How can we efficiently mitigate the impacts of dFADs ?

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Abstract

While drifting FADs contributed to the development of tropical tuna fisheries during the 1990s, their too extensive use during the following decades, especially the beginning of the 2010s, has raised concerns for tunas, non-targeted species and ecosystems. Though various dFAD management measures have been implemented in the Indian Ocean during the 2010s, the impacts of dFADs remain a serious concern for many stakeholders of the fishery. Here, we review the existing knowledge and management of dFADs impacts, focussing on dFAD impacts that are currently at the heart of the debates in the frame of the Indian Ocean Tuna Commission (IOTC). We propose a methodology for selecting among the dFAD management measures that have recently been discussed in IOTC based on several criteria : their ability to cover several impacts of dFADs, their ability to cover the full lifespan of dFADs, the enforceability of the measure and the absence of potential unwanted consequences. Finally, based on the experience of the French and associated fleet operating in the Indian and Atlantic Ocean, we question the efficiency of current dFAD management in IOTC and provide guidelines and recommendations to ensure that dFAD management measures are applicable and fully effective in the Indian Ocean.

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1. Introduction

Fishers have long known that many species of fish, including tropical tunas, naturally associate with the objects drifting at the surface of the ocean. For centuries, they have known that fish associated with Floating Objects (FOBs) are easier to detect and easier to catch. They have long used natural FOBs as an indicator of higher abundance, better catchability and increased fish school size (Hall, 1992; Fréon and Dagorn, 2000; Castro *et al.*, 2002) until they had the idea to mimic the natural behaviour of fish with the deployment of man-made FOBs. In the case of tropical tuna purse seine (PS) fisheries, the use of man-made drifting FOBs, called Fish Aggregating Devices (FADs) fast increase during the 1990s. At a time when the objective of fisheries science was to support the expansion of the world fisheries, drifting Fish Aggregating Devices (dFADs) seemed to be a promising tool to develop purse seine fisheries (PS) and their use was recommended to capture fast tuna schools (Bard *et al.*, 1985; Stretta and Slepoukha, 1986) and the "cryptic" fraction of skipjack stocks (Ariz *et al.*, 1999) that were less accessible to purse seine fishing.

During the 1990s and following decades, increasing numbers of dFADs were deployed in the world oceans (Fonteneau *et al.*, 2013; Gershman *et al.*, 2015; Maufroy *et al.*, 2017b) and the efficiency of PS fishing improved with a significant contribution of FOB fishing and FOB technologies (Lopez *et al.*, 2014; Tidd *et al.*, 2016; Maufroy *et al.*, 2017a; Wain *et al.*, 2021). These changes have supported the fast development of purse seine (PS) fleets in all oceans (Miyake *et al.*, 2010; Fonteneau *et al.*, 2013) and, by the end of the 1990s, dFADs had already become an important mean of catching skipjack, and juveniles of yellowfin and bigeye tuna by purse seiners (Fonteneau *et al.*, 2000). These changes have also lead to growing concerns of scientists for tuna stocks, non-targeted species and ecosystems (e.g. Hallier *et al.*, 1992; Ariz *et al.*, 1999; Fonteneau *et al.*, 2000), soon followed by concerns expressed by fishers representatives (e.g. Riva, 2014) and NGOs (e.g. Baske *et al.*, 2012). In the Indian Ocean, despite these concerns, FOB fishing kept on developing during the 2000s and the 2010s with increasing numbers of dFADs being used at sea (Maufroy *et al.*, 2017b), until the first self-imposed dFAD management measures were implemented (e.g. for the French and associated PS fleets : ORTHONGEL, 2011a, 2011b), followed by the adoption of the first mandatory limitation of FOB operational buoys in 2015 by the Indian Ocean Tuna Commission (IOTC Resolution 15/08).

Though dFAD use has been limited for seven years in the IOTC area of competence and various other dFAD management options have been implemented since 2013 (IOTC, 2013, 2015), the impacts of using too many dFADs remains a major concern for many stakeholders who advocate for stronger and additional management dFAD management measures in the Indian Ocean (Kenya, 2021).

Here, in order to inform management decision making we (i) provide an overview of dFAD impacts and how they are currently managed in IOTC (ii) question the efficiency of current dFAD management in IOTC and (iv) provide guidelines and recommendations to ensure that dFAD management measures are applicable and fully effective in the Indian Ocean.

1. What are the dFAD management priorities in IOTC ?

Relying too heavily on dFADs may impact target tropical tunas through alteration of their natural behaviour (Hallier and Gaertner, 2008; Sempo *et al.*, 2013), contribute to growth overfishing through excess fishing mortality of yellowfin and bigeye tunas (Dagorn *et al.*, 2013), increase levels of non-target catch (Amandè *et al.*, 2008, 2010; Hall and Román, 2013), contribute to ghost fishing of sharks and sea turtles when meshing elements are used for the construction of dFADs (Franco *et al.*, 2012; Filmalter *et al.*, 2013) and contribute to marine litter and deterioration of fragile habitats when dFADs are lost outside fishing grounds (Balderson and Martin, 2015; Maufroy *et al.*, 2015; Escalle *et al.*, 2021; Imzilen *et al.*, 2021).

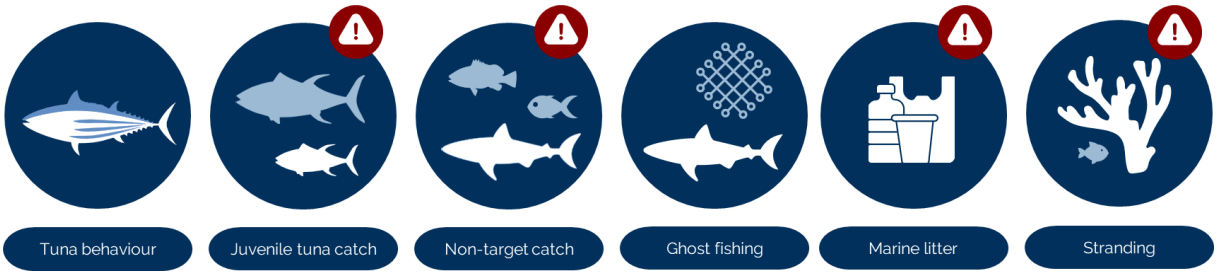

Figure 1 : **main consequences of relying too heavily on dFAD use / FOB fishing (ORTHONGEL, 2021).** Warning signs indicate the categories of impacts for which mitigation solutions are still under development or for which improved management options may be required.

Based on Conservation and Management Measures (CMMs) already adopted by IOTC, issues encountered by purse seine fleets to meet management targets within a short time frame and stock status of tropical tunas in the Indian Ocean, the following dFAD impacts could be considered as higher management priority :

(i) excess juvenile tuna catch (growth overfishing), in a context of overfishing of yellowfin tuna (YFT)
(ii) contribution of dFADs to marine litter and degradation of fragile habitats
(iii) contribution of dFADs to the mortality of Endangered, Threatened and Protected (ETP) species

2. What management options could be used to mitigate the impacts of dFADs ?

There is no such thing as a perfect management solution. In general, to manage dFADs and their impacts it is better to combine several solutions and to choose those that cover the full dFAD lifecycle, address more types of negative impacts and do not have unwanted consequences on fish stocks and ecosystems. Table 1 provides a review of the potential benefits of various dFAD management options based on these criteria.

Additional considerations, such as the enforceability of the proposed measure / combination of measures are discussed as well in this section. Potential socio-economic consequences are not addressed here but should be taken into account, including the consequences for PS fleets using dFADs, but also those for downstream operators in coastal countries and Small Island Developing States (SIDs).

Criteria 1: dFAD management should cover the full dFAD lifecycle

Ideally, a single management measure should be active for the whole time a dFAD is present at sea. Any measure that covers unwanted impacts of the construction of dFAD or the number of dFADs at sea is a good candidate to meet criteria 1.

This includes : limiting the number of operational FOB buoys, limiting the deployment of dFADs, using non-entangling FADs (NEFADs), using biodegradable FADs (bioFADs).

Criteria 2: dFAD management should cover as many dFAD impacts as possible

Ideally, a single management measure should address as many impacts of dFADs as possible at once. All the management options that can decrease the number of dFADs present at sea at a given moment may be good candidates to meet criteria 2 (table 1).

This includes : limiting the number of operational FOB buoys or limiting the deployment of dFADs. Additional measures such as a limitation of FOB buoy purchase and limiting the number of support vessels may be considered, but they are probably not necessary if one of the previous dFAD management options is correctly implemented and monitored.

Criteria 3: dFAD management should not have unwanted consequences

Fishers may change their behaviour as a response to a dFAD management measure, which may render the management measure less efficient or induce other unwanted impacts of dFADs.

For example : limiting the number of operational buoys reduces the number of dFADs at sea and is therefore likely addressing most dFAD impacts. However, FOB tracking buoys may be deactivated earlier, to comply with existing limits and decrease communication costs (Imzilen *et al.*, submitted). More generally, limiting the number of dFADs deployed or present at sea without setting the rules for their recovery is unlikely to efficiently fully prevent marine litter and stranding.

Criteria 4: dFAD management should be enforceable

Ideally, a given management measure should be enforced using information collected independently from fishers or fishers declarations that can easily be cross-verified.

For example : it is necessary to make sure that all operational buoys are reported, and in particular to ensure that purse seiners do not use cycles of activation/deactivation or other means to report less operational buoys than those actually at sea. Two verification mechanisms have been proposed : the verification that buoy are only activated onboard (Maufroy and Goujon, 2019; adopted in IOTC Res 17/08) and the verification that buoys are reactivated only after they have been brought back to port (Santiago *et al.*, 2017; adopted in IOTC Res 19/02). The cross-validation of buoy/vessel positions is likely more efficient than the cross-validation of self-declared buoys on stock and at port inspections.

Table 1: review of the potential benefits of a range of dFAD management options (ORTHONGEL, 2021)

When ?	How ?	What for ?						Potential unwanted consequences ? and other useful information	IOTC
		Tuna behaviour	Tuna juveniles	Non-target	Ghost fishing	Marine litter	Stranding		
Construction	Non entangling FADs							Used by most purse seine fleets since the mid 2010's.	✓
	Biodegradable FADs							Tests are currently being undertaken for a transition to bioFADs.	
	FOB buoy purchase limits							FOB buoys can be reused several times. Limiting the purchase is therefore less efficient than directly limiting use.	✓
Deployment	FAD deployment limits							A long FAD deployment moratorium, as already in place in ICCAT (3 months) may have similar effects.	
	FAD deployment zones								
	Support vessel limits							Support vessels may contribute to the recovery of derelict dFADs.	✓
Tracking	Operational FOB buoy limits							There are less dFADs at sea and therefore all FOB impacts are addressed. But FOB buoys are deactivated earlier to comply with limits.	✓
	Support vessel limits							Support vessels may contribute to the recovery of derelict dFADs.	✓
Visit and fishing	FOB fishing sets limits							If the measure is not combined with FOB buoy limits, more dFADs are deployed to ensure finding FOBs with fish.	
	FOB fishing moratorium							dFADs that are not visited during the closure are more easily lost outside fishing grounds.	
End of use	Derelict dFAD recovery							Tests are currently being undertaken in Seychelles (Indian Ocean).	

no effect | efficient impact mitigation | moderate impact mitigation | potential unwanted consequences on stocks and ecosystems

3. Do we need additional dFAD management in IOTC ?

FOB CMMs have progressively been implemented in IOTC (table 2). The measures that have been adopted aim at collecting data on FOB use at the scale of IOTC, reducing the number of dFADs present at sea, mitigating the impacts of dFAD design on ETP species and fragile coastal habitats and reducing the contribution of dFADs to marine litter (IOTC Resolution 19/02).

Table 2: dFAD management measures adopted in IOTC

Management measure	Adoption	Current reporting
CPCs FAD management plans	Res 12/08	Yearly CPCs FAD management plans
FOB use reporting	Res 13/08	3-FA form
NEFADs	Res 13/08	FOB logbook + scientific observers
Biodegradable FADs	Res 13/08	FOB logbook + scientific observers
Limits of FOB operational buoys	Res 15/08	3-BU form + buoys in stock
Limits of FOB buoy purchase	Res 15/08	FOB buoy purchase bills
dFAD marking	Res 15/08	FOB logbook + scientific observers
Limits of support vessels	Res 17/01	3-SU form
Derelict dFAD recovery	Res 19/02	FOB logbook + FAD management plans

Over time, each of the adopted dFAD management options has been refined, with the implementation of reporting forms (3-FA, 3-BU and 3-SU forms : https://www.iotc.org/data/requested-statistics-and-submission-forms) and the implementation of verification mechanisms (e.g. activation of buoys onboard and reactivation of buoys only after they have been brought back to port, IOTC Resolution 19/02).

In 2021 however, despite the large range of measures already in place in IOTC, additional measures are being requested by various stakeholders of the fishery (e.g. Kenya, 2021). Table 3 reviews the current dFAD management measures already implemented in IOTC and provides a qualitative assessment of their efficacy. The following observations can be made :

(i) Though some stakeholders remain concerned that dFADs built with meshing elements are used in the Indian Ocean, most PS fleets are using NEFADs since the mid 2010's (e.g. ORTHONGEL, 2011). Fishers report this use in their FOB logbook and these information are cross-validated with observer data.

(ii) Various solutions for bioFADs and dFAD recovery are currently being developed. This includes the identification of biodegradable materials (Franco *et al.*, 2012; Goujon, 2015; Zudaire *et al.*, 2019), the development of innovative FAD designs (Moreno *et al.*, 2021), the assessment of land based solutions for the recovery of dFADs (FAD Watch program : Zudaire *et al.*, 2018), the provision of detailed FOB trajectory data to CPC national scientists to identify other dFAD recovery mechanisms to be tested (Imzilen *et al.*, 2021, Imzilen *et al.* submitted).

(iii) Following the implementation of YFT catch limits in IOTC, an increased contribution of FOB fishing sets has been observed for some PS fleets, as a mean to avoid exhausting national YFT quotas too early in the year (Floch *et al.*, 2020). Science-based additional management solutions may be needed to avoid an undesired increase in tuna juvenile and non-target species catches.

Table 3: review of the potential benefits of IOTC measures on dFADs

How ?	What for ?						Current efficiency in IOTC ? and other useful information
	Tuna behaviour	Tuna juveniles	Non-target	Ghost fishing	Marine litter	Stranding	
Non entangling FADs							Used by most purse seine fleets since the 2010's.
Biodegradable FADs							Tests are currently being undertaken for a transition to bioFADs.
FOB buoy purchase limits							**All impacts:** limiting the purchase of FOB buoys is part of the control of the operational FOB buoy limit. It is probably not enough efficient alone.
Support vessel limits							**All impacts:** limiting the number of support vessels is part of the control of the operational FOB buoy limit. It is probably not enough efficient alone.
Operational FOB buoy limits							**Tuna juveniles and ETP species :** the YFT catch limit has lead to increased catches on FOBs **Marine litter and stranding :** FOB buoys are deactivated earlier
Derelict dFAD recovery							Tests are currently being undertaken in Seychelles for a land-based recovery.
Combined effect							

best addressed by another measure | low concern | work in progress or fine tuning required | additional solution needed

NB : the efficacy of current IOTC dFAD management CMMs are only reviewed qualitatively. Aggregated data reported to IOTC or detailed data available to CPC national scientists could be used to provide a quantitative assessment.

4. What should be the future steps to efficiently mitigate dFADs impacts in IOTC ?

4.1 Make sure to use the right vocabulary

The question of the appropriate vocabulary to be used to describe FOB fisheries has long been discussed in t-RFMOs. Considerable work has been done to clarify the notion of "FAD", their modalities of use and the options for FAD management (Fonteneau and Chassot, 2014; Goujon *et al.*, 2014; Gaertner *et al.*, 2016; Grande *et al.*, 2019). Among others, EU scientists and PS fleets have worked conjointly on definitions and data collection procedures that would allow evaluating separately the effects of FOB fishing in terms of fishing effort, habitat modification and pollution (Gaertner *et al.*, 2016; Grande *et al.*, 2019). The adoption of these definitions is critical to ensure that stakeholders speak the same language when discussing dFAD management options in IOTC but also to ensure that questions addressed by the Commission to the Scientific Committee can be answered by scientists.

4.2 Quantitatively assess the efficacy of dFAD current management measures

Various stakeholders are currently advocating that additional dFAD management measures are necessary in the Indian Ocean. Some of the proposed approaches are based on observations that were made a few years ago, that may not reflect the dFAD situation anymore. This includes concerns regarding entanglement of ETP species in the structure of dFADs (e.g. Ndegwa, 2021), doubts that all operational FOB buoys are reported (e.g. Ndegwa, 2021) and concerns that virtually no FOB data is available in IOTC (e.g. IPNLF, 2021)

Instead of accumulating dFAD management options, that may not have the desired effects or would unnecessarily put a strong burden on PS fleets, a full quantitative assessment of the efficacy of current IOTC dFAD management measures should be conducted. For some dFAD impacts however, recently published scientific dFAD literature or operational information provided by PS fleets could already provide guidance to fine tune existing dFAD management (see 4.3 and 4.4).

4.3 Consider the removal of redundant measures to limit the number of dFADs at sea

At first, the number of dFADs present at sea was limited through a single management measure : the limitation of operational FOB buoys (IOTC, 2015). Along the years, acknowledging that the verification of compliance with this measure was probably more difficult than initially thought, due to a risk of underreporting of buoys (Maufroy and Goujon, 2019b), a range of additional measures have been implemented. Not all these measures may actually be necessary to reduce the number of dFADs present at sea at a given moment.

Table 4 reviews potentially redundant measures and verification mechanisms. This review suggests that a properly monitored limitation of operational buoys, allowing the verification that there is no "ghost dFAD" in the Indian Ocean may be sufficient. Maufroy and Goujon (2019a) and ORTHONGEL (2021) propose a methodology based on the cross-verification of FOB buoy, purse seiner and support vessel trajectories. The methodology would require an update of the current IOTC 3-BU form to ensure that all vessels receiving information from a given FOB buoy declare its use. The verification would be carried out by CPCs who would report the results to the IOTC Compliance Committee.

Table 4: options to grant compliance with operational FOB buoy limits

Verification mechanisms	Comment	
Limits of FOB buoy purchase	Unnecessary if a mechanism if in place to ensure that there is no ghost buoy in the Indian Ocean.	
Limits of support vessels		
Onboard buoy activation	These verifications are redundant.	Can be verified remotely.
After port buoy reactivation		Requires physical control in port.
Daily FOB buoy positions	Necessary to verify declared FOB buoy numbers.	

4.4 Avoid unwanted consequences of IOTC management measures

One potential unwanted consequence of buoy limits is that buoys of FOBs drifting too far from fishing grounds are deactivated earlier, so as to avoid exceeding limits for FOBs that cannot be used for fishing (Imzilen *et al.*, submitted). A potential solution for this would be to declare "buoys to be recovered". Buoys would then be counted as "to be recovered" instead of operational and the position of derelict dFADs would still be available for recovery purposes.

Non-FOB management measures may also have a consequence on FOB use and impacts. This was the case for example with the implementation of yellowfin tuna (YFT) catch limits (IOTC Resolution 16/01). Indeed, targeting FOB instead of free swimming (FSC) tuna schools can be used a as mean to avoid exhausting YFT quotas too early in the year. An increased contribution of FOB fishing sets to PS catches has therefore been observed since 2017, though variations in the proportion of FOB fishing sets have been observed between years (Floch *et al.*, 2020). Since an increase in FOB catches may lead to increased catches of juvenile tuna and ETP species, additional management options may be required if this trend is confirmed.

YFT and BET juveniles : since implementing management measures without clear management objectives is unlikely to achieve the desired goals, defining such management objectives is critical to ensure that the risk of growth overfishing is addressed. This could be done, for example, by testing the effect a range of natural and fishing mortality assumptions for juveniles on the Maximum Sustainable Yield of YFT and BET. This would provide guidance to managers to anticipate the potential effects of a range of catches of juveniles of YFT and BET and could serve as a basis to set clear objectives to reduce FOB-associated catches of juveniles, if needed. Once such objectives have been set, the best combination of management tools would be more efficiently discussed (e.g. spatio-temporal management to reduce fishing in hotspots of juveniles).

In order to carry out this work properly, data on catches of juveniles reported to IOTC should obviously be of the best quality possible for all fleets. Potential tools to grant data quality would be to consider increased observer coverage to collect the data at sea or extending the current tuna discard ban (IOTC, Resolution 19/05) to all fleets, so that catch composition can accurately been assessed in port.

ETP species : of course, when it comes to ETP species, the approach should be different and does not require additional definition of management objectives, since the objective is to reduce ETP species incidental catches and mortality as much as possible. Potential mitigation tools include real-time

monitoring of hotspots of ETP species, avoiding setting on small schools of tunas (Dagorn *et al.*, 2012) and releasing individuals of ETP species using Best Practices (Poisson *et al.*, 2012).

4.5 Set gradual and realistic dFAD management time frames

A decade of tests has not allowed PS fleets to identify the perfect solution to mitigate the contribution of dFADs to marine litter and degradation of coastal habitats. Yet, this does not mean that no progress has been made, since feedback from past and current tests may be used to adopt a gradual and realistic mitigation of derelict dFAD impacts in IOTC.

Biodegradable dFADs : the EU funded BIOFAD (Zudaire *et al.*, 2019) has allowed identifying two potential options for the transition to bioFADs : (i) start replacing some components of current dFAD designs, using for example cotton ropes for the tail of dFADs, and continue research and development to replace plastic elements and (ii) change the design of dFADs using more compact and robust solutions (Moreno *et al.*, 2021)

dFAD recovery programs : land-based recovery of dFADs is currently being tested in Seychelles through the FAD Watch project (Zudaire *et al.*, 2018). Since 2018, the project has evolved to include most large purse seiners of the Indian Ocean. A solution to intercept dFADs before they beach will soon be tested and its efficacy will be assessed. In complement, detailed FOB trajectory data provided to scientists has allowed to propose ocean-based recovery solutions (Imzilen *et al.*, 2021) that could be tested in real fishing conditions to fully assess their efficacy.

These elements could serve as a basis to set realistic and gradual time frames for bioFADs and dFAD recovery programs. A similar approach should ideally been taken with all management measures. It is for course more likely that a given management measure is efficient and complied with if fishers have the time to adjust their practices to new management objectives, as it was for example the case with NEFADs (tests started during the early 2010's and full NEFADs are mandatory since 2019). It is also critical that management measures are adopted with a clear time frame (e.g. several consecutive years), so that PS fleets can redirect their investments according to management objectives.

4.6 Manage all fleets equitably

Of course, the race to dFADs that occurred in the Indian Ocean until they were limited in 2015 (IOTC, 2015; Maufroy *et al.*, 2017b; Chassot *et al.*, 2019) has had consequences for tropical tunas, non-target species and ecosystems. One can easily understand that this contributed to a distrust that dFAD fisheries can be sustainable and to a perception that dFAD fisheries should be the main focus of management discussions in IOTC. Nevertheless, recently published scientific literature suggest that anchored FAD management should be addressed as well, since unmanaged aFADs may be proliferating (Widyatmoko *et al.*, 2021). In addition, gear-specific dedicated IOTC management working groups may be necessary, so that known issues of each gear are equitably addressed in the Indian Ocean.

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