the data requirements in the final version of the logbook for MFAD fisheries (Figure 1) and ICCAT data requirements.

CRFM logsheet Information category	Entry requirement	ICCAT Requirement for catch recording (Annex 2 and 6)
Basic fishing trip information	Boat name	X
	Boat registration number	X
	Departure site	X
	Landing site	X
	Departure date	X
	Landing date	X
	Departure time	
	Landing time	
Fishing gear and effort	FAD identifier or fishing zone	X
	Number of fishers on boat	
	Gear type used	X
	Number of lines	X
	Number of hooks	X
	Number of hours fishing	
	Total number of boats fishing on MFAD	
	Fishing depth	
	Bait type: artificial lure vs natural species	
	Time of day: night vs day	
Catch	Species ID	X
	Weight caught (kg or lbs)	X
	Means of weight estimation	X
	Level of weight processing (gutted, gilled, headed, finned, whole)	X
	Number of fish	X
Fishing trip revenue	Target species	
	Weight sold (kg or lbs)	
	Unit price	
By-catch	Selected groups (turtles, seabirds, sharks, dolphins, porpoises, manatee, other)	X
	Numbers kept, discarded alive, and discarded dead	X
Fishing trip costs	Fuel volume and cost	
	Oil volume and cost	
	Ice, food and bait cost	
	Loss gear cost	
Sea conditions	Sea state (calm to very high)	
	Water colour (blue to purple)	
	Seaweed presence/absence	
Basic recorder information	Name of fisher	X
	Name of data collector	X
	Date	

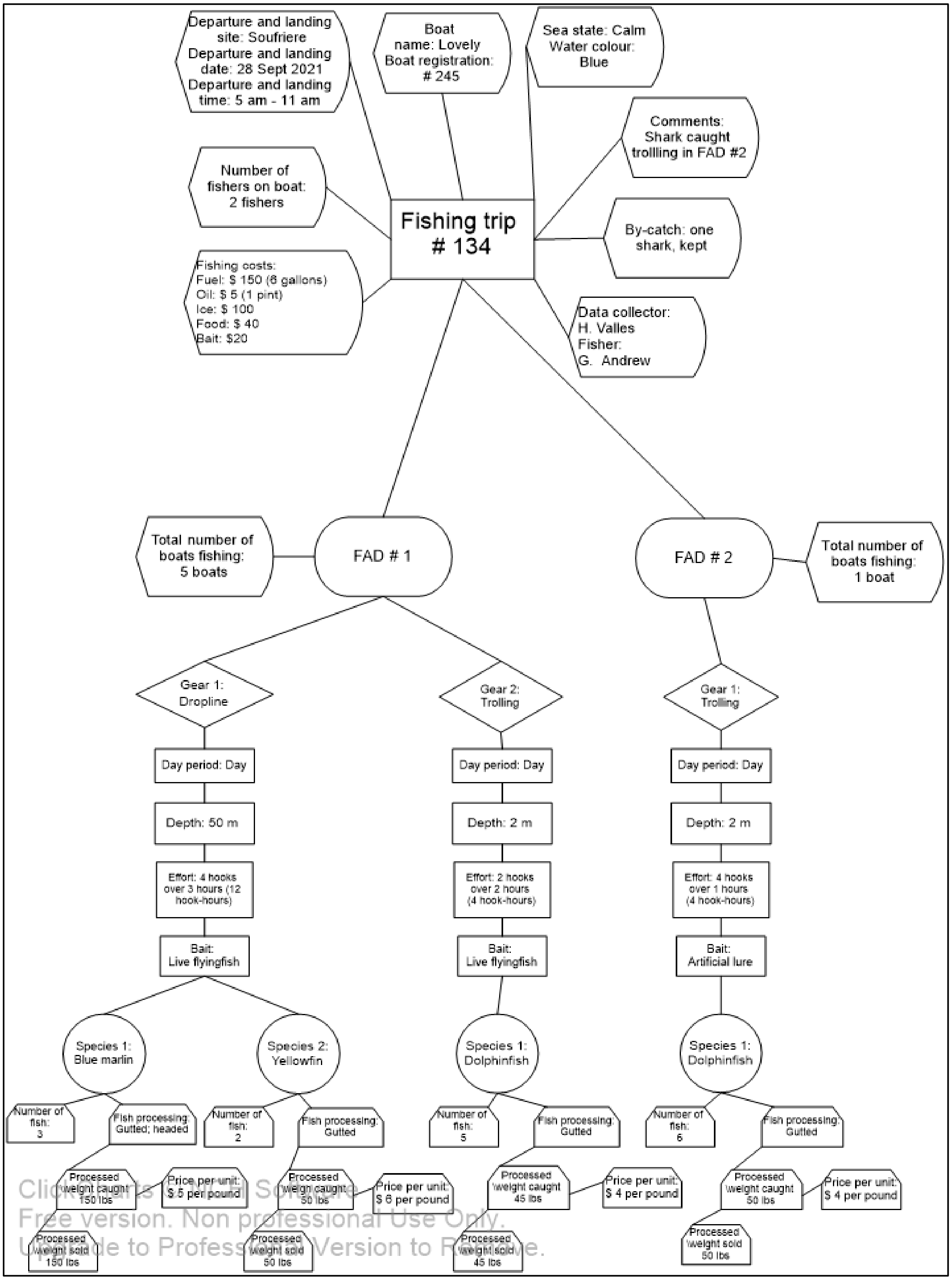

Figure 2 – Links between variables prescribed in the logsheets of the CRFM logbook for a fictitious fishing trip at two MFADs using different gear, spending different amounts of time and capturing different species

Table 3. Relationship between broad management objectives typically associated with MFAD fisheries in the Caribbean and performance indicators that can be derived from the minimum data requirements in the logsheets of the final version of the CRFM logbook for MFAD fisheries

Commonly management objectives – Socio-economic domain	**Performance indicator(s)**	**Relevance**
To increase fisher revenue	Total revenue per fishing trip; profit per fishing trip (revenue minus expenses); profit per fisher per hour per fishing trip	High
To reduce fuel consumption	Fuel consumption and cost per fishing trip	High
To increase fishing efficiency for fishers	Catch per unit effort (CPUE); Value of catch per unit effort	High
To support food security	Total weight landed	High
To increase local availability of fish products	Total weight landed	High
To reduce competition among fishers in resources/fishing grounds	Number of boats fishing in a MFAD at the same time	Medium
To decrease physical demands of fishing	Total number of fishing trips; average time at sea per fishing trip; average travel distance per fishing trip	Medium
To encourage fishers to remain within territorial waters	Average travel distance per fishing trip; Total number of fishing trips	Medium
To increase safety at sea	Average travel distance per fishing trip; Total number of fishing trips	Medium
To increase employment	Number of fishers per fishing trip; Total number of fishing trips	Medium
To support or develop a charter/sports fishing market	Number of fishers per fishing trip; Total number of fishing trips	Medium
To reduce fish imports	Total weight landed	Low
To increase fish exports	Total weight landed	Low
To generate new added value products	Total weight landed	Low
To reduce conflicts between fishers and other users of the sea (e.g. shipping, tourism)	-	None
To promote co-management	-	None
To promote social cohesion and collaboration among fishers	-	None
Recommended management objectives – Biological and ecosystem domain	**Performance indicator(s)**	**Relevance**
To reduce catches of juvenile fish	Average individual fish weight caught per species per fishing trip	High
To reduce catches of overexploited species	Total weight caught per species per fishing trip; Total number of individuals caught per species per fishing trip; CPUE per species	High
To reduce incidental by-catch of key groups	Number of individuals caught per group per fishing trip	High
To decrease coastal or nearshore fishing pressure	Number of fishers per fishing trip; Total number of fishing trips compared to baselines	Low
To minimize ecological trap effects	-	None

ALIGNMENT OF THE CRFM LOGBOOK WITH ICCAT DATA REPORTING AND FAD MANAGEMENT PLAN REQUIREMENTS

In line with previous efforts, the data requirements of the logsheets of CRFM logbook were developed to align as much as possible with ICCAT data reporting requirements at the time, particularly those dictated by Annex 1 and Annex 2 of the ICCAT Rec 14-01 – Recommendation by ICCAT on a Multi-annual Conservation and Management Program for Tropical Tunas (Mohammed 2015). This recommendation has received several amendments since 2015 (ICCAT Rec 16-01; ICCAT Rec 19-02; ICCAT Rec 20-01). It is important to note that in all amendments the data requirements only apply to fishing vessels from ICCAT's Contracting and Cooperating Non-Contracting Parties and Entities (CPCs) that are at least 20 m in length, typically purse seine and bait boat vessels. These requirements are thus not directly relevant to the smaller-sized vessels (<9 m long) engaged in the MFAD fishery across the WECAFC region, irrespective of the CPC status of their country of origin, except for those engaged in pole and line fishing in southern Brazil, which is one of ICCAT's CPC. However, as Mohammed (2015) points out, it is highly recommended that WECAFC countries engaged in MFAD fishing in the region integrate such data requirements in their fishery data collection systems, to the extent that it is possible, to support conservation and management efforts for tuna, given the importance of these stocks for food security and livelihoods in the region

Table 2 also highlights the alignment in data requirements between the logbook sheets and ICCAT's Annex 6 requirements and shows that it reasonably satisfies most of ICCAT's demands. Moreover, ICCAT requires that (1) the logbook is numbered by sheets, (2) the logbook is filled every day and before port arrival, (3) one copy of the sheets must remain attached to the logbook, and (4) logbooks must be kept on board to cover a period of one-trip operation. In that regard, the CRFM logbook is itself numbered and contains numbered logsheets; it was meant to be filled after each fishing trip, which in the context of MFAD fishing in the region would take place within the same day; it was also meant to be printed in a carbon-less copy paper so that fishers could retain one copy of the logsheets (Mohammed 2015). However, it remained to be seen whether the logbook could stay inside the vessel throughout the entire fishing trip, given the space constraints of small fishing boats and thus the increased likelihood of damage or loss (Mohammed 2015).

MOVING FORWARD: BUILDING ON THE CRFM LOGBOOK FOR MINIMUM DATA REQUIREMENTS

The data requirements contained in the CRFM logbook logsheets represent a significant step forward towards achieving data collection standardization to inform local management objectives with sufficient precision, while meeting ICCAT's minimum data requirements to support conservation and management of regionally shared stocks (CRFM 2015). Moreover, gear types, main target species, and fishing maps (and zones) can be easily customized to reflect local context across the region. Importantly, the logsheets can also be used to monitor the pelagic fishery that does not make use of MFADs (for example, by identifying location of fishing zone), helping integrate MFAD and non-MFAD fishing datasets. Thus, it is recommended that the data requirements and form layout of the logsheets of the logbook be used as the basic data template to support further efforts.

A RECOMMENDED ADDITIONAL DATA REQUIREMENT

A valuable addition to the logsheets of the CRFM logbook would be a data requirement item clarifying when fishing takes place under fish aggregating objects other than MFADs, which could distinguish between artificial logs resulting from human activities involving fishing (wrecks, old nets) or not (abandoned tanks) as well as between natural logs of plant (*Sargassum* rafts) or animal origin (whale sharks). Such distinction would also further align the logbook with ICCAT's 19-02 Recommendation for data requirements (Annex 3). Distinguishing among different types of fish aggregating objects is particularly important given the now well-established seasonal presence of *Sargassum* rafts across the region (Franks et al. 2012).

THE CHALLENGE

The logbook was originally conceptualized to be carried during each fishing trip and to be filled by the fishers themselves under an arrangement of shared responsibility in data collection. Recognizing the important challenge that the latter represents, Mohammed (2015) outlined a number of recommendations to facilitate the adequate and regular use of the logbook by fishers. These included (1) the need to raise awareness among fishers of the importance of the data collected to measure progress towards management objectives affecting them personally, such as increasing their revenue, and to continually maintain their engagement by providing them with regular feedback on the results derived from these data; (2) the need to raise awareness among decision-makers of the importance of the data to objectively highlight the socio-economic importance of the fishery so as to secure adequate financial and human resources to support the data collection system; and (3) the need to train fishers in identification of fish species to respond to the minimum data requirements in the logbook.

In reality, how to effectively delegate the filling in of the logbook to the fishers themselves in a sustainable way remains unresolved. During the CARIFICO project in Dominica, which promoted a co-management approach, it was proposed that fishers licensed to fish on MFADs would be required to keep records of their fishing trips in a logbook. Moreover, to further incentivize fishers, it was proposed that such logbooks, when certified by the Fisheries Division, could be used as income evidence to apply for bank loans (Fig 3 left panel) (CRFM/JICA 2011). It was also proposed that permission of the deployment of new MFADs by a fisher coop would be subject to the contribution of such fisher coop in logbook record and fees collected for FAD use (Fig 3 right panel) (CRFM/JICA 2011). However, the system did not ultimately work (J. Defoe, pers com). Thus, Mohammed (2015) recommended that provision of data by fishers should be mandatory or legislated, rather than voluntary, and subject to appropriate monitoring, control and enforcement, including meaningful penalties for breaching these obligations. However, as Tilley (2020) points out "*the promise of co-management or the potential of data systems to improve the sustainability of shared resources is unlikely to be a sufficient incentive on its own for fishers to engage and participate in data collection*… [] … *because people whose livelihoods are labor intensive and often subsistent, prioritize other activities over completing lengthy data forms".* Thus, it is unlikely that a system relying exclusively on logbooks being filled by fishers will be successful in the long-term, even if so legislated, unless it is integrated into a larger framework that, in addition to offer both incentives (improved personal finances) or penalties (non-renewal of licenses) to fishers, helps drastically minimize both the time and individual effort that is required by such data form filling.

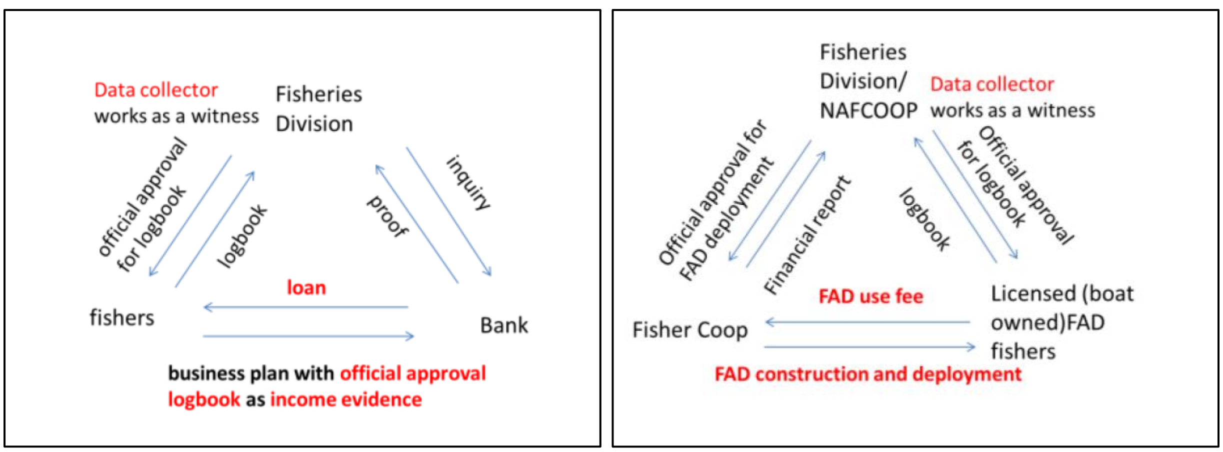

Figure 3. Schematic representation of relationships between logbook submission by fishers and proposed incentives such as logbooks acting as proofs of financial standing for bank loans (left panel) and conditioning the granting of MFAD fishing licenses to regular logbook submission (right panel). Excerpt from CRFM/JICA (2011)

THE SOLUTION: INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) TO IMPROVE DATA COLLECTION AND MFAD MONITORING

As previously stated, it is highly recommended that the data requirements and layout of the logsheets in the CRFM logbook become the basic template for data collection. However, the lack of success in the implementation of a fisher logbook system even in the context of a co-management approach, coupled with the difficulties of safely maintaining a logbook in the small fishing vessels that characterize the MFAD fishery in the region, highlight the need to look for alternative options for data collection. In that regard, Mohammed (2015) raised the potential of Information and Communications Technology (ICT) as an alternative worth exploring. ICT tools are increasingly being used in fisheries and can contribute significantly to data collection and Monitoring, Control and Surveillance (MCS) strategies, which are essential components of sustainable fisheries management (FAO 2007). As such, it is now widely recommended that governments and other agencies (1) integrate ICT into fisheries projects using people-centred and pro-poor approaches based on affordable technologies that can be supported locally and which are fit for purpose, and (2) promote the adoption of modern fisheries-specific technologies in the context of co-management (FAO 2007).

Two promising technologies that are currently being implemented under contexts of limited resources and data-poor information systems in small-scale fisheries are the use of (1) Vessel Tracking Systems (VTS), i.e. systems using satellite and cell network technology to monitor the location and movement of vessels of any size, and (2) electronic applications on smartphones or tablets allowing the capture of fisheries data and automatic transfer of such data to a centralized database. Moreover, the combination of both techniques provides a very powerful and efficient way to both map fishing effort and characterize fishing yields, while maximizing standardization of data entry and minimizing mistakes during data entry and transcription and with a potential for near-real-time analysis. Importantly, with carefully designed forms and adequate training, capturing fisheries data electronically has the potential to drastically reduce the time and individual effort (by data collectors or the fishers themselves) involved in recording data from individual fishing trips, and thus increase the chances of voluntary participation from fishers.

A recent example of the value of the combined use of these two ICT tools in a data-poor small scale fishery context is given by Tilley et al. (2020). Tilley and colleagues introduce a near-real-time, open-source monitoring and analytics system called "*PeskAAS*" for small-scale fisheries. In particular, this application goes beyond simply facilitating data collection and allows for the integration of data collection with the data analysis and visualization of data summaries for managers and fishers. This is an interactive web-hosted R *Shiny* application that access a database in real-time using several R packages. It allows bringing catch data recorded at landing sites into a web-based user-friendly interactive R session, where users can create informative summary plots of the data. The application is hosted remotely, but there are also ways to run it locally if needed. Importantly, the application is scalable for different levels of usage with modest subscriptions fees. In their case study, fishery catch data are obtained by data collectors at the landing sites using 3G-enabled tablets hosting a digital survey form developed in KoBo toolbox, which is a free suite of tools for field data (https://www.kobotoolbox.org/). The authors also developed the cloud-based MySQL database and R script to access the data, which are all open-source. Additional details about the application and its components are given in Tilley et al. (2020).

Moreover, the authors combined the use of the *PeskAAS* application with a VTS via the installation of tamperproof solar-powered GPS units on a sample of boats per landing site. These GPS units recorded point location data every 5 seconds and communicated those data to the cellular network. Importantly, by linking catch data with GPS tracks for individual fishing trips, the system can be used to train models to predict unknown variables such as gear and habitat type for trips with GPS data only. A diagrammatic illustration of the end-to-end integration of the data cycle is given in Figure 4.

In a related study, Tilley et al. (2019) used the PeskAAS application and framework to monitor and compare catches rates of MFAD and non-MFAD fishing trips in Timor-Leste. With these data in hand they were able to demonstrate the MFAD fishing led to higher catch rates and that MFADs could pay for themselves after only five months of fishing (Tilley et al. 2019).

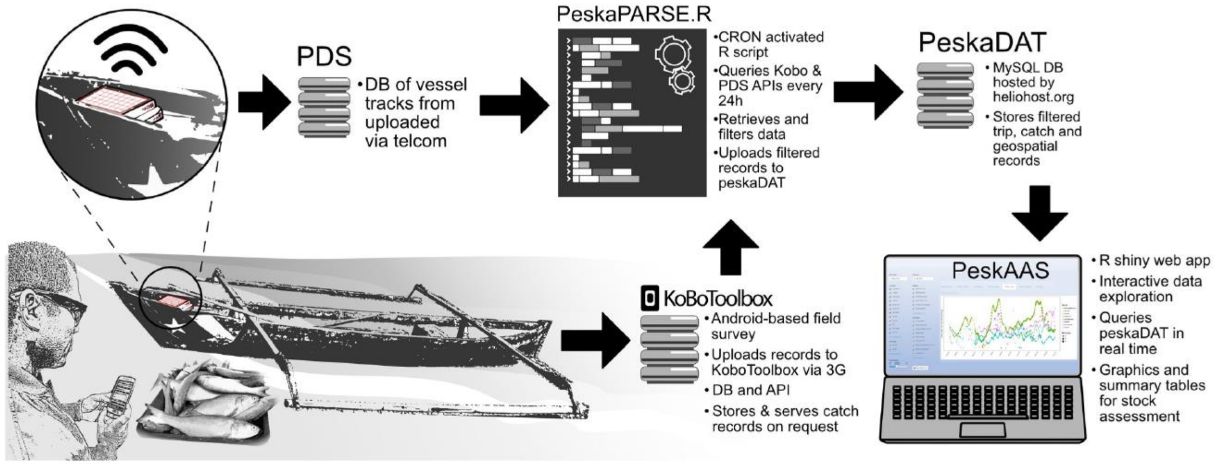

Figure 4 – Diagrammatic representation of the PeskAAS application. From bottom to left, catch data from a vessel are entered into a KoboCollect survey form on a smartphone. These data are uploaded into the KoboToolbox database. An R script (PeskaPARSE.R) pulls brings these data along with the vessel's movement data obtained by the GPS unit (PDS: Pelagic Data Systems Inc.) in the vessel. These data are then checked and filtered and uploaded into a database (PeskaDAT). The PeskAAS application can then be used to query the database and provide near-real-time graphics and analytics.

It is important to note that the fixed location of MFADs render them particularly amenable to monitoring via VTS. Indeed, VTS use should lead to better estimates of the number and location of MFADs that are being exploited by fishers at any given time; it should also lead to better estimates of the time that individual vessels spend fishing on these units. In Dominica, Alvard et al. (2015b) and Alvard et al. (2015a) used light and small waterproof GPS units that could be easily accommodated into MFAD fishing vessels to document their tracks at 1-s intervals. They were able to identify specific spatial patterns in the tracks and vessel speeds (e.g. area restricted search) that coincided with the location of MFADs (Fig 5 top panel); more refined analysis allowed them to even distinguish between fishing techniques (fishing for bait versus dropline fishing). Similarly, and more recently, Widyatmoko et al. (2021) also used small GPS units to tracks vessel movements in Indonesia and identify features of vessel movement that were associated with MFADs (Fig 5 bottom panel). In so doing, they were able to provide a minimal estimate of number and location of MFADs; they also confirmed that MFAD deployment was not in compliance with local regulations. In that regard, an interesting feature of Tilley et al. (2020)'s GPS units (manufactured by Pelagic Data System Inc.) is that they are solar-powered and cannot be turned off nor can they be tampered with, so positional data cannot be falsified. All the above studies make use of low-cost and/or publicly available technologies.

Finally, the use of ICT tools for fisheries monitoring seems to be organically gaining ground in the insular Caribbean. Dominica is leading the way by currently using an electronic data collection system based on the KoboToolbox with data collectors using tablets at the landing sites and the data being automatically uploaded into a database. The fishery officers of Dominica are also developing their own R scripts to generate fishery reports (J. Defoe, D. Theopille, and K. Hilton, pers. com.). On the other hand, Montserrat is currently experimenting with VTS technology for artisanal fisheries with positive buy-in from fishers (A. Ponteen, pers. com). It thus seems the right time to support the development of electronic data collection systems and VTS to support fisheries statistic systems across the region; if developed with a good understanding of local context, they have the potential to mediate a transformational change in fisheries monitoring in the region over a range of scales (local, national, and regional).

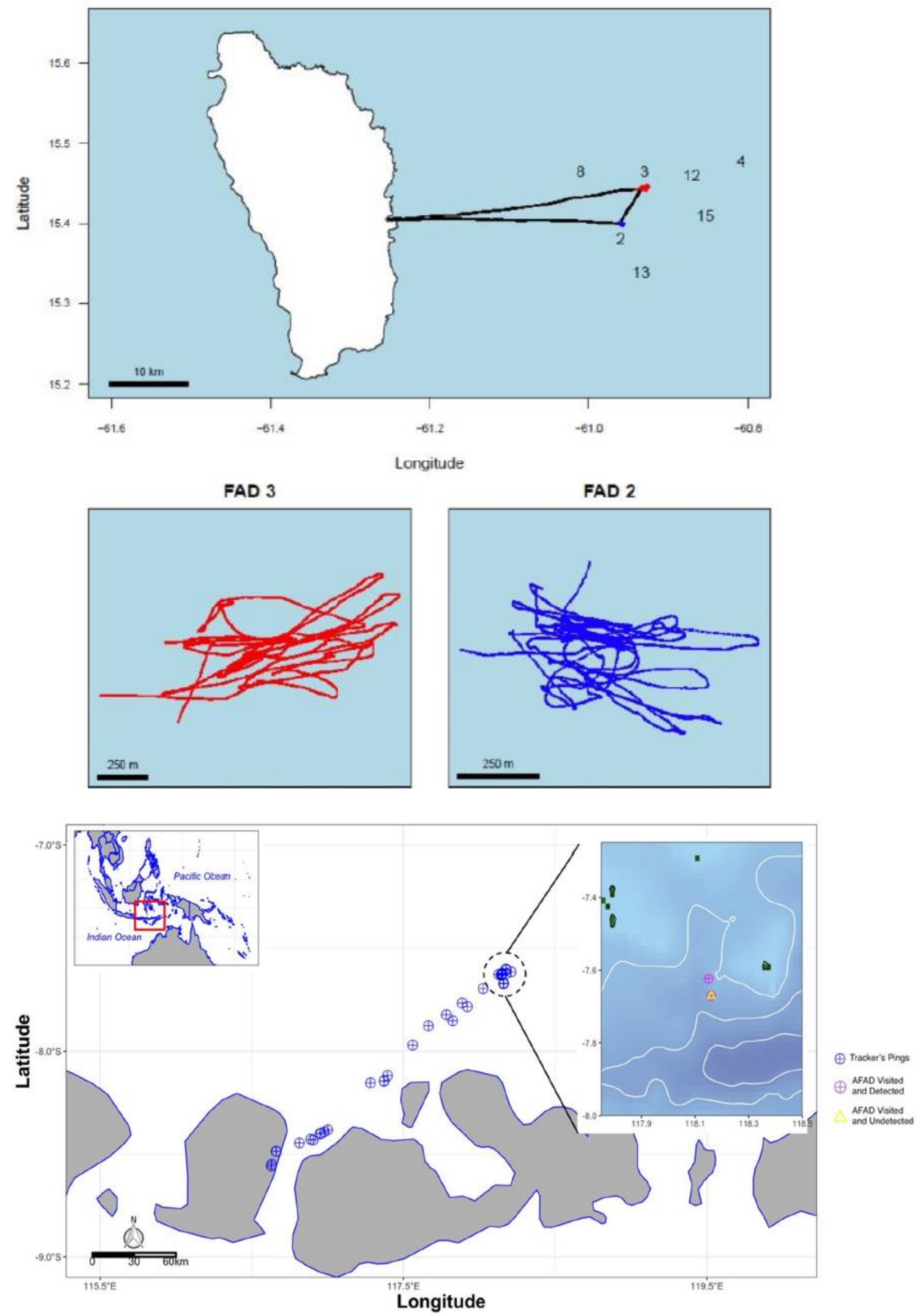

Figure 5. Tracks of MFAD fishing vessels in Dominica (top panel) and Indonesia (bottom panel) obtained using low-cost small-sized GPS technology. These tracks can be analyzed using publicly available applications to identity MFADs. For more details, see Alvard et al. (2015b) and Widyatmoko et al. (2021).

COLLECTION OF BIOLOGICAL DATA TO SUPPLEMENT CATCH AND EFFORT DATA

In addition to the collection of catch and effort data on MFADs, it will be important to periodically collect detailed biological data on the main target species or on species of special interest. Such data should at least include individual fish weight, length, and maturity stage (see also Data Sharing and Integration section). Such data are crucial to inform about gear size selectivity, natural and fishing mortality rates, and fish condition and reproductive status; these types of data are generally required in stock assessment models. Here, the data collection process could again be facilitated using electronic forms that automatically transfer the data to a central database. The more time-consuming nature of this sampling will mean that it will necessarily take place at a lower frequency than that of the catch and effort data and might involve selected species. However, efforts should be made to ensure that the biological sampling scheme captures with sufficient precision the overall population structure in the catches of the selected species and its potential variability in space and time.

IMPROVING SAMPLING AND DATA COLLECTION

A recent survey of key informants across 20 territories/countries with significant MFAD fisheries in the WECAFC region indicated that three quarter of these locations were engaged in systematic fishery data collection involving MFADs (Vallès in prep.). Most of these locations engaged in random (or haphazard) sampling of fishing trips. Only two out of 14 locations indicated that the fishers themselves participated in data collection, further highlighting the challenge of sharing the responsibility of data collection with fishers (Vallès in prep.).
The combination of Vessel Tracking Systems and electronic data collection systems could, on the one hand, help optimize sampling schemes by helping refine sampling strata based on vessel positioning at sea. On the other hand, it could further incentivize fishers to partake in the filling of electronic logbooks if the time required to do so is now drastically reduced and their data kept confidential but processed and returned to them frequently (or even in near-real time). A better delineation of sampling strata based on vessel activities at sea along with increased sampling of these strata via increased data collection by fishers will yield more precise and accurate catch and effort metrics and a more efficient use of limited human resources.

IMPLEMENTATION OF A MFAD REGISTRATION AND MONITORING SYSTEM

In line with Mohammed (2015)'s recommendations, it is critical that countries implement an official MFAD registration system that collects information on MFAD ownership, deployment depth and location, design and materials, and unit cost, and assigns a unique registration number to each new MFAD deployed. This number could then act as MFAD identifier in the field. To the extent that it is practically possible, national/local MFAD identifier systems should align with Voluntary Guidelines on the Marking of Fishing Gear (FAO 2019) and be harmonized across the region. This registration system should also be regularly updated with information about MFAD losses so that estimates of MFAD numbers at any given time are accurate. The requirement to register new MFADs and report MFAD losses should be supported with legislation. The implementation of such as registration system would further align with ICCATs 19-02 Rec. concerning the requirement to report MFAD deployment as well as MFAD losses. If adequately legislated, this system could be used to control total number of MFADs deployed at any given time and their location. It could also help monitor and enforce potential regulations on the types of materials used for MFAD construction such as prohibiting the use of entangling materials (see Annex 5 of ICCAT 19-02 Rec). Accurate estimates of MFAD numbers in territorial waters is likely to be key to help manage the MFAD fishery at local and regional scales (see section on Improving assessment of fishing impacts of MFAD on the ecosystem and stocks).

Again, low-cost ICT tools could be used to dramatically speed up the MFAD reporting and approval process via reporting/application forms supported by mobile devices. Moreover, other ICT tools such as freely available Geographic Information Systems (e.g. QGIS; http://www.qgiscloud.com) could be integrated with this registration system to identify most suitable areas for MFAD deployment and facilitate marine spatial planning. Such a system would also allow for data-driven assessments of MFAD lifespan and the factors that might influence it. Importantly, data from the registration system could be easily contrasted with fishery vessel tracks obtained via VTS to identify illegal MFADs and so facilitate enforcement in near-real-time.

IMPLEMENTATION OF A LICENSING SYSTEM

It will also be critical that countries implement a MFAD licensing system that integrates and distinguishes among all types of fishing on MFADs (subsistence, commercial, recreational, charter). This license system should also be legislated. Granting of MFAD fishing licenses should be made conditional on the users' history of compliance with rules and regulations governing MFAD use. As Mohammed (2015) rightly points out, such system could be used to not only to control access to the MFAD fishery, it could also provide valuable socio-economic and demographic data on the MFAD users themselves, thus facilitating further assessment of the socio-economic impact of the fishery and potentially helping project trends.

Low-cost ICT tools could again be used to acquire, store, and manage the data for this licensing system, with the added value that this should facilitate integration of different electronic databases such as the MFAD registration and MFAD licensing databases if needed, given that many MFAD owners are also likely to be MFAD fishers. The latter should provide a more nuanced description of the socio-economic dimension of the MFAD fishery.

DATA SHARING AND INTEGRATION ACROSS THE REGION

The use of the same standardized catch and effort data form, minimally adjusted to reflect the fishery context of each location (e.g. main target species, fishing gears, fishing locations), should allow for an effective and efficient integration of data across locations, which is an important step towards improving the management of shared exploited stocks (CRFM 2015). A lack of consistent technical support for specialized fisheries statistics software has been in the past a major hurdle to data integration within the region (Barnwell 2014; CRFM 2014). This hurdle can now be overcome given the present information technology tools readily available for free or at affordable prices, including user-friendly field data collection and database systems such the KoBo toolbox (https://www.kobotoolbox.org/), open-source data analytical tools such as the R environment, and the widespread use of mobile smart technology across the region. With adequate initial training, the unlimited access to these tools and technology should facilitate building up the necessary local technical capacity to maintain these data systems across locations with minimum external expert input.

As this integration is pursued, it will also be important to expand data collection systems and align them with the data requirements of the WECAFC Data Collection Reference Framework (DCRF), which was recently endorsed by WECAFC in its 17th Commission Session, to further facilitate the use of these data to develop, monitor, assess and review regional fishery policies and inform regional and sub-regional management plans (WECAFC 2019). Table 4 describes the broad data requirement components of the DCRF. The DCRF manual contains working definitions, further describes the structure of the data collection, and provides appendices with WECAFC standard classifications (e.g. gear type, vessel type; nominal effort by vessel type; etc) and lists of priority species and other reference species. It is important to note that the standardized data collection form developed for the CRFM logbook aligns well with the catch and effort component of the DCRF data prescriptions (Table 4).

The next step is the development of a regional WECAFC-CRFM-OSPESCA database to which the member states would contribute with their data and data sharing agreements among stakeholders operating at different hierarchical levels (e.g. fisher and local fishery authority; national fishery authority and CRFM/OSPESCA; CRFM/OSPESCA and WECAFC; WECAFC and ICCAT). Of critical importance will be to ensure that data provided by individual fishers remains confidential to facilitate their buy-in.

Table 4 – Data requirements of the WECAFC Data Collection Reference Framework (DCRF) broken down by components (tasks).

ID	Task	Sub-task	Data	Description
I	**Regional statistics**	-	Operating fishing vessel count; Total nominal catch; Total effort; Total capacity; Total engine power	General summary overview of the fishery sector in the wide Caribbean region. Data reported in this task are a sum of ot indicators available in the following tasks.
II	**Catch and effort**	**Catch**	Retained catch; Discarded catch; Nominal catch	Catches are defined in units of numbers as all the removed during the fishing activities whether targeted or taken as bycatch, and in weight units as the total weight of catches p species, area, fleet segment for the given year.
		Effort by fleet type	Days fishing; Nominal effort; Fishing vessel count	Effort will reflect the national fleet effort deployed during t reporting period to catch the above reported catches (and landings).
III	**Fleet statistics and vessels**	**Fleet by primary gear**	Number of active vessels	Number of vessels engaged in the fishery (i.e. active) by yea by primary gear and by fishing area and time unit.
		Vessel registry	Vessel descriptors	Regional vessel registry fed by the national vessel records o registries.
IV	**Biological information**	**Size data**	Total retained catch (weight); Total discarded catch; Total weight of samples; Length class /sex/maturity; Number of individuals at length; Total weight of individuals	Size frequencies of the samples (retained and discarded) measured for each species classified by major fleet, gear sample units, time strata and area strata and sex for select species.
		Catch at size data	Length Class; Sex; Stage of Maturity; Total Weight of Individuals; Total Catch	Reported catch at size (raised to Task II Catch data) classifie by primary fleet, gear, species time unit and area and by se (for select species).
V	**Incidental catches: Endangered, Threatened, Protected (ETP) species catches**	-	Landings (in numbers or weight as appropriate); Number of discards alive (in numbers or weight as appropriate); Number of discards dead (in numbers or weight as appropriate)	The discards resulting from endangered, threatened or protected species catches are reported.
VI	**Socio-economics**	**Employment**	Number of fishers for the specified gender / category / secondary workers	Employment in the fishery sector is a useful indicator of the importance of the fishery sector in the region. This indicato aims to present number of fishers by category (fully employ or part time ones), by gender (male / female) by the major fleet, and area for the reference year.
		Engagement in Fisheries	Count of fisherfolks Count of fisherfolks x days fishing	Number of fisherfolks actively taking part to fishing activitie and the intensity of such involvement.
		Value of catches	Monetary value of total landed fish for the given species	The value of Capture fisheries production at first sale after landing, in US$

It is important to recognize that, in spite, of the potential of ICT to facilitate the development and implementation of fishery data collection systems, countries will still differ in their capabilities to do so. This was explicitly recognized be the original CRFM/JICA (2012) study, which had at the time proposed a Plan for data integration with short- (1-3 years), medium- (3-5 years) and long- (5 -10 years) term goals for the different groups of countries, with all countries improving their respective capabilities over time (Table 5). Expected short-term outcomes in Group C countries included the timely provision, storage, processing and reporting of data suitable to describe landings. Medium-term outcomes for these countries included, in addition to the short-term ones, the provision of biological data capable of informing management and the development and use of a fishery database. Long-term outcomes for these countries included, in addition to the medium-term ones, the provision of data suitable for stock assessments and the provision of socio-economic data for the fishery along with the integration of the fishery database with other statistical sources. Countries in the B and A groups were expected to reach these outcomes over shorter time frames and subsequently continue to improve in data capabilities in the long-term as well as to contribute with data to regional assessments and management. This staggered approach provides a useful framework to facilitate the integration of such countries and should also be adopted here.

Table 5. Excerpt from CRFM/JICA (2012) showing the proposed integration of fishery statistic systems over time across countries with markedly different monitoring capacities

Data Item	Term	Short Term			Medium Term			Long Term		
	Group	A	B	C	A	B	C	A	B	C
Fishing Vessel and License Information										
Vessel count				O						
Vessel registration		O	O		O	O	O	O	O	O
Vessel inspection status		O	Δ		O	O	O	O	O	O
Issues on vessel registration		O	O		O	O	O	O	O	O
Fishing License data		O	Δ		O	O	O	O	O	O
Issues on fishing license registration.		O	Δ		O	O	O	O	O	O
Fish Catch and Landing Data										
Estimated landing data		O	O	Δ	O	O	O	O	O	O
CPUE per gear and vessel type (0-9%)*1				O						
CPUE per gear and vessel type (10-30%)*1			O				O			O
CPUE per gear and vessel type (50% -)*1		O			O	O		O	O	
Biological Fishery Data										
Detailed biological data for target species*2		O	O	O	O	O	O	O	O	O
Simplified biological data for target species*3		O	O	O	O	O	O	O	O	O
Analyzed data for fishery resource management*4		O	O		O	O	O	O	O	O
Analyzed data for stock assessment and fishery development*5		O			O	O		O	O	O
Fishery Statistic Report										
Updated stratification of landing sites		O	O	O	O	O	O	O	O	O
Fishery statistical data sampling program*6		O	O	O	O	O	O	O	O	O
Fishery statistic annual report		O	O	O	O	O	O	O	O	O
Regional fishery data report					O	Δ		O	O	Δ

*1 Rate of sample size is "number of samples"/"number of maximum possible samples" per gear and vessel type.

*2 The detailed biological collected data include fish weight, length, gonad weight, maturity, and so on. This data will be collected for the target species for at least a year, in order to optimize and simplify the biological fishery data collection.

*3 The simplified biological collected data include, for each target species, only landed total weight, number of fish, maximum fish size, and minimum fish size.

*4 Data analysis for the fishery resource management results in determination of restricted period for the target species, restricted fishing gear mesh size, and so on.

*5 Data analysis for the stock assessment and fishery development results in determination of trends and projection of the available fishery resources, development plan for fishery and aquiculture in fishery communities, and so on.

*6 The sampling program includes data sampling method, data sampling coverage, case of sampling schedule, implementation structure for the sampling, fishery data management method, estimation method for landings (CPUE, raising factor and estimation formula) and effect on the fishery statistical data, fisheries resource management, and fishery and aquiculture development.

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IMPROVING ASSESSMENT OF FISHING IMPACT OF MFADS ON THE ECOSYSTEM AND STOCKS

MFADS AS FISHERY-INDEPENDENT RESEARCH TOOLS

Moreno et al. (2016b) make a case for the need of fishery-independent methods to help assess the status of target stocks, given the variable quality of official catch and effort data and the frequent lack of standardization of collection and reporting of such fishery-dependent data. This is also particularly relevant for tropical tunas given the increases in fishing efficiency driven by technological advances in the purse seine fisheries that bring into question the value of CPUE as an index of relative abundance of their stocks (Fonteneau et al. 1999; Fonteneau et al. 2013). From an ecosystem-based fishery management perspective (Pikitch et al. 2004), fishery-independent methods are also necessary to assess the status of by-catch species, for which fewer fishery-dependent data exist and which are rarely the focus of stock assessments.

Currently, most industrial purse-seine fishing operations using drifting FADs to capture tropical tuna currently make use echosounder buoys on the FADs that provide crude estimates of FAD-associated tuna biomass and transmit those estimates via satellite communications to the fishers (Lopez et al. 2014; Lopez et al. 2016). These echo-sounder buoys can establish remote continuous communications with fishing fleets and receive communications from fleets to change their settings (Ehrhardt et al. 2017a). Moreover, they can incorporate multi-frequency transducers that allow for increasingly better capacity to discriminate among tuna species and sizes (Moreno et al. 2016a; Moreno et al. 2019). These technological advancements, which have led to increases in fishing efficiency and changes in fishing strategies in the purse-seine fishery making use of drifting FADs (Lopez et al. 2014), could also be used to generate fishery-independent indices of aggregated abundance on FADs to supplement fishery-dependent ones.

In that regard, Moreno et al. (2016b) and Ehrhardt et al. (2017a) highlight the great potential of FADs as windows of scientific observation into the animal communities (fish and sea birds, mammals, and turtles) that associate with them, as sampling tools of species composition and abundance, as passage points that inform on animal distribution and movement, and as sensors of the physical environment in which these animals are found. Indeed, in addition to low-cost satellite-linked echosounders, individual FADs can be equipped with various low-cost electronic tools such as under-water cameras, acoustic receivers, and hydrophones that provide diverse and increasingly detailed information about animal communities and physical environment surrounding them (Table 6). Acoustic receivers on FADs can be used to detect the presence of individual fish tagged with electronic transmitters as well as download any data collected by the transmitters themselves before the tagged fish encountered the FAD (archival tags; CHAT tags), thus providing valuable information about the movement, behavior, and environmental preferences of selected species (Table 6; Fig 6) (Voegeli et al. 2001; Moreno et al. 2016b; Ehrhardt et al. 2017a). Under-water cameras can provide valuable information about the diversity and aggregated abundance of the species that are not typically detected by echo-sounders, some of which might constitute important by-catch (e.g. sharks) (Table 6; Fig 6) (Moreno et al. 2016b).

Equipping MFADs with electronic instruments to conduct fisheries and biological research is increasing the Caribbean (Merten et al. 2018; Schneider et al. 2021), whereas oceanographic data buoys are currently being used as MFADs by some fishers (Silva et al. 2018), highlighting the dual role that MFADs can play. With current estimates of 3,500+ MFADs in the WECAFC region (Wilson et al. 2020), there is great potential to expand the spatiotemporal coverage of fishery-independent data collection by equipping strategically located MFADs with such instruments and in combination with fish tagging programs. This should increase our ability to identify the drivers of the abundance of target and non-target species over a range of relevant spatiotemporal scales to supplement fishery-dependent data (e.g. Orúe et al. 2020). This expansion could be facilitated by collaborations between MFAD fishers, fisheries departments, and researchers, with the fishers themselves benefitting from the same data to identify when and where to fish and so maximize fishing efficiency and minimize fuel costs. In the case of private MFADs, this would likely require data sharing agreements that protect the fishing strategies of the fishers (Dagorn et al. 2013). In addition to MFADs, which have a very clustered distribution in the region (Wilson et al. 2020), equipping selected oceanographic data buoys and oil rig platforms, which also aggregate fish (Franks 2000; Silva et al. 2018), would help expand the spatial coverage of the monitoring network beyond the insular Caribbean (Fig 7).

Table 6. Types of electronic instruments that can be integrated into MFADs along with the types of data that can provide, whether they are operational or developed but need testing, and the target users (fishers; scientists). Adapted from Moreno et al. (2016b)

Data	Type of instruments	Operational	Developed but need testing for this specific application	Fishers	Scientists
Species	Underwater cameras		X	X	X
Identification	Multi-frequency echo-sounders for tunas	X		X	X
Species	Underwater cameras for sharks		X	X	X
Abundance	Echo-sounders	X		X	X
Species association time and movements	Acoustic receivers	X			X
Biology and behaviour	Coded acoustic tags CHAT tags	X	 X		X
Biological environment	Echo-sounders	X			X

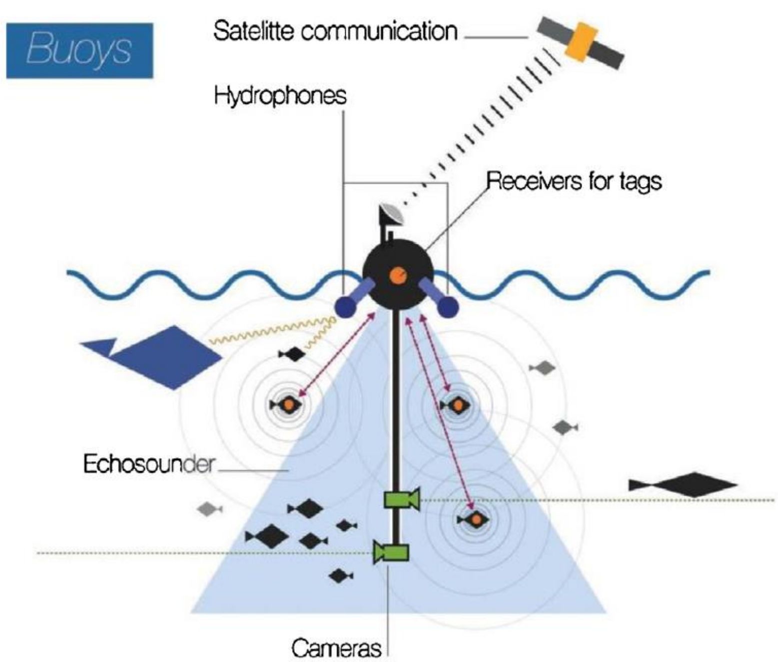

Figure 6 – Schematic representation of a MFAD buoy equipped with hydrophones, echosounders and underwater cameras recording information on (tagged and non-tagged) fish aggregated under the MFAD and transmitting that information via satellite. Adapted from Moreno et al. (2016b)

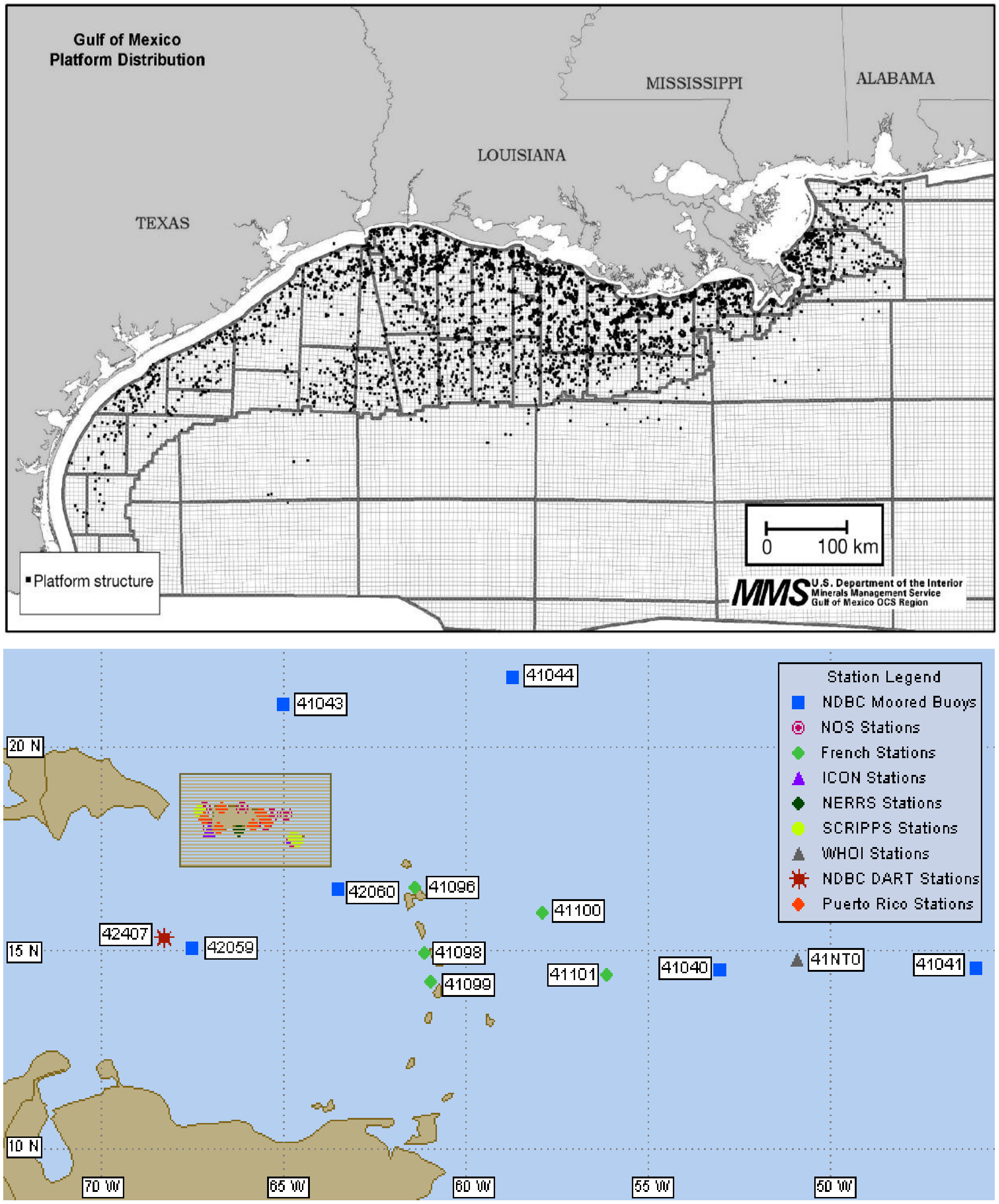

Figure 7 – Location of oil rigs in the Gulf of Mexico in 2004 (top panel) and location of oceanographic data buoys in a section of the Caribbean. Selected oil rigs and data buoys could also be equipped with technology helping identify and quantify fish aggregating under them for research. Data are from Sammarco et al. (2004)(top panel) and the National Data Buoy Center (https://www.ndbc.noaa.gov/) (bottom panel).

ADDRESSING HYPERSTABILITY ON MFADS USING FISHERY-INDEPENDENT DATA

A well-recognized challenge when assessing status of exploited stocks that associate with FADs is that catch-per-unit-effort (CPUE) might not be a reliable index of total population abundance because FADs might still attract, and thus continue to facilitate the catch of, stable numbers of individuals even though total population abundance might be quickly declining under over-exploitation (Ehrhardt et al. 2017a). This decoupling between CPUE and total population abundance is known as hyperstability and manifests itself in those species that are exploited while they aggregate (e.g. spawning aggregations; Erisman et al. 2011). Ehrhardt et al. (2017a) indicated that, in the context of FAD fisheries, the problem of hyperstability remained unresolved and so highlighted the need to the develop fishery-independent estimates of abundance to inform fishery-dependent ones, yet such fishery-independent estimates are particularly difficult to obtain for tropical tunas (Moreno et al. 2016b).

In this regard, Capello et al. (2016) recently offered an innovate and promising solution that would require measuring the residence and absence time around FADs of a subset of individuals of the population, which can be done using electronic tagging telemetry. These estimates are used to derive an association index representing the proportion of the local population (i.e. the subpopulation in proximity to the array of FADs) that is found on FADs. If actual abundance is also estimated at one of the FADs, which could be done using echosounder technology (Lopez et al. 2016; Santiago et al. 2017; Santiago et al. 2020), the association index can be readily converted in an index of abundance. They empirically validated several assumptions underlying their approach with yellowfin tagging data from an array of MFADs in Hawaii (Capello et al. 2016). The authors highlighted that, by expanding tagging studies on selected species and the spatiotemporal network of observational MFADs, their approach had the potential to scale up over wider regions and so yield fishery-independent estimates of abundance for potentially both target and non-target species that would complement fishery-dependent ones at meaningful scales for regional management. Here, as Moreno et al. (2016b) point out, maximizing MFAD observational coverage through technology and estimating MFAD densities with precision (rather than controlling MFAD numbers) is key because the abundance index will depend on the number MFADs in the study system; this will undoubtedly necessitate ambitious regional research programs built upon the cooperation among fishers, researchers and relevant fisheries authorities at local, national, sub-regional and regional scales.

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