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Fish Aggregating Devices (FADs) and Tuna

Impacts and Management Options

Summary

This report provides an overview of current literature on fish aggregating devices (FADs) and their impacts on tuna populations. It provides specific information on types of FADs, associations of tuna species with FADs, negative impacts of FADs on tuna populations, methods of limiting negative impacts on tuna and possible management options. Although bycatch of non-tuna species associated with FAD fishing can be significant, it is not the focus of this review.

The main findings for the negative impacts of FADs on tuna populations are:

- Recruitment overfishing of skipjack tuna in the eastern Atlantic Ocean.
- Overfishing of bigeye tuna in the western and central Pacific Ocean from a combination of purse seine fishing around FADs and longline fishing.
- Decreased health of tuna caught near FADs compared with tuna caught in free schools.
- Increases over time in biomass under FADs, reduced free-school abundance, differences in fish sizes and ages compared with free-school caught tuna and alterations in school movement patterns as a result of behavioral changes by tunas around FADs in the Pacific Ocean.
- Increased difficulty of properly assessing the status of individual tuna populations.
- High rates of bycatch, including sharks, sea turtles and juvenile tuna.

Management methods to document or reduce the negative impacts of FADs

Options that could be or have been used to limit the negative impact of FADs on juvenile tuna include:

- Prohibiting the use of FADs (prohibiting sets on FADs, the deployment of FADs or both).
- Restricting the depth of FADs.
- Vessel efficiency controls.
- Bans on discards.
- Bycatch limits.
- Restrictions on number of FADs used.
- Time and area closures (on FADs or for the entire fleet).

It should be noted that although some of these measures have been effective at times, all come with trade-offs such as difficulty in monitoring, loss of target catches, and fishing effort displacement.

Fish Aggregating Devices (FADs) and Tuna

Impacts and Management Options

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What Is a FAD?

There are two general types of fish aggregating devices (FADs): anchored (Figure 1) or free-drifting and floating objects (Figure 2) (Fréon and Dagorn 2000). The concentration or use of the two types of FADs can vary by geographic area, and fishermen employ a variety of fishing gear such as purse seines, trawls and passive gears such as longlines to capture fish around FADs (de San and Pages 1998). Large purse seine nets are often deployed—also known as "setting" the fishing gear—to capture schools of tuna that are within aggregations of various species found beneath FADs. The capture of fish around a FAD is a type of associated set, as opposed to sets on free-swimming schools of fish, referred to as unassociated sets. Other types of associated sets may be on other floating objects, such as logs, flotsam, dead and live whales and whale sharks and data buoys. In the eastern Pacific, a large proportion of purse seine sets are on dolphins; the association between dolphins and schools of tuna typically occurs only in this region.

How Did FADs Develop, and How Are They Used Today?

Artisanal fishermen in the Mediterranean, Southeast Asia and the western and central Pacific Ocean (WCPO) have been using FADs for hundreds to thousands of years (Kakuma 2000; Morales-Nin *et al.* 2000). This practice began when fishermen noticed that tuna and other pelagic species naturally aggregated under logs, seaweed mats and branches and even near larger animals such as whale sharks, and that fishing improved near these objects or animals (Higashi 1994).

When logs or other naturally occurring FADs were not easily found, fishermen created them so they could fish continuously (Atapattu 1991). Anchored FADs were first used in the 17th century in the Mediterranean (Desurmont and Chapman 2001), and by the early 1900s, fishermen in the Philippines and Indonesia were also using them (Prado 1991; Anderson and Gates 1996). Historically, anchored FADs have been used in shallow waters (Prado 2001) by small-scale fisheries (Reynal *et al.* 2000), but as a result of technological advances, commercially developed, anchored FADs can now be deployed at depths over 2,000 meters (Anderson and Gates 1996).

In the late 20th century, FAD fishing practices expanded into the open ocean, and the use of drifting FADs became a large-scale industrial fishing practice as fishermen on the high seas (areas beyond national jurisdiction) recognized the success of the coastal fishermen (Fonteneau *et al.* 2000b). More recently, there has been a rapid

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* *See back cover for biography and contact information.*

ANCHORED FADS

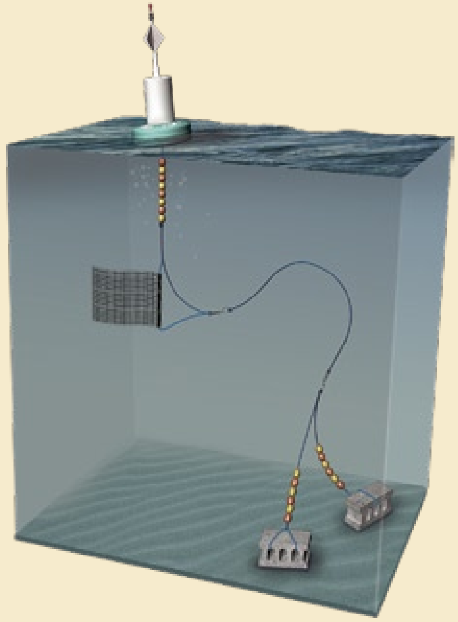

Figure 1: Anchored FAD

Anchored artificial floating objects are commonly used as FADs (Greenblatt 1979; Matsumoto *et al.* 1981; Kihara 1981) and are placed either on the surface or submerged in the water column (Ministry of Fisheries and Marine Resources 2008). Anchored FADs consist of a float, mooring line and anchor and some type of underwater structure or attractant (Malig *et al.* 1991) (Figure 1a). These FADs can be made out of tires, cement or engine blocks or a combination of logs and bamboo tied with rope (Atapattu 1991; Aprieto 1991) or commercially constructed of steel, aluminum or fiberglass with geo-locating devices attached to them (Anderson and Gates 1996).

The floating sections of commercially constructed FADs are typically made of steel containers filled with polyurethane foam (Matsumoto *et al.* 1981) topped with reflectors and flashing lights (Higashi 1994; Holland *et al.* 2000). The submerged section is often made out of panel netting, which can be weighted at the bottom to keep the net vertical in the water (Franco *et al.* 2009). There are other variations, including the "Korean design," built so that the submerged section spreads out like a sail, which makes the FAD drift slowly and keeps it within a concentrated area (Franco *et al.* 2009). Data buoys can also be used by fishermen as a type of anchored FAD, even though the World Meteorological Organization and the Intergovernmental Oceanographic Commission consider this vandalism, because the damage to buoys from fishing vessels worldwide is significant (Teng *et al.* 2009; Western and Central Pacific Fisheries Commission 2009b). Fishing around buoys has been banned in the western and central Pacific Ocean (WCPFC 2009b) and the eastern Pacific Ocean (Inter-American Tropical Tuna Commission 2010a).

evolution in the use of drifting FADs in large-scale commercial fisheries because of advances in fishing technology (Bromhead *et al.* 2003).

Today, the use of FADs is extensive, particularly the use of large-scale industrial FADs focused on capturing large schools of tuna. For example, in the Bismarck Sea of Papua New Guinea, there are more than 900 anchored FADs (Kumoro 2003). In the eastern Pacific Ocean (EPO), FAD deployments totaled 7,774 in 2006; 8,432 in 2007 and 9,813 in 2008 (WCPFC 2009a). In the WCPO during 2008, a total of 20,859 sets were made on free-swimming schools of tuna (i.e., no FAD used); 4,570 on logs; 9,508 on drifting FADs and 2,270 on anchored FADs, but the total number of FADs in use, deployed and retrieved per year or used by individual vessels in this region is not available (WCPFC 2009a). Also in the WCPO, purse seiners typically deploy 100 or more FADs (with satellite transmitters and echo sounders) at a time (Hampton 2010). Based on the reported size of the purse seine fleet (235 vessels), there could be as many as 23,500 FADs deployed at a time in the WCPO.

FADs are generally left in the water for the duration of their lifetime—dependent on type of FAD and how they are constructed. However, they are not always actively fished for the duration of their lifetime unless management measures require their removal during closures. However, even during closures, the number of FADs removed is undocumented (WCPFC 2009a) and overall global information on FAD use is poor (Macfayden *et al.* 2009).

In the EPO, the number of FADs that are removed during fishing closures is not known, and information on the number of FADs retrieved by vessels each year is limited (WCPFC 2009a). However, it was estimated that 5,917 FADs were retrieved in the EPO in 2006; 7,774 in 2007 and 7,391 in 2008 (WCPFC 2009a).

In the Indian Ocean, skipper surveys (French and Spanish vessels) indicate that about 2,100 FADs are actively monitored at any given time (Moreno *et al.* 2007). However, information on the number of FADs deployed, the number of sets made on a FAD and the number of FADs retrieved, lost or appropriated each year is not available in the Indian or Atlantic Ocean (WCPFC 2009a). Efforts are being made by some regional fishery management organizations (RFMOs) to collect more detailed information on FAD use in their respective regions.

Sets on drifting FADs are usually made at night and during early sunrise to capture fish as they move upward in the water column and to disguise the net from the fish (Hampton and Bailey 1999). Harley *et al.* (2009) found that 94

DRIFTING FADS

Fishermen have long targeted fish aggregating around drifting or floating objects such as naturally occurring trees or logs, planks, pallets, abandoned fishing nets and buoys (Castro *et al.* 2002), or around live animals such as whale sharks, manta rays and large marine mammals (MFMR 2008). These floating objects are variously referred to as drifting FADs (man-made), natural drifting FADs, floating objects and live animal FADs (MFMR 2008) (Figure 1b). Throughout this review, the term FAD does not refer to live animal FADs unless specifically stated.

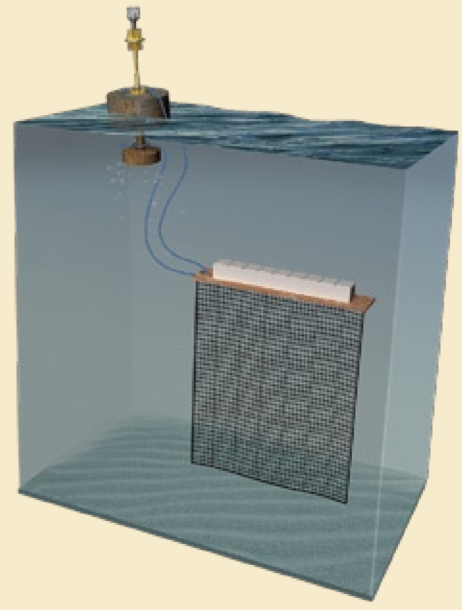

Figure 2: Drifting FAD

So-called log-school fisheries (purse seine fisheries that concentrate around floating logs) can be found in tropical coastal areas that are close to mangroves or large rivers (Castro *et al.* 2002). Other examples of drifting FADs include bamboo rafts with branches and palm leaves hung off the side, which are common in the Pacific and Indian Oceans (van Pel 1938; Marsac and Stéquert 1986; Biais and Taquet 1990; Josse 1992; Mathews *et al.* 1996; Ibrahim *et al.* 1996). In the Mediterranean Sea, tree branches are often fixed onto wood and cork blocks to create floating structures (Massutí and Reñones 1994; D'Anna *et al.* 1999). In the Indian Ocean, it is estimated that half of fishermen prefer to fish near natural floating objects, such as logs, compared with other types of FADs (Moreno *et al.* 2007).

In some areas, arrays of trawl buoys are used to create the floating sections of FADs, allowing the top of the FAD to be submerged. This creates less tension on the mooring that holds the entire drifting FAD together, allowing the FAD to last for several years (de San and Pages 1998), aggregate fish at a faster rate than surface FADs and attract larger schools of fish (Sokimi 2006).

Drifting FADs can be fitted with transmitter beacons so that they can be located, or with sonar equipment that indicates the amount of fish aggregating at the FAD (Castro *et al.* 2002; Hampton 2010). In some cases, drifting FADs are taken aboard vessels, modified and appropriated for use on other vessels by being given another radio beacon (WCPFC 2009a). Drifting FADs can be identified, and the amount of fish aggregating (size and species) can be determined using sonar a day in advance (Ariz *et al.* 1999).

percent of sets on FADs occurred before sunrise, but only three percent of unassociated school sets occurred before sunrise. The majority of these occurred during the day.

In the EPO, the number of purse seine sets made on FADs has increased over time from around 20 percent in 1990 to around 40 percent in 2006 (Miyake *et al.* 2010). As the proportion of FAD sets increased over time, sets made on dolphin schools decreased, and the proportion made on free schools remained relatively constant (Miyake *et al.* 2010). In the WCPO and Indian Ocean, the proportion of purse seine sets made on FADs, compared with free schools, has fluctuated from 60 to 70 percent and 40 to 60 percent respectively, while in the Atlantic, about half of the purse seine sets are made on FADs and half on free schools (Miyake *et al.* 2010).

Why Do Tuna Gather Around FADs?

Understanding fish behavior and the spatial structure of fish communities around FADs is critical to proper management of tuna fisheries (Josse *et al.* 2000). It is generally believed that fish use floating objects primarily for protection from predators (Gooding and Magnuson 1967; Hunter and Mitchell 1968; Hunter 1968), as a source of food availability (Gooding and Magnuson 1967), as a meeting location (Dagorn *et al.* 1995; Fréon and Dagorn 2000) and to increase survival of eggs, larvae and juveniles (Gooding and Magnuson 1967).

Juvenile bigeye tuna in particular are frequently found at FADs and are therefore caught by purse seine vessels (Harley *et al.* 2010). It is likely that FADs provide protection to juvenile bigeye tuna while also providing them with a good food supply, which increases their chances of survival (Castro *et al.* 2002). In addition, drifting objects may help juvenile bigeye and other species migrate to adult habitats (Castro *et al.* 2002). Juvenile bigeye may also use FADs as a meeting point to develop larger schools (Fréon and Dagorn 2000). While a number of studies on the behavior and vertical migrations of tuna aggregated around FADs have been done, the exact reasons for the association of juvenile bigeye tuna and FADs are still not known (Dagorn *et al.* 2007).

It is generally thought that drifting FADs must be in the water for at least a month to aggregate enough tuna to catch (Itano 2007; Moreno *et al.* 2007). Fishing captains that have been interviewed believe that non-tuna species must be aggregated around drifting FADs before tuna will aggregate and that non-tuna species arrive at FADs within one to four weeks of deployment (Moreno *et al.* 2007). Tuna are never the only species found at a FAD (Moreno *et al.* 2007). Captains use echo-sounders, sonar, prior knowledge of depth distributions and behavior of tuna species and visual observations of mix-species aggregations to help quantify the number and size of species around FADs before they set their nets (Schaefer and Fuller 2008).

Yellowfin tuna (the majority of research on aggregations around FADs has been done on this species [Dagorn *et al.* 2010]) tend to aggregate around FADs during the day and leave at night (Holland *et al.* 1990; Buckley and Miller 1994). Evidence from Hawaii suggests yellowfin and bigeye tuna remain near the same FAD for up to 150 and 10 days, respectively. When found in an array of FADs, these fish sometimes visit the closest neighboring FAD, although they spend the majority of their time at the FAD they originally colonized (Dagorn *et al.* 2007). Tagging studies in the Comoros Islands of the Indian Ocean have shown an association between yellowfin tuna and anchored FADs in the area, but not between skipjack tuna and FADs (Cayre 1991). Yellowfin tuna have also been shown to detect anchored FADs from five to eight miles away (Holland *et al.* 1990; Dagorn *et al.* 2000).

How Does the Use of FADs Negatively Affect Tuna?

Industrial-scale purse seining on FADs leads to the indiscriminate catch of tuna, including juvenile yellowfin and bigeye tuna, which is of concern to fisheries managers (Bromhead *et al.* 2003; Sokimi 2006), primarily because bigeye and yellowfin tuna associated with FADs are younger and smaller than those found in free schools (Ménard *et al.* 2000a; Fréon and Dagorn 2000). In some areas, such as the Pacific, there is already a concern that growth overfishing (fish are caught at an average size that is smaller than the size that would produce the maximum yield per recruit) and subsequently recruitment overfishing (adult population is reduced to a point where it no longer has the reproductive capacity to replenish itself) of bigeye and yellowfin tuna could occur as a result of increased FAD fishing. Recruitment overfishing may have already occurred on skipjack tuna in the eastern Atlantic Ocean (Bromhead *et al.* 2003).

The latest population assessment of bigeye tuna in the WCPO found that their spawning biomass is half the level seen in 1970, catches are currently well above maximum sustainable yield, the population is approaching an overfished state and overfishing is occurring (Harley *et al.* 2010). This assessment also suggested that the purse seine fisheries (majority of bigeye are taken from sets on FADs) have an equal or greater impact than the longline fisheries on bigeye tuna biomass (Harley *et al.* 2010). The status of bigeye tuna in the Atlantic is somewhat uncertain, although it appears that the current biomass is slightly larger than that required for maximum sustainable yield (MSY), while the fishing mortality is slightly below that associated with MSY (Scientific Committee on Research and Statistics 2010). Similarly, bigeye tuna in the Indian Ocean are currently assessed as not overfished or undergoing overfishing (IOTC 2009), and in the EPO they appear to be recovering despite being overfished in the recent past (IATTC 2008a; Aires-da-Silva 2011).

Research suggests that the majority of tuna caught on drifting and anchored FADs are under 70 centimeters in length (Marsac *et al.* 2000), and a worldwide analysis suggests that many bigeye and yellowfin caught at drifting FADs are around one year old (Bromhead *et al.* 2003). In addition, tuna caught associated with drifting FADs are less healthy (based on plumpness) than those caught in free schools (Hallier and Gaertner 2008). For example, the average weight of bigeye tuna taken around FADs in the Indian Ocean decreased from 1984 to 2001 (IOTC 2005), and the mean weight of skipjack tuna in the eastern Atlantic declined from 1991 through 1997 after FAD use became widespread (Ménard *et al.* 2000). This weight reduction in the Atlantic could be contributing to skipjack tuna being caught under FADs in warm water with poor food conditions, because they are unable to move toward more productive locations (Ménard *et al.* 2000).

The introduction of FADs in the Pacific also appears to have resulted in behavioral change in tuna that has caused increases in the biomass of tuna under FADs (Fonteneau 1991), reductions in free-school abundances (Fonteneau *et al.* 2000a; Marsac *et al.* 2000), differences between the age and size of free and FAD-associated schools (Ménard *et al.* 2000; Fréon and Dagorn 2000) and changes in school movement patterns (Ménard *et al.* 2000b) and structure (Josse *et al.* 1999; Josse *et al.* 2000). FAD-associated schools typically have a larger biomass than free-swimming schools, meaning more tuna can be caught during an individual purse seine set (Fonteneau 1991).

The large numbers of FADs now present in oceans increases the likelihood of tuna encountering them (Bromhead *et al.* 2003), leading to a cascade of effects. For example, the "ecological trap" hypothesis (Marsac *et al.* 2000) suggests that tuna and other fish can be trapped within networks of drifting FADs, which could alter the migratory paths of such fish and therefore affect characteristics such as growth and reproduction. The size of the networks can vary by location. For example, Hawaii has a network of 56 anchored FADs at locations that surround all of the main Hawaiian Islands (Holland *et al.* 2000), and within this network, the distance between individual FADs ranges from seven to 31 kilometers (Dagorn *et al.* 2007).

The aggregation of juvenile tuna around FADs also makes them more susceptible to predation from both larger tuna and other predators (Delmendo 1991; Bromhead *et al.* 2003). Hallier and Gaertner (2008) provided evidence to support this theory, showing significant changes to migratory patterns and increased displacement rates in the presence of drifting FADs, as well as differences in fish plumpness and growth rates (tuna found near drifting FADs were less healthy than those in free schools), but more research is needed. For example, differences in fishing time and sizes of fish caught near FADs versus free-swimming schools could have influenced these results (Hallier and Gaertner 2008).

The use of FADs has also made population assessments of tuna more difficult because of changes in the size of the tuna caught, the fishing zones, migratory patterns and the definition and use of fishing effort (Fonteneau *et al.* 2000a;

Gaertner and Pallarés 2001). The use of FADs has increased the catch efficiency of purse seiners (Bromhead *et al.* 2003), and in areas such as the EPO, more catch (weight) is caught on FAD sets than on sets made on free schools (Bromhead *et al.* 2003). For example, 90 percent of purse seine sets made on FADs catch tuna, compared with only 50 percent of free-schooling sets (Fonteneau 2000b), which is one of the reasons FADs have become so popular.

In summary, several negative impacts of FADs on tuna populations have already been observed and documented, including:

- Recruitment overfishing of skipjack tuna in the eastern Atlantic Ocean.
- Decreased health (plumpness) compared with tuna caught in free schools.
- FAD-related behavioral changes in tuna that lead to increases in biomass under FADs (which can make tuna more susceptible to capture), reduced free-school abundance, differences in sizes and ages compared with free-school caught tuna and changes in school movement patterns.
- Increased difficulty of properly assessing the status of individual tuna populations.
- Overfishing of juvenile bigeye tuna in the WCPO.

It is likely that other impacts may be occurring but have yet to be researched and/or documented (Fonteneau 2003).

How Do FADs Affect Species Other Than Tuna?

FADs affect a wide variety of species other than tuna, many of which are caught as bycatch in tuna fisheries (Gilman 2011). These include sea turtles, sharks and many juvenile tuna that are not the targeted catch of the fishery (Gilman 2011).

Bycatch rates for FAD-associated and unassociated sets have been reported in the WCPO (Lawson 2001) and the EPO (Hall 1998). In the WCPO, tuna (other than skipjack, yellowfin and bigeye) were the most commonly caught bycatch species, representing close to 100 percent of the bycatch in both associated and unassociated sets (Table 1). The next most commonly caught bycatch groups were sharks in unassociated sets and other fish in associated sets. In the EPO, small fish were the most commonly caught bycatch species in both types of sets, followed by triggerfish in associated sets and yellowtail in unassociated sets.

What Management Options Exist for Limiting Negative Impacts of FADs on Juvenile Tuna?

Tuna are managed within the coastal waters of individual countries by their respective governments. However, on the high seas, areas that are beyond national jurisdiction, a series of regional fisheries management organizations (RFMOs) are responsible for the management of many tuna

TABLE 1. BYCATCH RATES in FAD-associated and unassociated sets in theWCPO and the EPO

WCPO (percentage based on number of individuals)		
Species/group	**FAD-associated**	**Unassociated**
Tuna	98.34	99.86
Sharks	0.20	0.05
Billfish	0.06	N/A
Tuna-like	0.13	0.03
Other fish	1.13	0.03
EPO (catch rates per 1000 tons of tuna)		
Species/group	**FAD-associated**	**Unassociated**
Small fish	7286.3	1091.5
Triggerfish	4774.6	N/A
Mahi-mahi	4722.7	193.8
Wahoo	2034.6	N/A
Yellowtail	N/A	553.8
Large fish	N/A	457.3

TABLE 2. FAD MANAGEMENT TECHNIQUES investigated and implemented by RFMOs or others (e.g., individual companies or fleets)

Management technique	Investigated					Implemented				
	IOTC	IATTC	ICCAT	WCPFC	Other	IOTC	IATTC	ICCAT	WCPFC	Other
Prohibit use of FADs	✗	✗	✓	✓	✗	✗	✗	✓ Past	✓ Present	✗
Restrict number of sets on FADs	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗
Restriction on number of FADs	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Marking FADs	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Alternative or restricted FAD design	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗
Schooling behavior avoidance	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗
Depth of FAD	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Size limits	✗	✓	✓	✗	✗	✗	✗	✓ Past	✗	✗
Catch limits	✗	✓	✗	✓	✗	✗	✓ Past	✗	✗	✗
Vessel efficiency controls	✓	✓	✗	✓	✗	✗	✓ Present	✗	✗	✗
Ban on discards	✗	✓	✗	✗	✓	✗	✓ Present	✗	✓ Present	✓ Present
Time and area closures	✓	✓	✓	✓	✓	✓ Past	✓ Present	✓ Present	✓ Present	✓ Present

species. FADs are most commonly used in the areas that fall under the management area of the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), the Indian Ocean Tuna Commission (IOTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT).

Many FAD management techniques and options have been investigated by RFMOs, and in some cases these techniques have been implemented (Table 2). For example, the WCPFC has required all member countries that fish on the high seas to submit plans that include strategies to limit the amount of juvenile bigeye and yellowfin tuna that are caught during fishing on FADs (WCPFC 2008).

The management techniques investigated by RFMOs and their findings, when available, are summarized below. In addition, a summary of their effectiveness, of impacts mitigated and of trade-offs can be found in Table 3 on page 9.

Prohibit Use of FADs

In the management context, prohibiting the use of FADs refers to measures such as prohibiting sets on FADs, prohibiting the deployment of FADS or both. This management technique aims to reduce overall fishing effort on FADs but does not always require the removal of FADs from the water, so fish continue to aggregate around FADs (Harley *et al.* 2009). The WCPFC determined that prohibiting the use of FADs may reduce fishing effort over the short term but may also cause fishermen to start using alternative methods, such as helicopter surveys, to increase their catches on free-swimming schools of tuna (WCPFC 2004). The WCPFC also found that FAD prohibition could have negative economic impacts on the tuna fleet in its region (WCPFC 2004). In addition, prohibiting FADs could lead to changes in the targeted species and negatively affect the purse seine fleet while positively affecting the longline fleet (WCPFC 2004). Furthermore, these types of restrictions would also require extensive aerial and maritime surveillance to monitor compliance, which could be difficult in areas that do not have 100 percent observer coverage (WCPFC 2004). However, purse seine vessels fishing in the WCPO between 20 degrees north and 20 degrees south latitude have been required to carry fishery observers as of Jan. 1, 2010 under Conservation and Management Measure (CMM) 2008-1 (WCPFC 2008). More information on the WCPO's prohibition of sets on FADs during time and area closures and their use of observers can be found in the time and area closure section that follows.

During the 2010 WCPFC meeting, the Forum Fisheries Agency, which consists of 17 Pacific Island nations and was developed to help these countries sustainably manage their fishery resources and act as an advisory body, proposed a prohibition on setting purse seine sets on schooling tuna found around whale sharks (Fisheries Forum Agency 2010) that is now part of the third arrangement of the Nauru Agreement (Parties to the Nauru Agreement 2010). ICCAT recommended a moratorium on FAD use in the Gulf of Guinea in 1998 (ICCAT 1999). This is discussed in more detail under the time and area closure section below.

Restrict Number of Sets on FADs

Restricting the number of sets fishermen are allowed to make on FADs or the number of FADs allowed per vessel (described below) are other types of effort control management systems. The WCPFC found that restricting the number of FADs each vessel deploys is difficult to monitor, because vessels sometimes share FADs, and vessels can find and use other vessels' FADs (WCPFC 2004). The IATTC looked into setting limits on FADs and floating objects but did not adopt the management measure (WCPFC 2009a).

Restrict Number of FADs Per Vessel

The WCPFC investigated restricting the number of FADs deployed per vessel and found that this restriction would require 100 percent observer coverage and other types of surveillance (WCPFC 2004). Purse seine vessels fishing in the WCPO are required, as of Jan. 1, 2010, to carry an observer, so this information could be easily collected. However, because of logistical issues related to training observers, it is generally thought that 100 percent observer coverage did not occur in 2010 (information on observer coverage rates achieved during 2010 are not yet available), and therefore priorities for data collected should be considered (Hampton 2009).

Marking FADs

The IATTC implemented a project in 2009 to help fishery observers identify individual FADs by applying tags with markings (IATTC 2008b). This type of measure would allow managers to keep track of the number of individual FADs being fished, providing some sort of measure of effort (WCPFC 2009a). Observers in the EPO collect information on the time and location of FAD sets, description and dimension of the FAD and its components, how the FAD was located and information on the ownership or origin of the FAD through the Flotsam Information Record program (WCPFC 2009a). Details of this project are to be reported at the 2011 meeting of the IATTC (IATTC 2010b).

In addition, some FAD marking specifications were originally proposed in CMM-2008-01 in the WCPO (WCPFC 2009a). These included permanently marking each FAD with 1) the name of the parent purse seine vessel, 2) its identification number, 3) a unique number for the FAD and 4) the date the FAD was first deployed (WCPFC 2009a). In 2009, the FFA requested that the WCPFC Secretariat undertake a feasibility study on the marking, identification and tracking of FADs (WCPFC 2009d). According to WCPFC 2009a, specific regulations for the marking of FADS have not yet been passed in the WCPO. However, the majority of CMMs in the WCPO have fishery management plans that contain FAD marking and identification guidelines, but specific details are mostly lacking in these guidelines (WCPFC 2009a). The WCPFC plans to continue investigating the feasibility of 1) marking and identification of FADs, 2) electronic monitoring of FADs and 3) registration and reporting of FAD position information by the RFMO (WCPFC 2009a; WCPFC 2010). The Parties to the Nauru Agreement (PNA), a group of eight Pacific Island countries that have an agreement on terms and conditions for tuna purse seine fishing licenses in the region, also plans to develop programs for FAD registration, monitoring and management, and will implement trials in 2012 (WCPFC 2010).

Alternatives and Restrictions to FAD Design

Alternative FAD designs that may reduce the presence of juvenile tunas and bycatch species and have been investigated (by companies, not RFMOs) include use of a different type of floating structure (cylinders made of polyethylene pipes and bamboo rafts) tested with different

TABLE 3. LIST OF MANAGEMENT OPTIONS, their effectiveness (yes, no or unknown) in regions where they have either been implemented or investigated, what impact of FAD use is mitigated through these measures and associated negative tradeoffs.

Management Option	Effective	Yes	No	Unk.	Purpose	Tradeoffs
Prohibit use of FADs	WCPO		✔		Effort control	Aerial and maritime surveillance and observer coverage needed, fishermen switching to alternative methods (e.g., helicopters), negative economic impact, changes in target species
	Atlantic	✔				
Restrictions on number of sets on FADs	WCPO		✔		Effort control	Difficult to monitor, observer coverage needed
	Atlantic		✔			
Restriction on number of FADs per vessel	WCPO			✔	Effort control	Difficult to monitor, observer coverage and other types of surveillance needed
Marking FADS	EPO	✔			Measure of effort	Observer coverage needed
Alternatives or restrictions on FAD design	EPO			✔	Reduce bycatch (tunas and others)	Loss of target catch, more expensive materials, difficult to use
	WCPO			✔		
Schooling behavior avoidance	EPO			✔	Reduce bycatch (tunas and others)	Difficult to monitor, loss of target catch, observer coverage needed
	WCPO			✔		
Restrictions on depth of FADs	EPO	✔			Reduce bycatch (tunas and others)	Difficult to monitor, loss of target catch, observer coverage needed
Size limits	EPO		✔		Reduce bycatch (tunas and others)	Difficult to monitor, loss of target catch, observer coverage needed
Catch limits	EPO		✔		Limit catch	Difficult to monitor, observer coverage, port sampling and vessel monitoring systems needed, compliance issues
	WCPO			✔		
Vessel efficiency controls	WCPO		✔		Effort control	High economic costs, difficult to monitor, observer coverage and port sampling needed
	EPO	✔				
	Indian Ocean		✔			
Ban on discards	EPO	✔			Limit total catches	Difficult to monitor, observer coverage needed, may not benefit all species
	WCPO	✔				
Time and area closures	Atlantic	✔			Effort control, limit catches	Difficult to monitor, observer coverage and vessel monitoring systems needed, redistribution of fishing effort to other areas or fisheries, fish targeted by other fleets, compliance issues, inappropriate closures, high economic costs
	WCPO			✔		
	Indian Ocean			✔		
	EPO		✔			

submerged structures (sailcloth, jute, semi-natural fabrics, ropes, agricultural netting and palm leaves), but the results have not been conclusive (Franco *et al.* 2009). Alternatively, fishermen could tag empty salt sacks to the hanging net of a drifting FAD to produce a shadow effect that deters fish from aggregating (Franco *et al.* 2009). It does not appear that these alternatives have been applied by any purse seine fleets because fishermen consider rectangular FADs the best in terms of catches, bamboo and nets are cheap materials, and the alternative designs have not been properly tested (Franco *et al.* 2009).

IATTC has investigated the use of sorting grids on purse seine vessels that have provided a variety of results. Sorting grids do not alter the FAD design but provide a way to reduce juvenile tuna catch and bycatch by creating an opening in the net that allows smaller fish to escape. A single rigid frame is too difficult to use, and flexible grids do allow tuna to escape, but how substantial these escapes are is not known (IATTC 2008b).

The IATTC will continue experiments with sorting grids from 2011 to 2013, subject to funding (IATTC 2010b).

The WCPFC has also investigated restricting the design of nets that can be used with FADs (WCPFC 2004). For example, Hasegawa *et al.* (2010) tested the large mesh size of the purse seine net to determine whether small bigeye could escape. They were unable to record any escapes from the net, probably because of the small school size of bigeye around the FADs.

In addition, French and Spanish purse seine fleets are attempting to develop "ecological FADs," which are biodegradable and therefore are not conducive to ghost fishing, which is fishing that continues on fishing gear that has been lost or abandoned (Dagorn 2010). Self-destructing FADs are also being tested in the EPO (IATTC 2008b).

Schooling Behavior and Avoidance Techniques

Information on the spatial distribution and biomass of fish aggregations around FADs is also needed for sustainable management of these fisheries (Doray *et al.* 2006), because the information could be used to reduce interactions between juvenile tunas and FADs. The IATTC previously identified the need to understand schooling behavior of species such as skipjack tunas around FADs in order to determine ways to catch them without catching other tuna and non-tuna species (Sibert *et al.* 2005). Ultrasonic telemetry and acoustic imaging are being tested in the EPO to determine whether fishermen can avoid capturing bigeye tuna (IATTC 2008b).

In the WCPO, researchers are investigating juvenile tuna catch mitigation measures (Hampton and Harley 2009). For example, tests on the effects of blinking flush lights on bigeye tuna behavior have been conducted (Hasegawa *et al.* 2010). The results indicated various reactions to light such as quick downward movement after the light stimulus stopped. Other research in the WCPO has shown that limiting FAD sets to daylight hours, which would reduce a large amount of bigeye tuna bycatch, would also significantly reduce skipjack and yellowfin tuna catch and therefore is not a viable alternative (Itano 2009). It is thought that if it were widespread, the practice of fishermen not setting on juvenile tuna could have a positive effect on tuna populations (Hampton and Harley 2009).

Restrictions on FAD Depth

In some areas of the EPO, research suggests that fishermen can reduce the capture of bigeye tuna by changing the depth of material hanging from drifting FADs, or the fishing depth (Itano 2005). These types of restrictions would require 100 percent observer coverage (Schaefer and Fuller 2002, 2005; Josse and Bertrand 2000), as occurs in the WCPO (WCPFC 2008). In addition, bigeye tuna have regular diurnal shifts in depth, which would make them still vulnerable to shallow nets (Schaefer and Fuller 2002, 2005; Josse *et al.* 2000).

Additional research near Papua New Guinea suggests a large degree of depth overlap in the early morning (when purse seining usually occurs) among skipjack, yellowfin and bigeye, indicating that targeting restrictions based on depth will not work (Leroy *et al.* 2010). However, research on Japanese purse seiners in the WCPO found that bigeye were not more likely to be caught at deeper FADs (Satoh *et al.* 2008). It has therefore been determined that this management measure would not be practical in the WCPO (Opnai 2002). The IATTC plans to investigate whether shortening the depth of the webbing hanging below the FAD would reduce bigeye bycatch (IATTC 2008b) but has previously not able to adopt the measure (WCPFC 2009a).

Size Limits

Some evidence suggests that fishermen can judge the size of fish in schools around FADs and that weight or length restrictions could be used to protect juvenile yellowfin and bigeye tuna (IOTC 2000). However, effective implementation of this type of measure is not thought possible (IOTC 2000). For example, the IATTC determined that size limits are ineffective unless the mortality of small fish is reduced in addition to catches (IATTC 1999a).

Bycatch Caps

Bycatch caps could be used to close purse seine fisheries on certain types of FADs once the limit is reached (Bromhead *et al.* 2003). This type of control has been used in the EPO to regulate purse seine sets on drifting FADs (IATTC 1998a; Bromhead *et al.* 2003) but is no longer used because of compliance problems and because analysis showed the closures were triggered only during years when there were more fish in the area as a result of migration or abundant offspring (WCPFC 2004). However, with the addition of observer coverage and advances in technology, this type of control may be useful in the future.

The WCPFC investigated the use of trigger catch limits to prohibit FAD use, in which, for example, a specified amount of juvenile tuna catch triggers a prohibition (WCPFC 2004). Such a restriction would be dependent on excellent monitoring of landings, which is often challenging, as well as observer and vessel monitoring coverage (WCPFC 2004), which is now available in the WCPO (WCPFC 2008).

Vessel Efficiency Controls

Vessel efficiency controls (*e.g.*, limiting main engine size, power block size or hydraulic power or reducing search power by restricting the use of helicopters and support vessels or electronics), which can be used to reduce fishing effort on FADs, are often associated with high economic costs to the fishery (Itano 2005). Itano suggests that a combination of input controls (e.g., catch limits) and technical measures focusing on FADs would provide the best management solution.
In addition to being costly to the fleet, vessel efficiency restrictions are difficult to monitor. One of the WCPFC CMM's goals is to reduce bigeye tuna mortality by the purse seine fleets (Hampton 2010). However, because bigeye represent only a small percentage of the total tuna catch (less than five percent), effort control management measures cannot concurrently reduce catches of skipjack if they are to be accepted by industry, and thus it is believed that capacity controls will not work in this region (Hampton 2010). However, restricting the use of tender and supply vessels can be enforced and is in use in the IATTC (IATTC 1999b; Itano 2005). Restricting at-sea transshipments has also been shown to be successful in reducing vessel efficiency without being expensive or difficult to monitor and is used (IATTC 1999b; Itano 2005).

The use of supply vessels supporting FAD fishing was banned in the EPO in 1999 (IATTC 1999b). The IATTC also recommended at this time that parties should prohibit transshipments of tuna by purse seine vessels fishing for tunas in the EPO (unless at port) (IATTC 1999b). Another option would be to require vessels to remain at dock (known as a tie-up period) for a certain amount of time between trips. This has also been implemented in some areas, although specifics are not available (Itano 2005). The Indian Ocean Tuna Commission (IOTC) investigated the impacts of using trip and vessel limits to reduce mortality on juvenile yellowfin and bigeye tuna. They determined that trip limits would result in only a minimal reduction in the number of sets made on FADs (IOTC 2003) and that placing a limit on the number of vessels allowed to fish in a particular fishery does not reduce FAD use (WCPFC 2004). It appears that there are regional differences that affect the success of vessel efficiency controls.

Ban on Discards

The WCPFC requires 100 percent observer coverage to make sure fishermen retain on board all bigeye, skipjack and yellowfin tuna (WCPFC 2008). This measure was implemented to create a disincentive for fishermen to capture small fish and to help encourage technologies and fishing strategies to avoid the capture of small bigeye and yellowfin tuna (WCPFC 2008). A ban on discards has also been implemented in the Atlantic (ICCAT 2008) and EPO (IATTC 2006).

Research/Market Incentives

More research into what attracts tunas to FADs could aid in developing ways to reduce unwanted interactions, such as adding olfactory, auditory or magnetic cues, (Dempster and Taquet 2004) or restricting the use of chum, oil or bait, or using artificial lights (Bromhead *et al.* 2003; Itano 2005). Restrictions on the time of day that sets are allowed to be made (specifically after sunrise) could also significantly reduce catches of skipjack and yellowfin tuna (Itano 2005).

The International Seafood Sustainability Foundation is currently researching, on a global scale, bigeye bycatch mitigation measures (Hampton 2010). These include creating incentives for bigeye tuna avoidance, encouraging fishermen to select FADs with lower numbers of bigeye (Hampton 2010).

Market incentives that encourage industry shift from FAD-based to free-school-based fishing may also be an effective option (Hampton 2010). Such incentives could include certification for free-school catches that would make those fish worth a premium at market (Hampton 2010). Electronic monitoring of FADs is another option, but currently no RFMO has the ability to do this (WCPFC 2009a). It is likely that effective management measures will vary by region and fishery and unlikely that one measure will solve the issues (Bromhead *et al.* 2003).

Time and Area Closures

Time and area closures have been the most widely and effectively used FAD management measure (Bromhead *et al.* 2003; Itano 2005). Simulation modeling suggests that closures can decrease fishing mortality and catch and bycatch of juvenile tunas and can improve spawning success (Bromhead *et al.* 2003). However, fish populations do not always improve because other surface fleets may target them instead, fishing effort may be redistributed or the actual closures may be inappropriate (Bromhead *et al.* 2003). For example, in the Atlantic Ocean, fishing effort was redistributed to vessels in fleets that were not participating in the closure, and to areas that were not closed to FAD fishing (Bromhead *et al.* 2003). It is important that RFMOs have a solid knowledge of all the fishing gears used in a region to determine whether a time and area closure on FADs or fishing altogether is a better option (Bromhead *et al.* 2003).

It was initially thought that using time and area closures to prohibit FAD sets in the WCPO would result in a better cost-to-benefit ratio for the purse seine fleet compared with a full closure. This is because closures can be based on when catches of target species are highest (WCPFC 2004). The WCPFC determined that time and area restrictions in its region would need to be very large and would probably result in a high economic cost to the fleets (WCPFC 2004). However, the FAD closure in the WCPO is the only closure that targets bigeye tuna (a species of concern for the WCPFC), because few bigeye are taken during sets made on free-swimming schools (Hampton 2010).

The PNA recently instituted a prohibition on purse seine sets on floating objects in the high seas of the WCPO (20 degrees north and 20 degrees south latitude) from July 1 to Sept. 30, 2010, and required all purse seine vessels to carry an observer during this closure (WCPFC 2008; Hampton 2010; PNA 2010). During the closure, fishermen are not permitted to make a set within one nautical mile of a FAD and may not use their vessels to aggregate fish. FADs are not to be retrieved by a vessel, unless one of several conditions is met: 1) they are kept on board until the end of the closure, 2) the vessel does not conduct any sets for seven days after retrieval or 3) the vessel is outside a 50-mile radius of the point of retrieval of any FAD. In addition, vessels may not work together to aggregate fish (WCPFC 2009c). However, fishermen are not required to remove FADs from the water before the closure, because it was determined that there were too many anchored FADs and it would be “impossible to remove for a short-term closure” (Harley *et al.* 2009).

Juvenile bigeye tuna mortality was anticipated to be lessened because of this closure, but fishermen will still be allowed to fish on free-swimming schools. However, this is a more costly type of fishing, so there was opposition to the closure from within the industry (Hampton 2010). Initial analysis of closure (there was an initial two-month closure in 2009) showed a higher-than-average number of FAD sets during the open season, making the percentage of FAD sets in 2009 the highest since 2005. This indicates that bigeye bycatch (a main issue of the WCPFC) will remain high unless other measures that reduce bycatch are also implemented during the open season (Hampton 2010). Almost all of the FAD-associated set effort was reallocated to free-swimming school sets during the closure, in addition to increased noncompliance issues (Harley *et al.* 2010). The analyses indicated that the FAD closure did not offset the increase in purse seine catch that occurred between 2001 and 2004 (Hampton and Harley 2009). This means there probably will be only small reductions in fishing mortality of bigeye and yellowfin tunas (Hampton and Harley 2009).

In 1998, ICCAT recommended a periodic restriction on the use of FADs in the Atlantic (Gulf of Guinea). The closure effectively reduced fishing mortality on bigeye tuna when fleets complied with the closure, but there is some evidence that catches by nonparticipating fleets increased and that effort shifted to non-closed regions (Bromhead *et al.* 2003; ICCAT 2005) and to free-swimming schools (ICCAT 2005). Analysis of fishery observer data from the 2002-03 and 2003-04 closures showed that catches of juvenile tuna declined and that the presence of observers deterred vessels from fishing on FADs during the closure (ICCAT 2004, 2005). However, these analyses could not determine whether vessels without observers fished on FADs during the closure (ICCAT 2005).

A separate analysis conducted on a previous voluntary ICCAT FAD moratorium (1997-98) found reductions in catch (Gaertner *et al.* 2000) but also showed that a redistribution of the French and Spanish fleets occurred, as did the proportion of sets made on logs (Goujon and Labqaisse-Bodilis 2000). Artiz *et al.* (2001) did not find a significant change in the species or size composition of the Spanish fleet catches resulting from the closures (1997, 1998 and 1999). They found that small (less than 3.2 kg) yellowfin and bigeye tuna made up a high percentage of the catch and that there was a reduction in partial fishing mortality of juvenile bigeye tuna (Goujon and Labqaisse-Bodilis 2000; Ariz *et al.* 2001). However, the reduction in catches of small bigeye tuna that resulted from the closure was offset by increased catches by other fleets, some of which fished on drifting FADs during the closure, and it is speculated that even with perfect compliance, the closure would not have improved the status of the bigeye population (Bromhead *et al.* 2003).

In 2005, a substitute time and area closure was adopted that closed fishing to purse seine vessels in a smaller subregion of the original closure for one month (ICCAT 2006). However, in 2009, a larger and longer time and area closure was implemented that prohibited FAD use (ICCAT 2008). Analysis of this closure is not yet available, but the recommendation also calls for analysis of data to determine an effective restricted area that would reduce the catch of juvenile bigeye and yellowfin tuna and prevent overfishing (ICCAT 2008; WCPFC 2009a).

A time and area closure was instituted in the Indian Ocean during 1999, and analyses from fisheries observers indicated a redistribution of fishing effort to other areas outside the closure as well as a shift in fish mortality from FADs to free-swimming schools (Arrizabalaga *et al.* 2001). It was also determined that this closure did not adequately match the core area for log fishing during the selected closed time period and therefore the true effect of the closure was difficult to determine (Gaertner and Marsac 2000).

The IATTC also looked at using time and area restrictions on FADs and found that it was difficult to predict times and areas for high catches of tunas. In addition, Harley and Suter (2007) determined that a three-month closure that covered the equatorial region of the EPO could reduce bigeye catches by 11.5 percent but would also reduce skipjack tuna catches by 4.3 percent. They concluded that a much larger or longer closure would be necessary and that research should focus on the use of gear technology to reduce bigeye bycatch. The IATTC now relies on time and area closures applied to the entire purse seine fleet, not just for FAD fishing (WCPFC 2004; IATTC 2010b). It has also been suggested that time and area closures for FAD use may be less effective in areas with no clear seasonal trends in FAD fishing, such as the EPO (Bromhead *et al.* 2003).

Conclusion

Fish aggregating devices can negatively impact tuna populations. Many management methods exist that have the potential to reduce the negative impacts of FADs on tuna. However, many of the methods, while effective at times, come with trade-offs that must be evaluated.

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Dr. Alexia Morgan began her career in marine sciences in 1998, spending several months working in the Bahamas assisting on lemon shark research projects. Shortly after, Alexia started her master's work at Nova Southeastern University, analyzing current shark management measures in U.S. fisheries. Alexia then worked as a fisheries observer in the California drift gillnet and the southeast bottom longline fisheries before going back to school for her Ph.D. at the University of Florida, where her dissertation research focused on population assessment of dusky sharks in the northwestern Atlantic Ocean. While completing her doctoral degree, she continued to coordinate the U.S. bottom longline fishery observer program and conduct research on the mortality of sharks associated with longline capture. She is currently an independent fisheries researcher.

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