An analysis of the uses, impacts and benefits of fish aggregating devices (FADs) in the global tuna industry

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WWF commissioned this report as a contribution to the ongoing discussions regarding the use of fish aggregating devices (FADs) in global tuna fisheries. This report presents a synthesis on the most up-to-date research and offers recommendations to strengthen the management and scientific understanding of FADs. Please note that the recommendations do not necessarily represent the views of WWF.

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Acronyms

ABNJ	Areas Beyond National Jurisdiction
aFAD	Anchored fish aggregating device
ANABAC	Asociación Nacional de Armadores de Buques Atuneros Congeladores
CECOFAD	Catch, Effort, and eCOsystem impacts of FAD fishing
CMM	Conservation and Management Measure
CPC	Contracting and Cooperating Non-Contracting Party
CPUE	Catch per unit of effort
dFAD	Drifting fish aggregating device
EEZ	Exclusive economic zone
EMS	Electronic monitoring system
EU	European Union
FAD	Fish aggregating device
FAO	Food and Agriculture Organisation of the United Nations
FSC	Free swimming school
GPS	Global Positioning System
GT	Gross tonnage
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICS	Island Conservation Society
IDC	Islands Development Company Ltd
IEO	Instituto Español de Oceanografía
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IOTC	Indian Ocean Tuna Commission
IRD	Institut de Recherche pour le Developpement
ISSF	International Seafood Sustainability Foundation
IUCN	International Union for Conservation of Nature
IUU	Illegal, unreported and unregulated
LOA	Length over all
MADE	Mitigating ADverse Ecological impacts of open ocean fisheries
MARPOL	International Convention for the Prevention of Pollution from Ships
MSC	Marine Stewardship Council
MSY	Maximum sustainable yield
NOAA	National Oceanic and Atmospheric Administration
OPAGAC	Organización de Productores Asociados de Grandes Atuneros Congeladores
ORTHONGEL	Organisation des Producteurs de Thon Congelé
PNA	Parties to the Nauru Agreement
PVR	ISSF ProActive Vessel Register
RFMO	Regional fisheries management organisation
SCRS	Standing Committee on Research and Statistics
SFA	Seychelles Fishing Authority
SMART	Specific, measurable, achievable, relevant and time-bound
SPC	South Pacific Community
TAC	Total allowable catch
WCPFC	Western and Central Pacific Fisheries Commission

Preface

This independent report was commissioned by WWF in early 2016 to contribute to the ongoing discussions surrounding the use of fish aggregating devices (FADs) in tuna fisheries. This document presents a synthesis of the most up-to-date research and opinions on the potential impacts and benefits of FADs and their management at global and regional levels. It also offers a series of recommendations for how the management of FADs might be strengthened and how scientific understanding of the impacts of FADs could be further developed.

The study was framed around the priorities of WWF for ecosystem-based fisheries management and advancing key issues in tuna fisheries. Moreover, while recognising that FADs are used in a range of industrial, artisanal and recreational fisheries, this report concentrates on the use of FADs in industrial purse seine and pole and line fisheries.

The content of the report draws upon publicly available information and consultation with experts across the world. The literature that was reviewed included published scientific papers, technical reports, non-academic literature, proceedings of the tuna Regional Fisheries Management Organisations and other relevant documentation from science or industry. Key informants in the consultation process included researchers, fishery managers, industry stakeholders and other civil society groups from around the world.

This report was authored by Tim Davies and Daniel Skerritt, with contributions from Thomas Franklin, John Pearce and Chris Mees.

Executive Summary

What are FADs and why is there a discussion on their use?

The widespread use of fish aggregating devices (FADs) in tuna fisheries has become an increasingly important management concern. FADs are floating objects, either natural or artificial, used by fishers to attract fish and make them easier to catch. There are two basic designs of FAD: those that are anchored in place (anchored, or aFADs) and those that are untethered and free to drift on the ocean surface (drifting, or dFADs). While fishers regard the use of FADs as a highly effective way to improve catch rates and reduce operating costs, their use has also been associated with a number of potential negative impacts. As a consequence, FADs are at the centre of a global discussion regarding the long term sustainability of tuna stocks and the ecological impact of tuna fisheries.

What is the purpose of this report?

Much has been written and spoken about FADs in recent years, and several varying and often competing viewpoints exist. While each of the different perspectives on the benefits and drawbacks of FADs are valid, the issue of FADs has often been viewed by the different advocacy groups through a single lens. This has the potential to polarise the discussion on FADs, making it difficult to build consensus on how FADs, and tuna fisheries more generally, might be used and managed in a sustainable and environmentally-responsible way. This report responds to this challenge by presenting a synthesis of the most up-to-date information and opinions on the use of FADs in global tuna fisheries, and offers a set of recommended principles and actions that are needed to strengthen and advance the management of FADs.

What are the impacts of FADs?

FADs are associated with both positive and negative potential impacts. Floating objects aggregate sparsely distributed tuna schools, which makes them relatively easy to find in the open ocean, and they also stabilise schools and reduce the speed at which they travel, making them comparatively easy to catch. This is of considerable advantage to the tuna fishing industry. On the negative side, FADs are associated with the catch of juvenile tunas, bycatch of vulnerable non-target species, modification of tuna habitat, damage to coastal habitats and interference with other maritime activities. Although the extent and severity of these positive and negative impacts of FADs is uncertain due to limited information, the global proliferation in their use, without addressing these uncertainties, is a source of increasing concern to fishery managers, scientists and NGOs.

How are FADs and their impacts managed?

Industrial tuna fisheries that use FADs are managed primarily by the four tropical tuna Regional Fisheries Management Organisations (RFMOs). The most urgent concern of tuna fishery managers and researchers is the uncertainty surrounding the use and impacts of FADs; a priority, therefore, has been to gather data on the characteristics of FADs and how fishing fleets use them. Responding to the potential impacts of FADs, RFMOs have focused on protecting stocks of tuna, typically by adopting measures aimed at reducing the mortality of juveniles, and reducing bycatch of non-target species, especially sharks. Several of these measures have been aimed directly at the practice of FAD fishing, such as limiting FAD sets or requiring more sustainable designs, while others have been less direct, such as implementing closures, catch limits or discard bans. A number of non-governmental organisations and non-profit partnerships, including ISSF, the Pew Charitable Trusts and WWF, have also been active in advocating for greater control on the use of FADs, improving the monitoring of their use, and, in collaboration with research institutes and the purse seine industry, trialling new FAD designs with reduced environmental impact.

What research is being done on FADs?

The priorities of tuna fisheries managers change over time, and consequently so do the types of research questions asked and answered by scientists. Two topics in particular are currently the focus of intense research efforts: the contribution of FADs to fishing effort, and how to estimate and account for it in management; and the extent of bycatch and entanglement of animals in FADs, and how to mitigate this environmental issue. With respect to fishing effort, the recently completed 'Catch, Effort, and eCOsystem impacts of FAD-fishing' (CECOFAD) project (2014-2016) made progress in improving the understanding of the contribution of FADs to fishing effort, providing insight into the calculation of catch per unit effort and thus how to better assess the status of tuna stocks. The issue of bycatch and entanglement was the focus of the 'Mitigating ADverse Ecological impacts of open ocean fisheries' (MADE) project (2008-2012), which made progress in trialling non-entangling FAD designs that are able to attract tuna while avoiding entanglement of turtles and sharks. Ongoing research on this theme is being led by ISSF, who have trialled non-entangling and biodegradable FAD designs and more recently have explored acoustic discrimination at FADs to improve selectivity and avoidance of bycatch in purse seine fisheries.

What can be done to improve future management of FADs?

A series of recommendations are proposed for how the policy and management of FADs might be strengthened and how scientific understanding of the impacts of FADs could be further developed. These recommendations are intended to highlight key 'areas to watch' in FAD policy, management and science. A total of 12 specific recommendations are offered in the following areas:

1. **Strengthening data reporting and monitoring**: to ensure that data reporting requirements are adequate for use in developing and monitoring appropriate FAD management measures, and that data reporting is of a sufficiently high standard.
2. **Development of FAD management strategies:** to maximise the utility of current FAD management plans, and to raise the bar in terms of future requirements for FAD management.
3. **Mitigating impacts through FAD design and materials:** to promote the widespread use of non-entangling and biodegradable FAD designs throughout global tuna fisheries, building on progress that has already been made in this area.
4. **Limiting FAD use**: to ensure that meaningful limits on dFADs are introduced, based on robust scientific evidence, whilst keeping the management objectives and challenges in mind.
5. **Increasing fishing selectivity:** to facilitate 'thinking outside of the box' in terms of developing selectivity technology that reduces the catch of small tunas and non-target species.
6. **Understanding consequences of FAD management:** by encouraging further research into FAD impacts in terms of economic, societal and environmental issues to ensure the possible consequences of management actions are understood.
7. **Increasing communication and collaboration:** to support the progression of FAD related scientific research generally.

1 Introduction

Tuna fisheries are a major global industry. The total catch of commercial tuna species worldwide in 2014 was around 5 million tonnes, the highest on record and almost 10 times higher than when industrial fisheries began in the 1950s (ISSF, 2016). There are five main species targeted in commercial tuna fisheries throughout the world's oceans - bigeye, skipjack and yellowfin tuna (the so-called 'tropical tunas'), and albacore and bluefin (the 'temperate tunas') – which are managed as 23 separate stocks. Of these stocks, 48% are estimated to be at a healthy level of abundance, 39% are overfished and 13% are somewhere between these two states. Stocks of skipjack tuna, which make up more than half of global catches, are generally considered to be healthy, whereas all populations of bluefin and a third of albacore stocks are overfished, and some yellowfin stocks are declining (ISSF, 2016). With these catch trends continuing, and signs of overfishing in many stocks, there is a clear need to scrutinise the management of tuna fisheries worldwide.

Four tropical tuna Regional Fisheries Management Organisations (RFMOs) are charged with conserving and sustainably managing tuna stocks: the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). These tuna RFMOs face a number of considerations that must be addressed to ensure effective and environmentally-responsible management of tuna fisheries. On one hand, RFMOs must ensure that stocks are maintained at sustainable levels or, if already depleted, can be rebuilt. To achieve this, management needs to be based on reliable scientific information and an effective strategy of measures that are able to regulate key dynamics of the fishery. On the other hand, negative ecological impacts associated with fishing activities must be managed explicitly to maintain control over cumulative effects on the marine environment. This too requires a good scientific understanding of the different ecological impacts that result from fishing, and the design and implementation of effective measures to mitigate them.

The widespread use fish aggregating devices (FADs) in tuna fisheries is an issue of common interest to all four tuna RFMOs and has become an increasingly important management concern. FADs are purpose-built floating objects used by fishers to attract tunas and make them easier to catch. Fishers regard the use of FADs as a highly effective way to improve catch rates and reduce operating costs, especially when compared to the practice of targeting free swimming tuna schools. However, their use has been associated with a number of potential negative impacts, including the exacerbation of overfishing, high catches of juvenile tunas, bycatch of vulnerable species, modification of tuna habitat and the introduction of litter into the ocean (Dagorn et al., 2012). As a consequence, FADs are at the centre of a global discussion that cross cuts management concerns regarding the long term sustainability of tuna stocks and the ecological impact of tuna fisheries.

Much has been written and spoken about FADs in recent years, and several varying and often competing viewpoints exist. The fishing industry is a strong advocate of the use of FADs, and, due to their role in improving search efficiency, consider them to be one of the most important advances in tuna fisheries. The benefits of FADs are also perceived by many sustainable development agencies, especially in island regions, where FADs can be important in creating and diversifying fishing opportunities for coastal communities. In contrast, FADs tend to be viewed with greater unease by environmental NGOs and the sustainable seafood movement, who are concerned with the ecological impacts surrounding their use. These concerns are also recognised by the tuna RFMOs, although the overall view is that not enough is yet known about the use of FADs by tuna fleets, nor the extent of their impact on tuna stocks and pelagic ecosystems.

While each of the different perspectives on the benefits and drawbacks of FADs are valid, the issue of FADs has often been viewed by the different advocacy groups through a single lens. This has the potential to polarise the discussion on FADs, making it difficult to build consensus on how FADs, and tuna fisheries more generally, might be used and managed in a sustainable and environmentally-responsible way. This report responds to this challenge by presenting a synthesis of the most up-to-date information and opinions on the use of FADs in global tuna fisheries, including discussion on the potential impacts and benefits associated with FADs, and a commentary on how FADs have been managed to date by the tuna RFMOs. A set of recommended principles and actions are also provided that are needed to strengthen and advance management policy and measures on FADs, and identify where further scientific research should be prioritised.

2 Background

2.1 What are fish aggregating devices?

Fish aggregating devices are floating objects used by fishers to attract tunas and other pelagic species and make them easier to catch. Many wide-roaming pelagic species have an affinity to floating objects – whether seaweed, branches or man-made debris – with which they may associate for several days or weeks. The reasons behind this behaviour are not completely understood, but possible explanations include that floating objects provide a refuge from predators, serve as a meeting place for other schooling fish or a function as place of orientation (Hall, 1992; Dempster and Taquet, 2004). FADs are designed to exploit this associative behaviour and attract tunas to a location that is known to the fisher - either because the FAD is anchored in position or tracked using satellite technology - allowing tuna schools to be found and caught with relative ease.

FADs are a man-made version of naturally occurring floating objects, which tuna fishers also utilise in a similar way. Natural floating objects can be of plant origin (e.g. seaweed, logs, coconuts), animal origin (e.g. large sharks, dolphins, carcasses) or human origin (e.g. netting, rope, waste debris). The principal difference between natural objects and FADs is that they are not typically tethered in place or able to be tracked by fishers and so must be actively searched for.

Tuna can also be caught as free swimming schools, which are not associated with a FAD or other floating object. This practice of catching tuna, which was relatively more common before the advent of FADs, involves greater search effort and requires a different set of skills to ensure the fast-moving tuna do not escape.

Throughout this report FADs are referred to explicitly as anchored (aFAD) or drifting (dFAD) designs, and where the term ‘FAD’ is used, this refers to both designs generally. The term ‘floating objects’ refers to both FADs and naturally occurring objects.

2.2 FAD types

There are two basic designs of FAD: those that are anchored in place (anchored, or aFADs) and those that are untethered and free to drift on the ocean surface (drifting, or dFADs).

Box 1 Key features of drifting and anchored FADs

Drifting FADs	**Anchored FADs**
Used almost exclusively by industrial tuna purse seine fleets.	Used by a wide range of industrial pole and line fleets, artisanal fisheries and recreational fishers.
Deployed in offshore oceanic waters throughout most of the tropical Atlantic, Indian and Pacific Oceans.	Anchored inshore (artisanal and recreational fishers) or offshore at depths of up to 2,500 m (industrial fleets)
Low cost construction, made from floating rafts of bamboo or plastic fitted with instrumented buoys containing satellite tracking devices and eco-sounders for fish finding.	Typically constructed from a raft made from steel, aluminium or fiberglass, and equipped with radar reflectors and solar powered lights.
Owned by the vessel that deploys them, although in practice a fisher will fish on any dFAD that is encountered.	Industrial and recreational aFADs are usually state-funded and owned, with private use agreements in place in some regions.

2.2.1 Drifting FADs

Drifting FADs are used almost exclusively by industrial purse seine fleets that target skipjack, yellowfin and bigeye tunas throughout the world's tropical oceans.

The concept of the dFAD arose in the 1980s when fishers started experimenting with ways to maximise the potential of naturally-occurring floating objects as fishing tools. Fishers had long recognised the potential advantages of floating objects in finding tuna schools, but they were often difficult to find in the vast open ocean. Initially, reflectors and radio beacons were attached to logs and branches to improve their detection from greater distances, and eventually fishers started to construct purpose-built rafts – dFADs – fitted with electronic (instrumented) buoys that extended the detection distance further still. The use of dFADs in this way expanded rapidly throughout the 1980s and 1990s, as skippers realised that whilst they could not influence the number of schools of tuna in the ocean, they could feasibly provide a greater number of FADs for tuna to associate with.

It has been estimated that 81,000-121,000 dFADs were deployed globally in 2013, although this estimate is uncertain due to a lack of information regarding activity levels and usage patterns across fleets (Gershman et al., 2015; Scott and Lopez, 2014). Fonteneau et al., (2015) estimate that in the Indian Ocean, where dFAD use has increased by 70% since the early 2000s, the number of annual dFAD deployments may now be between 10,500 and 14,500. Given similarities in fleet composition, the deployment of a similar number of dFADs could currently be occurring in the Atlantic (Restrepo et al., 2015). In the Pacific, the Parties to the Nauru Agreement (PNA) have estimated that 80,000 dFADs have been deployed annually in recent years, based on declarations from purse seine fleets (WCPFC, 2015).

Figure 1 Fishing areas where drifting FADs are used extensively by industrial tuna purse seiners. Based on Fonteneau et al. (2013).

2.2.2 Anchored FADs

Anchored FADs are used by a wide range of industrial, artisanal and recreational fisheries, mostly in coastal and archipelagic regions and within a relatively short distance from shore.

Anchored FADs have long been used by artisanal fishers in parts of the western Pacific, although their use became globally widespread and more systematic from the 1970s when fishery managers started to install aFADs a short distance offshore to reduce the fishing pressure on nearshore coastal resources. Anchored FADs are now commonly used throughout the Pacific Ocean, the Indian Ocean and the Caribbean (Figure 2).

Anchored FADs can be split into industrial and artisanal forms depending on how and where they are used. Industrial aFADs are used most extensively by industrial pole and line fisheries to target skipjack and other tuna species. The industrial aFADs used by these fleets tend to be large robust structures, designed to last at sea for several years, and may be anchored reasonably far offshore at depths of over 2km.

Artisanal aFADs are primarily intended to improve the catch rates of subsistence and small scale fishers, but may also be utilised by recreational fishers in some areas to enhance their catches. These smaller, less robust aFADs tend to be anchored close to shore, typically within the range of small motor boats and canoes, and attract neritic tunas and other medium-sized pelagic species.

Scott & Lopez (2014) estimated that the number of aFADs worldwide exceeds 73,000. Most of these (about 60,000) are moored in the Mediterranean Sea and are used by small scale fishers to attract mainly dolphinfish, rather than tunas. Almost 95% of approximately 13,000 aFADs used to target tunas are deployed in the western central Pacific Ocean, while the Indian Ocean accounts for about 4%, and the eastern Pacific and Atlantic Oceans represent less than 1% (although the use of aFADs in West Africa is not well documented).

Figure 2 Location of industrial and artisanal anchored FAD deployments. Based on information from Fonteneau (2011) and Taquet (2013).

Table 1 Comparison of the characteristics of anchored and drifting FADs.

Characteristic	Drifting FADs	Anchored FADs	
		Industrial	Artisanal
Areas deployed	Oceanic waters including the high seas	Offshore and archipelagic waters inside EEZs	Coastal waters, usually close to artisanal fishing communities
Construction[1]	Typically low cost (<US$500) designs; bamboo or plastic rafts with material hanging beneath to depths >100 m; fitted with satellite buoys and possibly devices for fish detection	Heavy and semi-heavy designs ranging between relatively low (<US$1000) and very high cost (>US$1 million); large steel or PVC surface buoy, or multiple smaller buoys; anchored using heavy duty chain or cable wire up to 3 km long	Typically varied lighter, lower cost (<US$300) designs; small surface floats built from recovered buoys or cheap materials (e.g. bamboo, cork, vegetation); anchored using rope usually <1km long
Lifespan	Usually deployed for several days or weeks, but if lost/abandoned can drift for 6-12 months before breaking up	Deployed permanently or seasonally and usually robust enough to last many years	Deployed permanently or seasonally, but may break up after several months if not maintained
Ownership and access	Private but not fully controlled by industrial scale purse seiners	Private with use agreements for a mix of industrial vessels	Private or community based ownership by coastal communities
Number deployed	Estimated 81,000-121,000 globally in 2013[2]	Estimated 73,000 anchored FADs globally in 2014[3]	

1 Le Gall et al., (1999) and articles therein.
2 Gershman et al., (2015); there is uncertainty in this estimate due to a lack of data on FAD ownership
3 Scott and Lopez, (2014); includes approximately 60,000 aFADs used in the Mediterranean to target dolphinfish.

2.3 Industrial fisheries using FADs

While FADs are used in a range of industrial, artisanal and recreational fisheries, this fishing practice is most widespread – and most developed – in industrial purse seine and pole and line fisheries.

2.3.1 Purse seine fisheries

Purse seine fisheries target tunas that are swimming at or just below the surface. The basic purse seine fishing operation, termed a cast or a drop, involves encircling a tuna school within a long panel of net that is floated on the surface and weighted along the bottom. A steel cable running along the bottom of the net is tightened to 'purse' the net and trap the school inside. Once captured, the net is drawn up beside the vessel and fish are transferred aboard, where the catch is immediately frozen in a super-chilled brine solution.

Tropical tuna purse seine fisheries are amongst the most highly capitalised in the world. Modern purse seiners are large industrial vessels of 40-110 m in length and, with a fish well capacity up to 3,000 m^3. They are capable of making extended trips of several weeks before returning to port to land or tranship catch and resupply. In 2015 there were 693 purse seine vessels registered to fish for tuna worldwide.

The most important species in the purse seine catch is skipjack, particularly in the Pacific, followed by yellowfin and bigeye (Miyake et al., 2010). Purse seine catches rapidly increased throughout the 1980s and 1990s to reach a peak of around 3.2 million tonnes in 2014. The share of catches is highest in the Pacific and Indian Oceans, whereas in the Atlantic, purse seine catches peaked in the mid-1990s and thereafter started to decline. The catches of Japan, Spain, Taiwan and the Republic of Korea are all at about the same level and have been stable since the mid-1990s. These four countries/fishing entities together take nearly half of the world's purse seine catches. With the exception of Spain, catches of these countries/fishing entities are almost all from the western and central Pacific Ocean. The capacity of these major fishing countries is capped by some of the RFMOs (e.g. IOTC), although there is still room for growth in fishing fleet capacity for coastal states with smaller, less developed fleets.

Broadly speaking, tuna purse seine fisheries are considered to be mature and are no longer expanding significantly in terms in fleet capacity or fishing grounds. Nevertheless, technological development of fishing gear and its deployment is ongoing and is primarily aimed at improving fishing efficiency, shortening gear casting and lifting time, and reducing labour input. In many countries, including the European Union (EU), at-sea transhipments for purse seiners are prohibited, which are widely considered an avenue for illegal, unreported and unregulated (IUU) fishing. This is an important driving force toward building purse seiners with larger holding capacities and increased fishing capacity (Miyake et al., 2010).

2.3.2 Pole and line fisheries

Pole and line fisheries are also surface fisheries, targeting tunas that are feeding at the surface. Tuna are attracted by throwing live bait (generally small fish caught in coastal waters) into the sea around the vessel. Fishers use long poles with barbless hooks to snag tuna as they feed on baitfish, which are then swung on board and immediately put into holds with ice.

The pole and line vessels are, in general, reasonably large vessels up to around 40 meters in length. Larger vessels have up to 18 fishers on board, and smaller ones around 10. Unlike purse seine vessels, pole and line fleets are typically based in port and fishers travel to and from fishing grounds each day.

The main species caught by pole and line vessels is skipjack, followed by yellowfin. Pole and line fleets in Japan, Spain and Portugal also catch Atlantic bluefin, Pacific bluefin and albacore, and South African vessels target albacore, which is locally a preferred target due to its higher market price (Miyake et al., 2010). Almost 75% of global pole and line catches are made by

Japan, the Maldives, Indonesia, with active fleets also flagged to Ghana, Brazil and Spain (Miyake et al., 2010). Amongst these, pole and line catches from the Maldives, Indonesia and Brazil are exclusively coastal, whereas the others are a mixture of coastal and high-seas operations.

Globally, there has been a gradual decline in the size of pole and line fleets, most notably in the Pacific, and the annual pole and line catch has generally declined over the past 10 years. This is explained by economic factors, in particular fuel costs, and technological advances in competing purse seine fisheries. However, with pole and line caught tuna being promoted by some environmental groups as a sustainable alternative[1] to other sources of tuna, some operations have recently diversified into the sashimi market for high-quality frozen skipjack (Miyake et al., 2010).

Box 2 Difficulty in defining fishing capacity for tuna fisheries

A basic definition of fishing capacity is the ability of a fleet to catch fish, although there still is no generally agreed upon method for how capacity should be measured. In technological terms the word 'capacity' is used when describing physical measures of the vessel (e.g., hull capacity and the ability to hold fish) as well as the operational or technical efficiency of a fishing vessel and its gear. In tuna fisheries using hi-tech fishing aids to find fish, and tools such as FADs to attract them, the definition and measurement of capacity is especially complicated.

A number of factors contribute to a tuna vessel's increased ability to catch fish, including the use of FADs and support vessels; technological improvements in computers, sensors and navigation aids; larger, deeper and faster nets; increasing vessel size and hold capacity; and faster unloading at port. These factors increase the fish detection capacity of the vessel or contribute to reduce the duration of the fishing related activities.

A major difficulty encountered when estimating change in tuna purse seine vessels' ability to catch fish is to correlate technological change due to these factors with effective fishing effort. This is made more difficult by a lack of detailed information on the time of introduction and intensity of use of these various innovations on the tuna purse seine fleet.

There is general consensus amongst tuna fishery managers that although the traditional use of carrying capacity (i.e. the storage area of a vessel measured in cubic meters) as a proxy for a vessel's fishing capacity has its shortcomings, there are no obvious, universally agreed alternatives.

[1] This report does not attempt to support this claim. It is noted, however, that stock status is independent of the gear used to catch it. Moreover, where sustainability in this context is defined as "*conserving an ecological balance by avoiding depletion of natural resources*" (Oxford English Dictionary), one type of gear is not necessarily more sustainable than another assuming the fishery is managed appropriately.

3 What are the impacts of FADs?

The use of FADs has been associated with a number of *potential* positive and negative impacts, touching on a range of ecological, economic and social issues. It is important, however, to recognise these as *potential* impacts because, in most cases, their effects are not clear cut and further research is needed before firm conclusions can be made. These impacts are described below, along with a summary of the evidence and main uncertainties surrounding each.

3.1 Positive impacts

The worldwide growth in tuna catches over the past 30 years has been facilitated by the use of dFADs (Fonteneau, 2011), and these effective tools have been hailed by the tuna fishing industry as one of the most important developments in recent times. The association of tunas with FADs is highly advantageous to tuna fishing, in effect allowing fishing opportunities to be focused into a far smaller number of predictable locations. Firstly, FADs aggregate sparsely distributed schools, which makes them easier to spot than schools swimming freely beneath the surface. Secondly they stabilise tuna schools and reduce the speed at which they travel, making them comparatively easy to catch (Dagorn et al., 2012). Consequently, fishing around floating objects is associated with a higher successful haul, or ‘set’, rate than targeting free swimming schools (Chassot et al., 2015). These advantages have opened up the possibility of four positive impacts of FADs, namely increased profitability of fleets, contribution to food security, reduction in carbon emissions and the targeting of more resilient species.

3.1.1 Increased profitability of fleets

Fishers regard the use of FADs as a way to improve catch rates and reduce operating costs, especially compared to the practice of targeting free swimming tuna schools. The development of FADs has dramatically improved the searching and catching efficiency of tuna fleets, which in turn has lowered the operating costs of vessels. In this context, the benefits of FADs include:

- The known position of anchored and instrumented drifting FADs, and, increasingly, information on the size of the school associated with it, reduces the time required for searching;
- Information received from multiple drifting FADs simultaneously, or the construction of an array of anchored FADs, aids the identification of promising fishing areas;
- The higher probability of set success associated with FAD fishing reduces the risk of another vessel ‘hijacking’ a tuna school when multiple vessels are fishing competitively in close proximity;
- Fewer sets reduces the risk of damage to gear or injury to crew; and
- Potentially improved job security for fleet and ancillary sector workers on the basis of high and relatively steady catch rates achieved using FADs (note: this benefit is speculative as there is no existing supporting evidence).

The single greatest advantage of FADs to fishers it that they can be located quickly; aFADs are moored in known positions, and instrumented dFADs can be tracked on a computer screen, which minimises search time and vessel operating costs. The most recent generation of dFADs are equipped with echo-sounders that transmit daily or hourly estimates of biomass beneath it, allowing purse seine skippers to confirm the presence of a school beneath a dFAD before visiting it and, by considering information from many active buoys, select productive areas to visit. In some oceans (e.g. Atlantic and Indian Oceans), supply vessels allied with one or more purse seine vessels are used to deploy and monitor dFADs using sonar and other fish-finding technologies, further optimising searching efficiency and increasing their competitiveness.

The use of FADs has costs associated with construction and maintenance, mooring, purchase of buoys and transponders, the use of support vessels, and compliance with management and voluntary requirements (e.g. use of biodegradable materials, good practice guidelines for handling bycatch). Although these costs have not been comprehensively quantified[2], it is assumed that the financial gains from using FADs sufficiently outweigh their costs. This assumption is supported by a purse seine industry representative, who stated that "*no fleet would consider stopping dFAD fishing if it wanted to be cost effective as they are an absolute requirement for the fishery to be profitable*". It was also noted that FADs improve the productivity of a vessel and have no impact on quality of the catch, which instead depends on the fishing zone and the freezing capacity of the vessel.

The increasing use of FADs has allowed boat owners to develop the capacity of their fleets, especially in purse seine fisheries, in an attempt to exploit more of the resource. Throughout the 1990s and early 2000s French and Spanish fishing companies invested in larger purse seine vessels, which offered numerous commercial advantages including the ability to make extended fishing trips with larger fish-wells. The development of the fleet included the construction of several 'super-seiners' (>2,000 gross tonnage; GT) and even 'super super-seiners' (> 3,500 GT) and the increasing trend in capacity matched the proliferating use of FADs. However, because larger vessels are more sensitive to increasing operating costs (e.g. fuel price) it was necessary for fishing companies to adopt increasingly competitive fishing strategies to achieve high annual catch thresholds. Consequently, the purse seine fishery has become increasingly reliant on the use of dFADs to achieve the catch volumes needed to remain competitive and profitable.

3.1.2 Contribution to food security

Global catches of tropical tunas in 2015 were approximately 5 million tonnes. Of this total, approximately 60% was made by purse seine, and nearly 65% of the purse seine catch was reported to be made by fishing on floating objects (FADs and logs) (ISSF, 2016; Scott and Lopez, 2014). A much smaller proportion, around 10%, was taken by pole and line fleets (Miyake et al., 2010). This enormous quantity of tuna catch could not be achieved economically without FADs, and it might therefore be logical to argue that, in the context of global food security, the use of FADs in industrial fisheries, in particular purse seine, plays an important role in the availability of animal protein.[3] However, this depends to a great extent on how and where tuna caught by these fisheries is supplied and consumed.

The concept of food security considers availability and access to food that meets people's dietary needs, as well as their food preferences, and is considered achieved "*when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preference for an active healthy life*" (World Food Summit, 1996). Food security is a global issue, affecting both developing and developed countries, although insecurity in availability and access to food is greatest in Low Income Food Deficit Countries throughout sub-Saharan Africa and parts of Southern Asia and Central and South America (FAO et al., 2015). In these regions, fish contributes a significant source of protein to household diets, ranging from around 25% to more than 40% of total animal protein in some small island developing states (FAO, 2014). It is also likely that cheap seafood products (e.g. canned tuna) is an important choice of protein within the poorer elements of society of richer nations, although this aspect of food security is not well documented.

Industrial purse seine and pole and line caught tuna mainly supplies the canning industry, although some pole and line operations have established a sashimi market for high quality frozen skipjack (Miyake et al., 2010). Canned tuna production in the Western and Central Pacific is almost half of the total world production (including Thailand, Indonesia and the

[2] It was reported in interviews that requirement for non-entangling FADs by the tuna RFMOs has increased the cost of an individual drifting FAD from EUR 30 to EUR 200 (purse seine industry representative, pers. comm.)

[3] In this report we do not discuss the important issue of food security in the context of the use of anchored FADs by artisanal fisheries.

Philippines in this region), and together with the Eastern Pacific, three quarters of total production originates from the Pacific. Thailand has been a leading producer of canned tuna (24% of world production by net weight), exporting its products worldwide. The top five importers in quantity are the United States, the United Kingdom, France, Italy and Germany, together representing about 50% of global imports in 2006. However, the number of importing countries has increased, with the cumulative share of the major markets (i.e. United States, European Union, Japan) falling from 96% in the 1980s to 74% in the early 2000s (Campling, 2012; Miyake et al., 2010).

In most markets canned tuna has always represented a low-value product, and therefore a low cost source of protein food for many consumers: for instance, in the United States, a limit of US$ 1 per can has been an established price barrier. However, it is not clear what role canned tuna has or will play in food security as important questions remain on i) availability and access to canned tuna (from fisheries using FADs) in Low Income Food Deficit Countries; and ii) the contribution and importance of canned tuna to achieving the relatively high levels of food security achieved in the major canned tuna market countries. Answers to these questions are needed to fully understand the potential benefits of FADs regarding food security.

Tuna fisheries also catch many non-target species (bycatch) and small tunas. While much of the non-target catch is discarded at sea[4], some is retained and utilised by crew or in local markets, thus potentially contributing to improving food security. The economic viability of bycatch utilisation is directly related to the population size, income and demand at or near the landing ports. Within large populations with food security concerns, the market for lower quality and cost seafood becomes economically viable; for instance, demand for bycatch generated by industrial tuna fishery is reported to be particularly high in central African markets (fishing industry representative, pers. comm.). Fish that are damaged, too small or not fit for consumption, can be sold for the production of fishmeal or pet food, providing alternative options for bycatch utilisation. Conversely some high quality bycatch species (e.g. smaller tunas, dolphinfish and wahoo) can fall into higher value markets, even higher than that of tuna, in populations with higher incomes (Lewis, 2014). Indeed, prices per tonne for bycatch are occasionally higher than for commercial tuna species, and some purse seine vessels may be opportunistically targeting ‘non-target’ neritic tuna species when travelling to and from port (fishing industry representative, pers. comm.).

In the eastern Pacific and the eastern Atlantic, the proportion of bycatch being landed and fully utilised is estimated to be high (around 80%). Utilisation of purse seine bycatch is lower in the western Indian Ocean (probably less than 20%) and in the western and central Pacific (less than 5%) (Lewis, 2014). A lack of data prevents more accurate estimation of bycatch retention and utilisation, but increasing pressure for improved traceability, chain of custody and catch documentation schemes may improve future data collection. Despite this, however, 100% bycatch utilisation is likely unachievable due to some species not being marketable or being inedible. A recent ISSF report suggested that a bycatch utilisation rate of 80% should be considered as an appropriate target (Lewis, 2014). Concerns do exist, however, that bycatch utilisation could create conflict and competition with local domestic fisheries, and that the development of a viable bycatch market for some species could create unintended consequences by encouraging capture of these, sometimes less resilient species.

3.1.3 Reduced carbon emissions

The efficiencies delivered by using FADs have the potential to result in reduced fuel usage, and therefore reduced carbon emissions, for a given fishing trip. However, the extent of this potential environmental benefit is not clear. An anecdotal estimate by the purse seine industry suggests the use of FADs results in fuel savings of approximately 20% (purse seine industry

[4] It is noted that ISSF Participating Companies (processors, traders, importers, transporters and others involved in the seafood industry) have committed to restrict transactions to only those purse seine vessels that retain all caught tuna (skipjack, yellowfin and bigeye), with certain exceptions.

representative, pers. comm.), although this is based on internal calculations by purse seine companies, for which the underlying data are generally not available due to commercial sensitivity.

Evidence for reduced carbon emissions linked to FAD use from published studies is also ambiguous. Monintja and Mathews (2000) examined the fuel use of Indonesian pole and line vessels targeting skipjack before and after the implementation of anchored FAD schemes in the 1980s, and found that the fuel use intensity[5] of the vessels studied decreased by 46.3%. Conversely, an analysis of factors of fuel use by Tyedmers and Parker (2012) suggested that the use of dFADs in purse seine fisheries use may not significantly decrease fuel use. The conclusions of this study, however, must be considered carefully owing to potentially competing influences: a positive correlation was found between the use of dFADs and fuel use intensity, with vessels that reported to have relied more heavily on FADs to catch tuna generally also reported higher fuel consumption per tonne of tuna landed. The authors conceded it was impossible from available data to discern whether the use of dFADs was the leading factor in high fuel use, in light of the confounding effect of vessel size, i.e. larger vessels use more fuel and also tend to make greater use of FADs to remain competitive (Davies et al., 2014).

The findings of these studies are not enough to draw firm conclusions on whether fishing using FADs can result in reduced fuel usage. It must also be considered at what scale any fuel, and therefore carbon, savings are realised. For instance, while fishing vessels may fish more efficiently using FADs, completing fishing trips faster with lower fuel usage than if searching for free swimming schools, this may simply allow a higher number of trips in any given year, with no change in the total number of days at sea. In this situation, there would be no net reduction in fuel usage and carbon emission in the long term, with savings per tonne caught offset by a higher number of trips made in a given period.

3.1.4 Targeting of a more resilient species

Tuna purse seine and pole and line fisheries are multispecies fisheries that target three species of tuna – skipjack, yellowfin and bigeye – that are frequently found in association with one another, especially as juvenile fish around FADs. Single species schools tend to be made up of larger, mature fish, and are commonly free swimming rather than associated with a FAD. These three tuna species have different life history characteristics and vulnerabilities to fishing, with only skipjack considered resilient to high fishing pressures and currently (and, with a few exceptions, historically) fished at sustainable levels.

In both purse seine and pole and line fisheries FADs are predominantly used to target skipjack, ostensibly as this species has a particularly high affinity to floating objects. Small yellowfin and bigeye also associate with FADs and are therefore commonly taken in the catch (whereas adults of these species are more commonly caught as free swimming schools by purse seine and other gears, e.g. longline). Whilst schools of large adult skipjack do occur and are fished as free swimming schools this is not common, and FAD fishing contributes significantly to catches of skipjack (Chassot et al., 2015; Fonteneau, 2011). It could be argued at some level, therefore, that without a FAD fishery there would be increased pressure on free swimming schools, and thus on the more vulnerable yellowfin and bigeye that are already subject to overfishing.

This possible ecological benefit, which is far from clear cut, presents a trade-off between the targeting of a relatively resilient species (skipjack) with negative impacts associated with the use of FADs, and warrants further research to better understand its need for consideration in management decision making.

[5] Defined as litres of fuel burned per landed wet weight tonne.

3.2 Negative impacts

Despite the clear benefits of FADs to the fishing industry, their use is associated with several potential negative impacts, including the catch of small tunas, bycatch of vulnerable non-target species, modification of tuna habitat, potential damage to coastal habitats and interference with other maritime activities. Although the extent and severity of these negative impacts is uncertain (Dagorn et al., 2012; Taquet, 2013), the global proliferation of FADs, without addressing these uncertainties, is a source of increasing concern to fishery managers, scientists and NGOs. It is important to bear in mind, however, that while some of the impacts associated with FAD-fishing result from the FAD *per se*, such as entanglement of animals in netting, most result through a combination of the use of a floating object to attract fish and the fishing gear used to fish around it.

Considered separately to these impacts, the increased catchability of tunas resulting from fishing with FADs has improved the catching efficiency of vessels, resulting in higher fishing mortality of target tuna species. This effect is not necessarily a cause for concern if properly managed, but it is vital to understand changes in fishing power and the relationship between catch and effort. This effect has been difficult to quantify and is currently a major uncertainty in management of tuna stocks (see Box 3).

Box 3 Difficulty in understanding the contribution of drifting FADs to fishing power

There are many factors that affect the level of fishing mortality exerted by the industrial tuna fleets, including the use of dFADs. However, it is not easy to disaggregate the effect of FADs from the other factors.

One way to approach the task is by quantifying the relative fishing power of individual vessels. For example, one could try to estimate the relative fishing power of a purse seiner that uses 400 dFADs against that of an identical purse seiner that does not use any. However, the situation is not so simple in practice. Vessels with similar engine size may have differences between them that also affect fishing power, such as the experience of the skipper and crew, the use of bird radars, sonars, support vessels, helicopters, size and materials of the net, etc. Furthermore, the dFADs themselves are unlikely to be the same, for instance different depths of the submerged structure, or fitted with different types of buoys.

This large number of influencing factors complicates the standardisation of purse seine catch per unit effort (CPUE), which is required for the purpose of estimating fishing power. Unfortunately, the adoption of different fishing strategies and equipment by fleets is not well documented, or is kept confidential, and the necessary information is not always available to scientists for analyses (ISSF, 2012; Restrepo et al., 2015).

3.2.1 Impacts on tuna stocks

The majority of the catch from purse seine sets on schools associated with floating objects consists of skipjack tuna, which is the main target species for the high-volume canned tuna market. In 2014, around 2.9 million tonnes of skipjack tuna were caught worldwide, with about one-half of the catch from purse seine sets made around floating objects (ISSF, 2016). Globally, around 75% (by weight) of the purse seine catch of tunas around floating objects is skipjack tuna, followed by yellowfin (16%) and bigeye (9%). In comparison, purse seine catches on free swimming schools have much higher proportions of yellowfin tuna (35%) and lower proportions of bigeye tuna (2%), but with skipjack tuna still being the major species (63%) (Dagorn et al., 2012).

The large catches of tuna taken from around floating objects potentially has two impacts on tuna stocks: recruitment overfishing (catching too many fish that impairs reproduction), and a loss in potential yield through growth overfishing (catching too many small fish and reducing the number that reach maturity). The extent of these impacts is a subject of ongoing debate, and complicated by differences in the resilience of the three main species of tropical tunas caught in purse seine fisheries and the fact that they are frequently caught in mixed schools.

Recruitment overfishing

Skipjack tuna is a fast growing, highly fecund, and resilient species, and currently stocks are not considered to be overfished in any ocean.[6] Considering that the use of FADs has increased in the past two decades in both purse seine and pole and line fisheries, this observation suggests that the use of FADs at current levels does not *per se* result in overfishing of skipjack stocks.

The proportions of yellowfin and bigeye tuna in catches on floating objects are smaller (typically 14-25% and 4-28% respectively; Dagorn et al 2012), with notable variations between the oceans. For example, purse seine fishing on dFADs accounts for approximately 50% of the impact on the bigeye stock in the western and central Pacific, with the other half being through longlining. Catches of yellowfin and bigeye from around floating objects are mostly small or juvenile fish (see Bromhead et al. 2003), and as such, these stocks are thought to have less resilience to FAD fishing. High catches of small bigeye is a particular concern in the western and central Pacific due to the stock being assessed as overfished and subject to overfishing (ISSF, 2016). Yet whilst stocks of bigeye and yellowfin, are currently considered to be overfished in some regions it is difficult to assess the role of dFADs in this overfishing, with no obvious pattern between the relative magnitude of catch on floating objects and whether a stock is overfished (Dagorn et al. 2012).

Despite no clear evidence of overfishing from use of dFADs *per se*, some groups are concerned that the use of dFADs has, and will continue, to perpetuate the overcapitalisation of purse seine fleets to the point where overfishing will be a certainty. The increasing use of dFADs has been an important factor in allowing vessel owners to build the capacity of their fleets by investing in so-called ‘super-seiners’. These high capacity vessels, which require very large and steady catches to remain profitable, are entirely reliant on the use of dFADs. Furthermore, the existence of such vessels is likely to increase competition within and between fleets to achieve competitive catches. Therefore, there is a risk that, in the absence of appropriate management of fishing capacity, the current trend for larger, FAD-reliant vessels will eventually lead to the overfishing 3.of tuna stocks (environmental NGO representative, pers. comm.).

Growth overfishing (loss in potential yield)

The high catches of small tunas around FADs has led to concerns of a loss of potential yield through a reduction in the number of fish reaching maturity (i.e. lower yield per recruit). Species like yellowfin and bigeye tuna can grow to be quite large – much larger than the size at which they are typically caught around floating objects (average size approximately 50cm fork length, compared to free-schooling fish of over 100cm). Balancing natural mortality and growth rates to maximise yield would be most pertinent to fisheries such as longline that catch the larger individuals (average size approximately 100cm fork length), and conceptually, not catching small FAD-associated fish could increase the potential yield. Aires da Silva and Maunder (2011) have calculated that, due to high fishing mortality of small fish that will not reach maturity, the maximum sustainable yield for the eastern Pacific bigeye tuna stock had already been reduced to one-half of what it was by 1993, when catches were predominantly made with longlines and before large numbers of FADs were introduced. Whether or not the previous higher potential yield can be recovered is being explored (see Sun et al. 2010) as it is not certain that the additional surviving fish would become available to longline gear (Fonteneau and Ariz 2011).

[6] In the late 1990s, however, ICCAT determined that Atlantic skipjack tuna stocks were experiencing overfishing owing to the active dFAD fishery (Fonteneau et al., 1999); this stock is now considered to have recovered.

The evaluation of loss in potential yield depends on the rates of growth and natural mortality, and there remains much uncertainty around the estimates of this latter parameter. However, current analyses suggest higher natural mortality for small bigeye, yellowfin and skipjack tuna than previous estimates (Bromhead et al., 2003). Consequently, the potential effects of catching large numbers of small fish at FADs may not be discernible in tuna stocks unless the adult stock is also heavily fished (Dagorn et al., 2012).

3.2.2 Catch of non-target species

A more tangible ecological impact associated with anchored and drifting FAD fishing is bycatch of non-target species. Over time FADs attract whole communities of non-target species that can also be taken as part of the catch in both purse seine and pole and line fisheries. The term 'bycatch' can be used in different ways depending on the context. In the case of tuna fisheries, some studies have considered the discards of small individuals of target species (skipjack, yellowfin and bigeye tuna) as bycatch (Amandè et al., 2008, 2010) while others only considered non-tuna species (Romanov, 2002). These types of distinction are important, as some researchers argue that small tunas that are discarded or sold on local markets should not be considered as bycatch and should be included in the available statistics as inputs for stock assessment models. For the current discussion, bycatch is considered as the catch of non-target species, which can be either discarded at sea or landed.

Bycatch in purse seine fisheries recorded from sets on floating objects (dFADs and logs), measured as the proportion of total catch in weight, is generally low (average 4.2% worldwide) relative to other pelagic tuna fisheries (Gilman, 2011) but does vary between oceans: 1.7% in the western Pacific, 2.4% in the eastern Pacific, 3.6% in the Indian Ocean and 8.9% in the Atlantic (see Dagorn et al., 2012 for data sources; Justel-Rubio and Restrepo 2017 provide updated estimates). In three ocean regions (eastern Pacific, Atlantic and Indian Ocean), the catch of non-target species around floating objects is three to four times higher than it is on free swimming schools, and in the western Pacific Ocean this ratio goes up to almost seven times higher (Table 2). In the Atlantic Ocean, the notably high bycatch ratio is explained mainly by high catches of other tuna species (e.g. neritic species) and is probably driven largely by the local market in western Africa (Romagny et al., 2000).

Pole and line fisheries are usually considered to have very low bycatch rates (around 0.1% of total tuna catch), but catches of live bait have been estimated at 3.1% of total catch (Gillett, 2011). This bycatch should not be discounted, even though it is not usually taken from the same oceanic pelagic ecosystem as target tunas, bringing the average bycatch ratio of pole and line to 3.2% of total tuna catch, similar to that of purse seine fisheries (Dagorn et al., 2012).

The majority of non-target species caught incidentally around anchored and drifting FADs are small tunas (juvenile 'large' species as well as neritic species, such as bullet and frigate tuna) and other bony fishes (Dempster and Taquet, 2004). In the case of purse seine fisheries, although up to 55 different bony fish species can be taken from around dFADs (Amandè et al., 2008), the main bycatch tuna species are kawakawa, little tunny, frigate tuna, and bullet tuna, with variations among oceans. Non-tuna bycatch is dominated by a small number of species, mainly oceanic triggerfish, rainbow runner, dolphinfish, wahoo. For pole and line fisheries the composition of tuna bycatch is likely to be broadly similar; for instance, the retained bycatch of the Maldives pole and line fishery between 2009-2010 included mainly frigate tuna (4.1% of total catch), kawakawa tuna (2.5%), and a further 15% of 'other species', including mainly rainbow runners, dolphinfish and oceanic triggerfish (Anderson et al., 2012). Many of these species are known to be fast growing and have high fecundity, and thus their vulnerability to overfishing is likely to be low.

Table 2 Observed bycatch composition by weight in each ocean (tonnes per 1000 t of target tunas landed). Modified from Dagorn et al. (2012). Note that date ranges differ slightly by ocean. Target tunas are skipjack, yellowfin and bigeye. FSC= free swimming school.

Species	Atlantic		Indian		Western Pacific		Eastern Pacific	
	2003–2007		2003–2007		2005–2010		2000–2009	
	FSC	dFAD	FSC	dFAD	FSC	dFAD	FSC	dFAD
Target tunas (discards)	0	61	3.5	17.4	-	-	25.3	68.7
Other tunas	20.8	67.7	5.9	9.2	0.3	2	5.1	10.4
Bony fishes	0.8	17	1.5	19.7	0.8	13.7	0.7	10.4
Billfish	5.1	2.6	0.4	0.7	0.7	0.5	0.8	1.1
Sharks	0.3	1.8	0.3	3.6	0.9	1.1	1.4	1.9
Rays	1.4	0.2	0.2	0.2	-	-	0.4	0
Total bycatch	28.4	89.3	8.3	35.8	2.6	17.4	8.4	23.8
Ratio FAD/FSC	3.1		4.3		6.7		2.8	

Sharks, rays and billfishes, which are also taken as bycatch in purse seine fisheries (but rarely pole and line; Gilman, 2011), are considered to have much higher vulnerability to fishing. Shark bycatch by purse seiners on dFADs is almost exclusively composed of two species; silky shark and oceanic white tip shark, together comprising over 90% of shark bycatch by number in purse seine sets (Gilman, 2011). For example, Amandè et al. (2008) estimated that in the Indian Ocean, sharks (excluding whale sharks) made up 10.1% of total annual bycatch and tuna discards, or approximately 3.6 t for every 1000 t of target tuna caught. Silky and oceanic white tip sharks dominated this catch, representing 94% of the individuals caught and 90% of total weight. It is worth noting, however, the large differences in shark bycatch rates among oceans (see Table 2); sharks and rays combined together represent between 2% (Atlantic Ocean) to 17% (Indian Ocean) of all purse seine bycatch.

Sharks in general, and silky and oceanic white tip sharks in particular, are among the least resilient of fish species to intense exploitation. These species have slow growth rates, mature late and have long reproductive cycles with few offspring, and as such are highly susceptible to population decline from excessive fishing pressure. IUCN lists silky shark as Near-Threatened globally, and oceanic white tip shark as Vulnerable. The vast majority of silky sharks are caught in small coastal gillnet fisheries purposefully. The quantity of sharks landed by purse seine fisheries is relatively small[7], and appears to have declined in recent years due to a combination of non-retention rules for certain species, discards of live (and possibly dead) sharks, and a general decline in numbers (and size) of some species in purse seine catches as a result of over-exploitation by all tuna fisheries combined (Lewis, 2014).

Turtles are caught in small numbers by purse seiners and are released alive relatively easily. Of the estimated 5-200 caught per year per ocean, 95% were released alive (Gilman, 2011). In the Atlantic Ocean, Amandè et al. (2010) reported 40 individuals observed taken by purse seines over the 2003-2007 period, with roughly equal share between dFAD (or log) sets and free swimming school sets. Almost all turtles (98%) were seen being released alive by the crew. Over the same period in the Indian Ocean, 74 turtles were observed, mainly on dFAD associated sets (95%), and nearly 90% of them were released alive.

[7] See for example: https://www.iattc.org/Meetings/Meetings2014/MAYSAC/PDFs/presentations/SAC-05-11a-Silky-Shark.pdf. Accessed 12th September 2016.

FADs are also associated with the mortality of sharks and turtles through entanglement with the net hanging beneath the raft (i.e. ghost fishing), although the extent of this mortality is not usually estimated. Interestingly, some fishery managers and experts in the Pacific consider shark entanglement to be mainly an Indian Ocean issue, based on lower observations of entanglements, although this may be explained by differences between oceans in FAD-fishing behaviour, the frequency that FADs are checked and observer reporting rather than the absence of the problem (fishing industry representative, pers. comm).

Whilst bycatch associated with FADs should be minimised in purse seine and pole and line fisheries, it cannot be ignored that the rate and total volume of bycatch is estimated to be much higher using pelagic longline fisheries (Gilman, 2011). For instance, Kelleher (2005) found that pelagic longliners have non-target species discard ratios four to five times higher by weight than purse seiners (about 22% compared to 5%).

3.2.3 Damage to marine and coastal habitats

FADs are built primarily from non-biodegradable materials and so they can account for a significant source of marine pollution if lost or abandoned. The extent of this problem is only beginning to become known, with a recent study in the Indian Ocean estimating that 1,500-2,000 dFADs (9.9% of all dFADs deployed in the region) become beached each year (Maufroy et al., 2014). These beaching events generally occur due to the dFAD drifting outside of the main fishing grounds and malfunction or loss of the tracking buoy. These figures are probably an underestimate of the number of beaching events as they do not account for dFADs that are abandoned (or deployed in the case of some fleets) with no satellite buoy attached (e.g. in the Pacific, where non-instrumented FADs are still permitted). There is no information available on the number of aFADs that have escaped their moorings in recent years, although given that networks of aFADs tend to be well maintained, the loss of aFADs is likely to be a rare event.

The impact of dFADs beaching on coral reefs and islands has so far received little coverage in the literature (Balderson and Martin, 2015; Wilcox et al., 2015). In addition to the known issues of ghost fishing, it is thought that the netting and ropes hanging beneath FADs can cause significant damage to corals and other delicate marine life if they wash ashore. There is no clear consensus on whether dFADs breach international laws on marine pollution, but if the dFAD was deliberately discarded this would likely violate MARPOL Annex V[8], and would also likely contravene the London Convention (Fonteneau et al., 2015). In 2013, IOTC did not adopt a resolution proposed by EU-France to prohibit the abandonment of dFADs, but instead agreed that measures should be included in FAD management plans of individual members.

There is very little information available on the impact of aFADs on the marine environment, in particular seafloor habitats. In 2012 Hawaii report concluded that the metal parts of an aFAD (mast, chain, anchor, hardware) would undoubtedly corrode but this would have insignificant adverse impact on the ocean environment. Two features of aFADs can or may interact with the seafloor: the anchor, which may be deployed one time or repeatedly in an area; and the mooring line, which is typically negatively buoyant will sink to the bottom if it breaks from the buoy. The potential for negative impact depends on the type of habitat where the aFAD is moored; in Hawaii, aFADs are generally deployed in deep water location where the sea floor is typified as low relief silt and mud plains, and damage from anchor deployments or mooring lines is expected to be very limited.

3.2.4 Interference with other maritime activities

The use of FADs in some areas may interfere with the activities other marine users, potentially creating conflicts between fishers and other groups. In many EEZs, navies or other marine authorities have designated certain areas submarine transit lanes, and training and operating

[8] See: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Pages/Default.aspx. Accessed 16th June 2016.

areas for surface military vessels and aircraft. While anchored FADs are most likely to cause hazards in these areas, in the US (Hawaii) at least there have been no reported interactions between FADs and military vessels to date (Holland, 2012). No information is available from others areas where aFAD use is high, such as Japan, Maldives and the western Pacific Islands.

Similarly, anchored and drifting FADs, which are sizable floating objects, present a potential hazard to the navigation of some vessels, such as smaller fishing vessels, small ferries recreational boats and yachts. This is especially true for dFADs that do not have navigational lights, or for aFADs whose lights have failed. There has been no global or regional assessment of interactions between vessels and FADs, although it is likely that collisions do occur.

3.3 Modification of tuna habitat

In addition to the potential positive and negative impacts discussed in the previous sections, there has also been some theoretical discussion regarding the wider ecological and evolutionary aspects of dFADs. This is an interesting but conflicting topic, which is based on little empirical information.

While logs, branches and other floating debris have always been a component of the world's oceanic ecosystems, FADs are now a major new component of this surface habitat. The change resulting from increased use of FADs could be of two types: (i) FADs are deployed in areas where no natural floating objects would normally occur and (ii) FADs increase the total density of floating objects in areas where logs already occur. In examining this question, Fauvel et al. (2009) concluded that in the western Indian Ocean, FADs did not create new 'floating object areas', but considerably increased the existing density of floating objects in some areas (e.g. up to 40 times in the Somalia area) while having almost no effect on the density in southern areas (e.g. increase of only 10% in the Mozambique Channel as there was already a high density of natural floating objects). Similarly, Dagorn et al. (2012) found that in all oceans (except the eastern Indian Ocean, where FAD usage is low) the overall spatial distribution of FADs and logs is similar. It therefore appears that the major change in the environment caused by FADs is an increase in the densities of floating objects where logs naturally occur.[9]

Some scientists have suggested that, because tuna seem to have such a strong attraction to floating objects, such a change (increased density of floating objects) could significantly modify the behaviour and biology of tunas. The reason for the natural aggregation of tunas beneath floating objects is not entirely clear although the two most credible explanations for this behaviour are the 'meeting point hypothesis' (Dagorn and Fréon, 1999) and the 'indicator-log hypothesis' (Hall, 1992). The meeting point hypothesis suggests that fish associate with floating objects to facilitate schooling behaviour and subsequently benefit from this social interaction whilst the indicator-log hypothesis suggests that natural floating objects are indicators of productive habitat given that they originate from nutrient-rich areas (e.g. river mouths, mangrove swamps) and subsequently drift with these patches of productivity into the ocean.

Given these possible explanations for the association of tunas with floating objects there is concern that the deployment of large numbers of FADs in the pelagic ocean could change the natural environment of tunas, a theory known as the 'ecological trap hypothesis' (Marsac et al., 2000). Large numbers of floating objects could modify the movement patterns of tunas and carry associated schools into ecologically less suitable areas and thus affect their growth rate or increase natural mortality and/or predation. Although this subject has received considerable research attention it is difficult to evaluate the impacts of FADs on the ecology of tunas, largely due to uncertainty in how tunas interact with floating objects (e.g. length of association, reasons for joining/leaving an object etc.). For instance, Robertson and Hutto (2006) could only find five

[9] However, logs and FADs might drift into areas where purse seiners do not go (and therefore, cannot be reported by observers). For instance, it is known that many logs and FADs drift from the western to the eastern Indian Ocean, but purse seiners do not usually follow as tuna are not sufficiently abundant (Dagorn et al., 2012).

studies from a total of 45 providing strong evidence for the existence of such traps. This may be because investigating the existence of an ecological trap first requires knowledge of the original circumstances and the role of a particular cue under those conditions, which is still a topic of discussion for tunas. Consequently the ecological trap hypothesis remains open to debate.

Looking at this discussion from another perspective, an alternative school of thought suggests dFADs increase the availability of critical habitat for juvenile tunas, and therefore enhance tuna stocks in the long term. Moreover, some have argued that catching smaller fish around dFADs - and reducing fishing mortality of larger, more fecund fish in free swimming schools - may actually enhance recruitment particularly of the smaller tunas including skipjack through changes in the rate of tuna cannibalism. However, evaluation of either of these effects, which is likely to be influenced by a great many variables, is difficult and currently no meaningful conclusions can be drawn.

4 How are FADs and their impacts managed?

As the use of FADs by industrial tuna fleets has increased, so too has the need to manage their impacts on tuna stocks and the marine environment. Industrial purse seine and pole and line fisheries that use FADs are managed primarily by the four tropical tuna RFMOs – the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) – although some fleets are also subject to additional management under national fisheries laws, for instance when fishing inside their own or other EEZs. Responding to the potential impacts of FADs, RFMOs have focused on protecting stocks of yellowfin and bigeye tuna, typically by adopting measures aimed at reducing the mortality of juveniles, and reducing bycatch of non-target species, especially sharks. Several of these measures have been aimed directly at the practice of FAD fishing, such as limiting FAD sets or requiring more sustainable designs, while others have been less direct, such as implementing closures, catch limits or discard bans (see Table 1).

National fisheries laws that explicitly consider FADs, typically mirror the RFMO measures that apply to its fleets. Only very few countries have adopted rules that are more restrictive than those set by RFMOs, e.g. FAD deployment limits (France) or design specifications such as using only biodegradable materials (Maldives). National management of FADs is typically aimed at the full spectrum of fisheries that fish on floating objects, including small scale and artisanal fleets. Most domestic legislation applies to national flagged vessels, usually within and beyond the EEZ, although some national fisheries laws also apply to foreign vessels via the terms of access agreements.

Table 1 Summary of legally binding measures relevant to the management of FADs in the four tropical tuna RFMOs.

Management measure	IATTC	ICCAT	IOTC	WCPFC
Required FAD management plan	No*	Yes	Yes	No
Required marking of FADs	Yes	Yes	Yes	Yes
Required instrumentation of FADs	No	Yes	Yes	No
Capacity and/or fishing effort limitations on vessels setting FADs	No	No	No	No
Regulation of number of FADs/sets	No	No	Yes	Yes
Time and area closure for FADs	Yes	Yes	No	Yes
Required non-entangling FADs	No	Yes	Yes	No
Required biodegradable FADs	No	No	No	No

* Soon to be implemented in IATTC; see Resolution C-16-01.

4.1 Existing management measures

A number of measures, requirements and initiatives are in place, or have been used in the recent past, to control the use of FADs or mitigate their impacts. This also includes the adoption of voluntary measures by the tuna fishing industry to reduce their environmental impacts. Each of these are described in the following sections.

4.1.1 FAD management plans

The most urgent concern of tuna fishery managers and researchers is the uncertainty surrounding the use and impacts of FADs. Therefore a priority of those responsible for managing tuna fisheries has been to gather data on the characteristics of FADs and how fishing fleets use them.

ICCAT, IOTC and WCPFC and most recently IATTC have required their members (contracting and cooperating non-contracting parties; CPCs) to develop management plans for anchored and drifting FADs. These are intended primarily to generate better information of how FADs are used by CPC fleets, specifically purse seiners and pole and line vessels targeting skipjack, yellowfin and bigeye tuna. Management plans should include, *at a minimum,* information on number of FADs deployed, a description of FAD design, details of marking or identifiers to be used and specifications of a 'FAD logbook' used by skippers for data reporting. These requirements are similar for each of the tuna RFMOs, and must include information for both anchored and drifting FADs.

Management plans were first required by the tuna RFMOs in 2014, and must be amended and submitted as necessary on an annual basis. Compliance of the CPCs in filing plans on time and to the required specification is assessed by the respective RFMO compliance and/or scientific committee. At the time of writing, management plans have been submitted by most, but not all, CPCs to their respective RFMO. It is too early to judge the benefits and impacts that FAD management plans will have.

IATTC do not require CPCs to develop management plans *per se*, but have requested that CPCs provide detailed data on FAD use similar to that required by other tuna RFMOs.[10] These data are held by IATTC and protected to ensure confidentiality, and therefore not available for review by outside parties, at least not in raw, non-anonymised form. Based on analysis of these data, scientific staff at IATTC will make recommendations to the Commission for the management of FADs by 2018. This may include a region-wide FAD management plan that includes recommendations regarding FAD design, deployment and sets.

In a separate, but related, initiative, the ISSF ProActive Vessel Register (PVR)[11], to which a large number of purse seine operators are subscribed, encourages a high level of compliance from its listed vessels with respective RFMO data reporting requirements.

4.1.2 Ad hoc FAD working groups

Ad hoc FAD working groups have been set up by IOTC, ICCAT, IATTC and WCPFC, primarily to assess the fisheries and ecosystem consequences of the increasing number and technological developments of FADs. These multi-sectorial working groups are tasked with informing and advising the respective RFMO Science Committees and other working parties on future FAD-related management options. There appears to be close communication between the working groups and a joint meeting has been proposed for 2017

The ICCAT *ad hoc* working group on FADs has met twice, in 2015[12] and 2016[13], and has broadly evaluated previous attempts to manage the use of FADs and provided recommendations for improving information on their use. The WCPFC intersessional working group on FAD Management Options met for the first time in 2015. The main objectives of this workshop were to develop the foundations of a research plan based on research priorities and provide recommendations on marking and monitoring of FADs. There was a particular focus on issues related to reducing catches of juvenile bigeye due to its overfished status in the region. Both the ICCAT and WCPFC working groups noted there is scope to improve and strengthen FAD management measures. The IOTC *ad hoc* working group on FADs has not yet met and is expected to deliver it first outputs in 2017, most likely as part of a joint meeting of RFMO

[10] Resolution C-15-03 Collection and analyses of data on fish aggregating devices.

[11] Available at: http://iss-foundation.org/knowledge-tools/databases/proactive-vessel-register/. Accessed 16th June 2016.

[12] Report available at: https://www.iccat.int/Documents/Meetings/Docs/2015_FADs_WG_report_ENG.pdf. Accessed 12th May 2016.

[13] Report available at: https://www.iccat.int/Documents/Meetings/Docs/2016_FADs_2nd_Final_ENG.pdf. Accessed 1th May 2016.

working groups. The IATTC *ad hoc* working group on FADs has been very active via an online collaboration system. The group had its first face to face meeting in May 2016 and met again in June 2016 during the annual meeting of the IATTC, at which a work plan for 2016-2017 was agreed.

4.1.3 Limits on number of drifting FADs or sets

Given the uncertainty regarding the impact of dFADs on tuna stocks, there has been pressure on RFMOs to invoke the precautionary approach and set an upper limit on the use of dFADs. A limit on the number of deployed or monitored dFADs should, in theory, curb search efficiency and decrease (or maintain, depending on where limits are set) the total number of sets made. It is important, however, to note the distinction between the number of dFADs deployed and the number monitored; the former is relevant to modification and damage to marine habitat (and issues relating to their effect on tuna biology) whereas the latter is relevant to fishing capacity and efficiency. Limiting the total allowable number of sets on floating objects for an individual vessel (including both logs and dFADs) might have a more direct effect on the practice of dFAD fishing. Skippers usually fish on any floating object they come across, unless the associated school is very small (e.g. < 20 tonnes). Thus, placing a finite limit on the number of FADs that can be fished might incentivise skippers to be more selective in the objects they fish on, presumably favouring those objects with larger associated schools (Davies et al., 2014). However, this approach may not alter the total number of dFADs deployed, and so would not address the potential ecosystem impacts associated with dFAD fishing.

IOTC and ICCAT have set upper limits of 425 and 500 'active and followed' drifting FADs per vessel per year, respectively (in place since 2016 and 2015, respectively). This terminology is subtly different to the number of FADs deployed (i.e. set adrift), although almost all deployed dFADs are actively tracked so it may equate to the same number. The IOTC have also set a limit of 850 GPS buoys acquired by an individual vessel each year. Moreover, some purse seine fleets have implemented, through their management plans, a voluntary ceiling on the use of dFADs.[14] It is not yet clear how limits on the number of actively tracked dFADs are to be monitored, especially as detailed information on the use of dFADs is considered highly confidential by fishing companies, although ICCAT have proposed this might be verified using telecommunication invoices from companies that manage the tracking data.

The WCPFC has prescribed an optional[15] limit on the number of sets made on dFADs at a fleet level (in place since 2014). The limits vary for each fleet, and are set at circa 30% of average total sets using a 2010-2012 baseline. It is unclear, however, how the limits set by WCPFC relate to 'optimal' dFAD sets, and indeed (Fonteneau et al., 2015) have suggested that estimating a biologically meaningful, MSY-equivalent limit on dFAD sets based on the results of stock assessments is unlikely. Effective monitoring of the number of sets made on FADs is possible with full (human) observer coverage of fishing fleets, and may also be possible using electronic monitoring systems, depending on their ability to discriminate between FAD and free school sets.

In all regions, it is not clear how meaningful these limits are. In the Indian Ocean, and likely in the Atlantic, many vessels do not deploy anywhere near the upper limit on FADs (Davies et al., 2014; Maufroy et al., 2014), and as such they are unlikely to reflect a reduction in effort for all parts of the fleet. Furthermore, skippers in some fleets (e.g. Spain) pool FADs (Moreno et al., 2007), possibly allowing them access to more than the current FAD limit. Similarly, voluntary limits imposed by fishing companies are probably close to the number of FADs routinely used by their fleets. In the western and central Pacific, the average usage in the purse seine fleet is

[14] For example, Japan limited its purse seine vessels to a total of 150 sets on FAD in 2014; see IOTC collection of drifting FAD management plans: http://www.iotc.org/documents/collection-dfad-management-plans.

[15] A limit of FADs is one of two options CMMs can choose; the second is a one month extension of the annual FAD moratorium (CMM 2015-01).

about 100 drifting FADs per vessel per year (Hampton, 2010), which appears to be less than many of the national fleet limits. In IOTC, the limit on active FADs allowed was originally set at 550 but was lowered to 425 in 2016, suggesting some level of recognition amongst CPCs that the initial limit was set too high to provide any meaningful control. Nevertheless, these limits might represent future reductions when considering the increasing trend in drifting FAD use, at least for some vessels or fishing companies.

There are currently no formal limits on aFADs, although the national management plans of many countries with large aFAD arrays (e.g. Japan, Maldives, Indonesia, Philippines) do not indicate plans for further expansion in the short term.

Box 4 Collecting data using fisheries observers

In many fisheries worldwide, including purse seine fisheries, observers are placed on board vessels to observe the fishing operation and collect data on the catch and how fishing is conducted. Observers represent a critical feature of the fisheries scientific data collection system, and their presence is often vital to ensure that management measures are implemented and effective.

The use of human observers has both strengths and weaknesses. The presence of an observer allows for detailed data collection, such as biological sampling of catch. However, observers can only monitor one area of a vessel at any given time and are open to deception or bribery by the crew that may result in inaccurate data. Observers also potentially face high risks to their safety and wellbeing, including physical abuse from a hostile crew.

Electronic Monitoring Systems (EMS) offer an alternative way to observe fishing operations. Multiple video cameras placed in key location on board a vessel record for the duration of a fishing trip, with the video footage stored securely on a hard disk. The footage is reviewed by shore-based observers when the vessel returns to port, who can collect most of the same catch information as their vessel-based counterparts.

EMS removes some of the weaknesses of human system, most crucially the ability to observe all areas of the vessel simultaneously, and is less vulnerable to deception or corruption by the crew. However, the current state of the art in EMS does not allow for certain types of data to be collected, such as biological samples, and is prone to high levels of error in the estimation of some variables, such as length measurements. Also, in the context of purse seine fisheries, EMS can be poor at identifying interactions with FADs due to the restricted field of view of video cameras.

Further information is available in *Electronic Monitoring in Fisheries Management* (Course, 2015).

4.1.4 Time-area closures and moratoria

All tuna RFMOs have at some time over the past 20 years implemented time-area closures to reduce the impact of purse seine fisheries using dFADs[16] on tuna stocks and bycatch species. The objective of these measures has, in most cases, been to reduce catches of small yellowfin and bigeye tuna, ostensibly to address concerns over a loss in potential yield in stocks of these species. In theory, this is achieved by redistributing fishing effort away from fishing grounds associated with high juvenile catches, therefore modifying the selectivity of the fishery toward catching larger fish. Some of these closures have been implemented through resolutions and recommendations adopted by the RFMOs, while others have been initiated through voluntary agreements established among industry. Currently, time-area closures are operated by ICCAT and IATTC, and WCPFC has defined a general three month moratorium on FAD fishing. IOTC implemented a time area closure most recently between 2010 and 2013, but this annual

[16] In some RFMOs, closures have applied to all fishing gears targeting tuna; in others, closures have applied only to purse seiners using dFADs.

closure was abandoned in 2014 following recommendations from the IOTC Scientific Committee[17].

Simulation studies have shown time-area closures may, in theory, result in reduced catches of small tunas (Harley and Suter, 2007). However, in reality past examples of closures are considered to have been ineffective (Davies et al., 2014; Fonteneau et al., 2015; ICCAT, 2016). Whilst closures in the Atlantic have resulted in substantial reductions in mortality of small yellowfin and bigeye (Torres-Irineo et al., 2011), there is no evidence that closures have improved stock status in the long term. It should be noted however that these conclusions are based on qualitative evaluations; quantitative evaluations are difficult to undertake, with many confounding effects and changes in nominal effort year to year. The poor success of closures is likely due to a combination of factors including a lack of compliance by some fleets, inappropriate design (e.g. closures were too small or too short), a redeployment of FAD fishing activities elsewhere and larger than usual catches on FADs following the end of the closure (Bromhead et al., 2003; Davies et al., 2014; Maufroy, 2016; WCPFC, 2015). It is also important to note that fish populations may not improve if other surface fleets (e.g. gillnet) continue to target them with high levels of effort.

4.1.5 Restrictions on support vessels

The use of support vessels (also referred to as supply or auxiliary vessels), which in most regions are instrumental in deploying, maintaining and checking dFADs on behalf of one or more skippers, is believed to enable purse seiners to increase their catch. In truth, the exact role of support vessels in the evolution of fishing effort is not fully understood (ICCAT, 2016). IATTC introduced a ban on the use of support vessels with respect to fishing on FADs in 1999 (IATTC 99-07), although there have been no evaluations on the effect of this ban on the evolution of purse seine fishing effort or catches for small tunas. In 2016 IOTC introduced a limit of half the number of supply vessels relative to the number of active purse seine vessels; there are no reports on the impact of this measure as yet.

4.1.6 Small tuna and bycatch reduction initiatives

There are a number of gear modifications and fishing practices that allow tuna fisheries to minimise the catch of small tuna and bycatch from around FADs. These are summarised below.

FAD design

Lower entanglement risk and non-entangling FADs

Since 2005 managers, scientists and the fishing industry have been collaborating to design FADs that minimise the likelihood of entanglement of sharks and turtles, and to a lesser extent marine mammals and birds. This work has mainly focused on entanglement with dFADs used by purse seiners. The acceptance level of 'entanglement-reducing' dFADs by fishers has progressed rapidly since 2010, largely because the initiative is seen as a being relatively easy and inexpensive. Many purse seine fleets, in particular those of the EU, have replaced traditional dFADs with lower entanglement risk and non-entangling dFADs, while experiencing no decrease in tuna catches (Murua et al., 2016).

Currently, all tuna RFMOs, except for the WCPFC, have adopted requirements or recommendations for a transition towards non-entangling drifting FADs within their respective management measures. Progress toward the adoption of non-entangling designs appears to be highest in the Indian and Atlantic Oceans, followed by the Eastern Pacific and lowest in the Western and Central Pacific. This trend appears to be linked to the perception amongst some

[17] See http://www.iotc.org/sites/default/files/documents/2014/01/IOTC-2013-SC16-INF11.pdf. Accessed 24th May 2016.

managers in the Pacific that entanglement is 'an Indian Ocean issue', which is not necessarily true (see Section 3.2.2), and also limited exchange of ideas between the Pacific and Atlantic/Indian Ocean RFMOs (fishing industry representative, pers. comm.).

Biodegradable FADs

Drifting FADs, but also aFADs that break free of their moorings, represent a major (but unquantified) source of marine litter. Designs using biodegradable materials (e.g. bamboo, sisal, yute, palm leaves, coconut fibre, cotton) have been proposed as a solution to mitigate this issue, and in some RFMOs, experiments testing with various biodegradable materials for the construction of FADs are underway.[18] However, overall this initiative has not progressed far due to reluctance by the purse seine fishing industry. This appears to be for two reasons: primarily, concern that dFADs made using biodegradable materials do not have the same lifetime as traditional dFADs made using plastics and nylon, and secondarily because dFADs with biodegradable materials cost approximately twice as much as conventional dFADs (ICCAT, 2016). Whilst the cost issue may in time be overcome, especially when considering the relative cost of biodegradable materials is insignificant compared to the cost of a satellite buoy (fishing industry representative, pers. comm.), the question of biodegradable dFAD longevity will require further research. Pilot studies are already underway in the Indian Ocean, where around 100 biodegradable dFADs are being deployed to assess their durability in actual use conditions, and the absence of toxicity of the materials used in their construction. This trial is part of a collaborative research and development project being undertaken by OPAGAC with AZTI and ISSF.

The reluctance by the purse seine industry to use biodegradable dFADs is probably the principal reason that none of the tuna RFMOs have made their use a requirement (unlike non-entangling FADs in IOTC and ICCAT). Nevertheless, the concept of using biodegradable material to construct aFADs appears to be more widely accepted, most likely because aFADs are regularly maintained and failing parts can be replaced. To date at least one fishing nation, the Maldives, has required the use of biodegradable aFADs in its national FAD management plan.

Lighting of FADs

Some purse seine and pole and line vessels have experimented with attaching lights to FADs to attract fish during hours of darkness, which may as a result increase the effectiveness of the use of FADs further still. In the 2015, IOTC prohibited the use of artificial lights in combination with FADs, apparently in an effort to limit the extent to which FADs attract small tunas. No other tuna RFMO has yet adopted a similar measure.

Species discrimination

Many FADs are fitted with buoys that contain autonomous echo-sounders, powered by solar panels, which scan the water column to detect the presence of fish. Some manufacturers have begun to integrate multiple frequencies into their echo-sounder buoys that should allow for increased species discrimination capability, especially between swim-bladder (yellowfin and bigeye tunas) and non-swim bladder (skipjack) tunas. However, this technology is in the early stages of development and its potential benefits in selectivity have not yet been fully evaluated (Moreno et al., 2015).

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[18] See for example: https://www.iattc.org/Meetings/Meetings2016/SAC7/PDFfiles/SAC-07-07d-Extra-budgetary-research.pdf. Accessed 12th September 2016.

Fishing Practices

Minimum mesh sizes

Larger mesh for the main body of the purse seine net can be specified to allow fish under a certain size to escape while retaining the target catch of large adult fish. The size of the mesh must be set at an appropriate level to allow necessary levels of escapement of non-target and juvenile fish. These measures are not particularly effective in purse seine fisheries for excluding small yellowfin and bigeye tunas, as these are of similar size as the target skipjack tuna.

Manual release, medina panels and backing down

All tuna RFMOs have passed recommendations and resolutions encouraging the release of incidentally caught animals, particularly turtles. Turtles, sharks, rays and marine mammals captured in purse seine nets can be spotted during the closing period of the hauling of the net. Techniques and devices, such as sorting grids, have been developed to remove these species from the net on hauling and from deck. However, the post-release survival of some bycatch species is not well known.

Fine meshed medina panels at the top of the purse seine nets can be used to deter entanglements as the fine mesh can be detected by marine mammals and can reduce entanglements and drowning of turtles.

During hauling the purse seine net can be backed down to allow the escape of marine mammals, sharks and rays that tend to be found in the shallower areas of the net, while the tuna are retained in the deeper sections of the net. This requires a reasonably high level of crew experience in order to be successfully implemented.

4.1.7 Mitigating damage to coastal habitats

In the western Indian Ocean, the purse seine industry has engaged with at least one island state to develop a mechanism for reporting and retrieving instrumented buoys that are approaching islands and coral habitats and are likely to beach. OPAGAC have entered into an agreement with three partner organisations in the Seychelles - Island Conservation Society (ICS), Islands Development Company Ltd (IDC) and Seychelles Fishing Authority (SFA) - that aims to mitigate the impact of beached dFADs. Initially this project will identify and map sensitive coastal habitats and establish a buffer zone for real time buoy data transmission before beaching. When the initiative is active, data on the position of dFADs will be transmitted to ICS by the satellite tracking service provider, acting with permission from the ship owner, who will respond to the information and intercept of collect the dFAD as necessary. Supply vessels from OPAGAC companies will collect the dFADs stored by ICS for recycling (purse seine industry representative, pers. comm.). This is a new agreement that has not yet been fully implemented, and its success cannot yet be evaluated. Similar initiatives are not known for other regions.

4.1.8 Catch and effort limits

Catch and effort measures are aimed primarily at controlling fishing of target tuna species but are expected to have a proportionate impact on reducing catch of juvenile tuna. IOTC has agreed a suite of catch reductions for yellowfin relative to each fishing nations catches in 2014, introduced in 2016 in response to the overfished status of the stock. ICCAT has a total allowable catch (TAC) for yellowfin (with division into quotas) and a TAC with national quotas for bigeye applicable to purse seiners.[19] IATTC and WCPFC currently have catch limits for bigeye, but these are only applicable for longlines.

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[19] Recommendation 15-01 Recommendation by ICCAT on a multi-annual conservation and management program for tropical tunas.

The efficacy of catch limits depends on how well they are implemented. In some tuna fisheries, particularly those in the Pacific, there are ongoing issues regarding accurate reporting of catch data, largely due to inaccurate estimation by skippers (or observers) of catch weight or composition (WCPFC, 2015), which can reduce the effectiveness of catch limits. This appears to be less of an issues in the Indian and Atlantic Oceans, where port sampling and cross checking of landings at port appear to maintain a reasonably high level of accuracy (MRAG, pers. obs.) To date, no evaluations have been undertaken to judge to success of imposing catch limits in reducing catch of small tunas.

4.1.9 Discard ban

Partial discard bans currently apply in the convention areas of IOTC, WCPFC and IATTC where purse seine vessels must retain on board and land or tranship all yellowfin, bigeye and skipjack tuna caught (but other, non-target species may be discarded). The requirement to retain discards on board effectively reduces a vessel's hold capacity for commercial fish, and thus the aim of such a measure is to encourage the development of technologies and fishing strategies that avoid the capture of small tunas and non-target fish. A discards ban will only work effectively in accordance with an observer programme, using either human or electronic systems, to ensure fisher compliance. To date, no evaluations have been undertaken to judge the success of discard bans in reducing catch of small tunas.

5 What research is being done on FADs?

There is vibrant literature on many of the issues that are related to the use of FADs and, as the priorities of tuna fisheries managers changes over time, so do the types of research questions asked and answered by scientists.

Research on FADs used in industrial tuna fisheries began in the early 1980s, and has since taken many directions. Early research effort during the 1980s was focused on development of FAD-based fisheries, including the technical development of FADs themselves. During this period, studies on aFADs outnumbered those on dFADs (Dempster and Taquet, 2004), presumably reflecting the greater number of coastal and nearshore fleets developing with FADs at the time. As FAD fishing began to develop on an industrial scale, both nearshore and on the open ocean, more interest was directed at the evolutionary mechanisms behind the association of tuna with floating objects, and ultimately the consequences of the interactions of fish with FADs. Only relatively late in the development of FAD fishing, in the late 1990s and early 2000s, attention was turned more urgently to issues of bycatch, overfishing and the management of FAD-based fisheries; these issues continue to be key research topics today.

While many research questions have been posed by managers and are being studied by researchers worldwide, two topics in particular are currently the focus of intense research efforts: the contribution of FADs to fishing effort, and how to estimate and account for it in management; and the extent of bycatch and entanglement of animals in FADs, and how to mitigate this environmental issue.

5.1 Estimating fishing effort

Since the 1980s tuna purse seiners have continuously improved their fishing efficiency through the modification of vessel characteristics, the frequent introduction of new fishing devices and the development of new fishing strategies (Gaertner and Pallares, 2002; Torres-Irineo et al., 2011). Drifting FADs have greatly contributed to these changes and enhanced the catchability of tropical tunas by purse seiners. Due the mixture of practices used to locate tuna schools, including searching for free schools and remotely monitoring FADs, traditional measures of fishing effort such as days at sea or fishing time have become inappropriate. This complicates the definition of indices of CPUE to assess the stocks of skipjack, yellowfin and bigeye tuna in RFMOs and has contributed to concerns of overfishing.

In the early 2000s, attempts were made to improve indices of abundance in purse seine fisheries (e.g. ESTHER project; Gaertner and Pallares, 2002), but with varying success due to the poor availability of data on FADs. More recently, however, the Catch, Effort, and eCOsystem impacts of FAD-fishing (CECOFAD) project[20] has made progress in improving the understanding of the use of dFADs in tropical purse seine tuna fisheries. The project, which started in 2014 and was completed in summer 2016, was led by the Institut de Recherche pour le Developpement (IRD) and funded by the EU. The overall objective was to provide insights into the fishing effort units (for both fishing modes: FADs and free schools) to be used in the calculation of purse seiner CPUEs in the Atlantic, Indian and the Pacific Oceans, where EU purse seiners operate, to ultimately obtain standardised indices of abundance for juveniles and adults of tropical tunas. With regards to the ecosystem approach to fisheries management, the CECOFAD project provided new knowledge on the impact of FAD-fishing on the epipelagic ecosystem, which will be of relevance to support the future management of tuna fisheries. The work of CECOFAD has been generally well received by the FAD working groups of ICCAT and WCPFC, in particular efforts to standardise CPUE of FADs. When performing stock assessments it is important to standardise the catch rate, taking into account any changes in fishing strategies that affect catch rates. Changes in purse seine fleets have been rapid and complex and to date have prevented RFMOs from standardising the purse seine CPUE in any

[20] Official website available at: http://www.cecofad.eu/. Accessed 19th May 2016.

meaningful way, and hence the outputs of CECOFAD are highly relevant to ongoing improvement in scientific advice.

5.2 Bycatch and entanglement

The growth in use of FADs has been associated with increasing fishing mortality on non-target species. Whilst bycatch has always been an issue in all tuna fisheries, the widely publicised increase in the use of dFADs by purse seiners has increased awareness of the magnitude of the problem. In this context, the first estimations of bycatch levels were conducted for purse seine fisheries (Bratten and Hall, 1996; Stretta et al., 1998; Gaertner et al., 2002), and research has more recently focused on bycatch associated with FAD sets in the Atlantic and Indian Ocean (e.g. Amandè et al., 2010). Since the late 2000s there has also been considerable research examining the extent of entanglement in FADs (ghost fishing) of turtles, sharks and cetaceans (Anderson, 2014; Filmalter et al., 2013; Gilman, 2011). This work on bycatch has encouraged research and development into ways to minimise bycatch mortality, for example through non-entangling FAD designs or guidelines for releasing sharks. ISSF has been proactive in this field of work in all regions.[21]

The now-finished 'MADE' (Mitigating adverse ecological impacts of open ocean fisheries) project made considerable progress in understanding issues of bycatch in industrial tuna fisheries, and also in developing measures to reduce it. The project, which was funded by the European Commission (DG Research) and ran from 2008 to 2012, was coordinated by IRD (France) from the Seychelles office involved 13 institutions from eight different countries (France, Spain, Portugal, Italy, Greece, Belgium, Brazil, Seychelles). The primary objective of the project, which conducted research in three regions (Atlantic and Indian Oceans and the Mediterranean Sea), was to propose measures to mitigate adverse impacts of fisheries targeting large pelagic fish in the open ocean, specifically purse seiners using FADs and longliners.

The bycatch of sharks was major focus of the MADE project, especially silky and oceanic white tips sharks, which constitute the majority of purse seine bycatch of sharks. Topics of study included identification of spatial and technical management measures to reduce the bycatch of pelagic sharks and juvenile swordfish by pelagic longliners; determination of spatial and technical management measures to reduce the bycatch of pelagic sharks and other species using FADs; and assessment the effects of FADs on the behaviour and ecology of pelagic fish. The project produced numerous scientific papers from these lines of inquiry, many of which have been used to inform earlier sections of this report (Amandè et al., 2008, 2010; Dagorn et al., 2012; e.g. Filmalter et al., 2013). The MADE project was also proactive in reducing the issue of entanglement of sharks and turtles with FADs, and developed best practice guidelines for the design and use of ecological FADs (Franco et al. 2009) at an early stage of the project. It also undertook trials of non-entangling dFAD, in collaboration with the purse seine industry, to test the efficacy of different designs to attract tuna while avoiding incidental capture of turtles and sharks.

Since the completion of the MADE project in 2012, several elements of the work have continued to be explored further, for instance the use of FADs and scientific platforms (Moreno et al., 2015), and so too have trials of non-entangling dFAD designs (Murua et al., 2016). Much of the information and ideas generated through MADE have also percolated into the work and discussions of the various FAD Working Groups of the RFMOs.

[21] See, for example: ISSF 2016-08: Advances in the Use of Entanglement-Reducing Drifting Fish Aggregating Devices in Tuna Purse Seiners and guidelines.

6 Recommendations for improving future management of FADs

The use of FADs in tuna fisheries has increased at a much faster pace than the development of effective ways of managing their use and understanding their impacts. Attempts by fishery managers to gather comprehensive data on FAD use and to better understand how they influence fishery dynamics have been relatively late coming, and the previous section of the reports highlights several critical management gaps and uncertainties. In this section, a series of recommendations are proposed for how the policy and management of FADs might be strengthened and how scientific understanding of the impacts of FADs could be further developed. These recommendations are intended to highlight key 'areas to watch' in FAD policy, FAD management and science, and to provide suggestions for future activities, including advocacy and research.

This report makes recommendations in the following areas:

1. **Strengthening data reporting and monitoring**: to ensure that data reporting requirements are adequate for use in developing and monitoring appropriate FAD management measures, and that data reporting is of a sufficiently high standard.
2. **Development of FAD management strategies:** to maximise the utility of current FAD management plans, and to raise the bar in terms of future requirements for FAD management.
3. **Mitigating impacts through FAD design and materials:** to promote widespread use of non-entangling and biodegradable FAD designs throughout tuna fisheries around the world, building on progress that has already been made in this area.
4. **Limiting FAD use**: to ensure that meaningful limits on dFADs are introduced, based on robust scientific evidence, whilst keeping the management objectives and challenges in mind.
5. **Increasing fishing selectivity:** to facilitate 'thinking outside of the box' in terms of developing selectivity technology that reduces the catch of small tunas and non-target species.
6. **Understanding consequences of FAD management:** to encourage further research into positive FAD impacts in terms of economic, societal and environmental issues to ensure the possible consequences of management actions are understood.
7. **Increasing communication and collaboration:** to support the progression of FAD related scientific research generally.

Table 3 Relationships between the recommended actions and identified negative impacts of FADs.

Recommendation theme	Overfishing of tuna stocks	Catch of non-target species	Damage to marine habitats	Interference with other activities
Strengthening data reporting and monitoring	ü	ü	ü	ü
Development of FAD management strategies			ü	ü
Mitigating impacts through FAD design and materials		ü	ü	
Restricting FAD use through limits	ü		ü	
Effective spatial management of FADs	ü	ü		
Quantifying purse seine fishing effort	ü			
Increasing the selectivity of fishing	ü	ü		
Benefits to fisheries, communities and ecosystems	ü	ü	ü	
Increasing communication and collaboration	ü	ü	ü	ü

6.1 Policy recommendations

6.1.1 Strengthening data and monitoring

FADs have increased the efficiency of fishing effort considerably in purse seine and pole and line tuna fisheries. In order to inform the overall management of tuna fisheries, and to fully understand the dynamics of the fishery, it is therefore crucial to have comprehensive data on the use of FADs and the catches associated with them.

All tuna RFMOs have made headway in improving data collection standards for FADs (e.g. FAD logbooks) over that past five years or so, especially in regards to collecting information on the usage of dFADs by purse seine fleets. However, noting the necessity to use these data to inform management, it is not entirely clear to what extent these data are fit for the various purposes they are needed for. For instance, taking the example of standardisation of catch per unit effort (CPUE), there is question as to whether the data currently collected provides a sufficient measure of fishing effort? Are the key factors that may be important in the standardisation of CPUE included in the reporting requirements for purse seine fleets? To what extent are data requirements harmonised between the FAD management plans of national fleets? And what additional data can realistically be collected without overburdening vessel skippers?

Similar questions may be asked of the adequacy of existing data reporting for understanding the ecological impacts of FADs, investigating their possible role in growth and recruitment overfishing and monitoring trends and evolution in their use by fleets.

Three recommendations are given below, aimed at ensuring data reporting requirements are adequate, and that data reporting is of a sufficiently high standard, for effective monitoring and management of tuna fisheries by RFMOs.

Recommendation 1: robust management indicators are developed to monitor trends and key developments in the use of dFADs.

Tuna RFMOs are encouraged to develop robust management indicators that can be used to monitor trends and key developments in the use of dFADs. Indicators should reflect management priorities and uncertainties, and could, for example, be used to monitor compliance with rules on how FADs are used (e.g. requirement for non-entangling FADs) or detect unanticipated changes in FAD fishing practices. Informative indicators might require the need for detailed information, such as the type of dFAD deployed, incidents of lost dFADs, or the number of buoys purchased by a vessel, and as such will need to be aligned with reporting requirements. The need to ensure adequate data and reporting requirements is covered in the following recommendation.

Recommendation 2: FAD data reporting requirements are assessed to determine whether they are fit for purpose in relation to management priorities.

Tuna RFMOs, most likely through their *ad hoc* FAD working groups and ideally in coordination with each other, are encouraged to undertake an assessment to determine whether the data requirements set out in FAD logbooks and elsewhere are fit for purpose in relation to management priorities (and indicators). These assessments should consider not only the specific needs of the different RFMOs and different fisheries, but also the general needs common to all RFMOs and the extent to which these are reconciled. Informed by the outcome of these assessments, RFMOs can act to ensure that data reporting requirements are amended to accurately reflect data needs. Coordination between RFMOs will be especially important in ensuring that, in time, suitable datasets are available that will allow for harmonised, or at least comparable, research and monitoring by the four RFMOs.

Recommendation 3: data received from FAD logbooks is critically reviewed to determine its quality in terms of accuracy, timeliness and consistency.

Tuna RFMOs, through their most appropriate working groups, are encouraged to undertake a critical review of the quality of data received from FAD logbooks to determine its quality in terms of accuracy, timeliness and consistency (at a minimum). Currently data submissions are evaluated only as received or not received. For an example of a more extended review process, see a recent review of Spanish FAD logbook data by Soto el al (2016) presented to IATTC.[22] It is noted that data reviews must be done by the RFMOs given the tight confidentiality restrictions on logbook data that make fishery-wide information unavailable to any single external organisation. Following the assessments, RFMOs can draw upon the findings to develop or guide initiatives for improving data reporting standards across CPCs.

6.1.2 Development of FAD management strategies

Most tuna RFMOs require their members to have FAD management plans in place for their national fleets. The primary aim of these plans is to generate better information on FAD usage, although plans also cover aspects of FAD design and use (requirements for which vary slightly by the RFMOs). To date, most CPCs have developed management plans, although the quality and comprehensiveness of these plans varies considerably. Compliance of CPCs with the FAD management plan requirements is analysed by the respective RFMOs, usually by the Compliance Committees, although this analysis is not exhaustive. For instance, the IOTC noted that FAD management plans received from CPCs by early 2016 fell into three categories:[23]

[22] Available at: https://www.iattc.org/Meetings/Meetings2016/SAC7/PDFfiles/INF/SAC-07-INF-C(i)-Review-of-the-Spanish-FAD-plan.pdf. Accessed 3rd August 2016.

[23] Available at: http://www.iotc.org/documents/summary-compliance-drifting-fad-management-plan. Accessed 3rd August 2016.

1. Management plans with appropriate sections setting clear guidelines for the plan;
2. Incomplete management plans with only some parts setting clear guidelines and other parts containing statements of intention on what will be undertaken in the future to respond to the requirements for those concerned sections; and
3. Totally incomplete dFADs management plans, describing only the current status.

Whilst this review is appropriate for checking compliance at the most basic level, it is not particularly informative and does not provide those CPCs with incomplete plans with constructive feedback. It should, therefore, be a priority of the tuna RFMOs in the short term to get all CPC's FAD management plans up to minimum requirements. Going beyond this, there is also scope to further develop the requirements of FAD management plans to include more demanding standards relating to FAD data reporting, design or use. This should ideally be part of an adaptive process, where future iterations of management plan requirements reflect the changing priorities and data needs of fishery managers.

With this in mind, the following actions should be considered to maximise the utility of current FAD management plans, and furthermore to raise the bar in terms of future requirements for FAD management.

Recommendation 4: FAD management plans are critically reviewed and improved in line with current standards.

RFMOs are encouraged to undertake comprehensive reviews of CPC's FAD management plans against current standards, and to provide constructive guidance for improving the contents of plans. This should be done in the first instance by the RFMO Compliance Committees, with technical advice provided by the FAD working groups. There is also opportunity for NGOs and other interest groups to provide CPCs with general advice and guidelines for developing high quality FAD management plans, either indirectly through online materials or directly through consultation.

Recommendation 5: requirements for FAD management plans are evaluated within at least five years and amended in line with emerging management priorities.

RFMO *ad hoc* FAD working groups are encouraged to undertake an initial evaluation of FAD management plan requirements within at least five years of their initial implementation, and at regular intervals thereafter. These evaluations should consider how data needs and other management considerations have changed and provide recommendations on how plan requirements should be updated. Ideally these evaluations should consider the level of consistency in data requirements and standards between the RFMOs, and how this might be improved; for instance by supporting joint meetings of the FAD working groups or developing an online information sharing platform to be used by the working group participants.

Recommendation 6: ocean-basin-wide FAD management frameworks are considered by RFMOs at the level of their jurisdiction.

RFMOs are encouraged to explore the concept of developing FAD management frameworks at the level of their jurisdiction (e.g. ocean basin), including how management objectives might be set and what development and implementation challenges may arise. These management frameworks should go beyond the current requirements for CPCs to develop national FAD management plans and put in place a coherent framework for managing the use and impacts of FADs at an ocean basin scale. Such frameworks should be based on clear management objectives that should aim to minimise the impacts of FADs whilst promoting their positive aspects (e.g. efficiency). It is recognised that the development and implementation of RFMO-level management strategies would likely face challenges arising from differences in the relative use of FADs by CPCs. Similarly, there are likely to be divergent views on management objectives given differences in CPC's priorities for management. These challenges, however, are within the remit of RFMOs to resolve, and should not prevent this recommended action being taken forwards.

6.2 Management recommendations

There are a number of important considerations for the effective management of industrial tuna fisheries by RFMOs. On one hand, the management of tuna fisheries should be based on robust stock assessments, using effective input and/or output controls that aim to regulate key dynamics of the fishery, such as the total removals of fish and the fishing capacity of fleets. In this respect the use of FADs and their impact on tuna stock dynamics, e.g. possibility for recruitment overfishing, should be properly accounted for in the design of management and comprehensively monitored in the long term. On the other hand, the negative impacts associated with FADs specifically, e.g. entanglement and marine litter, should be managed explicitly to maintain control over their cumulative impact on the environment.

With this in mind, two key FAD management approaches are discussed below. Discussion on the development of appropriate stock assessments and effective input/output control, using tools such as harvest control rules (HCRs), is crucial but beyond the scope of this report.

6.2.1 Mitigating impacts through FAD design and materials

Considerable progress has been made in developing and testing FAD designs that reduce the risk of entanglement of sharks, turtles and other species. This work has come about through collaboration between researchers and industry, and should continue. However, investment of time and effort has not been the same in all regions, with trials of innovative FAD designs furthest ahead in the Indian and Atlantic Oceans. Moving beyond non-entangling designs, the next step should be to introduce biodegradable materials for FAD construction to address the issue of FADs as long-lasting marine litter. To date this has been a greater challenge due to fleets' concern about the longevity of biodegradable FADs and how this might affect catches.

The following actions should be considered to promote the widespread use of non-entangling and biodegradable FAD designs throughout global tuna fisheries, building on progress that has already been made in this area.

Recommendation 7: trials of non-entangling FADs are reviewed at a global level to identify areas that could be strengthened.

The development, trial and industrial use of non-entangling or entanglement reducing FAD designs should be reviewed at a global level to identify areas that could be strengthened. A cost benefit analysis of non-entangling versus conventional designs would also be useful as part of this work. This analysis should consider the stance of the different tuna RFMOs toward non-entangling designs (e.g. are new Resolutions required?) as well as the practical issues regarding their use (e.g. are designs used in one ocean suitable for use in another, given differences in fishing practices?).

Recommendation 8: biodegradable FADs are developed and trialled through a programme of design innovation.

An innovation programme could be established that encourages the development and trial of biodegradable dFAD construction materials and seeks ideas from fishers and researcher alike.[24] It will be critical to work closely with tuna fleets to ensure that biodegradable designs are practical in the long term and therefore likely to be used by fishers.

[24] Several global innovation platforms are in development and include OceansXLabs from WWF-US, which is looking at driving innovations in ocean technology, and WWF-X from WWF-UK, which is an incubator for larger-scale projects and initiatives.

6.2.2 Restricting drifting FAD use through limits

Most of the tuna RFMOs have set upper limits on the use of dFADs, either the number of instrumented buoys that can be actively followed or purchased by a vessel each year, or the total number of dFAD sets that can be made annually at the fleet level. Whatever limits are chosen by RFMOs, it is important that they are meaningful, insomuch that they truly control dFAD usage in some way, and that they address a specific fishery objective, such as to control fishing capacity or reduce ecosystem impacts. Limiting dFADs appears to a higher priority than limiting aFADs, which are fewer in number and generally limited by national fisheries development plans. Whilst the existing limits on dFADs appear to be in place as a precautionary measure, which is a positive move by RFMOs and should not be rescinded, it is not clear what they mean in practice; for instance, some vessels use substantially fewer dFADs than the upper limit, or how compliance with the limits will be monitored and enforced. Moreover, limits should be applied in concert with input or output controls as part of a broader harvest strategy. However, differences between fleets and fishing companies in the number of dFADs used will present a major challenge in finding and implementing meaningful limits, as some elements may be expected to strongly oppose restrictive limits, whereas others will welcome them.

The following action is recommended to ensure that meaningful limits on dFADs are introduced, whilst keeping the objectives and challenges outlined above in mind.

Recommendation 9: research into the role of dFADs in determining fishing capacity and fishing effort is prioritised in order to better determine FAD limits.

RFMOs, mostly through the CPCs and their national scientists, are encouraged to prioritise research into the role of dFADs in determining fishing capacity (i.e. ability to catch fish) and fishing effort (i.e. time or other investment needed to catch fish). Alternatively, this research could be conducted by an independent research organisation, although access to fine-scale fishing and FAD data is essential, which may restrict eligibility. This work is vital to better understand the effort dynamics of purse seine fisheries, and therefore how to effectively control fishing capacity and effort by limiting FAD use (e.g. avoiding unintended consequences of management, such as technical creep or similar). Moreover, this work should consider possible management objectives and indicators in the context of controlling FAD use, and explore the concept of optimum limits under different management objectives.

6.3 Science recommendations

Scientific understanding of the positive and negative impacts of FADs has improved, but it has advanced slower than the increase in use of FADs in tuna fisheries. This has led to a situation where concerns regarding the use of FADs have emerged before the science has matured sufficiently to provide satisfactory answers. Broadly speaking, the most important scientific questions regarding FADs in tuna fisheries are already being investigated or have been identified as a priority for forthcoming research effort, namely the role of FADs in fishing effort and how FADs can be designed to reduce bycatch (see Section 5). In this section, we have identified some of the key uncertainties that have received less attention to date, yet where research should progress in order to reduce the negative impacts associated with FADs and support management decision making.

Recommendation 10: research on bycatch of threatened species is continued to identify best practices that will reduce ecological impacts of fishing with FADs.

The bycatch of non-target and potentially threatened species associated with FAD fishing a particular focus in the conversation and work of FAD tuna fisheries. While a number of ‘best practices’ have been identified to reduce bycatch around FADs, further improvements are needed in order to reduce this ecological impact and assure greater adherence by fleets. While the reduction of bycatch lies largely within the realm of management, science has an important role to play both in providing evidence to support managerial decisions and in the continued improvement of technology and approaches that improve the selectivity of fishing. In taking this research theme forward, workshops or competitions that encourage ‘thinking outside of the box’ in terms of selectivity technology may prove to be helpful identifying and developing ideas and designs.

Recommendation 11: the economic, societal and environmental positives of FAD fishing are investigated to understand the potential repercussions of management.

Using FADs when fishing for tuna provides several positive impacts, in particular to fishers in terms of increased efficiency and profitability, and also to communities in terms of increased food security and even to wider-society in terms of affordable protein. As such, it is important to understand the repercussions that restrictive management of FADs might have on those that benefit from FADs. Research groups or NGOs are encouraged to further examine the economic, societal and environmental positives associated with FAD fishing. For instance, what are the perceived benefits to society and how can these be quantified? Very little work has been focussed on these questions, which are important in order to understand the potential consequences of management decisions regarding FAD use.

Recommendation 12: communication and collaboration between *ad hoc* FAD working groups and other research groups is encouraged and facilitated.

Vital to the progression of most understudied areas of FAD-research is the continued and increased communication and collaboration between *ad hoc* FAD working groups and other research groups. This is important to ensure that effort is not duplicated, to propagate ideas, solve problems and to corroborate findings spatially and temporally. It is interesting to note that the largest leaps forward in terms of FAD understanding often occur during or shortly after international or inter-RFMO conferences. Therefore, RFMOs and other interested groups are encouraged to organise conferences, working groups, and collaborations between tuna fishery researchers (and or other interested stakeholders) that work within or outside RFMOs.

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Annex 1 Recent innovation in dFAD design and management

Two case studies are presented that examine recent examples of innovation in dFAD design and management that have led (or aim) to reduce negative ecological impacts, whilst still achieving sustainable catch levels in the long term. Each case study describes the innovation and its purpose, the key players involved, and a brief discussion on what the innovation has or is expected to achieve in terms of reducing one or more negative impacts of dFADs.

Non-entangling dFADs

Background

The increasing use of dFADs in tuna fisheries has been associated with mortality of non-target species, particularly turtles and sharks, and public awareness regarding this problem has risen in tandem. Research taking place in the Atlantic and Indian Oceans has highlighted that although most dFAD bycatch of turtles and sharks is due to them being encircled by fishing gear alongside tuna, these species, especially sharks, also become entangled in the netting that hangs underneath the surface of the dFAD. As such, research examining the extent of dFAD-entanglement (ghost fishing) of turtles, sharks and cetaceans has increased (Anderson, 2014; Filmalter et al., 2013; Gilman, 2011). While the number of marine turtles entangled by dFADs is likely to be relatively small, research suggests that FAD entanglement mortality of sharks is significant; for instance, Filmalter et al. (2013) estimated the mortality of silky sharks in the Indian Ocean at 480,000-960,000 individuals from dFADs alone.

Using ‘non-entangling’ dFADs is potentially a straightforward solution to this problem, and in recent years a number of FAD designs and management strategies with this aim have been implemented. ISSF has been particularly proactive in this field of work in all regions and the EU-funded MADE project was also proactive in reducing the issue of entanglement and both developed best practice guidelines. Currently, all tuna RFMOs, except for the WCPFC, have adopted some form of requirement or recommendation for a transition towards non-entangling dFADs.

What is the innovation?

The design of dFADs varies widely between and within oceans and fleets, but predominantly dFADs have traditionally been designed with a floating structure covered with netting that extends 10 to 120 m beneath the surface to form an appendage with open net panels. The netting used is often large mesh, and subsequently turtles can become entangled on the surface structure, and to a much higher degree sharks can become entangled in the sub-surface panels.

For over a decade scientists and fishers have been trialling dFADs constructed to minimise non-target species entanglement while still ensuring that the structure continues to aggregate tunas and is low in cost to produce and is durable. Initial non-entangling dFAD designs were tested with insufficient replication and conclusions were unclear regarding their ability to aggregate tuna whilst also reducing entanglement. However, in 2010 via the CECOFAD program the French fleet in the Indian Ocean conducted trials with a significant sample size of non-entangling dFADs designed collaboratively between fishers and scientists. These trials successfully demonstrated that catches remained similar while the risk of shark and turtle entanglement was significantly reduced[25].

Improvements made to the structure of FADs were simple. In order to reduce the entanglement of turtles near the surface, the floating component of the FAD should not be covered at all, or at

[25] Outcomes of this research is summarised in a LDRAC report available at: http://www.cepesca.es/download-doc/59687. Accessed 18th August 2016.

least covered with non-meshed material or at a minimum covered tightly using small meshed netting (< 70 mm). Where the surface structure is covered, then a cylindrical or spherical shaped floating raft will deter turtles from climbing onto the FAD.

In order to reduce shark and cetacean bycatch in the subsurface component, the dFAD should again be constructed from non-meshed materials such as ropes or canvas sheets. Entanglement can also be substantially reduced by other methods such as tightly wrapping the hanging nets with ropes, resulting in a tight bundles or 'sausages'; however, these can eventually become loose and become an entanglement risk.

Since the large-scale trials in 2010, the adoption of improved dFAD designs to reduce bycatch of sharks and turtles has advanced rapidly in many tuna fleets. Joint collaboration of ship-owners, skippers, and scientists to solve the entanglement issue as almost certainly been critical in facilitating the relatively fast voluntary adoption of non-entangling design by fleets.

What is the benefit?

The acceptance level of non-entangling dFADs by fishers has progressed rapidly since 2010 in most oceans, largely as the initiative is seen as a relatively easy and inexpensive solution to an issue that had raised significant public concern. Many purse seine fleets, in particular those of the EU, have replaced traditional dFADs with lower entanglement risk and non-entangling dFADs, while experiencing no decrease in tuna catches (Murua et al., 2016). This is expected to reduce on a cumulative scale the amount of ghost fishing occurring underneath dFADs. This may also translate to a (potential) market benefit to fishers as a result of greater acceptance of their product by the public with reduced ecological harm.

How can it be developed further?

ISSF classify dFADs into four entanglement categories: highest entanglement risk dFADs, constructed with any netting materials, including with large mesh; lower entanglement risk dFADs, using small mesh netting, however nets can break and increase in risk of entanglement; non-entangling dFADs, which use no netting in their construction; and non-entangling biodegradable dFADs, which in addition to having minimal risk of entanglement are constructed of only natural or biodegradable materials, which would be the FAD with the lowest environmental impact. Ideally all RFMOs should put requirements in place to move down this scale of entanglement. At least one trial is currently being prepared for later in 2016 with biodegradable and non-entangling FADs, as part of the Korean FAD Management Plan required by IOTC.

Tracking and monitoring dFADs

Background

In 2011 the SPC noted significant data gaps and information needs that must be improved to allow for the effective management of global purse seine fisheries in the west and central Pacific, and indeed more generally worldwide. Most importantly, more and higher quality data on dFADs and fishing operations are necessary for management purposes. Therefore, it was recommended that basic technical data are collected on the number of unique dFADs used per trip per boat, the total number of active dFADs in a fishery and the trajectories of dFAD throughout a fishery region.[26]

[26] Secretariat of the Pacific Community "Artisanal and Industrial FADs: A Question of Scale—Tahiti Conference Reviews Current FAD Use and Technology," SPC Fisheries Newsletter 136 (September/December 2011).

Fishing vessels deploy dFADs equipped with instrumented buoys that allow skippers to easily locate these objects and track their movement in real time. The first generation of true 'tracking' buoys, developed in the late 1990s, were equipped with basic GPS devices that improved upon the radio beacons used previously to detect dFADs. Since then, the technology of tracking buoys has continually been upgraded to increase in the detection range, improve signal privacy, enhance battery life and allow remote sensing of tuna abundance under dFADs (Scott and Lopez, 2014). Modern tracking buoys transmit information at hourly or daily intervals, depending on the skipper's immediate need for information (e.g. higher polling rates when a vessel is approaching a dFAD to pin point its position).

Gershman et al. (2015) gathered information on market share, recent production and increased demand for satellite-tracked buoys from the five major suppliers of this technology and estimated an output of 47,500–70,000 buoys per year, which represents a high proportion of the estimated annual global deployment of dFADs. The resulting satellite transmissions from these buoys provide fishing companies with a rich and detailed body of information for tracking dFADs through time and space and monitoring schools of tuna associated with them.

What is the innovation?

In 2012, Pew and the PNA launched phase 1 of a trial that aimed to make the extensive real-time information on tracked dFADs available to fishery managers. The trial collected and monitored information on dFAD location within PNA waters, with the data provided at no additional cost to fishing companies as it simply required owners to authorise dual reporting (i.e. to the companies and to the PNA). The initial trial also developed the Fisheries Management Information System to facilitate the tracking of dFADs as an integrated component of the system currently used to manage the fishery. In 2014, Pew and the Gordon and Betty Moore Foundation funded phase 2 of the trial, which scaled up the dFAD tracking system so it could track tens of thousands of and monitor each time a fishing vessel sets its net on one.

This initiative has provided fishery managers in the PNA Office with complete, highly detailed information on dFAD location and movement within with eight Pacific island countries, from which around 50 percent of the global skipjack tuna catch is caught.

What are the benefits?

A number of realised or potential benefits of the FAD tracking system have been highlighted by Pew, including:

- **Up-to-date location data.** Electronic reporting can provide near-real-time data on the location of dFADs, which can initially be used to develop limits on deployment of the devices and subsequently control these measures effectively (e.g. suspend fishing without delay once fleets reach a pre-determined threshold).
- **Reliability and security of data.** Data from instrumented buoys can be relaying automatically, without human intervention, which provides greater assurances of data reliability and security than manual data reporting systems used elsewhere.
- **Reduced impact of marine litter.** Fishery managers can potentially identify the owners of dFADs that are abandoned on the high seas or in nations' EEZs. If such devices wash up on reefs or other coastal habitats, managers are able to determine ownership to aid in recovery and assigning clean-up costs.

How can it be developed further?

The marking of dFADs and the tracking of the buoys need to be considered together. The lack of a consistent unique identifier makes it very difficult to individually track a single dFAD, which creates a major limitation for analyses. Within the WCPFC, several proposals for marking schemes have been proposed by members and the Secretariat in the past, although an assessment of these proposals by ISSF suggests these are still lacking crucial elements. In particular, because many FADs change "owners" – i.e. they are found by other vessels – it is important to develop a marking scheme that tracks both the satellite buoys and the dFAD raft itself.