A Review of the impact of fish aggregating devices (FADs) on tuna fisheries

Final Report to Fisheries Resources Research Fund

Don Bromhead, Jennifer Foster, Rachel Attard, James Findlay, John Kalish
# Executive summary

**Tropical tuna show a natural behavioural tendency to aggregate around floating objects**
Tropical and subtropical tuna species, such as yellowfin, bigeye and skipjack tunas, show a natural behavioural tendency to associate to floating objects (e.g. logs). This behaviour is particularly apparent for smaller or juvenile tunas. The reasons why these species have evolved such a behavioural trait is currently unknown. However, it may be that they use floating objects as meeting points, a spatial reference point or feeding points.

**Fishermen exploit this behaviour using artificial floating objects or Fish Aggregating Devices (FADs)**
This behavioural tendency of tuna and other fish species was noticed by early 17th century artisanal fishermen, who would construct artificial floating objects and use them to attract and aggregate fish for easier capture. Oceanic purse seine fleets noted the success and efficiency of this method, and after a period of setting around logs and debris, started deploying huge numbers of drifting fish aggregating devices (FADs) to help them target tropical tunas. These devices are now widely distributed throughout the world’s tropical and subtropical oceans.

**Technological advances in FAD design have increased fishing efficiency**
Since the first deployments of drifting FADs, there has been a rapid technological advance in their design, resulting in increased fishing efficiency. Drifting FADs now employ satellite beacons to enable fast location, and sonar to monitor the presence and size of tuna aggregations beneath them. Small supply vessels often help the main purse seiner to deploy and monitor FADs.

**FADs have contributed to increasing global tuna catches**
Global catches of yellowfin, skipjack and bigeye tuna have been steadily increasing during the past 50 years, peaking at just over 3.5 million tonnes in 1998. Almost a third of this was caught by purse seiners using FADs, demonstrating that a significant proportion of the increase in catch since the late 1980s is due to the increasingly widespread use of FADs.

**FADs have resulted in increased catches of skipjack and juvenile bigeye and yellowfin tunas**
A large proportion of FAD caught tuna comprises smaller size classes, consisting of skipjack and juvenile yellowfin and bigeye. These size classes were not exploited to the same extent prior to introduction of FADs. Despite the smaller size of tuna caught, FADs fishing has increased due to the greater set success (percentage of sets which successfully capture a school of tuna) and greater yield per set gained from this method, relative to purse seine catches on free schooling tuna.

**Vulnerability to FAD fishing varies with species, size and age**
Skipjack tuna inhabit surface waters at all stages of their life, and as such are vulnerable to FADs based fisheries throughout their life. Yellowfin and bigeye tuna appear primarily vulnerable to FAD fishing during
juvenile stages, although larger adults are also caught by this method. Adult bigeye are predominantly targeted by longline fisheries.

**FADs contribute substantially to overfishing risks**

The intensive use of FADs to remove large numbers of small sized tuna has two main implications for tuna fisheries and their managers. Firstly, the targeting of juvenile tunas of yellowfin and bigeye under FADs has led to concerns that this fishing practice may substantially increase the risk of recruitment overfishing of these species, particularly in light of declining catch rates for longliners targeting adult bigeye. Similarly, it is believed that FADs may have contributed to growth overfishing of skipjack tuna in some areas (e.g. tropical east Atlantic Ocean) and may have the same effect in other ocean regions in the future.

**FAD fishing takes significant levels of bycatch**

FAD fishing has been conservatively estimated to account for over 100 000 tonnes of global bycatch annually. Bycatch on FAD sets makes up approximately 10% of catch per set (compared to 1-2% on free-school sets) and comprises both undersized tuna and a wide variety of pelagic non-tuna species. Most commonly these include dolphin fish, billfish, wahoo, triggerfish, barracuda, rainbow runners, sharks and turtles. There is some concern over the level of bycatch taken by this fishery, particularly in regard to effects on local abundance of particular species such as turtles.

**FADs may “trap” tuna in unproductive regions**

Concern has also been raised over the possibility that FADs may act to “trap” tuna in unproductive regions and impact negatively on tuna growth, condition and biological productivity. However, despite supporting evidence, this theory requires more research.

**Time-area closures are the predominant method used to limit impacts of FAD fisheries**

There is a common consensus globally that current catch levels for some tuna species are unsustainable and that the use of FADs needs to be more tightly controlled. The various international tuna commissions have considered and in some cases implemented a range of management measures to reduce catches of juvenile bigeye and yellowfin tuna by FAD fishing. These options include the use of quotas, time-area closures, size limits, and discarding bans. They have also considered restricting transhipment of tuna, use of supply vessels, number of sets on FADs, depth of nets, number of FADs, and fishing on seamounts. Of all these measures, time-area closures of FAD fisheries have been considered the most effective option and have been widely adopted in the Indian, Atlantic and Eastern Pacific Oceans.

**Effectiveness of time-area closures is uncertain**

Time area closures in the Atlantic Ocean have resulted in significantly reduced catches of juvenile bigeye and yellowfin by the participating fleets, but unfortunately this was offset by increased catches by non-
A Review of the Impact of FADs on Tuna Fisheries

participating fleets, and shifted effort to non-moratoria regions. While it is uncertain if these moratoria had a positive effect on bigeye tuna stocks, it is believed that their status would have been substantially worse if the moratoria had not been applied. Indian Ocean moratoria have been criticised as being inappropriate in time and area used.

Management of FAD-based fisheries will need to be assessed on a regional basis

Careful consideration needs be given in planning of moratoria times and areas and compliance to ensure beneficial effects on tuna stocks. Moratoria may be less effective in areas where there is no clear seasonal pattern in fishing with FADs, as noted for the Eastern Pacific Ocean. It is unlikely that time-area moratoria alone will prove sufficient to manage FAD fisheries in a sustainable manner. Depending on spatial and temporal nature of regional fisheries, other measures such as trigger catch limits, transhipment bans and discard bans may also be implemented, either separately or simultaneously.

Ocean wide FAD fisheries may have implications for Australia’s domestic longline fisheries

Australia does not as yet have a FAD based purse seine fishery. However, the widespread use of FADs by other countries operating in the Indian and Pacific Oceans has led to concerns over the escalating removal of juvenile bigeye and yellowfin tuna from stocks and the potential impact of this on Australia’s longline fisheries which target adults of these species.

Degree of local impact uncertain due to uncertainties over stock structure

Assessing the implications of FAD based fisheries upon Australia’s longline access to bigeye and yellowfin tuna resources is complicated by the fact that the stock structure of these species is uncertain in both the Indian and Pacific Oceans. If localised populations exist, then impact of oceanwide FAD fisheries will be reduced. However, if single, rapidly mixing stocks exist in each of the Indian and Pacific Oceans, then increasing catches of juveniles by FAD based fisheries will likely reduce domestic longline access to these resources. This situation highlights the urgent need for further research to delineate stock structure. A precautionary approach would be to advocate the use of restrictive management measures (such as time-area closures) to reduce juvenile bigeye and yellowfin catches by FAD-based fisheries.
A Review of the Impact of FADs on Tuna Fisheries

Contents

Executive Summary 2
Contents 5
Acknowledgements 7
1. Introduction 8
   1.1 Purpose 8
   1.2 Related studies 8
   1.3 Report structure 8
   1.4 Information sources 8
2. Fish aggregating devices: technology and methods 9
   2.1 Introduction 9
   2.2 Types of FAD 10
   2.3 Purse seining 12
   2.4 Drifting FAD design 15
   2.5 Summary and conclusions 20
3. Review of the biological features of tuna relevant to FAD fisheries 21
   3.1 Introduction 21
   3.2 Basic biological features of yellowfin, skipjack and bigeye tuna 21
   3.3 Thermoregulation 22
   3.4 Behaviour 24
   3.5 Summary and conclusions 28
4. The effect of FADs upon tuna behaviour and ecology 29
   4.1 Introduction 29
   4.2 Types of behavioural association exhibited by tunas 30
   4.3 Why do tuna associate to floating objects 31
   4.4 Effect of FADs on tuna schooling behaviour 34
   4.5 Effect of FADs on tuna feeding behaviour and diet 36
   4.6 Impact of FADs on tuna migration and movements 38
   4.7 Discussion of ecological impacts 41
   4.8 Summary and conclusions 42
5. Global catch statistics for yellowfin, skipjack and bigeye tuna 43
   5.1 Introduction 43
   5.2 Data source and quality 43
Acknowledgements

This report was made possible through the financial support of the Fisheries Resources Research Fund, which is administered by the Department of Agriculture, Fisheries and Forestry – Australia.

The following individuals and organisations have kindly provided their time and resources in processing data and expert knowledge and reviews, enabling the production of this report. We would like to acknowledge and thank them for their valuable contribution. They are Phil Sahlqvist, Brent Wise, Albert Caton, Benj Whitworth and Geoff Williams, all of BRS. Also to staff of the Indian Ocean Tuna Commission (IOTC), Secretariat of the Pacific Community (SPC), Inter-American Tropical Tuna Commission (IATTC), and the International Commission for the Conservation of Atlantic Tunas (ICCAT) for provision of catch data. Also to Alain Fonteneau (Institut de recherché pour le developpement) for advice pertaining to FAD fisheries.
A Review of the Impact of FADs on Tuna Fisheries

1. Introduction

1.1 Purpose

This report has been produced in response to concern expressed by local fisheries organisations over the removal of escalating numbers of juvenile bigeye from Indian Ocean stocks and the possibility that this may reduce future adult bigeye resources available to Australian longliners. The Australian longline fishery for adult bigeye tuna in the Indian Ocean has been expanding rapidly in recent years. At the same time, the foreign owned distant water tuna fisheries using fish aggregating devices (FADs) have also rapidly grown, and the catch of juvenile bigeye by these fleets has increased to unprecedented levels. The purpose of this report is to review relevant information on the biology and ecology of the three main tropical tuna species caught under FADs (bigeye, yellowfin and skipjack), how FADs impact upon their biological characteristics, and how the use of FADs in oceans adjacent to Australia are likely to impact upon the stocks exploited by Australian fishing fleets.

1.2 Related studies

Le Gall et al. (2000) “Tuna fishing and fish aggregating devices”


1.3 Report Structure

This report is divided into 7 chapters, which can be collectively grouped into 4 subject areas: FAD technology, ecological impacts, fisheries impacts, and management. The first chapter details FAD technology and global distribution. This is followed by chapters describing the natural biological and ecological characteristics of the tunas and how these change or are effected by the presence of FADs in their environment. These are followed by chapters detailing global tuna fishery catch statistics, and the potential effects of FADs-based fishing upon the stocks, fisheries sustainability and upon status of tuna resources currently exploited by Australian longline fisheries. The final section details current management and regulations pertaining to FADs.

1.4 Information Sources

This report involved the compilation of information from a variety of sources. These include papers presented at meetings and conferences, unpublished information, papers from scientific journals and books, magazine and online sources, as well as input from a number of experts in the topics being discussed (such as scientists and fishery managers and advisors). It should be noted that the literature review was limited, in the main, to articles written in English, however there is considerable information on FADs and tuna written in Japanese, and to a lesser extent in French. In some cases, attempts were made to translate these articles. However, most of these articles are not considered in the current review.
2 Fish aggregating devices: technology and methods

2.1 Introduction

The idea for the use of artificial logs or fish aggregating devices (FADs) originated over a century ago from artisanal fishermen in Mediterranean and Southeast Asia, and in the western and central Pacific (Higashi, 1994). They noted that tuna and other pelagic species tended to aggregate under natural floating objects such as logs, seaweed mats, branches and palm leaves, and that fishing success was greater near these objects than in the open ocean (Hallier, 1990; Higashi, 1994). When such objects were sparse or non-existent, fishermen would deploy their own artificial logs (Atapattu, 1991). In general these would be anchored, to allow easy location and continuous fishing effort on consecutive days. Oceanic purse seine fishing fleets noted the success of this method, and after a period of setting nets around logs and debris, started deploying large numbers of drifting fish aggregating devices (FADs). These devices are now widely distributed throughout the world’s tropical and subtropical oceans (Fonteneau et al. 2000) (Figure 2.1).

Bergstrom (1983) defined fish aggregating devices as “any method, object or construction used for the purpose of facilitating the harvesting of fish by attracting and thus aggregating them”. For fishermen, the benefits of this fishing method extend past that of increased catches, to reduced fuel consumption and travel time and increased safety (Anon., 1982; Anon.,1996). In addition, sport fishing and diving accessibility to concentrations of fish may be enhanced, with the potential transformation of non-productive fishing areas into productive ones (Polovina, 1991a; Garcia et al. 1999; Kingsford, 1999). The current chapter focuses predominantly on drifting FADs as they account for the majority of FAD-caught tuna (around 1 million tons per year worldwide) (Fonteneau et al. 2000). However, it should be noted that the amount of tuna caught under anchored FADs is significant, but due to the artisanal nature of most anchored FAD fisheries, reliable catch data are unavailable.

Since the first FAD deployments by western fleets, a rapid evolution of drifting FAD based fishing technology has occurred. While the advent of FADs has been generally accepted as having increased the catch rates (catch per unit fishing effort or CPUE) of purse seiners, the

Figure 2.1 – Distribution of drifting FAD based purse seine fisheries (red highlight) throughout tropical and subtropical waters of the Indian, Pacific and Atlantic Oceans.
contribution of each of the FAD related innovations to this trend has yet to be assessed. Initially, FADs were deployed with radio beacons, which were later superseded by satellite beacons for fast location. Purse seiners then employed smaller and faster supply vessels that could quickly locate and check FADs for tuna aggregations, and relay information back to the main vessel. More recently, FADs have been deployed with sonobuoys that allow real-time estimates of tuna aggregations, which can be relayed back to the purse seine vessel. While it is widely believed that these technological advances have increased the efficiency and catch rate of tunas over the past 20 years, there is little empirical evidence as yet to show that this is so. The following chapter details the types of FADs currently used, their distribution, and the technological advances that may have contributed to currently increasing exploitation rates.

2.2 Types of FAD

Fish aggregating devices (FADs) can be classified into three main groups, each of which meet Bergstroms (1983) definition of a FAD (see Introduction). These are the surface, mid-water and bottom FADs (Prado, 1991). This report only deals with surface FADs, which can be further divided into drifting (deepwater), permanent anchored (shallow and deepwater) and transferable classes (Prado, 1991). Anchored FADs are most common in near coastal and island regions, and are used by both professional and recreational fishermen. Transferable FADs are movable objects that can be used by artisanal fisheries to lure fish into nets, but which can then be removed from the water during non-fishing seasons or to protect them from rough weather. Drifting FADs are predominantly used by large industrial purse seine fisheries (Prado, 1991). The designs of anchored and drifting FADs differ considerably. Anchored FADs require high strength mooring structures, and drifting FADs are equipped with sonar and satellite transmission equipment to allow easy location and remote determination of the presence and size of aggregations underneath them. However, it should be noted that fishermen often keep many of the FAD design features secret, in an effort to maintain a competitive advantage (Fonteneau et al. 2000). The following is a basic overview of FAD types and designs.

2.2.1 Anchored FADs

History: Anchored FADs all comprise the same basic components; a float, a mooring line, an anchor and an underwater structure or attractant (Malig et al. 1991) (Figure 2.2). The original anchored FADs were first recorded from Malta in the Mediterranean in the 17th century (Desurmont and Chapman, 2000). Fishermen in the Philippines and Indonesia also started to use these devices in the early 1900s (Prado, 1991; Anon., 1996). In both cases, these traditional style FADs used all natural materials, such as bamboo for the floating raft, natural fibres for the mooring line, palm fronds as the underwater attractants, and baskets of stones as the anchor (Aprieto, 1991; Malig et al. 1991; Anon., 1996). These early FADs were generally anchored in relatively shallow waters (Prado, 1991). Today, such structures are still being employed by island countries to give their small-scale fisheries access to pelagic resources (Reynal et al. 2000).

However, the last few decades have seen nearly all aspects of anchored FADs design undergo considerable technological change. “Backyard” constructed FADs use various recycled materials such as tyres (floats), cement blocks or engine blocks (anchors), and logs and bamboo tied together by synthetic ropes (Atapattu, 1991; Aprieto, 1991). Commercially made modern FADs can now be anchored in waters of over 2000m deep, are constructed of steel, aluminium and fibreglass, are equipped with locating devices, and can be expected to last up to 5 years (Anon., 1996).
A Review of the Impact of FADs on Tuna Fisheries

A. Modern anchored FAD

B. Modern drifting FAD

Figure 2.2 – Schematics of two different types of FAD: A) Modern anchored FADs, and B) Modern drifting FADs.

**Commercial designs:** The constant evolution of FAD design is forced by the extreme conditions that these structures often have to endure, including strong currents, storms, and chemical processes such as oxidation and electrolysis (Anon., 1988). Thus design requirements include strength, buoyancy, stability, visibility and low drag, while at the same time allowing ease of construction, deployment and economic feasibility. Vandalism and theft, which are common in many FAD-based fishing industries, have also resulted in design changes aimed at making FADs more secure (Aprieto, 1991). The need to locate these structures easily has also played a role. Consequently, all four basic components of the anchored FAD have undergone considerable advancement when compared to the traditional FADs.

**Floats:** The floating section of anchored FADs varies considerably, but generally comprises large steel containers filled with polyurethane foam (Matsumoto et al. 1981), held together within a metal framework. On top of this are multiple reflectors and a battery or solar powered flashing light that is triggered by a light sensitive switch (Higashi, 1994; Holland et al. 2000). These features act as navigational aids for visual location, during day or night and in rough weather conditions.

**Moorings and attractants:** The mooring line is generally composed of galvanised chain and polypropylene sections, which may have weights and floats which act to allow some slack in the mooring line under calm conditions, without the line floating to the surface and potentially tangling with vessels (Higashi, 1994). Swivels are also used to prevent twisting based wear on the lines. The upper lengths of these lines are often reinforced to prevent vandalism and theft of FADs (Aprieto, 1991). Mid-water aggregating structures are generally fixed to the mooring line. The designs of these vary but are often composed of netting, streamers and ropes.
A Review of the Impact of FADs on Tuna Fisheries

(Matsumoto et al. 1981; Malig et al. 1991). The mooring lines are attached to an anchor, which in deepwater FADs can weigh over 2.5 tonnes (Higashi, 1994). Overall, FADs are designed to flex with the swell and to submerge under strong currents without the flotation being damaged. Submerging in these situations reduces the tension on the mooring lines and anchor (Anon., 1988). FAD placement also depends on target species and its abundance. (Prado, 1991; Lennert-Cody and Hall, 2000).

The majority of anchored FAD-based purse seine fisheries operate in the western Pacific (Fonteneau et al. 2000; Sibisopere, 2000). Large quantities of fish are taken in the Philippines and Indonesia by this method. Other non purse seine anchored FAD fisheries exist in the central Pacific (Matsumoto et al. 1981; Holland et al. 2000), the Caribbean (Prado, 1991) and off tropical east and west Africa (Prado, 1991), off Japan (Kakuma, 2000b) and in the Mediterranean (D'Anna et al. 1999). Anchored FADs are put in place not only for commercial fisheries but often for sports and recreational fishing as well (Anonymous 1988).

Of relevance to Australian fishing interests is the growth of the anchored FAD industry in the Eastern Indian and Western Pacific Oceans. Countries in these regions have deployed thousands of these devices, with most, but not all targeting tuna (Desurmont and Chapman, 2000).

2.2.2 Drifting FADs

Similar to the development of the anchored FAD fisheries around the world, the development of artificial drifting FADs has been accompanied by rapid advances in technology. Purse seiners are the predominant fishing sector using drifting FADs. The use of artificial drifting FADs has been accompanied by a rapid evolution of the associated FAD technology and fishing techniques, each of which have been assumed to contribute to the increase in the efficiency of this fishing method. The degree to which fishing efficiency has increased has yet to be determined.

Initially, purse seiners fished off natural floating objects (such as logs), but then started tying radio beacons to these for ease of tracking. Later, artificially constructed FADs were deployed to which radio or satellite beacons were added, along with radar reflectors and flashing lights as navigational aids (Suzuki, 1999). Supply vessels were then employed to monitor the FADs and sonobuoys attached to signal the presence and size of tuna aggregations beneath (Fonteneau, 2000).

Each of these steps is commonly believed to have increased the catch rates or catch per unit effort (CPUE), allowing greater overall catch returns. However, there has been very little empirical evidence gathered to support these assumptions. This fact has been noted by various tuna organisations (IOTC, IATTC) and the assessment of the effect of various FAD innovations and methods has been given high priority, under the auspices of projects such as ESTHER (Efficiency of the Tuna Purse Seiners and Effective Efforts) run by scientists from France and Spain (Gaertner and Pallares, 2001).

The following sections describe the various innovations that have been used since the introduction of artificial drifting FADs, starting with a basic outline of purse seining and moving through the progressive evolution of drifting FAD technology.

2.3 Purse Seining

Purse seining was developed as a means to entrap and harvest entire schools of fish. The process involves surrounding the fish with a net, impounding them by pursing the lower edge of the net, then drawing up the net to reduce the volume, and condense the tuna such that they can be brailed or pumped out (Ben-Yami, 1994). This process is described in more detail in the next section on purse seining on floating objects. The success of a purse seine set depends
Figure 2.3 – Purse seiner leaving port loaded with purse seine nets and FADs. (Photos: J.Kalish, Bureau of Rural Sciences)
on the size of the fish school compared to the size of the net, as well as the distance at which the tuna can detect the net or are affected by its presence. Environmental conditions such as wind, current, thermocline depth and turbidity also play a role in set success, as do the characteristics of the vessel and the net itself (Ben-Yami, 1994). Before FADs became predominant, purse seining was commonly used to catch free-swimming schools of tuna. Sets on unassociated (free-swimming) tuna schools are executed at all times of day, as opposed to FAD sets that generally occur just prior to sunrise (Sakagawa, 2000). Unassociated sets tend to catch larger tuna, fewer juveniles and the species composition tends to differ (i.e.; more yellowfin than in many areas) (Sakagawa, 2000).

The purse seine nets vary considerably in design, and can differ between fleets. One of the most important characteristics is the depth of nets, as this has implications for the species composition of the catch, especially when setting on multi species aggregations or schools. Even very small vessels can carry reduced size purse seine nets (e.g. 100m long) and there is considerable variation in the size of industrial nets used by the commercial "super-seiners" (Ben-Yami, 1994).

American oceanic super-seiners use nylon seines that are around 1800m long and 260m deep. Japanese super-seiner tuna nets are generally around 1600m long and 300m deep. Other fleets nets can fish as deep as 400m and are more likely to catch a higher proportion of larger deeper swimming tuna, such as bigeye tuna.

2.3.1 Purse seiners setting on floating objects.

The following description of a typical purse seine set on a natural floating object applies equally to methods used on FADs, and was developed from the original methods used to set on free-schooling tuna. In general the process is in four parts: location, tracking/approach, setting, and hauling. Natural floating objects are generally located by sight or by bird radar the day before the set is to be made (Ariz Telleria et al. 1999). The object is then evaluated for tuna aggregations using sonar to determine size and species (Ariz Telleria et al. 1999). This process may be done by a smaller support vessel launched off the purse seiner. A radio beacon may be attached to the log in order to allow the vessel to search the surrounding region for other objects, without losing track of the first one (Moron et al. 2001). Alternatively the vessel may drift overnight with the object in order to be in position to set early the next morning (Sakagawa, 2000). Setting on tuna just prior to sunrise is done for two main reasons. Firstly, some tuna species rise from deeper water at this time, and secondly, they are unable to see the net in the darkness and are much less likely to be alarmed and escape (Hampton and Bailey, 1999). Special underwater attractant lights may be used to encourage tuna and prey aggregation. Prior to the set being made, a support vessel with lights may be used to take over the light attracting task of the seiner, while the main vessel positions itself away from the object which will be the centre of the set (Ariz Telleria et al. 1999; Sakagawa, 2000). An auxiliary skiff is then launched which carries one end of the net, and the boat begins to circle. Once the circling is complete, the purse line can be drawn, and then the net hauled to concentrate the fish for easier capture and transfer aboard (Ariz Telleria et al. 1999). Before recovering the net the floating object is tied to the support vessel and carefully towed out of the circle. Depending on the catch and the remaining fish underneath, the captain may then decide to abandon the object, leave a beacon and come back later, or remain and keep fishing under the object (Ariz Telleria et al. 1999).

Decision making in relation to sets on natural floating objects are effected by the size of the log and the number of logs in the area (Hampton and Bailey, 1999). Most fishermen believe from experience that larger logs accumulate more tuna, and that the more objects there are in a region, the fewer tuna likely to be under any single log. Therefore if there are too many logs in a region, fishermen may tie the largest logs together and remove smaller logs from the water (Hampton and Bailey, 1999).
The process of setting on a floating object is basically the same, regardless of whether it is a natural floating object or a drifting FAD. However, the process of tracking, locating and monitoring the object obviously differs, as modern FADs generally have location devices and other technologies to aid vessels. The following section details the evolution of FADs design, technology and associated fishing methods, and where possible details evidence of the effect of various technological or methodological changes upon the efficiency of FAD based fisheries.

2.4 Drifting FAD design

Early drifting FADs used by some artisanal fisheries were constructed using natural materials, such as logs tied together to form the raft and palm fronds hung beneath as attractants (Morales-Nin et al. 2000). The industrial purse seine fisheries originally used to search for natural drifting objects such as logs, tie them together and set them adrift again with a radio beacon attached to allow tracking (Moron et al. 2001; Sakagawa, 2000). This method was first used by Spanish purse seiners in the 1980s. The Japanese fisheries researchers first experimented with man-made floating objects in the early 1980s and determined that this method of fishing was worth basing a fishery upon. By the early 1990s, drifting FAD design was fairly uniform, consisting of square bamboo rafts (approximately 1.5m by 1.5m) with radio beacon on top and some form of netting, usually old purse seine netting, hanging beneath, to increase its profile underwater and act as an attractant (Ariz Telleria et al. 1999; Lennert-Cody and Hall, 2000) (Fig 2.4). Bamboo was used due to its lightweight nature, strength and resistance to waterlogging. The upper side of the raft would often be covered in black net cloth to reduce the chance of it being spotted by other vessels (Ariz Telleria et al. 1999). The length of the nets hung underneath have shown an increasing trend and reach 50m in the eastern Pacific, although the effectiveness of larger nets to attract tuna has not been evaluated (Fonteneau et al. 2000). Many fishermen also used baits or underwater lights as attractant devices. Since this early standard design, the technology and methods used to track and monitor FADs has rapidly evolved. The following section details the main technological and methodological changes that have occurred since drifting FADs first became popular in
A Review of the Impact of FADs on Tuna Fisheries

the early 1990s. While overall it is recognised that FADs have increased fishing power (for example, successful sets under FADs average over 90% compared to 53% success on free-schooling tuna in the Western Pacific; Sakagawa, 2000) there is not much empirical evidence as to the effectiveness of these various changes in increasing fishing efficiency.

2.4.1 Radio beacons

Fishermen in the Indian Ocean started tying radio beacons to logs in the early 1980s, and by 1985 this was common practice. The use of radio beacons on man-made drifting FADs was concurrent with their introduction in the late 80s. There are a number of types of radio beacon used, with semi-continuous emitting beacons used in the early years. These were gradually replaced by “sleeper” beacons, which conserved energy by only transmitting in response to a trigger message from the main vessel. The evolution of beacons in the Spanish purse seine fleet in the Indian Ocean represent a reasonable example of what has occurred worldwide. The SELCALL radio beacon was introduced around 1986, having a sleep mode, low energy usage, better batteries and a lifespan of around 3-4 months. They had a directional range of 150 miles and a detection range of 400 miles (Moron et al. 2001). However, later SELCALL buoys were developed which used increased emission frequencies for transmission, meaning that the vessels were able to detect signals from 700 miles, and FAD direction from 200 miles. As this type of beacon became popular in the early 90s, its price dropped. Fishermen then started to tilt the beacon antennae on a lower angle to prevent detection by competitor vessel radar and subsequent piracy of FADs (Moron et al. 2001). Further advances in beacon technology and the introduction of the GPS buoy system meant that by 1996, not only could signals be detected at up to 700 miles away, but beacons could also relay the GPS position of the FAD. These advances resulted in the expansion of the fishery as vessels could now track buoys outside the normal fishing area. GPS also eliminated the problems associated with distance estimation that were associated with previous radio wave based methods (Moron et al. 2001). In addition, since 1998 these beacons have also been able to transmit information regarding sea surface temperature as well as battery charge status information, and now have a detection range of up to 1400 miles, and a battery life of up to one year. They can be traced by computer, allowing tracking of course and history (Moron et al. 2001).

2.4.2 Satellite beacons

Satellite beacons allow vessels to follow FADs in real time, providing information on the exact position of the FADs and the tracking and analysis of their course on a standard personal computer, either on the vessel or back at shore (Fonteneau et al. 2000). This analysis can be combined with other satellite-derived information, such as sea surface temperature maps, waves and ocean colour maps. This gives the fishermen a better idea of surface currents, fronts and convergences, and allows them to finetune and direct search patterns (Fonteneau et al. 2000).

The first testing of satellite beacons on drifting FADs occurred in the early 90s, though a joint initiative between the Inter-American Tropical Tuna Commission (IATTC) and the United States National Marine Fishery Service (NMFS). Initially, 2 FADs were deployed with satellite transmitters so as to determine the durability of the buoys, electronics, and practicality of tracking FADs by satellite (Oliver and Edwards, 1996). A larger scale test was then run, deploying 30 FADs, which consisted of 3 replicates of 10 different designs. For each replicate of three, one would have a satellite beacon, the other two fitted with radio beacons (Oliver and Edwards, 1996). The satellite beacons provided location information accurate to within one kilometre (through the Service Argos satellite system), regardless of distance to FAD, while radio beacons could only be detected within 200 km. Unfortunately, huge hurricanes pushed these FADs well outside the normal fishing zone and few were visited by fishing vessels. Hence a promising empirical study was eventually abandoned. However, 8 of the satellite beacon equipped FADs were still transmitting nearly 18 months later (Oliver and Edwards, 1996).
In the Indian Ocean, the Spanish purse seine fleet introduced a new type of satellite buoy in the late 1990s which had unlimited range, and a non-protruding antennae to prevent detection by competing fleets (Moron et al. 2001). These buoys were capable of sending positional data, sea surface temperature data, sonar data and battery status information. This model had solar panels to prolong battery life as well as flashlights to aid nighttime navigation. The sonar could be set to variable depths (see following section). A new buoy is currently being developed with an inbuilt echo sounder. More recently, some companies have started to develop satellite buoys that combine GPS technology with Inmarsat satellite receivers, and have encryption mechanisms that prevent other vessels from decoding FADs positions. It is thought that these new designs will increase FAD based fishing efficiency and reduce the number of FADs lost or stolen.

Figure 2.5 – Satellite beacons stacked on the deck of the purse seiner awaiting deployment.
A Review of the Impact of FADs on Tuna Fisheries

2.4.3 Supply vessels

Supply vessels are auxiliary vessels with several functions pertaining to the operation and efficiency of the purse seiner(s) for which they are working (Arrizabalaga et al. 2001). Originally, supply vessels were used as anchored FADs to attract tuna schools, but nowadays carry out a much more substantial and multifaceted role (Arrizabalaga et al. 2001; Ariz Telleria et al. 1999; Fonteneau et al. 2000). Their main purpose is to allow the main purse seine vessel more time to invest in fishing related activities, and in theory increase the searching capacity and fishing efficiency of the purse seiner at reduced cost (i.e. increase the economical yield) (Ariz et al. 2001). However it is still uncertain what the true effect of their current use is upon the activity and catch rates of the purse seiners (Arrizabalaga et al. 2001).

More specifically, the role of supplies can be divided into two categories: to search for and detect tuna schools, and assist in the activities of the purse seiner. The first category involves activities such as the location of FADs or floating objects, acting as a floating object, building and deploying FADs, and manipulating or repairing floating objects and FADS, as well as monitoring the tuna associated to these objects (Ariz et al. 2001; Fonteneau et al. 2000). Consequently supplies tend to carry equipment including radar, sonar, depth recorders, GPS, plotters and binoculars (Ariz et al. 2001). The second category involves duties such as exchange of crews, food and equipment supplies, and at sea boat repairs (Ariz et al. 2001).

Another role fulfilled by supply vessels is that of an anchored supply, which will spend the majority of its time tethered to the same spot and acting as an anchored FAD. It simply monitors the aggregations gathering beneath and sends the information to the purse seiner, which will make a decision as to when it might make a set on the tuna associated to the supply (Arrizabalaga et al. 2001) (Ariz et al. 2001).

The increase in the efficiency of purse seiners can be attributed to introduced methods and technologies that have led to increased speed and efficiency of fishing operations and improved capacity to detect and locate tuna schools (Ariz et al. 2001). Two studies have attempted to examine the possible effects of supply vessels upon purse seiner efficiency (Ariz et al. 2001; Arrizabalaga et al. 2001).

The first study examined the use and effect of supply vessels in the Spanish purse seine fleet fishing the Indian Ocean in 1998/9 (Arrizabalaga et al. 2001). This fleet utilised 10 supply vessels between them, including 2 anchored and 8 roving supplies. Only half the fleet of 30 purse seiners used the supply vessels, while the other half comprised lone operating purse seiners. The study compared the activities of purse seiners using roving supplies, anchored supplies or without supplies. It found that there was little difference in the time spent on different activities by purse seiners working with or without supply vessels and there was no significant difference in the yield between the purse seiners with or without roving supplies. Those using anchored supplies did however have higher yield than the other two categories (Arrizabalaga et al. 2001) (possibly due to the area they fished in, rather than as a result of being anchored). Further investigation is still required into how effort can be standardised to take account of the supplies effort, so that it can be included in the stock assessments of tunas (Arrizabalaga et al. 2001).

The second study analysed the time spent in various activities of a single supply vessel (Ariz et al. 2001). This study is of limited relevance given that the activities of the boat were curtailed by bad weather, and it doesn’t make any comparison to purse seiners operating without supply’s. However, it does offer some insights into supply vessel functions and the factors that dictate supply vessel and purse seiner behaviour. This vessel spent the majority of its time (73%) searching for floating objects, putting beacons on them or repairing them. The supply skipper is constantly emailing the purse seine skipper with information regarding objects, location, and the size and species associated with them, while the purse seine skipper
constantly sends instructions back. The behaviour of the supply is determined by whether there are other boats in the region, whether it suspects they have detected the object or not, and whether the activity of other boats suggests they themselves have located an object with associated tuna. The supply can choose to stay with an object to guard it, mark it with a beacon and move away, or move towards a location where another vessels activities suggest it has found such an object.

### 2.4.4 Sonobuoys

The use of sonar on FADs is one of the more recent innovations and means that purse seiners or their supply vessels need not visit FADs to check for the presence, size and species of tuna aggregations. The sonars can be programmed to scan at variable depths, such as 100, 200, 300 or 400m. Sonar information is relayed back to the purse seiner that can then make a decision as to whether it will travel to the FAD for a more thorough investigation and possible set.

All of these changes in purse seining fishing methods associated with FADs has meant that searching time can no longer provide a measure of fishing effort, because fishing effort is now a mixture of time devoted to visiting targeted FADs and randomly searching free schools (Fonteneau et al. 2000). Furthermore, the use of remote sensing (e.g. sonar on FADs) further changes the time spent searching and effort dynamics. The implications of these factors for stocks and fisheries assessments are discussed in Chapter 6.

### 2.4.5 Satellite derived information

Modern industrial purse seiners not only use satellites to relay information between FADs and the seiner, whether fishing on FADs or on free schools, but now also use a range of satellite derived information that can aid in their ability to pinpoint regions where tuna are more likely to aggregate. Satellite technology can now monitor and record changing environmental conditions both on land and at sea. For tuna fishing captains, it is satellite-derived information regarding sea surface temperatures and regions of high chlorophyll-a concentrations that are of most interest. Other satellite-derived information useful to current fisheries is environmental information pertaining to weather patterns (e.g. winds, precipitation), to environmental parameters that promote or are related to phytoplankton production (e.g. irradiation levels), to the monitoring and tracking of floating hazards such as icebergs. The satellite companies which provide these information services use teams of oceanographers to form and distribute “fish finding maps” to their clients. By 1998, Orbimage already had near 100 purse seiners as registered clients using their satellite derived data. Purse seiner skippers are able to use email and onboard computers to download the most recent sea surface temperature and productivity maps (produced daily) while at sea. Specialised software aids in the interpretation of these maps.

The combination of SST and plankton information can be used to indicate probability densities for several fish species in the open ocean. Tuna tend to aggregate in areas of high productivity, and such areas are typified by high concentrations of plankton. Phytoplankton contain large amounts of chlorophyll-a, and by using specialised filters to observe ocean colour, satellites can profile regions for chlorophyll-a (and therefore productivity). This information can be used by purse seine skippers to help them pinpoint regions to fish. Different tuna species also have preferred environmental temperature ranges and have often been associated with thermal fronts, hence sea surface temperature reading taken by satellite can also be useful to purse seine fleets in helping them to refine the search area.

### 2.5 Summary and conclusions

While there has been little direct study to compare the various advances in FAD-based fisheries and how these may have improved fishing efficiency, this chapter has described the
A Review of the Impact of FADs on Tuna Fisheries

some of the history and theory behind the adoption of different methods and technologies. The use of FADs was implemented to reduce search time and increase catch though the FADs ability to concentrate tuna from the surrounding region. Radio beacons were added to reduce search time, and satellite beacons to increase the detection range. Supply vessels supposedly allowed purse seiners to spend more time engaged in activities directly related to searching and fishing, thus increasing efficiency and catch per unit effort. Sonobuoys allow remote monitoring of aggregations under FADs, further reducing time spent checking and monitoring FADs, leaving more time to searching.

FADs are widely accepted as they are believed to increase efficiency (see Chapter 5: catch per set and percentage set success data), are easily deployed, tracked and located with radio or satellite beacons (Sakagawa, 2000). Trying to locate free-schooling tuna is more difficult and requires exceptional knowledge of fishing areas (Sakagawa, 2000). However, the ability of fisheries scientists to either assess the effects of each FADs related innovation, to predict fishing effort and to undertake stock assessments, has been confounded by the use of FADs for a number of reasons. Firstly, the use of various technologies is often kept secret by fishing fleets due to the competitive nature of the market, and "common property" nature of the resource they are exploiting, and there is a very low level of technical documentation on changes implemented. Furthermore, many of the changes related to FADs technology occur in conjunction with the introduction of other newly developed technologies (gear or electronic, radar related etc). There is currently a massive array of technology used to increase potential ability to detect tuna schools, hence it has become extremely difficult to separate out FAD-related effects from those of other on-board innovations. The implications of FAD-fishery development for stock assessments is discussed further in Chapter 6.

This chapter has detailed FAD technology and the associated methods used to aggregate and catch tuna. However, the question remains, why do tuna aggregate to FADs (or floating objects in general) and what might be the effect of the increasing deployment of FADs in tropical waters upon tuna biology and ecology? What might be the flow on effects of this for fisheries sustainability? These questions are dealt with in the following chapters.
3. Review of biological features of tuna relevant to FAD fisheries

3.1 Introduction

There are three main species of tuna targeted by FADs-based fisheries worldwide, these being skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tunas. The following sections will review the biology of tunas in two parts. Firstly, an overview of the basic biological features of these three species will be presented. Differences in basic biological features will be seen in future chapters to have implications for how FADs-based fisheries can impact differently on each species and on the fisheries that target them. The second section of the chapter details some of the physiological and behavioural adaptations of the tunas in general, and how these adaptations interact with environmental factors to determine the movements, distribution and abundance of these species. Highlighting these relationships will also aid in the understanding of the potential impact of FADs upon tuna fisheries and ecology (to be detailed from Chapter 4 onwards).

3.2 Basic biological features

The three tuna species most commonly targeted under FADs are skipjack, yellowfin and bigeye tunas. These species readily associate to floating objects; skipjack at all life stages while yellowfin and bigeye associate mostly during juvenile stages (but also to some degree when adults). Despite this common behavioural tendency, and a similar distribution pattern (tropical and subtropical waters worldwide) there are some significant differences in the biological features of these three species that are important to understand, before more general descriptions of tuna biology are entered into.

**Skipjack** are a relatively small tuna, reaching a length of around 50cm and a maximum size of 18kg. They are a fast growing but short lived species (~ 3 years) which reach reproductive age after only 1-2 years and spawn up to 1.2 millions eggs per spawning. They are multiple spawners able to spawn year round in tropical waters providing the water temperature is above 25°C. They inhabit the surface waters above the thermocline.

**Yellowfin** tuna are also a fast growing species, which can live for up to 8 years and reach a maximum size of 175 kg. Adults average around 20 kg. They mature more slowly, at around 2 to 3 years, but can spawn 2 to 3 times a year with up to 8 million eggs per spawning. They tend to inhabit surface waters above the thermocline but can venture into deeper colder waters in pursuit of prey.

**Bigeye** tuna grow more slowly than yellowfin or skipjack, but reach a much larger maximum size (~333kg). However, adults average around 90 cm and 15-20 kg. As will be explained below, bigeye have a greater thermoregulatory capacity, and spend much of their time in colder waters below the thermocline. This species is thought to have a maximum life span of around 11 years, and spawn in tropical waters throughout the year. Females are believed to reach reproductive size at around 100cm (~ 3 years of age).

In following chapters, the differences in basic biological features will be seen to have implications for how FADs based fisheries can impact differently on each of these species. The following section describes some other features of tunas which will also help to understand FADs impacts described later. For a more complete review of tuna physiology and ecology see Block et al. (2002).
3.3 Thermoregulation: Relationship to distribution and behaviour

The tunas stand out from other teleost groups by virtue of their unique morphological and physiological attributes. Morphologically, they are adapted for fast and energy efficient streamlined swimming. Physiologically, they are one of only two groups of fishes that have evolved the capacity to produce and retain body heat (thermoregulate), the other group being the lamnid sharks (Bernal et al. 2001). This ability is conferred by specialised vascular, respiratory and muscular systems and allows increased muscle function, digestion rates, metabolism and growth rates. Together, these features have enabled the tunas to evolve behaviours that can efficiently exploit a pelagic environment that is typified by patchy food resources (Sund et al. 1981). However, tuna vary in the degree to which they are able to thermoregulate, according to species and to developmental stage. Thermoregulatory capacity plays an important role in the distribution and behaviour of each of the three main tuna species being considered in this report (skipjack, yellowfin and bigeye tunas). As such, this will also relate to the differential effects of FADs upon the biology and ecology of each of these species. A brief explanation of the importance of thermoregulation to the biology and ecology of these tuna species follows.

3.3.1 Thermoregulation: Vascular adaptations

The circulatory system, which transports blood around the body of the tuna, has specialised structures called rete that act as heat exchangers and enable tuna to conserve heat produced by muscular activity. These heat exchangers comprise two sets of blood vessels, with one flowing to the gills, the other flowing from the gills to the muscle. They act to transfer heat from venous blood to arterial blood before it reaches the gills where it would dissipate to the much colder water interface. Instead, heat is conserved and used to warm the newly oxygenated blood travelling to the muscle and other tissues, which enables more efficient functioning of these tissues.

Most fish species are unable to conserve body heat. However, the rete enable tuna to maintain red muscle temperatures from anywhere between 3°C and 9°C above ambient, depending on the species and thermal environment (Block et al. 1997; Stevens et al. 2000; Marcinek et al. 2001) and has been recorded at up to 20°C above ambient during burst swimming. Rete can elevate stomach temperatures up to 14°C above ambient (Stevens et al. 2000). Being able to conserve body heat is advantageous to tuna as it increases their muscle function, power output and efficiency, as well as increasing their digestive rate. Therefore the tunas have a selective advantage over the majority of teleosts whose muscle temperature is dictated by the temperature of their immediate environment.

The ability of the tunas to produce and retain body heat varies quite significantly between species. The location and number of heat exchangers varies between species and effects the heat retention capacity, ability to exploit colder environments, and therefore the distribution of each species (given that ocean water temperature becomes colder as latitude increases). The tunas can be split into two groups, according to the number and location of heat exchangers in each species (reviewed in Block et al. 1997). The first group comprises warmer water species such as yellowfin (Thunnus albacares), skipjack (Katsuwonus pelamis), blackfin (Thunnus tonggol) and longtail (Thunnus atlanticus). This group is characterised by large central and reduced lateral heat exchangers, and occurs predominantly in tropical waters above the thermocline. The second group comprises colder water species such as bigeye (Thunnus obesus), albacore (Thunnus alalunga), northern (Thunnus thynnus thynnus) and southern (Thunnus thynnus orientalis) bluefin tuna. This group have a reduced or absent central heat exchanger, a highly developed lateral heat exchanger, and additional exchangers which act to elevate visceral, brain and eye temperatures. Adults of these species occur at higher latitudes or below the thermocline in tropical waters (Block et al. 1997). Given that the latter are typically cold water species, the differences in the vascular adaptations of the two
groups would seem likely to reflect differences in their ability to conserve heat, and play a large role in determining the distribution of these species (Block et al. 1997).

The size and developmental status of tuna also affects their ability to conserve heat. Larger tuna have a greater mass and are able to conserve heat through thermal inertia (Brill et al. 1999), while there is some evidence that the mechanisms controlling heat production and retention in juvenile tunas are not fully functional when compared to their adult counterparts (Dickson et al. 2000). Hence this may limit the ability of juveniles of some species, such as yellowfin to exploit the colder waters that the adults exploit (Cayre, 1990; Brill et al. 1999).

### 3.3.2 Thermoregulation and red muscle tissue

There are three main types of muscle tissue in tunas, these being red, white and cardiac muscle. The physical production of heat (thermogenesis) relies upon muscular activity, and in this regard the red muscle is the primary heat source for tunas (Bernal et al. 2001). It differs from the red muscle of other teleosts in its location, structure and relative size. Whereas in most teleosts the red muscle is located external to the white muscle mass, in the tunas the bulk of the red muscle is internalised, located more anteriorly and adjacent to the spinal column. This positioning prevents heat loss through the cold external skin surface and through the retention of thermal energy, simultaneously increasing the mechanical efficiency and power potential of muscle. The red muscle mass is also larger, relative to white muscle, than found in other teleosts (Hochachka et al. 1978). This combined with a highly modified and specialised red muscle structure, acts to “double the cruising power of these fish” (Katz et al. 2001). The biochemistry of red muscle also differs from that of other teleosts. Myoglobin is a protein that transports oxygen within muscle (similar to haemoglobin in the blood), and is present in extremely high levels in tuna red muscle, facilitating faster oxygen delivery (Brill, 1996). Furthermore, being “warm-bodied” helps increase the rate of chemical processes, and enhances the performance of tuna red muscle (see review Dickson, 1996). The capacity for red muscle to produce heat increases in tuna as they mature (Dickson et al. 2000).

### 3.3.3 Metabolism and respiration

Tunas possess a number of respiratory adaptations which enable them to massively increase the supply of oxygen to muscle and other tissues (relative to other teleosts) (Brill and Bushnell, 1991). Firstly, tunas are ram ventilators, meaning that they must swim continuously in order to force water through their open mouth and out over the gills (Brill, 1996). This mode of respiration may serve to reduce drag and the cost of ventilation. Secondly, the gills are extremely thin and have a very large surface area when compared to other teleosts, enabling a much greater diffusive uptake of oxygen than can be achieved by other teleosts (reviewed in Brill, 1996). Once oxygen has reached the muscle tissue, its passage to the mitochondria is facilitated by the extremely high level of myoglobin in tuna muscle. The high rate of oxygen supply is required as a result of endothermy and the extremely high standard metabolic rate of tunas.

### 3.3.4 Feeding and digestion

Tuna are capable of feeding to satiation in less than an hour (Olson and Boggs 1986) and have exceptionally high digestion rates, in some species up to 2 to 5 times higher than those observed in other teleosts of similar size (Carey et al. 1984). The digestive process is aided in colder water species by heat exchangers (rete) which act to warm the digestive system and speed up the action of digestive enzymes and stomach acids (Carey et al. 1984). Furthermore, absorption efficiency or the proportion of food ingested which is actually absorbed into the bloodstream, is extremely high (Kitchell et al. 1978). High digestion rates and efficiency are advantageous for species such as tunas which have high energy demands and which must be able to quickly and fully exploit prey patches whenever they are found (Kirby et al. 2000).
3.4 Behaviour

The behaviour of tuna is closely linked to the physiological adaptations detailed in the previous section. Such adaptations have evolved in concert with foraging, schooling and migratory behaviours of the tuna species, and together have enabled the tunas to efficiently exploit their environment. For the purposes of this report, an understanding of tuna behaviour in the natural environment is important, as Chapter 4 will demonstrate that the natural schooling, foraging and migratory behaviours of some tuna species may be significantly impacted upon by FADs-based fisheries and fishing practices. Changes in the way tuna behave when in a “high FAD” environment, when compared to free-schooling behaviours, appear likely to have implications for stock assessments, and ultimately the management of the species.

3.4.1 Feeding Behaviour

Introduction: Tuna inhabit a relatively unproductive environment in which prey resources (food) are “patchy” and relatively scarce. However, a fast metabolism means that the energy requirements of tuna are very high. Therefore tuna face the challenge of locating prey patches quickly and often to satisfy their energetic needs. Accumulations of prey tend to occur in areas where conditions promote productivity, i.e., nutrient upwellings and ocean fronts (Pitcher, 1995). Their ability to locate prey is thought to rely on a variety of sensory mechanisms such as smell (Atema et al. 1980), sight (Cahn, 1972), sensing changes in magnetic field (Walker et al. 1997), and memory based map sense (Carey and Robinson 1981; Milinski, 1994). Once a productive area is located, feeding activity tends to operate on a diel basis. The diet of tunas is opportunistic and varies between species, regions and time of year.

Feeding zones: The upper zone of the pelagic environment (i.e., above the thermocline) in which many tuna species are found is considered to be relatively unproductive (Sund et al. 1981). Hence phenomena which result in increased productivity will attract prey fish, whose distribution will be one of the key factors determining the abundance and distribution of the tuna species that predate them (Sund et al. 1981). Such phenomena usually entail the meeting of cooler nutrient laden waters with warmer surface waters under suitable conditions of irradiation (sunlight). This is generally associated with upwellings and surface fronts (Pitcher, 1995). Such fronts mark the boundary between two different water types and are typified by concentrations of zooplankton and small fish species. Field evidence, fishery data and modelling studies indicate that tuna will tend to aggregate at these fronts, presumably to feed (Lehodey et al. 1998). However, the conditions that promote productive regions may not last for very long (i.e. days to weeks). Therefore the ability of pelagic fish such as tunas to rapidly respond to prey patch dynamics is the key to their survival in such a dynamic and patchy environment (Pitcher, 1995).

Locating prey: Both field and modelling based evidence suggest that tuna locate prey using different mechanisms, with the mechanism employed being dependant on the scale of the search. Over large distances of searching for prey, the movements may be initially constrained by environmental optima relating to temperature, salinity and oxygen (Maury et al. 2001). However, within these boundaries, searches over large areas may involve random changes in direction. Modelling studies suggest that in low prey environments, tuna (or predatory animals in general) may travel for extended periods without change in direction. However, the time or distance between changes in direction becomes less (i.e., the number of changes in direction increase within a unit time) when tuna encounter signs of a high prey environment. This strategy increases the likelihood of staying in a high-prey area for longer (Mullen, 1989; Benhamou, 1992). In addition, it is likely that sensory detection of prey becomes important at smaller scales (i.e. hearing, smell, sight)(Atema et al. 1980). Schooling is another mechanism which is believed might increase the efficiency of prey searching and the likelihood of an individual locating prey (Swartzman, 1991). A number of studies have
suggested that tuna might adopt a wandering strategy in small schools when resources are scarce and form larger schools when resources are abundant (Roger, 1994). Associating with non-tuna species may be another feeding related behaviour. For example, it has been theorised that tuna may initiate associations with dolphins so as to benefit from their echolocating abilities to track prey (Clua and Grosvalet, 2001).

Feeding pattern: Feeding behaviour differs between tuna species but tends to show a daily pattern. In some studies, stomach contents of yellowfin and skipjack tunas caught in the West Indian Ocean have been found to contain mostly diurnal epipelagic fishes (Roger, 1994), suggesting that they are predominantly day feeders. However, there is also some evidence that yellowfin can feed at night also (Holland et al. 1990). Bigeye tuna often move from the cooler depths into warmer surface waters at night to feed on smaller pelagic fishes, and other organisms that rise to the surface layer at night (e.g. some squid). Recent studies have suggested that bigeye visual system was especially adapted to active predation in very dim light, such as occurs at depth or at night (Fritsches and Warrant, 2001). The presence of heat exchangers to warm blood travelling to the eyes and brain in this species appears to give bigeye much greater vision “speed”, that is, temporal resolution of images in low light (Fritsches and Warrant, 2001). Tracking studies have already demonstrated that bigeye (and to a lesser extent, yellowfin) tunas will track the sound scattering layer, the dense aggregation of invertebrates and small fishes that migrate from deep to surface waters at dusk and then back to the deep waters at dawn (Josse et al. 1998).

Diet: Most tunas are opportunistic feeders, and their diet can vary considerably between species and regions. Micronekton (small fish) are a major component of oceanic tuna diet, and their distribution is largely determined by thermal structure and oceanic currents (Lebourges-Dhaussy et al. 2000). The main prey of yellowfin and skipjack are fish, cephalopods and crustaceans (Roger, 1994). Large yellowfin are also known to cannibalise smaller juveniles of the same species quite heavily.

The amount of feed required per day also varies between species. Skipjack tuna can consume 10-15% of their body weight per day (Kitchell, 1978). Prey type and intake can vary for northern bluefin tuna depending on region but they can consume up to 20kg per day (may account for large daily movements) (Lutcavage et al. 2000). Some tunas are capable of feeding to satiation in less than an hour and they have exceptionally high digestion rates, up to 5 times faster than that of other teleosts (Kirby et al. 2000).

3.4.2 Schooling

Introduction: Schooling behaviour is an extremely important feature in the ecology of tuna. It is also the primary behavioural trait which allows fisheries (both FADs and free-school based) to exploit these species so successfully, as it promotes easy location and high catch per unit effort. Schooling fish species can be either obligate schoolers, which school for life, or facultative schoolers which only utilise this behaviour at certain periods in their life or under certain environmental circumstances. Furthermore, schools can be single or multi-species, polarised or loose (Pitcher, 1983). Tuna, in particular juvenile tuna and smaller species such as skipjack, have a tendency to form multi-species schools. The motivation behind schooling has been debated for many years, primarily because it is very difficult to test many of the assumptions in the field. However, knowledge of the motivation of schooling tuna may aid in determining the dynamics of tuna schools. This is important to fisheries scientists, as the relationship between CPUE and real abundance is often uncertain for highly mobile schooling species (Lutcavage et al. 2000). Stock assessments have recently been further complicated by advent of FADs and their ability to attract tuna schools and change schooling dynamics, behaviour and distribution (see Chapter 4), increasing the need to understand schooling phenomena in tuna.
A Review of the Impact of FADs on Tuna Fisheries

**Schooling motivations:** There is still little known of the role of school formation and dissolution in the biology of tunas (Cayre and Holland, 2000). However, tuna may school as a more energetically efficient way of travelling (migrating) and foraging for food (Stocker, 1999). It is thought that schooling may reduce energy expenditure through fish “slipstreaming”. It may also increase foraging efficiency through the presence of more eyes. There may be other factors involved also, such as reduced predation pressure and easier mate finding. The size of tuna schools may vary between species and may be determined by factors such as oxygen content between front and rear of schools. For example, modelling studies suggest that a school may be more likely to split when the oxygen concentration at rear of school goes below a critical limit, as a result of oxygen consumption by those at the front (Stocker, 1999). Another theory holds that school size will vary depending on the amount of prey in a region. (Roger, 1994) hypothesised from gut contents of tunas caught in small and large schools that when prey is abundant, schools tend to be larger but when prey is scarce schools break up into smaller foraging subunits.

**Multispecies schooling:** Tuna schools can be single or multispecies. Multispecies schools may intermingle but tend to be spatially segregated by species (Cayre and Holland, 2000), and in a sense don’t represent a single mass as such. For example, purse seine fishers setting upon a single school often catch skipjack and juvenile yellowfin and bigeye. However, sonar and visual observations have shown that such schools may be segregated by size and species, with larger individuals such as bigeye swimming deeper than smaller individuals. Mixed species schools tend to be dominated by a single species and in addition to energetic and foraging advantages may also represent a means by which minority conspecifics can find each other and form their own single species school (Cayre and Holland, 2000). The minority species within a school may face problems relating to feeding, reproduction and migration, as the choices of the majority species will dictate the behaviour of the school and may not suit the ecological requirements of the minority species which is forced to conform. Therefore it may be that one purpose of mixed schools is to allow minority species the benefits of schooling until they can meet conspecifics and split (into monospecific school) when the critical biomass reached. As will be detailed in Chapter 3, there is some evidence that the occurrence of free swimming mixed schools has dropped since proliferation of FADs in the east Atlantic.

**School fidelity and mixing:** Allegiance to schools varies depending on the species. Yellowfin tagged together (in same school) will tend to remain in the same school for long periods of time (Klimley and Holloway, 1999). In contrast, skipjack tuna show high rates of exchange between schools. Up to 63% of individuals can leave a school on any one day, and join other schools, resulting in very high rates of mixing within months and the extent of mixing in this species may vary with place, conditions and season (Bayliff, 1988; Hilborn, 1991). Observations suggest that some species schools may breakdown and reform regularly. In the context of the current report it is important to note that tuna may associate to each other by schooling, or they can associate in large numbers to a common point (e.g., a FAD) but that this may not represent schooling as such. The nature of tuna schooling, school fidelity and how this changes when tuna associate to floating objects, will be discussed in the following chapter.

### 3.4.3 Migration and movement

**Introduction:** The previous sections has detailed the specialised physiology and generalised behaviour of tunas. This section demonstrates how physiology and behaviour interact to determine the migration, movements, abundance and distribution of the tuna species. Such information will become critical in understanding the potential impact of FADs upon the ecology and abundance of tuna species, to be detailed in the following chapters.

**Migration:** As mentioned in the previous section, tuna tend to migrate as schools, and tagging studies have demonstrated that these schools may return seasonally to specific sites/structures,
suggesting that they have migratory waypoints that are visited with temporal regularity (Klimley and Holloway, 1999). Thus the migration paths of tunas seem to be fairly precise and deliberate, and it is generally believed that highly migratory fish such as tuna use a map sense with memory to orient to smaller spatial scales (Carey and Robinson 1981; Milinkski 1984) and geomagnetic cues to orient during long range migrations (Walker et al. 1997). Migrations occur on a seasonal basis and may be motivated by the need to reach spawning grounds (for adults), nursery grounds, and high productivity feeding grounds (for adults and juveniles). It is these set migration paths of pelagic species which make them more easily exploited by fisheries (Pitcher, 1995). The use of fixed structures as orientation points has been suggested as a possible explanation of the attraction of tunas to anchored FADs (Freon and Dagorn, 2000a; Freon and Dagorn, 2000b), an issue discussed further in Chapter 3.

Migration is movement at the largest scale, however, the movement and distribution of tunas can be considered at a number of scales, and indeed the main influencing factors tend to vary with scale also (Maury et al. 2001). Additionally these effects may vary with the age and developmental status of tunas.

Large-scale movements: At the whole ocean scale, physiological limitations with regard to factors such as temperature and salinity tend to shape the distribution and movements of tunas. In the Atlantic, salinity appeared to be the main factor defining the boundaries of the distribution of yellowfin, with juveniles having higher temperature (>27ºC) and lower salinity preferences (<35ppt) than those limiting adults (15-29ºC, <36ppt) (Maury et al. 2001). These findings suggest that the physiological mechanisms which allow tuna to cope with such environmental conditions are not yet fully developed in juvenile tuna. As noted in the earlier section “Vascular adaptations”, between species differences in distribution are predominantly shaped by thermoregulatory capacity, with species such as bigeye able to exploit colder water while species such as yellowfin and skipjack are confined to warmer waters (Holland et al. 1999). The thermal (and saline) structure of oceanic water bodies changes constantly over the seasons and hence the distribution of tunas changes also. Prey abundance may also be a factor at the oceanic scale. For example, the proportion of tuna migrating from the west to the East Pacific is thought to be determined at least partially by the abundance of sardine in the west pacific (Polovina, 1996). When these levels are low, the tuna tend to migrate eastwards. Productivity of oceanic waters will determine tuna forage and consequently tuna distribution (Lebourges-Dhaussy et al. 2000). The top level of tropical seas is relatively unproductive so food availability will be a key factor in determining the abundance and distribution of these species (Roger, 1994). Displacements of tuna prey and tuna concentrations have been shown to be closely linked to zonal shifts of ocean fronts (Lehodey et al. 1998).

Local movements: At a local scale (<100 km), factors like temperature and oxygen will still play a role, but the presence or absence of prey, its patchiness and diurnal movements will become much more important in the fine scale movements of tuna (Josse et al. 1998; Dagorn et al. 2000a). However the ability of tuna to exploit their immediate prey environment will vary depending on the physiological capacity of different species. Yellowfin and bigeye have been shown to have distinct diurnal pattern in vertical movement. This has been linked to movements of vertically migrating prey of yellowfin and bigeye (Josse et al. 1998).

Yellowfin, regardless of whether they are adults or juveniles, spent the majority of their time in the surface layer (< 100 m) with deep dives being limited in duration as a result of their inability to tolerate cold for long periods. Yellowfin thus are limited in their ability to exploit prey resources that may lie below the thermocline. Bigeye tuna can hunt in both surface (warm) and deeper (colder) waters while still maintaining the advantages of high muscle temperature (reviewed in Dagorn et al. 2000). The regular upward daytime excursions of bigeye are thought to represent behavioural thermoregulation related to keeping the body warm while exploiting otherwise unreachable prey resources (Holland et al. 1990). Bigeye tuna show clear daily depth patterns, being at less than 100m at night, and between 400-500m during day. They are tracking prey organisms which migrate to the surface at night and dive back to the depths at dawn (Dagorn et al. 2000). Small bigeye have to make more regular
A Review of the Impact of FADs on Tuna Fisheries

upward excursions, probably as a result of their reduced ability to conserve heat (lower thermal inertia) (Dagorn et al. 2000). Skipjack do not show marked differences in swimming depth between day and night and stay in the surface layer (Cayre, 1991).

3.5 Summary and conclusions

This chapter has reviewed some aspects of the biology of tunas, in particular as relates to the three species primarily targeted by purse seine fisheries using fish aggregating devices (FADs), these being skipjack, yellowfin and bigeye tunas. Understanding the importance of tuna physiology to their behaviours and distribution, and how these relationships differ between tuna species, will aid in understanding how FADs are believed to impact upon certain aspects of tuna biology and ecology, and again, how this might differ between species.

Skipjack tuna are short lived, fast growing species that because of their smaller size and reduced thermoregulatory ability, are restricted to inhabiting the warmer surface layers of the ocean at all stages in their life. Yellowfin are also a fast growing but longer lived species, which due to their larger attained size as adults, can use their greater mass and thermal inertia to travel for short periods into deeper cooler waters. In contrast to these two species, bigeye tuna are slower growing but can reach much larger size than even yellowfin tuna. This size, in combination with highly developed heat exchangers associated with their central nervous system, enables them to track prey in deeper cooler waters during the day.

Each of these species school, and in the younger juvenile stages, when thermoregulatory abilities are undeveloped, it appears that smaller juvenile yellowfin and bigeye tuna are limited predominantly to the warmer surface waters just like skipjack. Indeed, juvenile yellowfin and bigeye will often form multispecies (although spatially segregated) schools with skipjack. Like all tunas, these species are migratory, seasonally travelling considerable distances between feeding, nursery and spawning grounds, depending on developmental stage. At higher latitudes water temperatures tend to be cooler, so again this places constraints on seasonal movements of those developmental stages or species with limited thermoregulatory capacity.

The following chapter will demonstrate that these three species of tuna have a strong behavioural tendency to associate to floating objects. It would appear that while this is a natural behavioural tendency, particularly in smaller or juvenile tunas, the proportion of tuna exhibiting this tendency might increase due to deliberate seeding of oceans with floating fish aggregating devices. This has implications for the behavioural and biological characteristics of tunas discussed above.
4. The effect of FADs upon tuna behaviour and ecology

The following chapter reviews evidence to suggest that the increasing use of fish aggregating devices in global purse seine fisheries may be impacting upon the behaviour and ecology of tuna species which show a behavioural tendency to associate to floating objects. It does not deal with the effects of FADs in increasing the vulnerability of tropical tunas to fishing fleets, nor potential threats this technology poses to sustainability of tuna fisheries. Those and related fisheries issues are dealt with in Chapter 6 "Potential impacts of FAD-based fisheries upon global and domestic tuna fisheries".

4.1 Introduction

Tunas are known to demonstrate many different types of association (Scott, 1999; Freon and Dagorn, 2000b). An association in this context refers to “a spatial relation between a species and another species or inanimate object/structure which occurs as a result of a decision by a species to maintain contact, but not for purpose of feeding on other” (Freon and Dagorn, 2000b). The types of association range from those with fixed structures, moving animals or drifting objects (Gooding and Magnuson, 1967; Fonteneau, 1991; Gaertner and Medina-Gaertner, 1999). It is unknown for certain whether these different associative behaviours are driven by a variety of ecological or physiological factors, or have a single common underlying motivation. The theories put forward to explain such associations are still being investigated and intensely debated (Freon and Dagorn, 2000a). These will be detailed and assessed in this chapter.

Of current concern is the behavioural tendency of certain tuna species (predominantly yellowfin, skipjack and bigeye) to associate with floating objects, given that this type of association has become heavily exploited by tropical fisheries around the world (Fonteneau et al. 2000). Early artisanal fishermen noted that tuna would aggregate under floating logs and would search for and fish under these objects (Scott, 1999). More recently, modern fishing fleets have adopted the strategy of deploying artificial “logs” or fish aggregating devices (FADs) to attract large numbers of tuna and improve catch rates (Fonteneau et al. 2000). This deployment has added to existing floating debris, and resulted in man-made objects now accounting for over 50% of floating objects in the oceans (Freon and Dagorn, 2000b). There are currently many theories to explain the attraction of tuna to logs and artificial logs (FADs). The ideas that these objects may act as an indicator of productive areas, as a meeting point, or as a reference point for local and large scale movements/migrations have gained the most credibility, though a much greater deal of research is still required (Freon and Dagorn, 2000a).

Regardless of the reasons, there is increasing international concern surrounding the large-scale seeding of FADs in the world’s oceans, and the potential impact of these upon the both the ecology of tuna species (Freon and Dagorn, 2000b; Marsac et al. 2000) and the sustainability of fisheries that target them (see Chapter 6). There is a growing body of evidence to suggest that FADs may affect the dynamics and structure of tuna schools, their feeding ecology, and possibly act as a barrier against normal movements and migrations (Marsac et al. 2000). Furthermore, these effects appear to be more intense in relation to smaller or juvenile tuna, which show a higher degree of association to FADs than do adults of larger species (Fonteneau et al. 2000). Increased vulnerability and catch rates of juvenile stocks may have serious implications for the population structure and future breeding potential of these species, and therefore for fisheries management and sustainability. Clearly, a better understanding of the effect of FADs upon tuna species and their ecology, is required for good management of tuna resources (Freon and Dagorn, 2000b). The following chapter
details evidence which suggests that FADs are having a significant effect upon many aspects of the biology and ecology of tropical tuna species. It also examines current theories that have been proposed to explain the associative behaviour of tunas, in particular that relating to floating objects and FADs.

4.2 Types of Association

4.2.1 Introduction

Tuna are known to associate with both fixed structures, drifting objects and moving animals. Fixed structures include islands, reefs, seamounts, oil platforms and anchored fish aggregating devices (FADs). Drifting objects include drifting logs, seaweed mats, drifting FADs, boats, and man-made debris/discards (Freon and Dagorn, 2000b). Tuna may also associate with oceanic animals, including other tunas, dolphins, whales, whale sharks and other pelagic species. The associative behaviour of tunas has been demonstrated to vary between species, developmental stages, and regions. It is now recognised that many aspects of migration, foraging and schooling can involve or rely upon associative behaviours. The following section details the various types of associative behaviour exhibited by tunas and the possible reasons for such behaviours, with particular focus on associations to floating objects (logs and drifting FADs). Examining the broader role of associative behaviour in tunas may help in the understanding of those behaviours specific to FAD associations.

4.2.2 Associations with animals

Other tuna: Mixed species schools of tuna are commonly observed in all oceans. This behavioural tendency still requires some investigation, however its thought that such associations result from the benefits that come from schooling such as protection and increased foraging ability (Pitcher and Parrish, 1993). Joining a mixed species school may provide such benefits when too few conspecifics of acceptable size can be found to school with. However, it is also thought that multi-species associations may have costs not associated with pure schools, such as interspecies competition for food resource, increased conspicuousness, and the trapping of the “minority” species into non-ideal migratory and feeding movements (Freon and Dagorn, 2000b).

Marine mammals and whale sharks: Certain species of tuna have been observed to associate to larger marine animals such as dolphins, whales and whale sharks (Hampton and Bailey, 1993). The eastern tropical Pacific is considered the main region where tuna-dolphin associations are common place (Freon and Dagorn, 2000b), and indeed, considerable controversy was generated in this region by the commercial fishing practice of setting on tuna associated to dolphins, due to the high mortality of dolphins that resulted. In general, tuna-dolphin associations comprise of pure yellowfin schools associating to spotted dolphin pods, but other species including skipjack and bigeye have also been observed associating with dolphins (Freon and Dagorn, 2000b). A number of theories have been proposed to explain this type of association. Two of these theories state that tuna may be seeking cover by schooling with dolphins, or are only found together as a result of having the same prey species. However, these seem unlikely as, firstly, tuna don’t directly intermingle with dolphins but remain spatially separated, and secondly, tuna can be found together with dolphins even when they are not feeding. More commonly accepted theories are that tuna initiate the association for potential predator avoidance/protection and to take advantage of dolphins sonar based food-finding ability (Freon and Dagorn, 2000b). Dolphins may tolerate the association as tuna, which generally swim deeper, might act to flush prey up towards the dolphins.

In general, associations between whales or whale sharks and tuna are not common in most oceans, however in the western tropical Atlantic, nearly half of the yearly yellowfin catch is caught in association with whales (Gaertner and Medina-Gaertner, 1999). In the western
Pacific, pure schools of skipjack and yellowfin were commonly caught in association with sei and minke whales (Hampton and Bailey, 1993). Theories for why these associations occur are fairly weak at present, but may be due to these animals having similar prey and distributions (Freon and Dagorn, 2000b). Tuna have also been noted to associate to whale carcasses, perhaps for similar reasons to those for associating to logs (see below)(Freon and Dagorn, 2000b).

4.2.3 Associations with fixed structures

Associating to fixed structures is a common behavioural trait in many tuna species and in most oceans, and include associations to seamounts, reefs, islands and anchored FADs. Many other types of pelagic fish also associate with these fixed structures. Various theories have been put forward to explain these behaviours. For example, seamounts are often associated with productive regions, due to nutrients brought to the surface by upwellings of deeper currents, forced by the slope of the seamount. It has been proposed that this productivity may be the primary reason for tuna associating with these structures. However, Fonteneau (1991) noted that that richness was not high at all east tropical Atlantic seamounts, and yet tuna still associated with these areas. More likely it appears that fixed structures such as seamounts, reefs and anchored FADs, act as spatial reference points by which tuna and other pelagic species can navigate during daily movements and extended migrations (Fonteneau, 1991; Holland et al. 1999). Fonteneau (1991) also noted that the size classes of tunas associated to and caught near seamounts were smaller than those in the open ocean. This observation is similar to observations of size classes under drifting and anchored FADs, and as will be discussed later, suggests that such associative behaviours are related to size and maturity in tuna.

FADs may have different significance to tuna behaviour and ecology, depending on whether they are fixed or anchored (see sections 4.3 and 4.4). Anchored FADs effectively act as fixed structures, which do not move with oceanic currents. The most popular theory to explain tuna associations to fixed objects, as discussed above, holds that these objects can be used as a spatial reference point for use in navigation and orientation. However, the motivations behind associations with drifting FADs are subject to more intense debate and are discussed below.

4.3 Why do tuna associate to floating objects

A number of theories have been proposed to explain why these species may associate to drifting objects, such as logs and FADs. The following sections discuss the pros and cons of each of these theories.

4.3.1 Shelter from predator

This theory states that the under structure of a FAD (or submersed branches of a log) might be used as a refuge from predators, or as a way of ensuring that a predator cant approach from behind in the tunas “blind spot”(Freon and Dagorn, 2000b). Many smaller species of fish have been observed to use floating objects as shelter when predators are near by (Gooding and Magnuson, 1967). However, many tuna would be too big to use such shelters and certainly such objects don’t provide shelter for even small schools, let alone schools massing over 100 tonnes (Freon and Dagorn, 2000a). Furthermore, sonic tracking studies have shown that fish are rarely directly under a floating object, but often dispersed within a few hundred meters. Deeper swimming tuna will tend to be even further dispersed, up to 1500m (Josse, 2000).

4.3.2 Concentration of food supply

Floating objects tend to attract smaller fishes, not just larger pelagic species such as tunas (Kojima 1956). This theory holds that it is these concentrations of smaller potential prey fish,
which would act to attract tunas to the floating object. However, against this theory is the fact that the amount of smaller fish attracted would never support the large tuna schools that are known to aggregate under logs and FADs (Freon and Dagorn, 2000a). Furthermore, gut contents analysis of tuna caught under drifting FADs suggests that they do not forage on other associated fish and in general may be feeding less than tuna from the same region which are free-schooling (Potier et al. 2001; Menard et al. 2000b).

4.3.3 Spatial reference

Floating objects can provide a reference point for tunas in what is generally an environment with few structural reference points (Klima and Wickham, 1971; Klimley et al. 1988). However, some researchers reason that because free drifting objects such as drifting FADs and logs will change position in relation to the surrounding environment, this theory would seem more likely to apply only to anchored FADs (Freon and Dagorn, 2000a).

4.3.4 Comfortability stipulation

This theory proposes that tuna might stay close to FADs/logs when resting and digesting food caught on foraging expeditions (Batalyanis, 1992; Freon and Dagorn, 2000a; Freon and Dagorn, 2000b). However, this theory might only make sense if logs acted as a meeting point also, as tuna should not need to associate to an object simply to rest and digest food (See 4.3.6).

4.3.5 Indicator log

This theory states that natural floating objects, such as logs washed down from rivers, will act as indicators of productive areas (or areas likely to have high concentrations of tuna prey) (Reviewed in Freon and Dagorn, 2000b). This is based on the idea that these objects will be transported by the same currents that transports river nutrients, which are known enhance the productivity of oceanic waters. Nutrients enhance planktonic production, which attracts small school fish and other planktivores, which are the primary prey of tunas. However opponents to this theory point out that there is no evidence as yet that floating objects are more easily detected than prey (Freon and Dagorn, 2000b). Why wouldn’t tuna simply look for the prey itself, rather than floating logs? However, some researchers have suggested that if logs tend to accumulate in convergence zones, which are highly productive areas, it may be that when prey is scarce, tracking a log might increase the tuna’s chances of encountering such an area with increased prey levels. Conclusive proof of accumulation of logs in convergence zones is still needed however.

4.3.6 Meeting point

This theory states that floating objects may be used as a meeting point, to increase the likelihood of encountering conspecifics or other tuna species with which to school, while conserving energy which otherwise might be spent searching (Dagorn and Freon, 1999). This theory is supported by modelling studies which find that logs may hold potential as meeting points for school formation (Dagorn and Freon, 1999). Small tuna require more numbers to reach the critical schooling biomass, and are more commonly found under FADs than large tunas. However, opponents to this theory argue that it has not been shown, and does not logically follow, that floating objects will be more easily detected than other tuna (Freon and Dagorn, 2000b). Therefore, why would tuna not simply swim directly to other tuna within their detection range, rather than to a floating object? Furthermore, the fact that small tuna are caught under FADs in larger numbers may be partly related to the fact that the larger tuna swim deeper and may be less susceptible to capture. These theories and questions require a further investigation. Investigations into the sensory capabilities of tunas are required in order to explain why floating objects might be more easily detected than other tuna.
4.3.6 Generalist meeting point theory

Freon and Dagorn (2000b) proposed that perhaps the “meeting point” is a common underlying motivation driving not just associations to floating objects, but any of the associations formed by tunas (i.e. to whales, seamounts etc). They suggest that all of these associations act to increase the chances of tunas finding conspecifics with which they may join and form pure schools, for foraging or migrations. In other words, associating to a fixed or drifting structure, which may be detectable by other conspecifics, means that these objects can be used as meeting points. Waiting at a meeting point would be less costly than actually searching for conspecifics. However, again this theory only seems plausible if the objects to which they associate are more easily detectable than other tuna. For fixed objects this seems reasonable, as various sensory mechanisms combined with “memory” might allow fixed points to act as meeting places. For example, large natural structures such as seamounts may be detectable at long distances due to associated geomagnetic anomalies which tuna may be able to detect using specialised magnetite structures in their heads (Walker et al. 1997). However, drifting objects change position with respect to the surrounding environment, and therefore need another explanation for why they might be more easily detected. (Freon and Dagorn, 2000b) suggest that, on a case by case basis; dolphins are noisy and therefore easily detectable, as are whales and whales sharks, with these species having the added benefit of increased food finding efficiencies (Freon and Dagorn, 2000b). Mixed schools might function to allow conspecifics to find each other and form their own schools, with most mixed schools comprising a minority species. However, fisheries data of the catches made on free and FAD associated schools in the Eastern Atlantic suggest that the occurrence of free-mixed schools has dropped since FADs have proliferated in this region, indicating that FADs (or floating objects) may be a more preferred meeting point than free mixed schools (Freon and Dagorn, 2000b).

It is unknown whether behavioural associations to floating objects are “learned’ or “evolved” (Freon and Dagorn, 2000b). It seems unlikely that these behaviours are learned, because one might then expect a predominance of older “wiser” tunas under these objects, but this does not occur. It may be that these behaviours have evolved, and that the different types of associations that predominate in different oceans have all evolved separately towards a common purpose, i.e.; meeting conspecifics (Freon and Dagorn, 2000b). These trends also vary with age. For example in the eastern Pacific, young yellowfin commonly found under FADs, and older yellowfin with dolphins (Freon and Dagorn, 2000b). This trend is likely because the younger yellowfin may be unable to keep up with dolphins, and furthermore, might fall prey to the dolphins or adult yellowfin that associate also.

4.3.8 A multiple motivation theory

Each of the theories described so far has been proposed separately. However, it seems quite possible that there may be multiple factors motivating tuna to associate to (drifting) floating objects. There is no reason to believe such associations might not benefit tuna in more than one way. The following theory presents a combination of elements from each of the previous theories, and is supported by a number of recent observations of tuna behaviour and ecology. Tuna might use floating objects as a meeting point, a site of comfortability, and an indicator of productive areas:

Gut contents analysis of tuna caught under FADs and in free schools suggest that most tuna do not feed under floating objects (with the exception of predatory adult yellowfin which cannibalise juveniles) (Potier et al. 2001; Menard et al. 2000b). But they do return to FADs after foraging expeditions, creating a daily pattern of associating and then dispersing to feed (Chabanne, 1991; Cillaurren, 1994; Holland, 1996; Bach et al. 1998). Hence, association to FADs (or logs) is likely to represent time to rest and digest food caught during previous foraging period. This supports the “Comfortability theory”.
Given that logs will travel on the same currents that transport river nutrients (from which logs originate), and given that river nutrients promote productivity and prey forage, tuna might associate to logs while resting so as to stay in touch with the productive region in which prey concentrations are likely to be high, without wasting energy trying to actively track and stay in touch with specific prey schools/patches. Furthermore, logs typically accumulate in convergence zones (Freon and Dagorn, 2000b), which are known to be very rich and productive areas. Thus by “following” a log, tuna are more likely to encounter such a productive region, with minimal energy expenditure. That this tendency is apparent in smaller or younger tunas may be due to their lower fat and energy reserves (refs) (i.e., they can afford less energy expenditure in the search for prey). Hence the “comfortability” and “indicator log” theories are not mutually exclusive.

Two tuna species in the same region can target different prey types (Potier et al. ). Mixed tuna schools generally have a minority species, whose movement and prey selection may be dominated by the choices of the dominant (more numerous) species (Cayre and Holland, 2000). Aggregating under floating objects may offer the opportunity to meet with conspecifics, (while maintaining contact with the productive region) with which to school and forage in the next feeding period (Freon and Dagorn, 2000b). Aggregating (similar to schooling) also reduces the likelihood of an individual encountering or being eaten by predators (see section 3.4.2 on schooling advantages). At the same time, as stated before, tuna aggregations can stay in contact with the productive region by drifting with the log. Thus a third element, logs as “meeting points”, may also play a role.

Overall, there seems reasonable evidence to suggest that aggregating to natural floating objects such as logs, might from an evolutionary and ecological viewpoint, hold the same advantages that free-schooling offers, with additional advantage of energetic savings while maintaining contact with prey-rich regions.

The following section discusses known and potential effects of increasing FADs deployment upon the natural biology and ecology of tropical tuna species.

### 4.4 Effect of FADs upon tuna schooling behaviour

#### 4.4.1 Introduction

As discussed in the previous chapter, schooling is an extremely important mechanism in the ecology of pelagic species, and is thought likely to afford many benefits such as predator protection, increased foraging efficiency, and reduced energetic expenditure while travelling (Stocker, 1999; Freon and Dagorn, 2000a). Prior to the proliferation of FADs in tropical and subtropical regions, free-schooling tuna were very commonly observed. However, since this proliferation, a number of effects upon schooling dynamics of tuna have been noted. These include:

- reduced free-school abundance (Fonteneau et al. 2000; Marsac et al. 2000);
- a disparity between the age and size of free and associated schools (Menard et al. 2000b; Freon and Dagorn, 2000b);
- increase in mean school biomass of tuna under FADs (Fonteneau 1992);
- changes in school movement patterns (Menard et al. 2000a) and in school structure (Josse et al. 1999; Josse, 2000).

These effects are discussed below.
4.4.2 School composition

Before FADs became popular in tropical regions, both free-swimming, *single* species (pure) as well as *mixed* species schools were commonly observed and captured. However, since the massive seeding of FADs, free-swimming *mixed* species schools are less commonly seen or caught in these regions (Fonteneau et al. 2000; Marsac et al. 2000). It appears that these schools are now predominantly associated to FADs (Fonteneau et al. 2000; Marsac et al. 2000). Furthermore, FAD associated bigeye and yellowfin tuna tend to be both younger and/or smaller than those found in free schools (Menard et al. 2000b; Freon and Dagorn, 2000b), which suggests that there is a behavioural and physiological control on this type of aggregation which is related to ontogeny (Marsac et al. 2000). Smaller species, such as skipjack, and the juveniles of larger species, such as yellowfin and bigeye tend to predominate (Marsac et al. 2000). Although significant numbers of larger yellowfin are occasionally associated with these, it is thought these may be present to predate on smaller tuna, rather than associating to the FAD (Potier et al. 2001; Menard et al. 2000b).

4.4.3 Schooling size classes

Despite the fact that FAD associated tuna tend to be smaller, FAD associated schools (or at least FAD associated catches) tend to have a larger biomass than free-swimming schools (Fonteneau 1992). These larger schools are reflected in increased CPUE (catch rate as kilograms per set) (Scott, 1999). In addition, there is some anecdotal fisheries evidence that larger logs appear to attract larger schools, and that logs close to other logs have smaller schools. The latter trend might be expected, as the added logs "share" the tuna in the region which had detected their presence.

4.4.4 School structure

Studies of tuna schools under anchored fads have demonstrated that there is a distinctive structure to these aggregations (Josse et al. 1999; Josse, 2000). Three classes of aggregation have been identified, each of which can occur in isolation, or in association with the other classes underneath a FAD. These are shallow schooling, intermediate scattered and deep scattered. Shallow schooling aggregations are characterised by smaller, closely spaced individuals that stay within roughly 50m vertically and 200m horizontally of the FAD. Intermediate scattered tuna aggregations comprise slightly larger individuals, more widely spaced and between 0-200m in depth and within a horizontal distance of the FAD of 700m. Deep scattered aggregations comprise much fewer, but larger individuals, scattered widely about the fad (up to 1.5 km away) and at depths between 100 and 350m) (Josse, 2000). However, whether these aggregating and schooling dynamics occur under drifting FADs is unknown at this time.

4.4.5 School fidelity: evidence from baitboats

Baitboating uses a similar principle to FAD based fishing, whereby the boat is used as the floating object (or FAD) to which tuna schools associate. These boats can stay associated with an aggregation or school of tuna for months. However, they differ from FADs in that baits are thrown overboard and night-lights used to encourage tuna to stay with the boat and attract new fish (Hallier and Delgado de Molina, 2000).

A baitboat based tag and recapture study revealed numerous details about the schooling characteristics of baitboat associated tunas (Hallier and Delgado de Molina, 2000), which may have some relevance to the schooling behaviour of tunas in relation to FADs. Baitboat associated schools off Senegal comprised skipjack, yellowfin and bigeye species. These all showed considerable fidelity to their school over long periods (months), although the likelihood of fish leaving a school increased with time. Yellowfin were the quickest to leave a school, while bigeye appeared to be the most faithful to their original school. This finding is
A Review of the Impact of FADs on Tuna Fisheries

in agreement with other research on association times of these species to seamounts (Holland et al. 1999). Interestingly, purse seiners operating in the same and adjacent areas at the time caught almost exclusively skipjack, while baitboats were catching all three species (18%YFT, 48% SJT, 34%BET). Baitboat capacity in the Atlantic is around 125 tonnes and they are continually harvesting from the school (and then "tranferring" the school to another boat while they travel to Port to unload). However, the schools themselves maintain a biomass of around 100 tonnes, so it is clear that considerable immigration, and very little emigration, is occurring in these baitboat-associated schools. The high recapture rates of tuna tagged and released into the same school suggest high exploitation rate under the boats (i.e. few tuna leave, so eventually all will be harvested). Unfortunately this study only tagged smaller tuna, so the school fidelity of larger tuna is unknown.

While one might suggest that the motivation for tuna to stay associated could differ from FADs, it is unlikely to be as a source of food (far too little bait is thrown over to feed the large schools that gather). Perhaps the bait acts as an additional “indicator” of environmental richness. Once tuna have associated to a baitboat, they can remain associated for extremely long periods of time (months, to over a year) (Hallier and Delgado de Molina, 2000). However, the fishermen also maintain this association to some degree themselves, so relating baitboat associated motivations to FADs or other drifting objects should be done cautiously.

4.5 Effect of FADs upon tuna feeding behaviour and diet

4.5.1 Introduction

There is a growing body of evidence that FAD associated tuna differ in their feeding ecology from free-schooling or non-FADs associated tuna. These feeding dynamics can vary further depending on whether tuna are associated to fixed (Brock, 1985; Buckley and Miller, 1994) or drifting FADs (Freon and Dagorn, 2000a). To date there has been two main studies comparing the drifting FAD-associated and free-schooling feeding ecology of tunas (Potier et al. 2001; Menard et al. 2000b). These concluded that FAD associated and free-schooling tuna differ in their food consumption and diet composition. Other studies have demonstrated differences in feeding time, pattern, and condition (Marsac et al. 2000). Drifting FADs may also offer some larger tuna predatory (and cannibalistic) opportunities (Potier et al. 2001). Additionally, anchored FAD studies have demonstrated that diet can vary between tuna species inhabiting the same area and between areas. Such variations in feeding behaviour and ecology are explained in more detail below.

4.5.2 Drifting FADs

Free-schooling and FAD associated tuna differ in their diet composition and the amount of prey consumed (Potier et al. 2001; Menard et al. 2000b). Menard et al (2000) examined gut content of FAD-associated and free-schooling skipjack, yellowfin and bigeye in the Gulf of Guinea. Most FAD associated tuna were small in size (plus some large yellowfin), while free-schooling tuna were mostly large yellowfin. There was no variation in level of food consumption between species within each school type (FAD associated or free schools) but there was a difference in number of tuna with food in their stomachs when comparing FAD associated tuna against free-schooling tuna. 85% of FAD caught tunas (mostly small skipjack) had empty stomachs compared to 25% of free-schooling tunas. A more recent preliminary analysis of stomach content of yellowfin, skipjack and bigeye tunas caught free-schooling and under FADs showed similar trends (Potier et al. 2001). FAD associated skipjack had higher incidence of empty stomach than free-schooling skipjack. Diet varied with species and size. Free-schooling skipjack were feeding exclusively on crustaceans whereas FAD associated skipjack were more opportunistic and varied in their prey selection (including fish, crustaceans and other). Juvenile yellowfin preys mainly upon fish and some crustaceans. Part of this diet was replaced by cephalopods in adult yellowfin, while FAD associated bigeye
preyed mainly upon cephalopods (Potier et al. 2001). It is possible that diet relates to different behaviours (i.e. diel vertical migration) between species and size groups (Potier et al. 2001). Available prey (mainly crustaceans) likely influence prevalence of different species in an area (i.e., skipjack most common in current survey). Both skipjack and yellowfin under FADs had diets that indicated they could feed on prey not found exclusively under FADs. This study also suggests that these tuna leave the FADs during the day and may form loose formation free-swimming shoals while foraging (Menard et al. 2000b).

These results, and the small amount of potential prey normally found under FADs, imply that feeding off FADs associated prey is not a primary motivation in the association of smaller or younger tunas that predominate at FADs (Freon and Dagorn, 2000a). Not surprisingly, given their low food consumption, tuna associating to drifting FADs have been shown to have a lower condition factor (i.e., skinnier) than free-schooling individuals (Marsac et al. 2000). It should be noted however, that larger tuna (e.g. yellowfin) will feed on the younger tunas or other fish that are associated to drifting FADs. Therefore, for more mature individuals, feeding may be a motivating factor in their association (Menard et al. 2000b). The fact that drifting FAD associated tuna feed less may be connected to the tendency of some fishermen to seed FADs in areas which are typically unproductive and have little prey.

Tuna associated to FADs may not remain entirely associated for 24 hour periods. Sonar and tracking observations suggest that tuna associated to drifting FADs are likely to leave the FAD during the day to forage, and then reassociate to the drifting FAD at night (Holland et al. 1990). In contrast, tuna associated to anchored FADs appear to leave the FAD at night to forage and re-associate to the FAD during the day (Holland et al. 1990; Chabanne, 1991; Cillaurren, 1994). The exact reasons for this difference in daily feeding pattern is as yet unknown.

4.5.3 Anchored FADs

It is unlikely that tunas associated to anchored FADs will gather under these structures to feed, for these structures do not attract enough prey to support the feeding needs of a school of tuna. There is however, some evidence for occasional opportunistic foraging (Marsac and Cayre, 1998), with observations on anchored FADs suggesting a tendency for tuna to position themselves upstream (up current) and pick off current borne prey items (Franks, 2000). There is evidence also for cannibalism by adult yellowfin upon juveniles of the same species under anchored FADs (reviewed in Buckley and Miller, 1994).

There is a large degree of regional variation in the feeding of tunas associated to anchored FADs. These variations were highlighted by (Buckley and Miller, 1994) who compared his own findings of feeding of yellowfin under FADs off American Samoa to previous yellowfin studies in the Philippines, French Polynesia, and Hawaii. In the Philippines, large yellowfin were found to cannibalise smaller YFT (in addition to other small associated fish) under FADs, but not in the open ocean (Buckley and Miller, 1994). No cannibalism was noted in FAD associated yellowfin in French Polynesia or Hawaii however. In the Philippines study, large FAD associated yellowfin had higher stomach content than large unassociated yellowfin, and a similar situation was observed in the French Polynesia study, with fewer FAD associated tuna having empty stomachs. However the Hawaii study demonstrated that diet composition can differ between FAD-associated (shrimp only) and unassociated yellowfin (assorted organisms) (Brock, 1985). The latter study concluded that the tapping of food resources otherwise not utilised by yellowfin furthermore suggests that Hawaiian FADs are truly causing an enhancement of these resources (Brock, 1985). However, Buckley and Miller (1994) demonstrated for yellowfin off American Samoa that there was little dietary difference between FAD associated or unassociated yellowfin tuna.
While the trends are region specific (Buckley and Miller, 1994), it is important to note that while preliminary investigations indicate that drifting FAD tuna have lower food intake than free-schooling tuna, the opposite may be true for anchored FAD tuna. This supports the argument that the reasons (motivations) for associating to drifting and anchored FADs might differ. However, most anchored FAD studies were conducted in nearshore island regions where prey levels may be naturally higher than those available to offshore free-schooling counterparts. Further research into these relationships is required.

4.6 Impact of FADs upon tuna migration and movements

4.6.1 FADs as ecological traps

Free-schooling tuna typically show large daily displacements (movements). However, given that tuna also show a natural behavioural tendency to associate to floating objects, it is not surprising that their movements may differ in FAD seeded areas when compared to their normal free-schooling movement patterns (Menard et al. 2000a). Currently there is a growing concern that areas seeded with high concentrations of FADs might disrupt the natural migratory movements of tunas (Menard et al. 2000a), “trapping” them in areas with large numbers of FADs (as opposed to being trapped by a single FAD).

The “Ecological Trap” hypothesis presents some evidence to suggest that FADs will have a negative biological and ecological impact upon tropical tunas, regardless of whether or not the fish are actually removed from the population by fishing (Marsac et al. 2000a). In other words, their effect extends beyond the danger posed by increased vulnerability and overfishing. The ecological trap hypothesis consists of three parts, which state that because smaller tuna can quickly aggregate to drifting FADs, and maintain strong associations for extended periods, FADs seeded in tropical currents may transport tunas away from their traditional forage areas to areas of low productivity, thus resulting in reduced growth and condition, and increased natural mortality.

Fast, strong and lasting associations: Experiments have demonstrated that large numbers of tuna may aggregate to drifting FADs soon after deployment, in some cases this period being only a matter of hours, and in others a few days (reviewed in Marsac et al. 2000a). Tagging of tunas under baitboats, which are similar to drifting FADs in their ability to aggregate smaller tuna, demonstrated that schools can maintain associations to drifting objects for periods of several months (Hallier and Delgado de Molina 2000). Tagging and recapture of the same tuna from under a particular drifting FAD, on dates up to 90 days apart (Takahashi et al. 1988), further suggests fidelity to FADs. While the results from this study couldn’t prove that tuna hadn’t left the FAD in the mean time, it did demonstrate that they had not undertaken the large oceanic movements that they might normally be expected to undertake in such a time frame (Marsac et al. 2000). In contrast to this, a study on tagged tuna caught under a drifting log demonstrated that these tuna had left the log after only a few days (Hampton and Bailey 1999). However the same study also tracked tuna tagged under drifting FADs, and found that the larger daily displacements of tuna when compared to anchored FADs resulted from the displacement of the FAD (to which the tuna associated) by the currents they travelled on. Despite the large variability in the strength of individual tunas associations to drifting objects, Marsac and colleagues (2000) suggest that FADs might “trap” tuna within an area, not necessarily due to long lasting associations to single objects, but as a result of the combined influence of many such objects within a relatively small oceanic region. In partial support of this hypothesis, they stated evidence that in some regions virtually all mixed species schools of tuna are now caught under FADs, when once they were caught as free-schools (Fonteneau et al. 2000). However, the validity of the hypothesis is still to be empirically tested and proven.
**Movements and distribution effects:** The second part to the ecological trap hypothesis states that large numbers of seeded FADs have the potential to alter the natural movement and migration patterns of smaller tropical tunas (Marsac et al. 2000). It is believed that tuna may have originally evolved to associate with logs. These tend to be carried by currents that travel towards convergence areas, resulting in an accumulation of logs in these regions (Ariz Telleria et al. 1999). Such convergence zones are typified by high forage concentrations, hence a tuna associating to a log may use it to locate areas with high prey concentration (Ariz Telleria et al. 1999). However, FADs tend to be seeded in equatorial currents, and given that they subsequently exhibit zonal drift with these currents, the tuna which are associated to these FADs will be artificially transported from the one area to another. In the absence of FADs these tuna populations would likely show a different movement pattern. Thus, FADs may have a negative impact upon tuna populations by redirecting movements and distributions. Marsac and colleagues (2000) stated evidence from the East Atlantic Ocean to support this hypothesis. East Atlantic skipjack populations once tended to migrate polewards (i.e. north-south) from the Gulf of Guinea to access highly productive regions such as those off Senegal and Angola. However, current large scale deployment of FADs, of over 3000 per season, into westward moving equatorial currents (specifically the South Equatorial Current) is likely to result in tuna becoming trapped under FADs and transported to offshore areas of warm water and poor trophic conditions (i.e. trapped in unproductive regions). It seems possible that this theory would explain the much greater catch of tuna in the western part of this region in recent years since the development of the drifting FADs fishery, although it is possible that this may be due to FADs increasing the vulnerability of schools which would previously been free-schooling in the western area (Marsac et al. 2000). This latter explanation is supported by the fact that catches increased in the eastern region at the same time (a region which had previously been exploited). Further research is required into this phenomena. However, (Marsac et al. 2000) pointed out that the increase in CPUE (based on tons/fishing day) was greater in the western sector than the eastern after FADs were introduced. However examination of this data shows that the increase in CPUE was roughly double for both sectors, and the CPUE was not maintained at these high levels in the western sector but drop in the mid-late 90s.

**Growth, condition and natural mortality:** The third part to the “ecological trap” hypothesis states that the ability of FADs to transport associated tuna away from their normal productive feeding grounds to areas with low forage, will result in tuna with lower growth rates, lower condition and higher natural mortality (Marsac et al. 2000).

Evidence for decreased growth rates of tunas caught under FADs in the East Atlantic has been presented in the form of decreasing sizes of yellowfin and skipjack tunas, as well as decreasing weights as estimated from commercial catches in this region since 1991. This trend is supported by observations that tuna associated to FADs will tend not to feed on other associated fish species and that tuna under drifting FADs tend to have much higher percentage of empty guts than do tuna caught from free schools in the same region (Potier et al. 2001; Menard et al. 2000b). The latter suggests that drifting FADs do not have a direct forage function for tunas as such. However, it should be noted that such trends in size and weight could also be due to overfishing or overexploitation of the tuna population as a result of the huge number of FADs deployed in the area. It could also indicate increased competition for feed among individuals. A reduced feed intake would suggest reduced nutritional condition. Marsac and colleagues (2000) presented a regression of length and weight of FAD and free-schooling skipjack which suggests that FADs caught tuna are indeed in worse condition than free schooling counterparts. In addition to effects upon growth and condition, it is thought that aggregating smaller tuna to localised points may make them more vulnerable to predation. Indeed there is considerable evidence that large adult yellowfin tunas can aggregate to FADs so as to feed on the juvenile tuna that are already associated. Delmendo (1991) reported that 70% of the gut content of adult yellowfin caught under drifting FADs comprised juvenile yellowfin. Other predators are also likely to make easy pickings of smaller
tuna which aggregate under FADs in unproductive areas and hence mortality increases through competition for food also.

4.6.2 FADs as navigation points

The other proposed effects of FADs upon tuna movements is that these objects might be visited and used by tuna as spatial reference points, to orient themselves during migrations (Freon and Dagorn, 2000a). This theory seems more likely to apply to anchored FADs, as drifting FADs do not represent a constant and fixed point of reference with respect to the surrounding environment. Considerable investigation into the behaviour of tuna in association with anchored FADs has been conducted over the past 15 years, resulting in a greater knowledge base of tuna behaviour under anchored FADs than is currently available in relation to drifting FADs. As with drifting objects, anchored FADs tend to attract the smaller (juvenile) size classes of bigeye and yellowfin as well as adult skipjack (Holland, 1996). The effect of increasing numbers of anchored FADs upon large scale tuna movements is unknown but, given that these structures seem likely to serve as reference points, similar to seamounts, reefs, islands and other fixed structures, the effect upon tuna migration may be small, simply giving them more points by which to navigate. While there are differences in the fine-scale movement patterns of tunas associated to anchored FADs when compared to free-schooling tuna, these behaviours don’t seem to differ from those of tuna associated to other fixed structures such as seamounts (Fonteneau, 1991) and reef drop-offs (Holland et al. 1990).

4.6.3 Range of attraction and positioning

Investigations to date have determined that the range of attraction of anchored FADs is likely to be between 5 and 10 nautical miles (Cayre, 1991; Holland et al. 1990, Holland, 1996) and the aggregating effect of these devices extends to 100’s of meters below the surface (Josse et al. 1999; Josse, 2000). However, the means by which tuna detect FADs from such distances are unknown and require investigation. In contrast to the night-time association to drifting FADs, tuna tend to aggregate around anchored FADs during the day, and then leave and disperse at night time, presumably to forage on vertically migrating prey (Holland et al. 1990). Aggregating tuna tend to position themselves upstream (up current) of anchored FADs, though the reasons for this are unknown. It may have to do with opportunistic feeding on prey which have detected and are tracking to the anchored FAD. Associated tuna also tend to swim closer to the surface than do free swimming schools of same species (Holland, 1996). The reasons for this are yet to be determined. (Kakuma, 2000a) noted that anchored FADs are visited regularly on a seasonal basis by up to three different age cohorts of yellowfin tuna. These tended to vacate the FADs in winter and reappear in spring and summer months. Catches of tuna at these FADs was noted to be highest when current speed was lowest and the authors hypothesised that tuna may vacate FADs when current speed makes the energetic cost of staying associated too high (Kakuma, 2000a).

4.6.4 Tracking evidence

A large number of tracking studies have now been conducted on individual skipjack, and sub-adult yellowfin and bigeye tunas (Holland et al. 1990; Cayre, 1991; Marsac and Cayre, 1998; Bach et al. 1998; Klimley and Holloway, 1999; Dagorn et al. 2000b; Dagorn et al. 2001). These studies have demonstrated that while the above generalisations hold true, there is a considerable amount of intra and inter individual variation in the behaviour of tuna in response to the presence of FADs (Holland, 1996; Bach et al. 1998). This variability seems likely to depend on the local environment (e.g. prey) and on individual biological differences (internal state and history) (Dagorn et al. 2000b). Furthermore, despite different diel patterns of association, there is a similar range of behaviours exhibited by tuna associated to drifting objects as to anchored (Bach et al. 1998). Three basic behaviours exhibited by tuna tracked around anchored FADs are: a) leave FAD and don’t return, b) stay at FAD during study and don’t leave, c) associate to FAD during the day and disperse at night (Bach et al. 1998). The
A Review of the Impact of FADs on Tuna Fisheries

last behaviour is the most commonly observed both from tracking studies of individual tuna and from sonar observations of aggregations under FADs (Josse, 2000), particularly in relation to yellowfin tunas. A note of caution should be added however, as the effect of capture and handling stress upon tuna behaviour after release has not been investigated in any of the tracking studies to date. It has been suggested that an injured fish might associate to an object while recovering from injury of stressful exertions (Dagorn et al. 2001).

4.6.5 Anchored versus drifting FADs

It would seem likely that the motivation behind tuna associations to drifting or anchored FADs will differ. Tuna are likely to be able to distinguish between a drifting and an anchored FAD through the visual (and possibly hydrodynamic) presence of an anchor line and the stationary nature of anchored devices with respect to surrounding environment (Kojima, 1956). This seems even more likely when one considers that the daily behaviour patterns (e.g. time of feeding) of tuna may differ between the two FAD types (Holland et al. 1990). Note there have only been a few preliminary comparative studies to date. However, if the motivations behind such associations differ, and behaviours differ, then it seems very likely that anchored and drifting FADs will differ in their impact upon tuna ecology and therefore upon tuna fisheries. This may act to further complicate the assessment of stocks based on fisheries data. The common factor is that, regardless of reasons for associations, both types of FAD aggregate and concentrate skipjack and young yellowfin and bigeye, making these groups more easily exploited by fisheries.

4.7 Discussion of ecological impacts

Tuna aggregate under natural floating objects such as logs. Hence their behavioural tendency to associate to fish aggregating devices (artificial logs) is a natural but misplaced behaviour. The massive increase in the number of floating objects in the ocean, which might trigger such behaviours, is primarily a product of FADs seeding by tropical fisheries. The main effects of this trend upon tuna ecology are:

- The behaviour and biological characteristics of tuna associated to FADs differs in numerous respects when compared to their free-schooling characteristics. These differences are evident in many aspects of their schooling, feeding and migratory behaviours.
- As a result of FAD seeding, the number and density of floating objects in the ocean is now much higher. The likelihood of tuna encountering a floating object is much higher and therefore the proportion of tuna exhibiting this form of associative behaviour is much higher than would naturally occur. This represents a potential shift in the behaviours, particularly of skipjack, juvenile yellowfin and bigeye tuna.
- The areas in which drifting FADs are seeded are often offshore and unproductive. The attractive power of FADs (perhaps as false indicators of productive regions) may have the capacity to change the distribution patterns of tunas and even “trap” tunas in non-productive regions (with associated flow on effects to condition, feeding and migration).

As will become evident in the following chapters, FADs associated tunas are more vulnerable to fisheries than free-schooling tuna, and the implications of this to tuna stocks will be discussed.
4.8 Summary and Conclusions

This chapter has explained how certain aspects of tuna biology and ecology differ depending on whether tuna are associated to FADs or are free schooling, including aspects associated with schooling, feeding and migratory behaviours. It has presented a review of evidence which suggests that the increasing seeding of FADs in tropical and subtropical waters may have negative impacts upon tuna movements, with implications for their growth, condition and productivity. However, there is still a need for considerable research into all these factors.

The overriding factor remains that there is simply not enough known of many aspects of tuna biology and behaviour in relation to schooling and associative behaviour. Until a greater level of research into these issues has been achieved, the reasons for tuna association to FADs will remain uncertain. There is a requirement for more tracking studies which take into account environmental conditions and factors, so as to better understand the motivations driving these behaviours (Dagorn et al. 2000b). Modelling studies are currently trying to determine motivations based on the limited knowledge of these species ecology (Dagorn et al. 2000). Detailed knowledge is required of the biological processes involved in such behavioural tendencies, if accurate indices of abundance are to be formed for the assessment of exploitation effects (Freon and Dagorn, 2000b). FAD based fishing has changed the dynamics of the catch per unit effort (CPUE) indices, and quite probably the relationship between CPUE and actual abundance. This relationship has and may continue to change as the technology involved in FAD based fishing continues to become more advanced and efficient. Many of the questions regarding tuna associative behaviour are currently being addressed experimentally as part of the ECOTAP Project, a combination of research interests from EVAAM, IFREMER and ORSTOM (Bach et al. 1998). The following two chapters outline the effects FADs have had on fisheries catches and implications for fisheries sustainability.
5. Global catch statistics for yellowfin, skipjack and bigeye tunas

5.1 Introduction

Global catches of yellowfin, bigeye and skipjack tuna have been increasing steadily ever since tuna fisheries records were first systematically introduced in the mid 1900s (Figure 5.1). In 1998 the world catch of these three species peaked at just over 3.5 million tonnes. Of this, nearly 1 million tonnes was caught by purse seiners using FADs. The massive increase in the proportion of tuna caught under FADs has occurred since the expansion of this fishery from the late 1980s. A large proportion of this catch comprises a smaller size class, consisting of skipjack and juvenile yellowfin and bigeye. Consequently there is now considerable worldwide concern that FADs might contribute to growth and recruitment overfishing of these species (concerns outlined in Chapter 6).

The following chapter details trends in global catches of yellowfin, bigeye and skipjack. These trends are analysed by ocean, species, and gear. Particular emphasis is placed on the increasing catch of these species taken under FADs and how this compares with purse seine catches taken on free schooling tuna and catches taken by other gears such as longline. These analyses will set the scene by which the ocean-wide impact of current catch trends upon future sustainability of tuna fisheries will be analysed in Chapter 6.

5.2 Data

5.2.1 Data sources

The following graphs and figures have been compiled using data from reports and websites of the following sources:

- Inter American Tropical Tuna Commission (IATTC)
- Indian Ocean Tuna Commission (IOTC)
- Secretariat of the Pacific Community (SPC)
- Food and Agriculture Organisation (FAO)
- International Commission for the Conservation of Atlantic Tunas
- Other, non-online sources.

These data sources are detailed in Appendix 11. It should be noted that the majority of data are presented using cumulative graphs, a factor which should be kept in mind when comparing between categories within a single graph.

5.2.2 Data range and quality

Different databases varied in the time span of catch data which they represented. The following summarises the times spans covered by data collected for each of the ocean areas discussed in following sections: Western and Central Pacific Ocean – 1950-1998; Eastern Pacific Ocean – 1970-1999; Atlantic Ocean – 1950-2000; Indian Ocean – 1950-1998. In some instances, more recent catch data was obtained relating to specific gears or fishing methods.
A Review of the Impact of FADs on Tuna Fisheries

In each case where data has been supplied by tuna commissions, these organisations note that a number of cautions should be kept in mind regarding accuracy and quality of data. The level of catch reporting by different countries and different fleets varies, and in some instances catches have to be raised (estimated), often based on knowledge of fleet size and catches by other fleets operating in same areas and times. In some instances, illegal and unreported catches can not be estimated, leading to underestimate of total catches. Catches by artisanal fleets also comprise an unknown and unaccounted for portion of tuna catches, again leading to underestimation. Catch levels can also be effected by species misidentification. The data presented represent the best available estimates.

5.3 Global catches

The total annual worldwide catch of skipjack, yellowfin and bigeye has been increasing steadily since the early 1970's (Figure 5.1), and in 1998 reached a peak of 3.51 million tonnes. Skipjack comprised the largest portion of this catch (1.87 million tonnes or 53.3% of total) followed by yellowfin (1.24 million tonnes) and bigeye (0.4 million tonnes). The increase in overall catch slowed somewhat during the early to mid 1990s, and then increased again between 1996 and 1998.

5.4 Catches by ocean, species and gear

5.4.1 Indian Ocean

The total combined catch of yellowfin, skipjack and bigeye tunas in the Indian Ocean slowly increased from 14 300 mt in 1950 to 174 281 mt in 1983, before a sudden and rapid acceleration in catch rates of all three species. This trend continued into the mid-1990s and total catch peaked at 708 265 mt in 1995 (Figure 5.2A). Subsequent decrease in total catch is mainly attributed to reduced catches of yellowfin (from 293 964 mt in 1995 to 260 963 mt in 1998). Total bigeye catches in the Indian Ocean have increased steadily throughout the mid to late 1990s. Yellowfin and skipjack catches each comprise around 40 - 42% of the annual catch by weight, with bigeye making up the remainder (around 16%). These figures can vary by a few percent between years.

Figure 5.1 – Cumulative world annual catches of yellowfin, skipjack and bigeye tunas. (Source FAO 2001).
5.4.2 Atlantic Ocean
In the Atlantic Ocean, yellowfin and skipjack tunas each comprise around 36%, of annual catch by weight, while bigeye tuna comprise around 26%. These figures can vary by a few percent between years. The total combined annual catch of yellowfin, skipjack and bigeye in the Atlantic Ocean did not exceed 10 000 mt until after 1955, and then started to increase more rapidly, peaking initially in 1982 at 393 392 mt (Figure 5.2B). The highest annual catches for each species were recorded during the 1990s. Yellowfin catches peaked at 170 000 mt in 1994, skipjack at 213 000 mt in 1991 and bigeye catches peaked at nearly 132 000 mt in 1994. However, for each species, catch levels have declined since these peak years. By 2000, catches of yellowfin had fallen to 135 000 mt, skipjack to 139 000 mt and bigeye to 99 000 mt.

5.4.3 Western and Central Pacific Ocean
The total combined annual catch of yellowfin, skipjack and bigeye tunas in the WCPO increased steadily from the 1950s, when it comprised almost 90% skipjack and totalled around 120 000 mt, to just over 1.6 million mt in 1999. The 1999 catch comprised 1.1 million mt skipjack (70% of total), 0.1 million mt bigeye (6%) and 0.4 million mt of yellowfin (24%). Total combined catch of these species fluctuated considerably in the 1990s, due mainly to large fluctuations in skipjack catches between years (Figure 5.2C). In contrast, yellowfin and bigeye catches were relatively steady. The total catch for either yellowfin, skipjack or bigeye in this region is close to or greater than the catches taken for these species in other oceans.

5.4.4 Eastern Pacific Ocean
Data for tuna caught in the EPO is only available from 1970 onwards (Figure 5.2D). Total catch increased during the 1970s to peak at 442 800 mt, then declined dramatically in the early 80s (to 226 700 mt in 1983) before recovering to 458 900 mt by 1986 and remaining relatively steady. There is a notable increase of more than 140 000 mt between 1998 and 1999, which was due mainly to an unusually large increase in the skipjack catch for 1999. It resulted in a peak total catch of 637 900 mt for the region. With the exception of 1978, yellowfin have dominated the tuna catches in this region from 1970 until 1999, and over the last 15 years have accounted for between 47 to 66% of the total annual catch. The proportion of skipjack in the catch has increased from 15 to 42% in the last decade, while bigeye catch has slightly decreased both in proportion and total tonnage.

5.4.5 Species: by ocean trends (Figure 5.2)

**Bigeye:** Prior to 1990, the Eastern Pacific bigeye fishery accounted for the highest regional catch of bigeye tuna worldwide. However, annual catches of bigeye in the Eastern Pacific were subsequently overtaken by bigeye catches in other ocean regions. Hence by 1998, the Atlantic, Indian, and Central and Western Pacific Oceans accounted for 27.3% (110 000 mt), 35.2% (143 000 mt), and 19.7% (80 200 mt) of worldwide bigeye catch respectively, eclipsing the catch of bigeye in the EPO (17.8% or 72 400 mt).

**Yellowfin:** Yellowfin was also caught in the greatest numbers in the Eastern Pacific prior to 1977, however since this time the Western and Central Pacific Ocean has emerged with the highest yellowfin catch (43.8% or 541 400 mt in 1998), and more recently the Indian Ocean has also experience a surge in catch rates (22.2% or 274 600 mt in 1998) to rival that of the EPO (22.5% or 277 900 mt in 1998). The Atlantic catch of yellowfin accounted for only 11.6% (143 200 mt) of the total worldwide.

**Skipjack:** The Western and Central Pacific Ocean (WCPO) has always recorded the highest regional catch of skipjack since annual catch records were first taken. In recent years the Indian Ocean skipjack catch has also increased considerably, but is still only a quarter of annual catch in the WCPO. In 1998 the WCPO accounted for 68.2% (1.28 million mt), the
A Review of the Impact of FADs on Tuna Fisheries

Figure 5.2 - Cumulative annual catch of yellowfin, skipjack and bigeye in the A) Indian Ocean; B) Atlantic Ocean; C) Western and Central Pacific Ocean, and D) Eastern Pacific Ocean. (Sources; IOTC 2001; ICCAT 2001; SPC 2001; IATTC 2001)
5.4.6 Catch by gear

Introduction: The predominant mode of fishing used to catch tuna associated to FADs is purse seining. However, many other different gear types are used to catch these species when they are not associated to FADs, with some species being more vulnerable to certain gear types than others. Furthermore, a species’ vulnerability to a particular gear type can change as the species matures. Thus juvenile bigeye are more vulnerable to purse seine nets than adults of this species, as the juveniles tend to swim closer to the surface. Likewise, adult bigeye are more vulnerable to deep-set longlines. The vulnerability of these species to a gear type is predominantly influenced by the depth at which they spend most of their time. Depth preference is influenced by thermal and other environmental conditions, as discussed in Chapters 2 and 3. Many other environmental, gear and cultural factors also play a role (e.g. regional habits of fishermen). Consequently, there is considerable variation in the total catches of yellowfin, skipjack and bigeye which can be attributed to the use of different gear types in the different oceans. The following sections demonstrate that despite regional variability, the greatest percentage of skipjack and yellowfin are caught by purse seining. In contrast, the majority of bigeye are caught by longlining, although the proportion caught by purse seining in recent years has been increasing.

Atlantic Ocean: The purse seine catch of yellowfin has dramatically increased in the Atlantic since the early 1960s, to account for nearly two thirds of the Atlantic catch for this species (Figure 5.3A). However, this catch has decreased since 1990. Longlining also catches significant numbers of yellowfin, mainly adults, as does baitboating and gillnetting. The purse seine catch of skipjack in the Atlantic Ocean has also increased dramatically since the late 1960s, both in total tonnage and as a proportion of catch by all gear types (Figure 5.3B). In the last decade however this catch has declined quite considerably. Baitboating and gillnetting catches also increased during this period but by 1998, purse seining (154 810 mt) accounted for just over half of the skipjack catch in the Indian Ocean, followed by baitboating and gillnetting (127 285 mt) and other gears (25 593 mt).

Indian Ocean: Longlining accounted for the majority of the yellowfin caught in the Indian Ocean prior to 1983 (Figure 5.4A). It also increased after 1983, including an unusually high longline catch in 1993 of 183 000 mt, an increase of nearly 70 000 mt on the previous year. Up until the mid 1980s, the majority of skipjack catch in the Indian Ocean was caught using baitboating and gillnets (Figure 5.4B). Various other gears also collectively accounted for significant catches of skipjack. However, the 1980s saw a dramatic increase in the amount of skipjack caught using purse seining, a trend which continued through the 1990s with the introduction of FADs into the purse seine industry. Baitboating and gillnetting catches also increased during this period but by 1998, purse seining (154 810 mt) accounted for just over half of the skipjack catch in the Indian Ocean, followed by baitboating and gillnetting (127 285 mt) and other gears (25 593 mt).

Up until the mid 1980s, virtually all bigeye catches in the Indian Ocean could be attributed to longlining, and while the total tonnage taken by longliners has continued to increase rapidly, a growing purse seine catch has also become evident, particularly since the late 1980s and the introduction of FADs which increased catches of juvenile bigeye (Figure 5.4C). Baitboating and gillnetting hardly contribute to bigeye catch in the Indian Ocean. In conclusion, the main trend in gear related catches in the Indian Ocean is the sudden emergence and increase in catches of all three species by purse seining since the mid 1980s.

Western and Central Pacific Ocean: The purse seine catch of yellowfin in the WCPO also increased from the late 1970s, gradually taking over from longlining as the gear by which the
Figure 5.3 - Cumulative annual catch of A) yellowfin, B) skipjack, and C) bigeye, in the Atlantic Ocean using either purse seine (PS), longline (LL), baitboating and gillnets (BB and Gill) or other types of gear.
Figure 5.4 - Cumulative annual catch of A) yellowfin, B) skipjack and C) bigeye, in the Indian Ocean using either purse seine (PS), longline (LL), baitboating and gillnets (BB and Gill) or other types of gear.
A Review of the Impact of FADs on Tuna Fisheries

greatest tonnage of yellowfin was caught in this region (Figure 5.5A). The 1990s were notable for a very significant decrease in the purse seine catch of yellowfin in the mid part of this decade, followed by a sharp increase. However recent years have indicated another decline in purse seine yellowfin catches. It is worth noting that another gear type, handlining, also accounts for a smaller but still significant amount of yellowfin caught in the WCPO.

The predominant gear used to catch skipjack in the WCPO up until the early 1980s was pole and line (Figure 5.5B). However, the total catch of skipjack by this method has slowly declined in the years since, though it still represents a substantial catch today (1999 catch 241 081 mt). This is still less than half that attributable to purse seining (1999 catch 741 691 mt). Purse seine catches fluctuated through the 1990s, with a particularly large skipjack catch in 1998 of 898 330 mt.

As with other oceans, the WCPO bigeye catch is attributable mainly to longlining (Figure 5.5C). However, the total tonnage of bigeye caught by longlining in this region has been relatively stable for a long period, fluctuating around 55 000 mt since the mid to late 70s. In contrast, the purse seine catch of bigeye in the WCPO has increased from under 1000 mt in 1973 to 34 516 mt in 1999.

Eastern Pacific Ocean: The yellowfin catches in this region are mostly made by purse seine, with a small but significant catch made by longliners. The purse seine catch of bigeye in the EPO has shown an increasing trend over the second half of the 90s, reaching similar levels to those of the late 1980s. Longline catch of yellowfin appeared to be declining slightly in the late 1990s. The current data record extends only from 1987, due to available catch data not being separated by gear before this period (Figure 5.6A). Skipjack catches are almost purely attributable to purse seining, and overall have increased from 1994 onwards. There is a small amount of catch attributable to other surface gears. The purses seine catch of bigeye tuna in the EPO has increased to such an extent over the 1990s that it now accounts for a greater proportion of bigeye catch than does longlining.

The Eastern Pacific Ocean appears to be the only ocean region in which more bigeye are caught by purse seine than by longline. The longlining catch of bigeye in this region has declined to less than a third of the catch that was recorded in the early 1990s, however the purse seine catch has increased during this period.

5.5 Catches on associated (FADs/logs) and unassociated schools

The worldwide trend of purse seiners to switch from fishing on free-schooling and log associated tuna to setting on schools associated to FADs has occurred rapidly since the late 1980s. This use of man-made FADs appears to have contributed substantially to already accelerating catch rates of tropical tunas (and in addition has resulted in a shift in the size classes being caught: see Chapter 6). The following section examines the catch records for tuna caught by purse seine, either under floating objects (including FADs) or from free-schools, from each of the major ocean regions. It should be noted that “floating objects” can include many different objects, including FADs, debris and dead and live whales amongst others. However this will be defined specifically in each section according to the database being used.

5.5.1 Western and Central Pacific Ocean

The WCPO purse seine fishery started in the late 1960s. Initially, boats were setting on floating logs but by about 1990, had expanded the types of sets being made such that the purse seine catch consisted of significant catches from sets on logs, drifting and anchored FADs, marine animals (whales and whale sharks) and free schools. Now, the WCPO contains the most productive tuna fishery in the world (Hampton and Bailey, 1999) with approximately
A Review of the Impact of FADs on Tuna Fisheries

Figure 5.5 - Cumulative annual catch of A) yellowfin, B) skipjack, and C) bigeye, in the Western and Central Pacific Ocean using either handline, purse seine (PS), longline (LL) or other types of gear. (Source: SPC 2001)
Figure 5.6 - Cumulative annual catch of A) yellowfin, B) skipjack, and C) bigeye, in the Eastern Pacific Ocean using either purse seine (PS), longline (LL), or other types of gear (Source: IATTC 2001).
A Review of the Impact of FADs on Tuna Fisheries

1.5 million tonnes of tuna caught annually. Of this, the purse seine industry accounts for nearly three quarters of the catch, and of this, over 500,000 tonnes is taken from sets around floating objects (Fonteneau et al. 2000).

The SPC maintains a database of historical purse seine catch records for the WCPO and defines unassociated catches as being on free-swimming or baitfish feeding schools of tuna. “Floating objects” are defined as drifting logs, debris, dead animals, drifting or anchored FADs, live whales and whale sharks. Prior to 1992, the majority of yellowfin and skipjack caught by purse seiners in the WCPO was obtained from sets on floating objects (Figure 5.7A). However, since 1992 greater catches of these species have been obtained from free schools in some years. For yellowfin, years of high catches on free schools correspond to years of low catch on floating objects during the 1990s. 1996 was a significantly low catch year for both set types, resulting in much lower total yellowfin catch for this region. 1996 was a significantly low catch year for both set types, resulting in much lower total yellowfin catch for this region. Skipjack catches under floating objects continued to increase through the late 1990s while catches on free-schools levelled or declined slightly (Figure 5.7B). Skipjack have accounted for the majority of the catch, from both set types, since the mid-1970s. In the mid 1990s, for catches made under floating objects, skipjack typically accounted for around 78% of the catch, yellowfin 21%, and bigeye just under 1% (Fonteneau et al. 2000). For purse seine catches of free schooling tuna, skipjack generally account for 65-79%, yellowfin 14-34% and bigeye less than 1%. It is clear that bigeye catches are comparatively low for both set types when compared to yellowfin and skipjack catches in the WCPO. The total annual catch of bigeye by purse seine has rarely passed 25,000 mt, compared to recent catches of more than 900,000 mt for skipjack and 250,000 mt for yellowfin in this region. However, it is still worth noting that the proportion of bigeye taken from free-schooling sets is considerably less than that taken from sets on floating objects (Figure 5.7C). The main trend to note is that for yellowfin and skipjack, catches have increased both on free schools and under FADs, however for bigeye the increase in catches is predominantly due to FAD fisheries.

5.5.2 Eastern Pacific Ocean:

Purse seining for tuna has been prevalent in the Eastern Pacific ocean since the 1960s. Up until the creation of the “dolphin safe” canned tuna label in 1990, the majority of yellowfin catch in this region was attributable to dolphin sets, as well as upon floating objects and some free-school sets. Between 1980 and 1990, dolphin sets accounted for just over 400,000 mt of yellowfin while log sets accounted for only 64,800 mt and school sets just under 100,000 mt (Hall et al. 1999) (Figure 5.8). Skipjack and bigeye were taken in roughly equal numbers from floating objects and free-schools in the late 1980s. Total bigeye catch generally amounted to less than 10,000 mt. However, since 1993 and the introduction of large numbers of FADs into the Eastern Pacific Ocean, bigeye catches under floating objects have increased from less than 5,000 mt to over 60,000 mt, and skipjack catches under floating objects have increased from 50,000 mt to peak at near 180,000 mt (1999) before dropping off in 2000 to 140,000 mt. Yellowfin catches from free schools are still greater than those from under floating objects. However the latter catch has been increasing since 1992/3 and if the trend continues will soon overtake the free-school purse seine catch, which has varied between 60,000 mt and 110,000 mt throughout the 1990s.

5.5.3 Indian Ocean

The purse seine fishery for tuna in the Indian Ocean started to rapidly expand in the early 1980s (Hallier and Parajua, 1999). This was in part driven by a new trend used by fishermen of tying radio beacons to natural logs to help locate these at sea and allow continuous fishing effort on individual logs. By 1985 this was a very widespread practice. Consequently, greater number of skipjack and bigeye were caught associated to logs than were caught from free-schools during the 1980s (Figure 5.9). Yellowfin however were caught in greater numbers from free-schools than from log sets. By 1990, European and USSR purse seine fleets catch on logs made up half their total tuna catch, while Japanese and Mauritian fleets were fishing.
Figure 5.7 – Purse seine catch of A) yellowfin, B) skipjack or C) bigeye tuna either associated to floating objects or unassociated (free-schooling) in the Western and Central Pacific Ocean. Note these figures are not “cumulative” catches.
A Review of the Impact of FADs on Tuna Fisheries

Figure 5.8 - Purse seine catch of a) yellowfin, b) skipjack and c) bigeye, which are either associated to floating objects, or caught as free-schools (unassociated) in the Eastern Pacific Ocean.
exclusively off FADs (Hallier and Parajuwa, 1999). The use of FADs by European (French and Spanish) fleets took off around 1993-4, resulting in a large increase in the “log” associated catch of bigeye tunas. The catch of skipjack also continued to increase, as it had all throughout the 1980s. Interestingly, the catch of free schooling bigeye and skipjack did not increase during the 1990s, while the purse seine catch of free schooling yellowfin has actually decreased.

5.5.4 Atlantic Ocean

Sets on floating objects have been commonly used in the Atlantic Ocean ever since the 1960s, however, such practices were not routinely recorded in logbooks until 1988 (Ariz Telleria et al. 1999). Hence, there is no accurate record of such catches prior to 1988. Up until this time only about 15% of purse seine catches in the region were taken from floating object (log) sets. Logs were mostly from natural sources and tended to accumulate in the northern convergence zone (Ariz Telleria et al. 1999). However, since the late 1980s FADs use in the area rapidly increased, having very noticeable effects on the purse seine catch volume and composition in this region. However, the catch history in this ocean region is distinguished from other ocean regions by the substantial declines in purse seine catch rates of both FADs based and free-schooling tuna of all three species during the mid- to late1990s. Given that these declines occurred a relatively short time after the large-scale deployment of FADs in the region, the cause of these declines has been linked to overfishing on FADs. However, part of the decline is also due to the adoption of voluntary time-area moratoria (November to January) for each season between 1997 and 2000. This is discussed in more detail in chapter 7. The following section describes these trends in more detail.

Despite increasing FADs usage in the Atlantic during the late 1980s and early 1990s, yellowfin catches under FADs did not increase greatly during this period (Figure 5.10A). Furthermore, total yellowfin catches off FADs declined by 53.6% between 1994 (23 402 mt) and 1998 (10 868 mt). This dramatic decline in catch rates occurred in the midst of a similar decline (40.9%) in free-schooling yellowfin catches between 1992 and 1999.

FAD-based catches of skipjack in the Atlantic were relatively steady between 1992 and 1995, but then declined from 75 706 mt in 1995 to 29 834 mt in 1998, representing a drop in total catches under FADs of 60.5% (Figure 5.10B). This FADs based trend was pre-empted by an even more dramatic collapse of the purse seine free-schooling skipjack catch between 1993 (51 540 mt) and 1996 (15 428 mt), a decline of just over 70% in 3 years. However, the free-school catch rates partially recovered (to 43 448 mt in 1999), while more time is required to determine if the FADs based catches will recover, after the adoption of voluntary moratoria have been undertaken in the region since 1997 (See chapter 7 for more information on moratoria).

The increasing use of FADs in the Atlantic in the early 1990s was most noticeably reflected in the increased catch of bigeye under FADs, which doubled between 1991 and 1994 (Figure 5.10C). However, as was observed for skipjack, the bigeye catch under FADs suffered a marked 60.8% decline, starting in 1994 (26 479 mt) and reaching a low of 10 385 mt in 1998. A decline of 51.5% in purse seine catch of free-schooling bigeye also occurred between 1993 (11 639 mt) and 1997 (5 642 mt).

Overall it should be noted that, in contrast to the Indian and Pacific Ocean regions, where a general trend of increasing catches of FAD-associated skipjack and bigeye have prevailed throughout the 1990s, Atlantic catches of these two species have experienced considerable declines. It has proven difficult so far to separate the effects of moratoria from declines.
Figure 5.9 – Purse seine catch of A) yellowfin, B) skipjack or C) bigeye tuna either associated to logs or unassociated (free-schooling) in the Indian Ocean. Data pertains to French, Spanish, Seychelles and NEI purse seine fleets. (Source; IOTC 2001)
Figure 5.10 – Purse seine catch of A) yellowfin, B) skipjack or C) bigeye tuna either associated to FADs or unassociated (free-schooling) in the Atlantic Ocean. Data pertains to French, Spanish, and NEI purse seine fleets (ref). Free schooling data include BB.
possibly due to overfishing. The reasons for and implications of these catch trends in the Atlantic will be further discussed in Chapter 6.

5.6 Catch rates

Data were available from the IATTC for the Eastern Pacific Ocean which allowed comparison of average catches per set for purse seiners fishing under floating objects and on free schooling tuna. It has been recognised for some time that catch tonnage from sets around floating objects will on average, be higher than for sets on free schooling tuna (Fonteneau et al. 2000). The data for the Eastern Pacific Ocean tuna fishery certainly support this belief for two of the three species being investigated in this report. While mean catches of associated yellowfin per set have tended to be similar to mean catch of free schooling yellowfin (Figure 5.11), the mean skipjack catches from sets around floating objects (e.g. 28.13 mt/set in 2000) average at least 2-3 times more weight than do catches from sets on free schools (e.g. 7.27 mt/set). An even larger disparity is apparent for bigeye, with sets on floating objects catching 5-10 times more weight of bigeye than would be caught from a free schooling set. Again this results from the increased vulnerability of juvenile bigeye to purse seine gear when associated to floating objects.

An interesting trend over the past decade has been for catch per set under floating objects to increase, for both skipjack and bigeye. However the exact reasons for this are uncertain. More floating objects in the ocean (due to the advent of FADs during the early 1990s) would, in theory at least, be more likely to reduce the number of tuna under each floating object, assuming equal attractivity of floating objects, through a diffusive effect. However it may be that FADs designs (which can use baits, lights and other attractants) have created objects which are more attractive to skipjack and bigeye than natural floating objects such as logs, and consequently aggregate a greater proportion of the population within the objects range of attraction. Furthermore, distribution of natural floating objects would be an event determined by currents and wind. Distribution of FADs would be planned to intercept tuna populations in time and space.

A final point worth noting is that, with the exception of one year in the past decade (2000), unassociated yellowfin catch per set (6-10 mt/set) was consistently greater than was unassociated skipjack catch per set (2-7 mt/set). However, the opposite holds true for catches under floating objects, where skipjack catch per set (10-35 mt/set) is greater than yellowfin catch (4-12 mt/set). Bigeye has the lowest mean unassociated catch per set (<1 mt/set), but floating object associated catches (0-14 mt/set) nearing those for yellowfin.

5.7 Summary and conclusions

Global catches of yellowfin, skipjack and bigeye tunas have been rapidly increasing since before the 1970s. There are many reasons for this trend, including increased effort worldwide, increased fishing technology and better fishing knowledge. However, a significant proportion of the increases in global catches since the late 1980s can be attributed to the introduction and increasingly widespread use of fish aggregating devices (FADs). These devices mainly attract the smaller size classes, these consisting of skipjack and juvenile bigeye and yellowfin. These size classes were not exploited to the same extent prior to the introduction of FADs, and represent an additional catch on that taken by other gears or setting methods. The implications of this for sustainability of tuna fisheries, and for Australia’s own domestic longline fisheries, is discussed in the following chapter.

This chapter has detailed global catch statistics for these three species over the past 5 decades, with a particular focus on the role of fishing on floating objects (including FADs) and the influence of this fishing mode on overall catches. These analyses have demonstrated a number
Figure 5.11 – Catch (kg) per purse seine set of a) yellowfin, b) skipjack and c) bigeye in the Eastern Pacific Ocean, according to whether sets are made on floating objects or on free-schooling tuna. (Source: IATTC 2001)
A Review of the Impact of FADs on Tuna Fisheries

of important trends in catch statistics which relate to the effect of purse seining, particularly using FADs, upon catch rates worldwide.

Species trends: Skipjack comprises the majority of tuna (by weight) caught globally, due in main to the massive skipjack catches taken in the WCPO (near 1 million tonnes). Importantly, skipjack are restricted to the surface layers as a result of their inability to cope with colder deeper water, and hence this species is highly vulnerable at all stages of maturity to purse seining under FADs. However, while skipjack dominate the WCPO catches, all three species are caught in significant amounts in each of the oceans.

Gear trends: Purse seining now accounts for the majority of the catch of yellowfin and skipjack in each of the four regions (WCPO, EPO, IO, AO), while longlining accounts for the majority of bigeye caught. However, purse seining is accounting for an increasing proportion of bigeye caught in the IO, AO, and WCPO, and has overtaken longlining in the EPO since the early 1990s. This coincides with an increase in the practice of fishing under floating objects and subsequent increased catch rates of juvenile bigeye by this method.

Catch trends under floating objects versus free-schools: Fishing on natural logs and other floating objects has been prevalent in the WCPO since the purse seine fishery in this region first started. Catches under logs have historically dominated total purse seine catches for yellowfin, skipjack and bigeye. Hence the increased use of FADs does not appear to have accelerated catch rates to the same extent as has occurred in other ocean regions during the 1990s. In the EPO, the increased use of FADs coincides with the massively increased catches of floating object associated skipjack, bigeye and to a lesser extent, yellowfin. A similar trend is evident in the IO, but for both the EPO and IO, free-school catches of yellowfin have, until the proliferation of FADs use, been much greater than catches under floating objects.

Catch rates per purse seine set: In the EPO, average catch per set is generally similar for yellowfin caught from free-school or associated to floating objects. However, associated skipjack catch per set has been historically higher than that for free-schooling skipjack. Furthermore, both skipjack and bigeye catch per set from floating objects has increased substantially in the period after FADs use has become popular in this region. This may be due to the ability of fishermen to place FADs in optimal catch regions and times.

Final comment: It should be noted that set type data from the Pacific Ocean region is thought to be less reliable in its accuracy than is data from the Indian and Atlantic Oceans. Furthermore, in the EPO, IO, and AO, various moratoria have been enforced for 2-3 months periods since 1998. These moratoria may have had some effect on some of the catches for these and subsequent years but unfortunately it is too early to determine the impact of these measures on observed catch rates. These moratoria are discussed in much greater detail in Chapter 7.
6. Potential impacts of FAD based fishing upon global and domestic tuna fisheries

6.1 Introduction

The previous chapter highlighted how rapid increases have occurred in both FAD and non-FAD associated global tuna catches, in the Atlantic, Indian and Pacific Oceans, over the past 20 years. The present chapter will discuss four key concerns surrounding the potential impact of these catches and of FAD fisheries expansion upon:

- **The sustainability of tuna fisheries**: There is considerable concern over the future sustainability of both global and domestic tuna fisheries. In particular, FAD-based fisheries significantly increase the risks of recruitment and growth overfishing of tropical tuna species.

- **The assessment of stocks**: The very nature of the FAD-based fisheries has further complicated fisheries assessments and the ability of scientists to determine the effects of this fishery upon stock status.

- **Non-target species**: Purse seine sets on FADs catch a significantly greater and more diverse level of bycatch than do sets on free-schooling tuna.

- **Domestic longline fisheries**: The final discussion will focus on possible flow-on impacts that FAD-based overfishing scenarios on domestic longline fisheries.

An understanding of these issues will highlight the need for much tighter and more controlled management of FAD-based purse seine fisheries around the world, a topic discussed in detail in Chapter 7.

6.2 Potential impact of FADs upon the sustainability of tuna fisheries

6.2.1 Introduction

The elevated catch of juvenile tunas under FADs has led to concerns that this fishing practice may result in growth overfishing (and eventually recruitment overfishing) of bigeye and yellowfin tunas. Similarly, it is believed that fishing on FADs has contributed to recruitment overfishing of skipjack in some regions (e.g. East Atlantic Ocean) and is likely to contribute to recruitment overfishing in other ocean regions in the future. The following sections will explain the mechanisms of growth and recruitment overfishing, and the potential role of FAD-based fisheries in overfishing.

6.2.2 Defining overfishing

A species is considered to be overfished when the stocks size for that species falls below the minimum stock size required to produce the maximum sustainable yield (MSY) on a continuing basis. However, overfishing can occur in different forms. Growth overfishing can occur when tuna are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit. Consequently, growth overfishing reduces the potential yield from a fishery. Recruitment overfishing is the rate of fishing above which the number of young fish joining the exploitable stock (recruitment) becomes significantly reduced. This is characterised by a greatly reduced spawning stock, a decreasing population of older fish in the catch, and declining or low recruitment year after year. The removal of large numbers of adult tuna (e.g. skipjack) can cause short term recruitment overfishing while
the removal of large numbers of juveniles may lead to a smaller spawning stock in future years. Recruitment overfishing poses the greater risk to the continued existence of a resource than does growth overfishing.

6.2.3 FADs and overfishing

The rising concerns over FAD-based fisheries and their potential to contribute to overfishing of tropical tunas stem from 6 main observations:

1) Catch efficiency of purse seiners has increased dramatically with the use of FADs

2) Species composition of tuna caught under FADs differs to that of free schooling tuna

3) Juvenile tuna are significantly more vulnerable to capture using FADs

4) Advent of FADs means some species now caught by multiple gears, both as young and adults.

5) FADs may “trap” tuna in unproductive regions, with implications for condition growth and biological productivity

The following sections will discuss these factors in light of other observations relating to species biology, associative behaviour and catch levels that have been described in previous chapters, drawing these together and putting in them in context of their relevance to fisheries sustainability and overfishing risks.

6.2.4 FADs increased purse seine catch efficiency

As highlighted in Chapter 5, FAD-based purse seine catches account for over 1 million tonnes of tuna caught annually, almost 1 third of total annual catch of tunas. The increase in catches under FADs since they were introduced into each region was extremely rapid and it is widely accepted that this method of purse seining has increased fishing mortality for a given unit of nominal effort, in other words, increased the catching efficiency of purse seiners. This assumption is supported not just by dramatically increased total catches, but by the fact that over 90% of purse seine sets on FADs are successful, compared to only 50% of sets on free-schooling tuna (Fonteneau, 2000). Furthermore, according to the IATTC statistics presented in Chapter 5 (section 5.6) the total catch of tuna per set (in weight) is greater for sets under FADs than it is for sets on free schools, at least in the Eastern Pacific Ocean for which this data is available. This was particularly evident for catches of skipjack and bigeye tuna (IATTC, 2001). An additional indicator of the efficiency of FADs in aggregating tuna from surrounding regions (for subsequent capture) is evidence that mixed free-schools of juvenile tuna are caught far less frequently in heavily FAD seeded areas (than they were prior to the introduction of FADs), but rather are tending to be caught under FADs only (see Chapter 4).

The increasing catches of tuna under FADs is of concern in the first instance because it is an additional catch upon already increasing catch levels taken by purse seiners setting on free-schools, and on tuna taken by other gear types, whose catches have also increased (see 6.2.6 below). In the case of skipjack tuna, huge amounts of skipjack were already taken on free-school sets. Now, with the added tonnage taken by FADs, there has been some concern expressed that declines in skipjack catches during the mid 1990s in some regions of the Eastern Atlantic Ocean were a result of the substantial increase in catches attributable to FADs-based fishing. ICCAT suggested that skipjack may have already suffered growth overfishing in some parts of this region, based on catch declines and declining mean sizes of fish caught by purse seine. Evidence for a decline in mean size of purse seine caught skipjack has also been noted in the Indian Ocean (IOTC, 2002).
6.2.4 Species composition differs under FADs

Purse seining on free-schooling tuna generally targeted skipjack tuna, and in some regions, yellowfin tuna, although these were often associated to dolphins (Eastern Pacific Ocean) and to whales (Western Pacific Ocean). Bigeye tuna made up a minor percentage of the catch taken on free-schools. However, the species composition of tuna caught under FADs is significantly different from that of free-schools. Fonteneau (2000) estimated that while skipjack still comprise the majority of global FAD catches (63%), followed by yellowfin (~25%), bigeye tuna also contribute a very significant proportion of the catch with around 12%. This constitutes 66% of the total global purse seine catch of bigeye tuna, and represents a tripling of bigeye catch taken by purse seine. As such, it represents a dramatic increase in the catch of bigeye over what was previously taken by purse seine, representing an added pressure on bigeye stocks. In contrast, the skipjack taken under FADs only represent half that taken by purse seine, while yellowfin taken under FADs represent only 21% of total yellowfin taken by purse seine.

6.2.5 FADs have increased the capture of juvenile tuna

The increase in catch of bigeye tuna is of particular significance in FAD-based fisheries, as the majority of these fish are only juveniles, and have not yet developed to spawning age and thus have not contributed to future recruitments. The same situation is evident for yellowfin tuna caught under FADs.

As noted in Chapter 4, there appears to be a behavioural and physiological control on the aggregating tendencies of tuna which may be related to ontogeny (size and developmental stage). This is reflected by catch data, which show the vast majority of tunas caught under FADs (both drifting and anchored) to be from the smaller size classes, less than 70cm (Marsac et al. 2000). An analysis of drifting FADs catches worldwide demonstrates a distinct fork length mode with a mean near 48cm. This length mode is apparent across all oceans and comprises juvenile bigeye and yellowfin of around 1 year’s age, as well as adult skipjack, which are smaller and faster maturing than adults of larger species (Fonteneau, 2000). There is also a proportion of even smaller tuna caught and their fate (either discarded dead back into the sea or shipped to market) depends on the region and availability of markets or canneries that will accept smaller tunas. Larger individuals (adults of yellowfin and bigeye tuna) are also caught in lower but still significant numbers under FADs. This produces a second significant mode in catch size at 120-130 cm.

The large-scale removal of juvenile tuna from stocks can potentially lead to growth overfishing, which if unchecked over an extended period can lead to recruitment overfishing. Various moratoria (See Chapter 7) on FAD fishing have been applied in the Atlantic and Indian Oceans in an effort to reduce FAD based mortality of juvenile bigeye. However, unfortunately the assessment of bigeye stock status (and the impacts of FADs catches and of applied moratoria) is hampered by a lack of biological knowledge of these species.

One of the key indicators of stock status and potential fishery (eg FADs) effects upon stocks is the yield per recruit. Calculation of this parameter requires knowledge of the growth and natural mortality (M) of each species at various ages. However the natural mortality of juvenile tunas has yet to be accurately estimated (Fonteneau et al. 2000). If M was high then the FADs based removal of juvenile tunas may have a little effect upon the yield per recruit, however if M was low then the effects of FADs fisheries could be major (Fonteneau et al. 2000). Current estimates of M for juvenile bigeye are very high (4.0) (Hampton and Bertignac 1999), for skipjack (2.0) and for yellowfin also high (Hampton and Fournier 1999). The uncertainties surrounding the current estimates of M are too high to use these to precisely evaluate the effects of FADs fishing on the yield per recruit. Natural mortality may be better estimated using large scale tagging programs. The present uncertainties surrounding M of juveniles are potentially too large to evaluate precisely the changes in the yield per recruit due.
A Review of the Impact of FADs on Tuna Fisheries

to increased FAD fishing. Intensive tagging of small tunas is probably the best way to estimate this key biological parameter (Fonteneau et al. 2000).

6.2.6 Tuna are now being caught by multiple gears, at multiple developmental stages

As noted above, the advent of FAD-based fisheries has increased catches of juvenile yellowfin and bigeye. Not only does this increase total purse seine catch of these species, but it adds to catch taken already by other gears. Of particular concern is the fact that long established fisheries such as longline fisheries, already take substantial catches of adult bigeye and yellowfin tuna. Along with FAD-based fisheries, these species are being efficiently exploited at “both ends” of their development. For example, currently about 70% by number of bigeye caught in the Indian Ocean are taken by purse seine (mostly juveniles) but 80% by weight are taken by longline (mostly adults)(IOTC, 2001: see appendix V). Of considerable concern for this species is the fact that Japanese longline catch rates of bigeye have been declining over a long period (since before FADs were introduced even) in the Atlantic and Indian Ocean regions. However, longliners catches have increased (due to increased effort) over the same period that FAD based catches of bigeye have increased. There is now concern that the number of bigeye recruits being produced now may be already decreased (Fonteneau et al. 2000), but shielded by the increased efficiency of the FADs fishing method (i.e. FADs increase the accessible/exploitable population size, despite a decrease in overall population size). Clearly the risk of overfishing of bigeye is one that is generated by all gear types, not only FADs, and indeed the IOTC WPTT has recommended that the increase in catches of bigeye tuna by all gears, be ceased immediately (IOTC, 2001).

6.2.7 Can FADs “trap” tuna in unproductive regions?

Fisheries impacts are in part due to the behavioural and ecological characteristics of tunas and how these might be effected by the increased seeding of FADs in the world’s oceans. The “Ecological Trap” hypothesis (See Chapter 4 for full discussion) put forward by Menard et al (2000a), presents some evidence to suggest that FADs will have a negative biological and ecological impact upon tropical tunas, regardless of whether or not the fish are actually removed from the population by fishing (Menard et al. 2000a). In other words, their effect extends beyond the danger posed by increased vulnerability and overfishing. The ecological trap hypothesis suggests that FADs seeded in tropical currents may transport tunas away from their traditional forage areas to areas of low productivity, thus resulting in reduced growth and condition, and increased natural mortality. An overall negative effect upon biological productivity might occur, and if so, then any fisheries analyses “which assume that these characters (movement, growth, natural mortality) are unaffected will be biased” (Fonteneau et al. 2000). However it is yet to be determined whether FADs aggregation acts to redistribute the biomass that is being exploited or whether they act to attract a biomass that was not previously exploited, thus increasing the exploitable biomass. The suggestion of this hypothesis that the impacts of FADs upon the sustainability of tuna fisheries extends beyond direct fishing mortality, is something that warrants further and urgent investigation.

6.2.8 Summary

The factors discussed above warrant some concern over the potential of FADs to substantially increase overfishing risks in global tuna fisheries. Clearly they have increased purse seine catch efficiency and resulted in dramatically escalating total catches taken. This has already impacted on skipjack stocks in the eastern Atlantic Ocean. FADs have also resulted in increased catch of juvenile bigeye and yellowfin tunas, species already heavily exploited as adults by longline fisheries. Bigeye tuna make up a substantial proportion of catch under FADs, when previously they were only a very minor component of purse seine catch on free-schools. Additionally, there is concern that FADs might trap tuna in unproductive regions, creating additional productivity impacts not directly related to fishing mortality. Part of the problem in assessing the impacts of FADs upon tuna stocks is that they have introduced
A Review of the Impact of FADs on Tuna Fisheries

further complexity and uncertainty into stock assessment procedures, which were already extremely difficult to undertake even just for purse seine fleets setting on free schools (See next section for full discussion). It has been acknowledged that FADs may have already contributed to declines in populations, but that these declines may be masked by increasing catch efficiencies of FAD and purse seine fisheries. This point is supported by evidence that catch rates in adult fisheries already indicate declining stocks of bigeye tuna.

6.3 Stock assessment issues

As a result of concerns regarding overfishing of tropical tuna species, there is considerable need for stock assessments of these species. However, the widespread use of FADs in purse seine fisheries has caused an unfortunate feedback effect. The need for an assessment of the impact of FAD-based fishing on tuna stocks is hindered by the fact that their very use has further complicated the assessment procedure itself.

Before FADs became popular in purse seine tuna fisheries, stock assessments were already hampered by numerous factors associated with inconsistent data collection and reporting, undocumented changes in the time and area strata of fishing, ageing of vessels, and uncorrected variations or increases in fishing power between fleets and between vessels (Fonteneau et al. 2000).

However, the introduction of drifting FADs has added even further complexity to stock assessment processes, with many fishery aspects relating to stock assessments having changed, including the size of fish caught, size and extent of fishing zone (i.e. the zone of exploitation has increased), fishing patterns and most importantly, the concept of fishing effort (Fonteneau et al 2000; Gaertner and Pallares, 2001). The relationship between search time and fishing effort is now based on a mix of two elements, these being time devoted to randomly search and encounter of free-schools, and time devoted to targeting beacon tracked FADs. However, assessments are hampered by the fact that purse seiner logbooks rarely distinguish between the two types of effort, or detail the time devoted to each, so CPUE is no longer an appropriate index of abundance. Furthermore, given that beacon and satellite technologies are used to monitor FADs, search time can no longer be used as a reliable measure of fishing effort. Thus fisheries scientists attempt to come up with other more appropriate indices of local abundance, such as catch per set on FADs. This still requires knowledge of the number of FADs in an area as the number of tuna under each FAD will decrease as the number of FADs increases (for a given biomass per area) (Fonteneau et al. 2000). The issue is further complicated by the fishing methods and behaviour of tuna in relation to FADs. Vessels can now make consecutive sets on the same school as tuna tend to continuously recruit to FADs. This differs greatly from free-school methods that allow one set only, without subsequent recruitment.

The constant increase in FAD and non-FAD associated purse seine technology has also added complexity to assessment processes. The adoption of new changes in FAD technology can occur very rapidly throughout fleets and the window of opportunity to simultaneously analyse catch statistics from vessels with and without the new equipment is very small (Moron et al. 2001). Secondly, there is constantly an evolution of non-FADs related fishing technology. This makes it very difficult to assess whether a change in catch per effort is due to a new FAD-related innovation or other technologies introduced to the vessel at the same time (Gaertner and Pallares, 2001). Technologies increasingly being adopted and used include bird radar, sonar, echo-sounders, more powerful winches, larger nets etc. (Gaertner and Marsac, 2001). Fishing captains are also using remote technologies and data bases, such as satellite imagery derived “fish finding maps”, that plot sea surface temperatures and productivity (phytoplankton), to help them in the decision making process. On a similar level, analyses are complicated by the fact that there are many factors associated with environmental conditions
and behaviour of individual fishing captains, which are very difficult to standardise (Gaertner and Pallares, 2001). Finally, there is very little technical documentation on the drifting FADs used by seiners as they are generally deployed and financed by the fishermen themselves (Fonteneau, 2000), and a degree of secrecy surrounding FADs technology makes it quite difficult to describe exactly the characteristics of the FADs used, evaluate their effects and importance with relation to fishing success and specific species and sizes (Fonteneau et al. 2000). In addition, the information on the associated bycatch is often of variable quality.

These are all problems encountered by fisheries scientists trying to estimate tuna abundance using purse seine fishery catch and effort data (both FADs and free-school based) (Fonteneau et al. 2000). There are currently efforts being made to understand and account for the various factors complicating stock assessments that have resulted from the advent of FADs. The ESTHER project is run by scientists from France and Spain (Gaertner and Pallares, 2001) and aims to investigate the efficiency of tuna purse seiners and effective efforts, by determining the main factors that may contribute to the increase in fishing power of the French and Spanish purse seine fleets in the East Atlantic and Indian oceans (Gaertner and Pallares, 2001). This is due to recognition that standardised measures of fishing effort must account for both shifts in fishery grounds, as well as changes over time in the efficiency of the fleet before they can be used in abundance and mortality estimates (Gaertner and Pallares, 2001).

6.4 By-catch impacts

6.4.1 Introduction

It is now well recognised that the level of bycatch taken by purse seiners setting on FADs is greater and more diverse (in species composition) than that taken by purse seiners setting on free-schooling tuna. For the purposes of this report, by-catch is defined as any species taken which are not specifically targeted by the fishing gear, and which may consequently be taken to market or discarded dead back into the water. Bycatch taken under drifting FADs comprises both undersized tuna and a wide variety of pelagic non tuna species, which may aggregate to FADs for a variety of reasons. A large proportion of fish caught are juveniles of pelagic species, although adults of some species may associate in a predatory role. The species composition of bycatch taken under FADs is very similar worldwide and amounts to roughly 100,000 tonnes annually. There is concern over the impact of this bycatch upon the pelagic ecosystem.

6.4.2 Trends in bycatch levels

As the amount of purse seine fishing operations using FADs increases, there is an increasing level of concern surrounding the likely increase in the associated by-catch (Prado, 1997). This by-catch has been estimated to approximate about 10% of the average catch per set, comprising both undersized tunas and other pelagic species. For example, in the eastern tropical Atlantic, discards of tuna (frigate and little tunas) comprise 7.6% of catch while species such as wahoo, billfish, triggerfish, sharks and dolphin-fish make up an extra 2.3% of catch (Fonteneau, 2000). Worldwide by-catch amounts to around 100,000 tonnes annually. This is not overly large when one considers the size of the pelagic ecosystem or when compared to by-catch from other fisheries, such as the trawl fishery for shrimp which averages around 9.5 million tonnes of by-catch per year. However, it is considerably greater than the level of bycatch taken by purse seining on free schools, which has been estimated to be around 1-2% of total catch per set. Romanov (2002) analysed bycatch data for Russian purse seiners operating in the western Indian Ocean. He found that bycatch occurred in 45% of free-school sets compared to 93% of sets on logs, with bycatch not being taken on logs only when successive sets were made on the same log.
Furthermore, while by-catch from FADs may only have a low to moderate impact on pelagic species overall, it has the potential to cause more severe problems on local sub-populations of some species such as turtles, which have shown a behavioural tendency to associate to floating objects. Unfortunately, it appears likely that by-catch estimates may be underestimated as by-catch is often only reported when it is particularly high and noticeable. It seems that there is a need for observer programmes that would enable the accurate assessment of by-catch from this fishery.

6.4.3 Species composition of bycatch

Floating objects attract a very diverse range of pelagic animal species, with the majority of these being fish, but including other non-fish species such as turtles. The most common of species caught as bycatch comprise undersize tuna of target species or tuna of other non-target species. In the western Indian Ocean, non-tuna bycatch is much more common in sets on logs (87% of sets) than sets on free-schools (22% of sets)(Romanov 2002). In this study, 19 different species of fish were taken on free-school sets compared to 45 species taken on log sets. The most common non-tuna bycatch species taken in sets on free-schools were sharks, rays and marlin. These species were also taken in sets on logs, but many other species were also commonly caught in these sets, including rainbow runners, dolphinfish, triggerfish, wahoo and mackerel scud. In addition, one sea turtle was also caught (Romanov, 2002). This study demonstrated that the diversity of bycatch species taken on logs in the Western Indian Ocean is more than double that of species taken on free-schools. While bycatch levels are likely to vary considerably by year, area and fleets, the types of species taken as bycatch show a high degree of similarity between the Pacific and Indian Oceans.

It is also worth noting that anchored FADs may differ to drifting FADs in the species composition as a result of the closer proximity of anchored FADs to the coastline and reefs, and possibly as a result of the their fixed nature, which may make them attractive for different reasons. Experimental FADs anchored off Majorca in the Mediterranean were sampled fortnightly for two years (Deudero et al. 1999). During this time 26 species from 16 families were recorded in sample catches, with pelagic species dominating. The majority of fish were juveniles for all species, and their recruitment to the FADs only took a few days, but for many species the association seemed to operate on a seasonal basis. Similar to the situation for species composition under drifting FADs, Relini et al. (1994) noted that fish assemblages under anchored FADs in the Mediterranean were similar to those under anchored FADs off Hawaii in the Central Pacific Ocean.

A high proportion of the bycatch fish species that aggregated to floating objects (anchored or drifting) are juveniles or smaller species. However it should be noted that thigmotropism (attraction to floating objects) is not a general phenomena common to all pelagic species juvenile stages (Deudero et al. 1999). In addition, larger fish such as marlin and sharks are caught in sets on floating objects, but it is thought that their motivation for this association might be predatory and therefore differs to that of juvenile fishes. Large species such as whales and whale sharks which are occasionally encircled within purse seines generally escape or are released prior to hauling (Hampton and Bailey, 1993).

6.4.3 Motivations behind non-tuna species aggregations

It seems likely that the motivations driving tuna associations to FADs may be similar to those for other pelagic species. Similarly the motivations behind associations may differ for anchored and drifting FADs associations, as may be the case for tunas, as fixed and drifting objects may serve different purposes within the ecology of pelagic species. The same sized based eco-physiological constraints seem to apply to many of the non-tuna species as is the case for tunas, with the majority of individuals caught under FADs being juveniles of pelagic species (Deudero et al. 1999). However, the specific motivations for associating to drifting FADs may differ between species (Deudero et al. 1999). Floating objects such as logs and
FADs have a submerged portion which may act as a substrate for many organisms, and these organisms might possibly attract fish species which may feed off them. For example, some evidence has been found for a trophic link between wreckfish (*Polyprion americanus*) and various prey fish and isopods also associated to the FAD. Alternatively, FADs may represent a shelter from predators for some species, a schooling companion for others (Deudero et al. 1999). Whatever the motivation, it seems likely that heavy FADs seeding might influence the distribution, feeding and survival of young fish of many species. The mortality rates may be effected in juveniles of species other than tuna as FADs aggregations may represent sites of increased vulnerability to predation.

### 6.5 FADs based fisheries: An Australian perspective

#### 6.5.1 Introduction

The previous sections have outlined the problems for fisheries, fisheries assessment, fisheries bycatch, and tuna ecology that have resulted from the increased use of FADs by purse seiners worldwide. Australia does not have a FADs-based purse seine fishery, however, the widespread and increasing use of this fishing method has raised concern locally that FADs based removal of juvenile yellowfin and bigeye may significantly impact on Australia’s longline fisheries which target adults of these species. These concerns are outlined in the following section.

Australia has two fisheries which may be impacted upon by FAD fishing in the Indian and Pacific Oceans. Both the Eastern Tuna and Billfish Fishery (ETBF) and the Southern and Western Tuna and Billfish Fishery (SWTBF) (Figure 6.1) have grown dramatically in recent years. The species targeted by these fisheries include bigeye, skipjack and yellowfin tuna. Broadbill swordfish are also a key target species. Summaries of the total catch and monetary value for these species, in both the ETBF and SWTBF are given in Table 6.1.

While uncertainty surrounds the stock structure and stock status of all three species, both locally and in the wider Indian and Pacific Oceans, the major and immediate concern is the impact of ocean wide FAD based fisheries upon local bigeye resources. This is due to the high value of bigeye tuna taken by Australian longliners and the associated demand in the Japanese sashimi market, making this the most desirable target species for local longliners. For example, the ETBF bigeye longline catch was 679 tonnes in 2000, worth $11.6 million, while 1538 tonnes of yellowfin were captured worth $18.3 million. The same year and regional catch of skipjack was 3945 tonnes, but worth only $7 million. The concern over local bigeye resources stems from recent record catches of both juveniles under FADs and of adult bigeye by international longliners. This has led to fears of ocean wide overfishing, which could lead to the collapse of local stocks. Further concern is held that, without much tighter regulation of FAD based fisheries in the Indian and Pacific Oceans, similar overfishing scenarios may soon face local yellowfin and skipjack resources, and may even extend to impacting on marlin species.

The following discussion of Australia’s tuna fisheries draws factual descriptions of these predominantly from the BRS Status Reports. The likely impacts of ocean wide FAD fisheries upon our domestic longline fisheries are discussed in light of this information.
6.5.2 Domestic longline fisheries

The Eastern Tuna and Billfish Fishery (ETBF) extends from the tip of Cape York to Tasmania and the South Australia–Victoria border (Figure 6.1). Broadbill swordfish, bigeye tuna and yellowfin tuna are the most valuable commercial species targeted by this fishery. They are caught by pelagic longline, with domestic longline effort having increased to over ten million hooks since the exclusion of Japanese long liners from the Australian fishing zone (AFZ) in 1997. Other vessels in the ETBF use purse seine and pole-and-line to catch low-value skipjack tuna. Currently, yellowfin, swordfish and bigeye catch rate declines are of concern in this fishery. These concerns are dealt with in more details in the species by species sections to follow.

The Southern and Western Tuna and Billfish Fishery (SWTBF) extends from the South Australia–Victoria border, around western and northern Australia to Cape York in Queensland (Figure 6.1). Despite this broad geographic range, the commercially valuable tuna resources are predominantly concentrated in oceanic waters along the western and southern coasts. A pelagic long line fishery has been developed since Japanese long liners were excluded in 1997. The fishery concentrates on broadbill swordfish, in addition to bigeye and yellowfin. Interest in the SWTBF increased significantly in 1998 when twenty vessels operated, compared to previous years when there were few if any dedicated SWTBF domestic longline vessels and most longline activity was by Japanese fleets. Most longlining activity is within the AFZ, but some have fished beyond it. The range offshore is limited for the majority of vessels by their small size and lack of freezer facilities. However, better equipped boats with longer range are currently being fitted out for use in this fishery.
A Review of the Impact of FADs on Tuna Fisheries

As detailed in previous chapters, there are major FADs-based purse seine fisheries for skipjack, yellowfin and bigeye tuna in the western Indian Ocean and the central and western Pacific Ocean. The next section discusses current knowledge of stock status of these species in both the Indian and Pacific Oceans, and how these stocks may interact with those been exploited by Australian longliners.

6.5.3 Bigeye tuna

Introduction: Recent years have seen a rapid increase in the Australian longlining effort for bigeye in both the ETBF and the SWTBF, due to the high value of bigeye tuna at Japanese sashimi markets. The status of these stocks in both the Indian and Pacific Oceans are believed to be fully fished and there is now considerable concern over the increased catch of bigeye by surface fisheries in the adjoining oceans, particularly of juveniles under FADs. This is likely to impact upon future recruitment of bigeye to the AFZ.

AFZ Catches: The WCPO bigeye catch has been increasing as a result of both FADs based fisheries and recent record longline catches (See Chapter 5). Likewise, domestic longline activity for bigeye has increased in the both the northern ETBF region and the SWTBF and adjacent regions during the 1990s. For the ETBF, unstandardised catch rates were low until the mid-1990s, but increased five-fold in conjunction with the increased central-region activity on swordfish. Catches peaked at 1031 mt in 1998, declined to 679 mt in 2000 before increasing to 1050 mt in 2001. The SWTBF, which predominantly targets swordfish, bigeye and yellowfin, has grown rapidly since the exclusion of Japanese longliners in 1997. Between 1997 and 2000, the number of Australian licensed longliners increased from 9 to 48, and effort has increased ten fold (based on increase in number of hooks set from 0.5 million in 1997 to 5.3 million in 2000). Over this period the catch of bigeye has increased from 44 mt to 416 mt.

Stock structure: Despite the development of the bigeye fishery in the ETBF and SWTBF, there is currently little data to provide an indication of the interactions that are likely to occur among bigeye fisheries throughout the Indo-Pacific region. A reasonable foundation to understand these interactions must include fisheries, genetic and ecological data. There is presently no clear genetic evidence of separate Pacific bigeye stocks, despite tag-recapture evidence for localised long-term residence by these fish, which is suggestive of stock structuring. However, other evidence has also shown this species to be capable of long-range movements, perhaps across the entire Pacific. There is no corresponding information for Indian Ocean bigeye. The origin of bigeye recruits to both the western and eastern AFZ is unknown, and there is no specific bigeye assessment for either region. It is unlikely that SWTBF bigeye represent a separate stock but there could be some level of isolation from the broader Indian Ocean resource. The same can be said for the ETBF bigeye in relation to the Pacific Ocean resource. Programs are underway to determine the structure of bigeye stocks in the Indian and Pacific Oceans and a tagging program on bigeye in the Pacific has demonstrated the link between bigeye in the western and central Pacific Ocean. A similar link almost certainly exists between bigeye tuna in the western and eastern Indian Ocean and a bigeye-tagging program is in the development phase under the umbrella of the IOTC. If the results are similar to the findings in the Pacific, it will provide clear evidence that there are strong links among the various bigeye tuna fisheries. This then suggests that overexploitation by FADs fisheries will impact on recruitment of bigeye to AFZ and access or our longline fleet to adult bigeye resources.

Stock status: Results from the MULTIFAN-CL and A_SCALA assessment model for bigeye in the Pacific Ocean indicate a declining biomass for this species, with recent fishery...
Figure 6.2 – Total annual catches (tonnes) of skipjack, yellowfin and bigeye caught in the: A) Eastern Tuna and Billfish Fishery, B) Southern and Western Tuna and Billfish Fishery.
A Review of the Impact of FADs on Tuna Fisheries

mortality rates near of exceeding overfishing reference points (SPC 2002). At the very least, this stock is considered to be fully fished in the Pacific. The continuing increase in Pacific bigeye catches in both surface and longline fisheries, has led to a recommendation against further increases in fishing mortality in surface fisheries and for close monitoring of the condition of the stock.

The IOTC's Working Party on Tropical Tunas has determined that recent and current catches of bigeye tuna in the Indian Ocean are well above the maximum sustainable yield (MSY) and that the stock is clearly being overfished. In the Western Indian Ocean large numbers of juvenile bigeye tuna are caught by purse-seine fishing on drifting fish-aggregating devices, while adults are taken by longline. Adult skipjack and juvenile and adult yellowfin tunas are taken concurrently. The Committee has recommended that a reduction in the catch of bigeye by all gears is required, eventually to the level of MSY, and should be started as soon as possible (IOTC 2002).

Conclusions: The impact of FADs upon bigeye tuna stocks is of serious concern to Australia. The relationship between stocks in the AFZ and the broader ocean basins is still uncertain, however, if these constitute single oceanic stocks, then the overfishing of bigeye tuna that is currently occurring in the Indian Ocean, and possibly in the Pacific Ocean, will directly impact on local abundance and therefore upon the future of domestic longline fisheries targeting this species. However, actual data are required to support the assertion that the industrial purse seine fleets have a direct impact on Australian fishing operations. Ultimately, this information can be used to support any requirement to reduce further development or the current level of purse seine fishing on FADs.

6.5.4 Yellowfin

Introduction: Yellowfin stocks in the western and central Pacific Ocean are not thought to be overfished at the current time, however like bigeye, it seems likely that yellowfin are overfished in the western Indian Ocean, with current catch levels thought unlikely to be sustainable. The interaction between yellowfin in the ETBF and the wider Pacific Ocean, and in the SWTBF and the wider Indian Ocean, respectively, is uncertain and requires considerably more investigation before firm conclusions can be drawn regarding the effect of industrial purse seine fleets fishing on FADs upon local yellowfin recruitment and exploitable resources.

Catch: About half of the WCPO yellowfin catch is taken by purse seine, with strong inter-annual variability in nominal catch rates but no clear trend. Standardised catch rates for the major longline fleets also display large inter-annual variability but no overall long-term trend. Annual WCPO catches of yellowfin have exceeded 400 000 t annually for the past four years, with increasing catches of juvenile yellowfin being taken by purse seine fishing on floating objects. In comparison, the ETBF longline catch of yellowfin tuna is still relatively small, despite more than doubling between 1993 and 1998 (1846 tonnes). The two subsequent years yielded lower catches of 1576 tonnes (1999), 1491 tonnes (2000) but higher catches were taken in 2001 (2193 tonnes). The mean weight of yellowfin caught by ETBF longliners is about 30 kg. The nominal catch rates for this species in the ETBF have declined since the mid 1990s. This may be partly due to changes in line-setting, by fishermen targeting swordfish and bigeye. However, the possibility of local depletions can not be ruled out either. There has been no significant catch of yellowfin by ETBF purse seiners in recent years.

The annual total Indian Ocean catch of yellowfin has ranged between 245 400 t and 397 700 t during the 1990s, peaking in 1993. The total catch by Australian longliners in recent years in the SWTBF is increasing but still comparatively small, around 406 tonnes in 1999 and 416 tonnes in 2000. The average dressed weight of those caught by Australian longliners operating in the Indian Ocean is less than 40 kg.
A Review of the Impact of FADs on Tuna Fisheries

Stock structure: Yellowfin from the ETBF appear to predominantly recruit from the Coral Sea, however there is evidence that in some years recruits may come in from other WCPO regions. Preliminary results of genetic studies suggest that yellowfin in the tropical southwestern Pacific may constitute a single stock, but further research is required. Tagging studies indicate that yellowfin move between the ETBF and the WCPO, although even after prolonged periods a large proportion of tagged yellowfin recoveries tended to occur in areas where they were tagged.

There is little data on stock structure of Indian Ocean yellowfin tuna. Longline-caught yellowfin were tagged by Japanese researchers in the western Indian Ocean. Recaptured fish were not reported east of the Maldives, suggesting stock structuring; however, this was a relatively small study with few fish recaptured. Further research is required, using both traditional- and archival-tagging techniques.

Stock status: The SPC has developed an integrated, spatial and age-structured model (‘MULTIFAN–CL’) that estimates population parameters at regional and sub-regional levels. Results are consistent with a previous tag-based assessment (which indicated high population turnover) but in addition indicated that recent fishing mortality may have increased, largely due to catchability increases in purse seine fisheries. In addition, recent recruitment appears to have significantly decreased. The reason for the recruitment decline is unclear but one possibility could be a regional shift to a lower productivity regime, in which case it may not be possible to maintain present catches. This has led to a recommendation against further increases in fishing mortality (particularly on juveniles via FADs) and for the close monitoring of the WCPO stock over the next few years.

The CSIRO has developed abundance indices for eastern AFZ yellowfin based on historical Japanese longline catch and effort data. While the analyses indicate large inter-annual variation in the abundance of the resources in the ETBF, they indicated no long-term decline in the abundance of yellowfin between 1970 and the mid-1990s. Declines in catch rates since then may be due to either poor recruitment in recent years which may have influenced the availability of yellowfin to the ETBF, or reflect changes in line-setting practices associated with increased domestic focus on swordfish and bigeye. Nevertheless, depletion in local areas cannot be ruled out as a possible cause.

Uncertainty remains as to whether there is any effect of WCPO purse seining on ETBF longline catch rates. Management decisions have been predominantly influenced by the tagging-based assessment of exploitation rates in the wider WCPO region. However, care is required in applying those assessments to the ETBF because of uncertainties with the level of mixing between the WCPO and the ETBF.

In the Indian Ocean, the IOTC Working Party on Tropical Tunas has determined that yellowfin catches are close to or possibly above the MSY level, with catches by all main gears having increased substantially over recent years (IOTC; 2002). They have recommended that further increase in effective effort and catches should be avoided. Stock status assessments for the AFZ are unreliable because the interactions between those stocks and broader regional stocks are uncertain.

Conclusions: Stock status assessments for the AFZ are unreliable because the interactions between those stocks and broader regional stocks are uncertain. Therefore, uncertainty remains whether SWTBF longline catch rates experience any effect from broader Indian Ocean longlining, from the intensive western Indian Ocean purse seining (which catches both juvenile and adult yellowfin), or from artisanal fisheries throughout the tropical Indian Ocean. Management decisions are complicated by these uncertainties about the level of mixing between the SWTBF and broader region. The possibility of local depletion in the AFZ,
A Review of the Impact of FADs on Tuna Fisheries

combined with uncertainty over wider ocean interactions, might warrant effort or catch controls in the SWTBF.

6.5.5 Skipjack tuna

Introduction: The status of skipjack in both the EBTF and SWTBF is uncertain. However it is believed that the WCPO stocks are under-fished, with the impact of fishing on the total biomass of skipjack estimated to be low, which may have implications for the adjoining EBTF. The IOTC has concluded that the skipjack stock in the Indian Ocean is in good condition (IOTC, 2002). Most of the current knowledge of skipjack in AFZ is from the ETBF and surveys conducted there and in the wider Pacific Ocean.

Catches: Prior to 1990, annual domestic skipjack catches mostly ranged between 50 mt and 800 mt, although 2500 t were reported in 1974–75. Catches increased markedly, reaching 7000 mt in 1991–92. Subsequently they have been quite variable, to as low as 826 mt in 1997–98 but back around 4000 mt since 1998–99 (Figure 7.2 and 7.3). Skipjack caught in Australian waters are typically 1.5–3 kg.

Status: Tag-based assessments in the 1980s and 1990s indicated low to moderate WCPO skipjack-exploitation levels at current catch levels. Preliminary results from SPC’s MULTIFAN-CL analysis also agreed with the tag-based assessments, and indicated that fishing mortality at age has been smaller than that of natural mortality. The impact of fishing on the total biomass of skipjack is estimated to be low, with estimates of recent recruitment and skipjack biomass being at historically high levels. The IOTC Working Party on Tropical Tunas has not put forward any specific management recommendation for this species as the Indian Ocean stock is believed to be in good condition.

Conclusion: While exploitation rates remain low in the wider WCPO, there are no biological reasons to limit total skipjack catch levels in the ETBF. Instead, establishing a management regime that takes account of catch fluctuations is a key issue for future development and management. The potential for increased skipjack catches in the WCPO does not necessarily extend to the ETBF, which is at the extreme of the species’ range. Furthermore, skipjack appear to not mix rapidly or thoroughly in the WCPO, hence increasing the dangers of localised depletions in stocks. Declines in localised CPUE and fish size have already been observed for skipjack in the Atlantic Ocean. These are concerns that need be considered in the management of this species. However, virtually no fishing for skipjack takes place in the north-eastern AFZ where the availability of skipjack is likely to be less variable than in more southerly waters. For the time being it appears that FADs based removal of skipjack in the WCPO is too low to effect recruitment of skipjack to the ETBF.

6.5.6 Marlin

There is some concern regarding the potential impact of FADs on various marlin species. Both black and blue marlin are associated with FADs, however, they often remain at considerable distance from the FAD (~4 km). This association has been recognised by both recreational fishers and artisanal fishers. However, the issue of marlin bycatch in FADs based fisheries needs to be further investigated. Very little research has been done on the association of marlin with FADs and therefore it is difficult to assess the effect of FADs upon the vulnerability of marlin to different fishing gears (Fonteneau; personal communication). There are currently plans for a 5 year long observer program that will target estimates of shark and billfish bycatch in the European purse seine fisheries in the Indian Ocean (Fonteneau; personal communication). This will hopefully determine the likely impact of FADs fisheries on marlin, and enable comparison with marlin bycatch on other gears such as longline.
6.6 Summary and Discussion

The current and expanding use of FADs around the world appears likely to have a number of detrimental effects, both to the long term sustainability of tuna fisheries, to the ecology of the tuna species, and to a lesser extent, the ecology of other pelagic species. It has also been recognised however, that this mode of fishing offers some advantages to the efficiency of purse seine fishing. This has led to a general agreement within the fisheries and scientific communities that this fishing mode needs to be strictly controlled so as to maintain sustainable biological catch levels, and reduce impacts on both pelagic ecosystems and other fisheries that exploit these ecosystems.

The major concern of fisheries scientists currently is that FADs based fisheries are causing an excessive catch of juvenile tuna, which will in years to come greatly reduce the spawning stocks, representing recruitment overfishing and having severe impact on the yield per recruits for some tuna species. This potential future problem is exacerbated by the fact that this fishing mode has introduced major uncertainties into the assessment of tropical tuna stocks, so it is currently very difficult to determine the “quantitative” effects of FADs. As Fonteneau and colleagues (2000) stated: “The present biological knowledge and models do not allow for realistic projections of the potential effects of increased FADs fisheries”. Given that the problems surrounding the impacts of FADs upon stock levels and their assessment are the same worldwide, it seems that the most effective approach to tackling these problems would be through the combined and collaborative effort of various tuna commissions and fisheries bodies. Together, these organisations could implement comprehensive monitoring of potential changes in catch levels, CPUE and sizes taken for both FADs and non FADs fisheries, for all three main target species (bigeye, yellowfin and skipjack), and in all four ocean regions (Fonteneau, 2000). This approach would greatly aid the scientific assessment and consequently the management of these stocks. In the meantime, potential measure to regulate and control the catch levels in FADs fisheries are being considered by tuna bodies, including supply vessel bans, FAD number limits, net size limits, catch quotas and area closures. These options are discussed in detail in the following chapter.

In addition to impacts due to the mass removal of juveniles from tuna populations, there is concern that mass deployments of drifting FADs may act as an “ecological trap” for tropical tuna species, luring them away from their normal productive forage areas to areas with low productivity and consequently negatively impacting growth and condition and biological productivity (Menard et al. 2000). Considerable research is needed before this hypothesis can be accepted. Testing of the hypothesis will require large scale conventional and acoustic tagging experiments, and the analyses of tuna condition and trophic biology in traditional feeding and expanded FADs areas. A historical comparison of changes in the size composition of catches will also aid in interpretation of current size trends.

The third main concern over the ocean wide impacts of FADs fisheries relates to the increasing incidence of by-catch. The incidental mortality of bycatch species equates to a yearly total estimated to be in the region of 100 000 tonnes. However, research is required to determine if a better understanding of the temporal aspects of species aggregation to FADs might not allow the development of more species selective fishing and consequently reduced bycatch.

It is quite clear from the preceding sections that far too little is known regarding the stock structures or stock status of the tropical tunas in any of the worlds oceans. From an Australian perspective, a much greater level of research is required in order to determine the recruitment dynamics and status of stocks being exploited by our fishing fleets, namely those stocks located in the eastern Indian Ocean or south west Pacific and how these interact with the wider Indian or Pacific Ocean stocks. Of the tropical tunas targeted by our fleets, the most economically valuable species is bigeye. However, we know very little of the biology of
bigeye in our region. This makes it exceedingly difficult to assess the effect of either our own fishing practices (predominantly longlining for adults) or those of other nations (e.g. FADs fishing for juveniles) upon this species and makes future management decisions regarding the species more uncertain. Similar situations are faced by fisheries managers in relation to both local skipjack and yellowfin resources, although there is less evidence to suggest that skipjack resources face an immediate threat of overfishing in the near future.

The decline of skipjack stocks in the Eastern Atlantic Ocean in the mid 1990s was attributed in large part to overfishing of juveniles by FADs based fishing methods in that region. Local stocks of skipjack off Australia are thought likely to interact with the wider Pacific and Indian Ocean stocks, but given that skipjack mixing rates in the WCPO are believed to be relatively slow, it is uncertain how local skipjack resources might be effected by any FADs-based overfishing by international fleets fishing these oceans. Currently the Pacific Ocean is thought to be under-fished for skipjack, so locally exploited stocks in the southwest pacific seem likely to be stable in the near future. A similar situation exists in the Indian Ocean, where skipjack stock is believed to be in good condition. However, proper assessments are required for this species in the Indian Ocean.

Bigeye and yellowfin tuna are targeted by Australia’s longline fleets, with both these species being more commercially valuable than skipjack. Currently it is believed that local resources of yellowfin and bigeye are fully exploited in the ETBF, and that an increase in catch and effort would be unwise. As with skipjack, local yellowfin and bigeye resources appear likely to interact with the wider ocean areas, both between the ETBF and Pacific Ocean, and the SWTBF and the Indian Ocean. However the level of interaction requires further research. Again, FADs based overfishing of juveniles of these species in either Pacific or Indian Ocean could potentially reduce the exploitable adult stock accessed by Australian longliners. Given that these species are of considerable commercial value, and in the SWTBF at least may have room for further expansion of the fishery, Australia cannot afford to be silent in regard to current trends in the foreign FADs based fisheries. The large-scale use of FADs by foreign fisheries should be of significant concern to Australian fisheries managers.

In relation to this need for a voice on foreign FADs fisheries and their regulation, it should be noted that Australia is not the only country with longlining interests in adult bigeye and yellowfin tuna. Many longliners from Japan, Republic of Korea and Taiwan fish outside the AFZ across the Indian Ocean, targeting southern bluefin, bigeye, albacore and yellowfin tunas. In international waters between northern Australia and Indonesia there has been a growing Indonesian-based longline fishery, involving several hundred vessels from Indonesia and Taiwan, targeting bigeye and yellowfin for airfreight fresh to sashimi markets in Japan. Countries such as Japan, Taiwan and Korea with distant water longline fleets are among those that, like Australia, will be most significantly affected by the increased catch of juvenile bigeye tuna as a result of FADs. This situation presents the opportunity to develop new alliances in international forums, and may provide a stronger “voice” in discussions regarding the regulation of FADs based purse seine fisheries.
7. Management of the FAD-based purse seine fisheries

7.1 Introduction

The increase in the global catch of juvenile tuna in recent years has been widely attributed to the extensive use of Fish Aggregating Devices (FADs) by purse seine fishing fleets operating in tropical and subtropical waters of the Indian, Pacific and Atlantic Oceans. (Gaertner and Marsac, 2000). Scientific assessments of tuna stocks suggest that the current catch levels for some species may be unsustainable in the long term and there is a general consensus that the use of FADs needs to be more tightly controlled (Fonteneau et al., 1999).

The responsibility for the conserving and managing tuna and tuna-like species in the Indian, Atlantic and Pacific Oceans lies primarily with four international organisations. These are the Indian Ocean Tuna Commission (IOTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Inter-American Tropical Tuna Commission (IATTC), and the Secretariat of the Pacific Community (SPC). It is the responsibility of participating member nations of these organisations to adopt and implement the commissions resolutions and recommendations through their national legislation.

These tuna commissions have considered and in some cases implemented various management measures to reduce the catch of juvenile bigeye and yellowfin tuna. These measures include:

- Use of quotas, time-area closures, size limits, discarding bans;
- Restrictions on: a) the transhipment of tuna, b) the use of supply vessels, c) the number of sets on FADs, d) the depth of nets, e) the number of FADs, and; f) fishing on seamounts.

Of all these measures, time-area closures on floating objects by purse seiners have been considered to be the most effective option to reduce catches of juvenile bigeye and yellowfin tuna and have been adopted by the IATTC, the IOTC and ICCAT. However, because the nature of the fishery on floating objects has changed considerably during recent years, it has so far proven difficult to estimate the effect and success of management changes (Anon., 2000a).

This chapter summarises the primary management measures either considered and/or adopted by the IOTC, ICCAT, SPC and IATTC to reduce catches of juvenile bigeye and yellowfin tunas. It focuses on those management measures (primarily time-area moratoria) that were adopted by participating nations and on the effectiveness of these measures. To aid in this description, case studies are presented describing moratoria on purse seine fishing on FADs implemented in the Indian, Atlantic and Eastern Pacific Oceans. A summary of recommendations on the management of the purse seine fishery on FADs will be provided taking into consideration the feasibility, strength, weaknesses and effectiveness of the management measures outlined in this chapter.

7.2 Management Measures to Reduce Catches of Juvenile Tuna

Measures considered by tuna commissions have included both input and output controls. Input controls are designed to limit either the number of vessels fishing or the efficiency of fishing and are considered to be an indirect means of limiting the exploitation of fish stocks as
they do not directly control the amount of catch. Input controls considered by the tuna commissions as possible regulatory measures of catch taken in FAD fisheries include: time-area closures, size limits, bans on discarding, restrictions on the transhipment of tuna, restrictions on the use of supply vessels and on fishing on seamounts. Output controls are designed to directly limit catch and rely on the ability to monitor total catch. This management technique can be used to set catch limits for an entire fleet or fishery, specific vessels, owners or operators.

7.2.1 Catch limits

The implementation of catch limits to particular countries, gear sectors or companies operating in tuna fisheries, is a potential means to regulate catch. Such output controls have been adopted by the IATTC as a means to reduce catches of small bigeye and yellowfin tuna.

The Director of the IATTC first recommended that an annual catch limit be set on the catch of yellowfin in the Commissions Yellowfin Regulatory Area (CYRA) in 1962, however, the member governments could not reach agreement on a yellowfin catch limit until 1966 (Anon. 2000d). Agreement was reached on a catch limit for every year from 1966 through 1986 and 1988 through 2000. The regulations were implemented during each year of the 1966-1979 and 1998-2000 periods. As of the date on which the yellowfin catch limit is reached in the CYRA, purse-seine vessels and baitboats must refrain from fishing for yellowfin tuna in the restricted area during the restricted period as specified in the resolution. The landings of fish caught in the CYRA during the restricted period by any individual purse seiner with an observer on board may include a maximum of 15 percent yellowfin (relative to its total catch of all species of fish during those periods) caught while fishing for other species of tunas. The yellowfin catch limit is always conservative relative to estimated maximum sustainable yield, but can be raised by increments of 15,000 mt if the Director of Investigations of the IATTC concludes from ‘examination of the available data that such increases would pose no substantial danger to the stocks’.

The IATTC also established a catch limit for bigeye tuna in 1998 and 1999. In 1998 a resolution was adopted that called for the cessation of making purse seine sets on schools of tuna associated with all types of floating objects when an annual catch limit of bigeye tuna had been caught in the EPO. In 1998 the total catch of bigeye tuna did not reach the catch limit, so there were no restrictions on the catch of that species, however in 1999, the fishery on floating objects closed after the catch limit was reached.

The IATTC have considered the catch limit enforced by seasonal closures, to be sufficient to achieve their conservation objectives, however, concerns have been expressed about the quality of data used to establish the IATTC catch limit. There has also been controversy over the ability of observers to distinguish between small yellowfin and bigeye tuna, and the use of data obtained from foreign longline vessels, which may not have observers onboard. The Director of the IATTC at it’s commission meeting in October 1999 noted that it appears that the observers were overestimating the bigeye landings by about 30% compared to the unloading figures (Anon 1999e). However he also noted that vessel captains tend to underestimate the unloadings by about 30% therefore these two biases tend to cancel each other out (anon 1999f). This caused some controversy as it was also estimated that 58% of the data used to establish the bigeye catch limit comes from the vessel unloading (Anon 1999e). Some members of the IATTC requested that the catch limit be altered and it was agreed that more sampling of unloadings is needed, to improve the estimates of the species composition of the catch (Anon 1999f). The likely date on which the catch limit was to be reached in 1999, was reassessed taking these aspects into account.

In 1998, the ICCAT adopted a recommendation that requested Chinese Taipei to limit catches of Atlantic bigeye tuna to 16,500mt (Appendix VII). The recommendation was entered into
force in June 1999 and according to its catch report, the bigeye catch for Chinese Taipei was below that level (16,314mt), thus the measure was strictly abided by Chinese Taipei (Anon, 2000f). This recommendation was extended in 2000 by the ICCAT at its 12th Special Meeting and requested the Chinese Taipei and China to limit, in 2001, catches of bigeye to 16,500mt and 4000mt, respectively. This recommendation also requested that each Contracting Party and Cooperating non-Contracting Party, Entity or Fishing Entity limit, 2001 catches of bigeye to the average taken by all their vessels in 1991 and 1992, excluding those whose reported catch in 1999 was less than 2,100mt. It was also noted in the recommendation that underages/overages of the 2001 catch limit for bigeye may be added to/must be subtracted from the 2002 and/or 2003 catch limits for bigeye.

The IOTC have perceived catch limits as difficult to monitor as they require the use of observers on board vessels. This is in part due to the difficulties in discriminating between small individuals of yellowfin and bigeye tuna. The IOTC have not adopted any recommendations or resolutions that introduce catch limit measures for bigeye or yellowfin tuna caught by purse seiners in the Indian Ocean.

7.2.2 Size Restrictions

Size restrictions, in weight or length, directly limit the catch or landings of tunas by longline or purse seine vessels and could be implemented to provide some protection for juvenile bigeye and yellowfin tunas. Evidence suggests that it is possible for purse seine fishermen to know the approximate size of the fish in a school prior to setting and thus may be able to refrain from setting on schools of small fish (Anon., 2000b). It is well established that bigeye and yellowfin tuna caught on FADs are predominantly juvenile fish (i.e. in the smaller size classes). Consequently, the implementation of this size restrictions would most likely imply restrictions on FAD fishing.

The ICCAT adopted in 1973 and 1980 recommendations on size limits for yellowfin and bigeye, respectively. It was recommended that Contracting Parties take the necessary measures to prohibit any taking and landing of bigeye or yellowfin tuna weighing less than 3.2kg, with a tolerance level of 15% in number of fish. Despite this the percentage of Atlantic bigeye tuna smaller than the minimum size has been generally increasing since 1991 and was at 55% for 1996-1998 (Anon 2000f). The overall percentages of undersized yellowfin tunas are also considerably higher than the 15% tolerance level. Over the period 1991-1996 the overall catches by purse seiners averaged 41.8% undersized yellowfin tuna and in the same period baitboat fisheries landed 71.6% undersized fish (Anon 2000). The ICCAT recommended in its report for 1998-1999 that this measure be further analysed.

The IOTC Working Party on Tropical Tunas, noting ICCATs experience with size limit regulations, agreed that it is not possible to implement this management measure effectively (Anon 2000b). The IOTC also noted that because small bigeye and yellowfin tuna are taken as part of a multispecies fishery, this measure would lead to an increase in discards and could only be properly enforced if all boats carry inspectors on board (Anon., 1999a).

The IATTC have also considered this measure and noted that size limits are totally ineffective unless they reduce the mortality of the smaller fish, rather than just the landings (Anon., 1999b).

An “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean” was established in 1997 between the tuna producer organisations ORTHONGEL, OPAGAC and OPTUC-ANABAC. In regards to skipjack tuna, this voluntary agreement enforced a ban on catching and marketing fish weighing less than 1.5kg with a weight tolerance of 10%. The agreement also encouraged all canneries not to buy tuna and related species weighing less than 1.5kg, regardless of where they came from. This
A Review of the Impact of FADs on Tuna Fisheries


7.2.3 Restrictions on Supply Vessels

Supply vessels are non-fishing vessels which may deploy, maintain, repair and pick up FADs (see chapter 4). The IOTC Working Party on Tropical Tunas in 2000 examined a comparison of the catches by Spanish and French purse seiners on drifting objects in the Indian Ocean and suggested that the higher catch rates obtained by Spanish fleets were as a direct consequence of the use of supply vessels (Anon., 2000b). The IOTC agreed that more research needs to be conducted on this topic and that data on the number of purse seiners and associated supply vessels operating each year needs to be obtained to improve the preliminary analyses examined. The IOTC Working Party on Tropical Tunas in 1999 also suggested that the biological and economic effects of this measure need to be investigated (Anon., 1999a). However, to date there is little conclusive evidence of the effect of supply vessels on purse seine catch efficiency (see Chapter 4).

The IATTC adopted resolutions in October 1998, June 1999 (appendix I) and July 1999 (appendix II), that prohibited the use of supply vessels operating in support of vessels fishing on FADs in the EPO, to assist in the control of the catch of bigeye tuna.

7.2.4 Restrictions on the Transhipment of Tuna

The transhipment of tuna involves the transfer of catch from one vessel to another and often occurs at sea. A restriction on the transhipment of tuna at sea implies that landings must occur in port.

The IATTC adopted resolutions October 1998, June 1999 (appendix I) and July 1999 (appendix II), that prohibit the “transhipment of tuna on the high seas by purse-seine vessels fishing for tunas in the EPO”. This measure has facilitated the monitoring of the catch relative to quotas and supported timely data collection and fishery assessments needed to determine whether the bigeye or yellowfin quota established by the IATTC should be adjusted.

7.2.5 Ban on Discards

Studies have shown that FADs aggregate not only tuna but also a community of bycatch species that are of no value to purse seiners, such as wahoo, dolphinfish, marlin and sailfish (see chapter 6). Both undersize tuna and other bycatch species are often discarded back into the ocean by purse seiners (Anon., 1999c). Much of this bycatch is dead by the time it is discarded.

A ban on discarding would require vessels to keep all discards on board. This would effectively fill their wells faster, thereby reducing the hold capacity for carrying the commercial catch and resulting in shorter trips (Anon., 1999b). While such an endeavour would likely require observers to ensure that the ban was complied with, it would also make it possible to more accurately estimate fishing mortality. It might also encourage fishing practices that result in high value catch as opposed to lower value small bigeye and yellowfin.

Experience from observer programs conducted on purse seiners by the IOTC indicates that the amount of discards in the Indian Ocean is low (relative to some other fisheries), thus the benefit of applying such a measure in the Indian Ocean would not be great (Anon., 2000b). The IOTC also identified that enforcing this measure would require having inspectors on board permanently.

The IATTC Working Group on FADs in 1999 considered a report (Anon. 1999b) which examined the effects of a ban on discards on purse seine vessels through a simulation model.
A Review of the Impact of FADs on Tuna Fisheries

Under the simulation, the total catch of bigeye tuna was reduced by 10-20% more than other species due to juvenile bigeye being caught mostly on floating objects. The ban on discards was shown to have little effect on yellowfin catches and indicated that yellowfin may experience a small increase in yield per recruit, given the reduced fishing mortality associated with a ban on discards. The simulation also suggested that the skipjack catches would be reduced by up to 10%.

7.2.6 Restrictions on the Number of Sets on FADs

The increases in global catches of juvenile tunas over the past few years has been largely attributed to an increase in the number of sets by purse seiners on floating objects. The maximum number of sets on floating objects which the tuna fishery can support depends on management objectives because yellowfin, bigeye and skipjack tuna are taken as part of a multispecies fishery and caught with the same gear.

The IATTC Working Group on FADs in 1999 examined a report (Anon., 1999b) which investigated the effects of a total ban on sets on floating objects and reducing the number of sets on floating objects to the levels seen during 1991-1992 and 1995. The data used in the report were compiled by the IATTC staff and analysed for 1987-1998 to calculate a set of fishing mortality vectors. The fishing mortality vectors were modified to encapsulate various scenarios for the 1997-2003 period. Mean estimates of recruitment and fishing mortality from 1997-1998 were used for 1998 onwards. Each of the simulations were compared to a baseline simulation in which a moratorium on the growth capacity of the fleet was applied and the floating-object sets for 1999-2003 were limited to 1998 levels.

The simulation that explored the effects of a total ban on sets on floating objects, indicated a slight increase in yellowfin catches and a reduction in skipjack catches after 1994 by 50 to 60% from the baseline. Bigeye catches initially increased followed by a substantial rise in 1988 to almost double the baseline and thereafter they declined. By 2003 the simulation predicted that the bigeye tuna catch would be 114% more than the baseline. In the simulation where the number of sets on floating objects was reduced to the 1991-1992 average, the changes in the catches of each species was about half the changes seen in the simulation of a total ban on sets. The total bigeye tuna catches rose to 45% more than the base line. In another simulation the number of sets was limited to 1995 levels and the results followed a similar pattern as those of the previous simulation, but the effects were reduced.

In 2000, the IATTC Scientific Working Group considered restricting the number of sets on FADs to reduce the catch of juvenile tuna in the EPO. They identified two scenarios which highlight the difficulty of managing FADs fisheries: If the management objective is to maximise catches of yellowfin or bigeye, there should be no sets on floating objects. This allows juveniles to grow and contribute to adult recruitment and increases yield per recruit. If the objective is to maximise catches of skipjack, then there should be no limit on the numbers of sets on floating objects.

Clearly the first scenario would maximise longline catches and the second scenario maximises purse seine catches, but each at the expense of the other fishery. The working group noted that “conclusions on this subject are based on models in which all areas of the EPO are combined and thus may overestimate the effects of measures taken in one area on fish caught in another” (Anon., 2000a).

7.2.7 Restrictions on the depth of nets

It has been suggested that the use of deeper nets can lead to greater catches of bigeye, yellowfin and skipjack tunas. The extent to which this occurs is currently not very clear and analyses have suggested that the location and the time of year of FAD sets can have a greater effect on the catches of tuna than the depth of nets (Anon., 2000a). The IATTC Scientific
A Review of the Impact of FADs on Tuna Fisheries

Working Group (April, 2000) considered that “variation in the effect of net depth and FAD depth on capture per set by area or season may reflect spatial or temporal changes in the thermocline depth or other variation in the physical environment”.

The IOTC have agreed that more research needs to be conducted on this subject as there is currently not enough evidence to support such a measure.

7.2.8 Restrictions on the number of FADs

The IOTC Working Party on Tropical Tunas in 2000, stated that there is no information about the relationship between the number of drifting objects deployed and the resulting catches.

While, the IATTC and IOTC have both considered monitoring the number of drifting objects deployed by purse seiners, they have noted that enforcement would also be difficult and would require having observers on board permanently. In addition, FADs could easily be constructed and deployed while the observer slept and vessels may also be more inclined to utilise FADs deployed by other vessels, with or without their consent (Anon., 1999b). The IATTC Working Group on FADs in 1999 suggested that to overcome these problems, vessels could be required to only make sets on a limited number of FADs that are identified by a radio beacon monitored by satellite.

7.2.9 Other measures

Tuna commissions have considered a number of other management measures, including:

- Restriction on the use of bait’s with FADs
- Cap on fishing capacity
- Restrictions on fleet size: In 1998 a recommendation was adopted by the ICCAT, that requested Contracting and non-Contracting Parties, Entities or Fishing Entities to limit the number of fishing vessels, larger than 24m length overall, to the average number of vessels that fished in 1991 and 1992 (Appendix VI). Chinese Taipei were also requested to limit, in 1999 and thereafter, their number of vessels fishing for bigeye to 125. This recommendation was readopted in 2000 (Appendix VII) to request the Philippines, China and Chinese Taipei to limit their number of vessels fishing for bigeye, in 2001 and thereafter, to 5, 30 and 125 vessels, respectively. In 1993 the ICCAT recommended “that there be no increase in the level of effective fishing effort exerted on Atlantic yellowfin, over the level observed in 1992”. An analysis by the ICCAT on the effects of this regulation, indicated that although the total carrying capacity has declined somewhat in recent years the direction and amount of change in fishing effort depends on changes in gear technology and fishing strategies which are assumed to have increased efficiency (Anon. 2000f).
- Restrictions on fishing on seamounts: Catches from seamounts have sizes and species compositions that are similar to those taken on drifting objects (see Chapter 4), thus restrictions on fishing on seamounts may reduce the fishing mortality on small fish (Anon., 2000b). However, there has been little attention directed by the tuna commissions towards exploring this as a measure that could lead to a decrease in the catches of juvenile tunas. The 2nd IOTC Working Party on Tropical Tunas briefly examined purse seine fishing on the Coco de Mer seamount, however concluded that the total catch is so small (about 5,000 t per year) that a ban on this activity would not reduce juvenile bigeye tuna mortality significantly.

However, of all the management measures considered by various commissions to date, the use of time-area closures has been the most extensively adopted in relation to controlling
FADs based fishing. The following section details the reasoning behind the use of time area closures and presents a number of case studies which describe the implementation of time area closures and the effect of these upon catches of juvenile bigeye and yellowfin tuna.

### 7.3 Time-Area Closures

In the current context, a time-area closure refers to the closure of a specified fishing ground, or part thereof, for a specified period of time, via mutual agreement by fisheries normally operating in that particular time and area. Such closures, when imposed on FADs-based purse seine fisheries, have been identified by the international tuna commissions as a potential measure to effectively control catches of juvenile tunas.

Moratoriums that restrict purse seine vessels from fishing on FADs have been implemented during three fishing seasons in the Atlantic Ocean, once in the Indian Ocean and twice in the Eastern Pacific Ocean (described as case studies in the following sections). Some of these moratoria have been implemented through resolutions and recommendations adopted by the IATTC and ICCAT, while other closures have been initiated through voluntary agreements established among industry.

The enforcement of time area closures requires the presence of observers on board all fishing vessels to ensure that purse seine vessels set only on free schools and not on FADs. The IATTC places observers on all trips made by purse seiners with a carrying capacity greater than 363 mt (except half of those trips made by Mexican vessels which carry observers from the Mexican national program). The observers of both programs record details of fishing activities and monitor compliance with regulations. The IATTC has been asked about the possibility of putting observers onboard all purse seiners, however, previous experience in the late 1980’s by the IATTC found that the lack of appropriate living space on smaller vessels was a problem (Anon. 1999b).

The ICCAT have also established an observer program and recommend that Contracting Parties ensure that all purse seiners concerned by time-area closures on FAD fishing, have an observer on board during the whole duration of the period. The ICCAT require observers to possess experience in identifying species and gear, navigation skills, knowledge of ICCATs conservation measures and of the language of the flag of the vessel, as well as the ability to carry out scientific tasks (Appendixes III and IV). The biological data collected by these observers is provided to the Standing Committee on Research and Statistics (SCRS) for analyses on the impact of time-area closure. The ICCAT encourage Contracting Parties, non-Contracting Parties, Entities and Fishing Entities to establish internal procedures to penalise any surface fleet flying its flag which is not complying with the closures (Appendix IV).

An alternative means of enforcing these moratoria is by means of a Vessel Monitoring System (VMS). VMS is a satellite technology system designed to monitor fisheries, enhance fisheries compliance, increase maritime safety and improve the reporting of catch and effort data. VMS may provide a more efficient and cost effective enforcement capability, however would require the closure of the area to all fishing for the specified period.

Simulation studies conducted on the effects of closures have indicated that moratoria can potentially decrease the catch, fishing mortality and bycatch of juvenile tuna and effectively improve the yield per recruit and spawning stock size of the tuna populations. However, most of the analyses conducted on the effects of time-area closures have indicated that the stocks did not improve very much as a result of the moratoria, because of the lack of compliance of other surface fleets or that the strata chosen for the closure was inappropriate (see following
### Table 7.1 – Outline of time-area moratoria that have been applied to FAD fishing in the Indian, Atlantic and Eastern Pacific Oceans.

<table>
<thead>
<tr>
<th>Ocean</th>
<th>Year</th>
<th>Area Description</th>
<th>Compliance</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic</td>
<td>1 November 1997 – 31 January 1998</td>
<td>Latitudes 5° N to 4° S Longitudes 20° W to the African coast</td>
<td>3 European organisations of frozen tuna producers ANABAC-OPTUC (Spanish), OPAGAC (Spanish) and ORTHONGEL (French)</td>
<td>A voluntary “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean” prohibited casting anchor or fishing under objects in the specified area.</td>
</tr>
<tr>
<td>Atlantic</td>
<td>1 November 1998 – 31 January 1999</td>
<td>Latitudes 5° N to 4° S Longitudes 20° W to the African coast</td>
<td>3 European organisations of frozen tuna producers ANABAC-OPTUC (Spanish), OPAGAC (Spanish) and ORTHONGEL (French)</td>
<td>A voluntary “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean” prohibited casting anchor or fishing under objects in the specified area.</td>
</tr>
<tr>
<td>Atlantic</td>
<td>1 November 1999 – 31 January 2000</td>
<td>Latitudes 5° N to 4° S Longitudes 20° W to the African coast</td>
<td>All surface fleets -French/Spanish and other flag vessels managed by EU countries (Anon., 2000c)</td>
<td>ICCAT Recommendations 98-1 and 99-1</td>
</tr>
<tr>
<td>Indian</td>
<td>5 November 1998 – 15 January 1999</td>
<td>5° South – 10° North in latitude. 53° East to African Coast</td>
<td>3 European organisations of frozen tuna producers ANABAC-OPTUC (Spanish), OPAGAC (Spanish) and ORTHONGEL (French)</td>
<td>A voluntary “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean” prohibited casting anchor or fishing under objects in the specified area.</td>
</tr>
<tr>
<td>EPO</td>
<td>8 November 1999</td>
<td>40° N to 40° S150° W to mainland America</td>
<td>Recommended to the Parties and non-parties under whose jurisdiction vessels operate in the EPO</td>
<td>IATTC “Resolution on the Conservation and Management of Bigeye Tuna in the Eastern Pacific Ocean”, July 1999</td>
</tr>
</tbody>
</table>
sections). Despite this, the ICCAT have noted that if the closures had not been implemented then the situation of the stocks would be worse. Unfortunately the available data and analysis do not allow the future long-term consequences of such moratoria to be estimated (Fonteneau et al., 2000).

The following sections examine six case studies of time-area closures that have been implemented in the Indian, Atlantic and Eastern Pacific Oceans. These case studies outline the agreements or resolutions that established the moratorium, the planning and research that was involved, an analysis of the effects of the moratoria and future recommendations.

7.4 Moratoriums implemented in the Atlantic Ocean (1997-2000)

In April 1997, following the recommendations of the ICCAT on the need to reduce fishing mortality of bigeye tuna, especially that of juvenile bigeye, the associations of community producers of frozen tuna, ORTHONGEL (French), OPAGAC (Spanish) and OPTUC-ANABAC (Spanish) established an “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean”. This agreement was a voluntary regulation that prohibited fishing with floating objects in the Gulf of Guinea between latitudes 5° North to 4° South and Longitudes 20° West to the African coast. Under this agreement, a voluntary time-area moratorium on anchoring or fishing on supply vessels, artificial and floating objects was adopted in the Atlantic Ocean from 1 November 1997 to 31 January 1998. This agreement was later extended to the same months in 1998-1999 in both the Atlantic and Indian Oceans. To control these operations observers were placed on board each of the tuna purse-seiners during the season with the major part of the funding provided by the Governments of Spain and France (Anon. 1999d).

In July 1998, the ICCAT adopted a recommendation on ‘The Establishment of a Closed Area/Season for the Use of Fish-Aggregation Devices’ [98-1] (see appendix III). This recommendation was established along the same lines as the voluntary agreement of the Tuna producers organisations and was later extended in 1999 [99-1] (see appendix III) to cover all fleets. During the last two ICCAT meetings in November 1999 and November 2000, the recommendation was readopted for the period 2000-2001 and 2001-2000 (Morón, 2001). The recommendation was supported by an evaluation of the effect of the moratorium performed by the SCRS during its 2000 session. This report indicated that the bigeye population was unlikely to benefit significantly as a result of the previous moratoria in the Atlantic Ocean because of the lack of compliance of other surface fleets. Despite this, a moratorium on FADs in the Gulf of Guinea will be implemented by the European fleet during November 2001-January 2002 because it has been legislated by the EU in the EC Regulation 973/2001 (Morón 2001).

7.4.1 1 November 1997- 31 January 1998, Atlantic Ocean

The 1997-1998 moratorium was the first closure to be implemented in the Atlantic Ocean. The idea of this voluntary closure was proposed by the Tuna Producers Organisation OPAGAC and prohibited fishing with floating objects in the Gulf of Guinea between 1 November 1997- and 31 January 1998. According to Morón (2001) this closure was implemented with a very high level of compliance (over 95%) and was praised by the President of the SCRS, Dr. Powers who stated that “data from 1997 show clearly that this voluntary action has proved beneficial for the stock of yellowfin tuna, bigeye tuna and skipjack with a reduction in the catch of these three species, particularly juveniles”. Dr Powers also recommended that the implementation of these measures should continue, since benefits will be obtained in the long term and will be increased if other fleets fishing in this area cooperate in the application of these measures.
A Review of the Impact of FADs on Tuna Fisheries

An analysis conducted on the French fleet indicated that, during the 1997-1998 moratorium, the tuna catches decreased by 38% with respect to the catches made during the same spatial and temporal strata in the previous year (Goujon, 1998). During the 1997-1998 moratorium, the whole proportion of sets on FADs also decreased by 20-30%, although a fraction of the French fleet continued to fish on FADs outside the moratorium area. Gaertner and Marsac (2000), noted that there was no evidence of a relocation of the fishing effort from FAD schools to non-associated schools during this period as it was observed that the total purse seine catch from school sets was stable compared to previous years. However other analyses have indicated that the moratoria since 1997 have resulted in spatial redistribution of fishing effort (Ariz et al., 2001; and Goujon and Labqisse-Bodilis, 2000). Further analyses on the effects of the 1997-1998 moratorium are outlined in section 8.4.4.

7.4.2 1 November 1998 – 31 January 1999, Atlantic Ocean

The 1998-1999 moratorium implemented in the Atlantic Ocean was an extension of the 1997-1998 “Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean”. Renewal of the agreement was difficult to achieve as companies had to consider losses incurred as a result of the previous moratorium, however, a new agreement was signed in September 1998 to repeat the moratorium in the Gulf of Guinea and to introduce a new moratorium in the Indian Ocean in an area off Somalia (Morón 2001). The effects of this moratorium have been extensively analysed together with the 1997-1998 and 1999-2000 moratoria and are outlined in section 8.4.4.

7.4.3 1 November 1999- 31 January 2000, Atlantic Ocean

In 1998 the Standing Committee on Research and Statistics (SCRS) of the ICCAT, conducted a preliminary analysis on the voluntary closures implemented in the Atlantic Ocean during 1997-1998. It was recommended that the ICCAT encourage other fleets using floating objects to join this voluntary measure. Following these suggestions, the ICCAT adopted at its session in 1998, a recommendation [98-1] (see appendix IV) whereby all purse-seiners flying the flags of contracting parties, non-contracting parties, entities and fishing entities, were obliged to comply with the conditions reflected in the 1997-1998 and 1998-1999 voluntary agreements. This recommendation was extended in 1999 [99-1] (see appendix IV) to cover all surface fleets and prohibited fishing by means of floating objects in the Gulf of Guinea from 1 November 1999 to 31 January 2000. It was the first time in tuna management history that a regulatory measure promoted and applied first by industry, became a regulatory measure used by the ICCAT (Morón 2001). The ICCAT adopted this recommendation noting that the SCRS had considered that area-season closures of the FAD fishery can significantly contribute to the reduction of the catches of juvenile bigeye and that the effects of this measure would be higher if all the surface fleets fishing on FADs participate in this closure. The recommendation was applied in the Gulf of Guinea from the 1 November of 1999 to 31 January 2000.


Ariz, et al. (2001), analysed the short term effects of the moratoria implemented in the Atlantic Ocean during 1997, 1998 and 1999 and noted that the total catch for the Spanish fleet declined by 40% during the moratorium years, with an average decrease of 59% for FAD associated catches and 20% for free school catches. They also noted that while global catches have been relatively stable in recent years, FAD associated catches have diminished by 15% and free school catches have been increased by 27%.

From the collected data, Ariz, et al. (2001), estimated a 23% reduction in the number of age-0 bigeye caught, 33% reduction for age-1 bigeye (or equivalent to a 25% reduction for
individuals smaller than 3.2kg). Similarly for yellowfin tuna, they calculated a 5% decline in the number of age-0 fish caught between 1997 and 1999, and a 32% decline in the number of age-1 fish (~17% decline in number of individuals smaller than 3.2kg).

The analysis conducted by Ariz, et al. (2001) indicated that the species and size composition of the catches taken by the Spanish fleet had not changed that significantly as a result of the moratorium, with a high percentage of the catch still comprised bigeye and yellowfin individuals less than 3.2kg. However, despite this it was concluded that “the important reduction in the catches must obviously have a positive effect on the mentioned stocks unless the positive effects have been diminished by other fleets or by other fisheries”.

Delgado de Molina et al. (2000) have also examined the effect of the voluntary moratoria since 1997 on the Spanish fishery and concluded that the application of this measure has achieved its objectives, with a significant reduction of catches taken with floating objects, particularly in the bigeye fishery.

A preliminary analysis on the 1997, 1998 and 1999 moratoria conducted by Goujon and Labqaisse-Bodilis (2000), indicated that the closures in the Atlantic Ocean resulted in a spatial redistribution of the fishing effort of the French and Spanish fleets as well as a reduction of the proportion of sets on logs. A decrease of 33% in the landings of tuna weighing less than 10kg during the moratorium period compared to those recorded in preceding years during the same months was also noted. The report indicated that the closures led to a decrease in the partial fishing mortality of juvenile bigeye tuna (for those fleets) by 45% for age-0 fish, 30% for age-1 fish and 10% for age-2 fish. Length frequency data indicated a reduction in the European purse seiner’s fishing mortality of juvenile bigeye and yellowfin by 40% and 20% respectively.

In 1999 the ICCAT Standing Committee on Research and Statistics (SCRS) conducted an analyses of the impact of the 1997-2000 moratoria on the stocks. Their analyses indicated that as a result of the moratoria, the total catches in the European and associated NEI purse-seine fleet were reduced by 34% with respect to the previous period (1993-1996), with catches under floating objects decreasing from 53% to 40% of the total catch. The proportion of bigeye caught decreased from 13% to 9%. They found evidence for a significant switch in fishing effort from FADs to free-school sets. However, a comparison of the expected catches in the event of no moratorium, with those obtained during the moratorium, suggested that a decrease of only 12% in the total catch could be attributed to the moratoria. In other words, a lowered catch was expected in these years anyway, regardless of the moratoria.

The decrease in the catches taken by the European fleets, particularly for small bigeye tuna, were found to be offset by increasing catches taken by other fleets (e.g. Ghanaian and Chinese Taipei purse seiners), some of which fished on floating objects during the moratoria. The analyses concluded that even in the hypothetical case where all purse seine fleets implemented the moratorium and reduced fishing mortality in the same proportion as the European purse seine fleets, the moratorium would not have improved the situation of the bigeye stock. However, the report also noted that if the moratorium had not been implemented then the situation of the bigeye stock would have been worse.

7.5 Moratoriums implemented in the Indian Ocean (1998-1999)

Only one closure of the purse seine fishery for tunas on FADs has been implemented in the Indian Ocean. This moratorium was conducted in 1998-1999 and was an extension of the voluntary agreement established between three European tuna producer organisations in the Atlantic Ocean. There have been no further closures of the FAD fishery in the Indian Ocean,
however, the IOTC has been considering the use of time-area closures as a management measure to reduce juvenile bigeye mortality and has initiated research to explore the feasibility of this measure.

7.5.1 15th November 1998 – 15th January 1999

Three European organisations of frozen tuna producers, ANABAC-OPTUC (Spanish), OPAGAC (Spanish) and ORTHONGEL (French), implemented a voluntary time-area closure from 15th November 1998 to 15th January 1999 in the Indian Ocean, from the African coast to 53° East in longitude and 5° South to 10° North in latitude. This voluntary agreement was an extension of the protection plan established by the tuna producers organisations in 1997 and implemented in the Atlantic Ocean during the 1997-1998 and 1998-1999 seasons. This agreement prohibited the use of fishing for tuna on FADs in this area and was enforced by observers aboard the purse seine and supply vessels.

The Spanish organisations ANABAC-OPTUC and OPAGAC placed observers aboard 10 supply vessels and 30 purse seiners. A preliminary analysis on the data collected by these observers was conducted by Arrizabalaga and Artetxe (2000). All information utilised in the analysis corresponds with fishing activities located outside the specified moratorium area. This includes route parameters of 1 vessel (whose behaviour was considered to be representative of the majority of Spanish vessels in that period) and catch, effort and discard size distributions from 12 of the tuna fishing boats. The analysis demonstrates that 3 main fishing grounds (Eastern Somalia, West Indonesia and an area between Maldives-Chagos and SE Seychelles) were explored by this single vessel outside the moratorium area between 20th November 1998 and 13th January 1999. This trend may suggest the redistribution of effort. The analysis also shows a shift in fishing modality from FAD to free school for this single vessel. During November, 84% of the operations were sets in association with drifting objects, however, in December 1998 and January 1999, 63% and 86% of the sets were on unassociated schools. The 2nd Session of the IOTC Working Party on Tropical Tunas (WPTT) in September 2000, also reviewed the data on total discards presented by Arrizabalaga and Artetxe (2000) and noted the difference between the level of discards in FAD-associated sets (9.76%) in comparison with sets on free-swimming schools (0.08%).

The IOTC Working Party on Tropical Tunas also noted that it appears that the time chosen for the closure was inappropriate and that in the case of the Atlantic and Indian Oceans, the FAD fishery for tunas is mainly concentrated in specific times and areas.

Gaertner and Marsac (2000) also examined the 1998-1999 closure in the Indian Ocean and noted that it is not easy to assess the effect of this moratorium because the strata chosen for the closure did not match the core area for log fishing in the selected period.

7.5.2 Proposed future management of FADs in the Indian Ocean

In December 1999, the IOTC adopted a resolution [99/01] (appendix V) which requested scientific advice on precise areas, periods and conditions for a moratorium on the use of FADs that would bring about a reduction in the fishing mortality of juvenile bigeye. The Commission also requested that various options be presented along with estimates on their likely effects on the catch rates of the three species of tropical tunas. On the basis of these recommendations the Commission engaged to adopt, at its Session in 2000, a season and area closure of the use of floating objects in the IOTC area of competence.

At its meeting in 2000 the IOTC Working Party on Tropical Tunas analysed a number of options for the times and areas most effective for the imposition of a moratorium. The Working party examined a document (Fonteneau et al., 2000) that reviewed the trend of catches in association with drifting objects by purse seiners and identified 10 areas and
A Review of the Impact of FADs on Tuna Fisheries

seasons where these catches are important. Of these areas, the East Somalia region was considered the most suitable for an area closure during August to November as it shows the largest concentration of catches of juvenile bigeye in association with drifting objects that is consistently large enough to significantly reduce their fishing mortality. Also significant is the fact that there is very little catch on free-swimming schools in that area and season. However, the analysis did not show that the proportion of juvenile bigeye and yellowfin associated with floating objects was significantly different in any other areas or times – the area was selected simply because the catches were larger there.

The WPTT noted that within the East Somalia region, an area located between the African Coast and 60° East, shows potential to be effective in reducing the total tuna catches between 10,000t and 40,000t, with a reduction in the fishing mortality on juvenile bigeye between 20% and 40%. This reduction is expected to result in more fish becoming available over time to longline fisheries. The analysis also indicated that a moratorium at that time could also reduce juvenile yellowfin catch by 17-33% in numbers which will likely benefit both longline and purse seine fisheries.

The WPTT noted that the moratorium is opposed by the European purse seine fleet as it covers the area and season where they concentrate their FAD fishery which largely targets skipjack. The closure could reduce skipjack catches by 18-36,000 t and these losses will not be recovered, as the skipjack will not be available to any other fishery due to their high natural mortality. Hence, these vessels are being asked to restrain their catches because of the bycatch of a species that is of marginal interest to them.

The WPTT agreed that implementing a moratorium could improve the long-term yield per recruit for bigeye and yellowfin tuna and decrease the total discards of fish of non-commercial sizes and species from the fishery. It was noted that for stocks that may be approaching full exploitation (e.g. yellowfin) or are fully exploited (e.g. bigeye), a reduction in the catch of juveniles may lead to an increase in yield per recruit and spawning stock size. In the case of yellowfin tuna, the benefits would be experienced by both the purse seine and longline fisheries, while for bigeye the longline fishery would be the main beneficiary.

The time-area closure on floating objects explored in the analysis, only involved a moratorium on fishing on floating objects, with no restrictions being placed on fishing on free schools. In principle, this would allow fishermen to fish on free-swimming schools during the moratorium, however, enforcement of this measure would require the presence of inspectors on board all vessels. If the moratorium was implemented by closing the area to all fishing (on both free schools and floating objects) for a specified time period, the closure could be enforced through a VMS system, without the placement of inspectors aboard vessels. This would, however, impose a restriction on fishing free schools, which is not necessary to achieve a reduction in fishing mortality on juvenile bigeye tuna. However, it was also noted in the report that if a moratorium were to be imposed some owners would still prefer a total closure of the fishery for a limited period. Others suggest a limit on the number of FADs deployed or a total ban on the use of supply vessels.

It was noted that there is a high initial cost of implementing a moratorium incurred from disruption to the activities of the fishery. Therefore, the expected benefits (in terms of reduction of juvenile mortality) should be sufficiently large to compensate for that initial cost, as well as for expected catches outside the moratorium area. In this respect, the IOTC Scientific Committee, considered that a shorter moratorium based on the larger of the two areas presented is more likely to be effective than a longer one based on the smaller area. It was also stressed that actions should be taken to ensure that all purse seine and associated supply vessels operating in the Indian Ocean, including those from non-Contracting Parties, comply with the moratorium. Otherwise, the intended benefits might not be attained.
Unfortunately the available data and analyses do not allow estimating the future long-term consequences of such moratoria. In December 2000, the IOTC decided that before a decision is made on imposing a moratorium, the long-term effect of a moratorium needs to be investigated including the compliance of all the purse seine fleets. The debate has been deferred to future IOTC sessions.

The 3rd Session of the IOTC WPTT in June 2001 considered the likely long-term effects upon the longline and purse seine fisheries of a possible time-area closure for purse seine fishing on floating objects. Using a simulation model, it was determined that if moratorium applied every year would result in a decrease in fishing mortality by 20%, and an increase in stock size. However, the analysis did not take into account the redistribution of effort, and the potential effects of this on fishing mortality and stock size.

The IOTC Working Party on Tagging is proposing to conduct intensive tagging in the Indian Ocean. It was noted at its 2000 meeting that within the tagging program a core objective would be to determine the movement patterns and residency of fish at FADs and to examine the interactions between FADs. This data would allow scientists to advise managers on the likely impact of time-area closures, taking into account the residence times, movement patterns and rates of fish movement within different areas of the Indian Ocean. While pilot tagging studies commenced in 2002, the future of the large scale tagging program is now considered uncertain.

7.6 Moratoriums Implemented in the Eastern Pacific Ocean (EPO) 1999-2000

In 1999 and 2000 the IATTC adopted resolutions that restricted the fishery on floating objects to protect the bigeye tuna population in the EPO. These resolutions were based on data indicating that the stock of BET was being exploited at or possibly above the sustainable level. However, despite these closures, evaluations made by IATTC haven’t indicated a serious decline in the EPO bigeye population (Morón 2001).

7.6.1 8th November 1999- 31st December 1999, EPO

In June 1998, the IATTC passed a resolution calling for the cessation of making purse-seine sets on schools of tuna associated with floating objects after 45,000 metric tons of bigeye had been caught in the EPO by surface gear, however this quota was not reached in 1998, so there were no restrictions on the catch of that species during the year.

In July 1999, the IATTC adopted a resolution on the ‘Conservation and Management of Bigeye Tuna in the Eastern Pacific Ocean’ that set a quota of 40,000mt for BET taken by purse seine vessels in the EPO for 1999. This was to be implemented by prohibiting sets on floating objects once the quota was reached. This resolution was drafted taking into consideration the documents “Assessment of Bigeye tuna in the EPO”, the Report of the Bycatch Working Group and “Estimated Effects of Various Restrictions on the Fishery for Tunas in the Eastern Pacific Ocean”.

The document “Estimated Effects of Various Restrictions on the Fishery for Tunas in the Eastern Pacific Ocean” analysed the effects of limiting the fishery on floating objects through a series of simulations that were conducted on the fishery between 1987 to 2003. Some of these simulations explored the effects of a total ban on sets on floating objects, reducing the number of sets on floating objects to the levels seen during 1991-1992 and 1995, closed seasons and time-area closures. The Working Group on FADs discussed this document in June 1999 and agreed on the need to establish management measures for the fishery on FADs, in particular to reduce the catch of juvenile BET and YFT.
A Review of the Impact of FADs on Tuna Fisheries

The report of the Bycatch Working Group 1999, stated that blanket actions such as a closure on the fishery for floating objects in an area, or a size limitation to protect juvenile bigeye and yellowfin tuna would result in reduced catches of skipjack, because the three species mix in schools, which is not desirable since the stock appears to be in a healthy condition. The working group also considered spatio-temporal closures in the EPO and examined an analysis in which the effects of closing certain areas of the EPO to fishing to reduce bycatch were presented. It was noted that some species of bycatch are caught only in a few areas, while others are present almost everywhere in the EPO. If certain areas where bycatch is concentrated were closed and the fishing effort redistributed, the bycatch could be reduced without a proportional reduction in the catch of tuna.

In October 1999, the IATTC reviewed available data on effort and catch of bigeye in the purse seine fisheries throughout the year, and estimated that the likely date on which 40,000mt of bigeye from the EPO would be reached was November 8. The Commission agreed that purse-seine fishing on floating objects would be stopped then in the EPO unless there were significant changes in the reported catches. On December 29, 1999 the NMFS announced in the Federal Register, the closure of US purse seine fishery for Bigeye Tuna on floating objects after midnight on November 8 1999, between latitudes 40° N to 40° S and from the mainland of the Americas to 150° W Longitude.

The IATTC resolution on BET that was adopted in June 1999 also recommended that a scientific working group be established to carry out comprehensive research on the impact of permanent or temporary closure of areas. In April 2000, the 1st meeting IATTC Scientific WG examined the impact of permanent or temporary closure of areas to the use of FADs, especially in combination with other regulatory measures being considered by the Commission. The Working group noted the recommendation of the Bycatch Working Group that ‘the commission should request that the Director evaluate the effectiveness of other measures such as area and time closure, to reduce bycatch of tuna and other species’.

7.6.2 15 September 2000 – 15 December 2000, EPO

In June 2000, the IATTC agreed that a ban on FADs similar to that implemented in 1999 would be imposed from September 15 through December 15, 2000. A resolution to that effect was drafted and approved. This action replaced the recommendation of the IATTC in October 1999 that set a provisional quota of 40,000mt for BET in 2000. On 30 August 2000, the NMFS announced a three-month closure of the purse seine fishery on floating objects in the EPO, effective from 12 midnight on September 14, 2000, through 12 midnight December 15, 2000 (Federal Register). It was stated that “the reason for choosing to close the fishery on floating objects, is that sets on floating objects are the major strategy the purse seine fishery uses to catch bigeye tuna. Sets on floating objects are generally more likely to catch juvenile bigeye tuna with the result that future yields from the stock could be jeopardised if juvenile bigeye mortality is excessive. To date in 2000, however, catches of bigeye tuna in the purse seine fishery have been minimal. The seasonal closure is believed to be sufficient to achieve conservation objectives.”

The IOTC WPTT in 2000 examined previous experience with time-area closures and noted that in the EPO, the use of drifting objects does not show any seasonal pattern which may explain why studies by IATTC have suggested that time-area closures would not be an effective means of reducing mortality on bigeye tuna within that region.

7.7 Summary and Conclusions

As detailed in this chapter, many different management regulations have been considered or implemented by the various tuna commissions in an effort to reduce the mortality of juvenile
A Review of the Impact of FADs on Tuna Fisheries

bigeye and yellowfin tuna due to FAD-based purse seine fisheries. Many of these measures appear to offer promise as appropriate management tools, but all of them have drawbacks which need to be overcome. In the end, it seems likely that different management measures will be appropriate for different regions and fisheries. Furthermore, it is unlikely that any one management option will solve the current problems by itself, in any region. Each tuna commission is faced with a different set of circumstances relating to the temporal and spatial nature of the fisheries, levels of observer coverage, and competing national interests. Careful consideration of these factors will likely result in the use of multiple management regulations in different regions. The following summarises the pros and cons of management measures considered to date, and suggests those which, on the weight of evidence seem most likely to offer the most appropriate measures.

Many of the management measures discussed in this chapter require observer coverage to ensure their implementation. Catch limits require observers to verify species identification and total catch numbers for vessels. Size limit regulations also require observer coverage as they do not limit discard related mortality, hence while landing of juvenile fish may be reduced, fishing mortality of these size classes may not be. Banning discarding, restricting the number of sets on FADs, or restricting the number of FADs to use would also require observer coverage to monitor whether these measures were been followed.

Time area moratoria have been shown to reduce the catch level of juvenile bigeye and yellowfin, but again, require observers. However, it is possible that the use of vessel monitoring systems could be employed in the place of observers to promote compliance. Both the use of observers and VMS are costly, and this has negatively impacted on the implementation of either measure, as the costs generally come back on the industry itself. However, if FAD based fishing is to be allowed, either measure could be offset by the cost savings from vessels no longer requiring equipment and personnel associated with searching for free schooling tuna (eg helicopter and pilot).

The use of time-area moratoria needs to be considered carefully. FADs contribute to overfishing effects but do not constitute the only gear contributing to these scenarios. In that case, should time-area moratoria be used on FAD fisheries or fishing all together? This will depend on the region and current status of fisheries and stocks. In addition, the time and area selected for a closure should also be extensively researched to ensure that the expected benefits are sufficiently large enough to compensate for the costs involved in implementing a moratorium.

Time-area closures can also used in combination with other management measures such as restrictions on the transhipment of tuna and use of supply vessels, limiting the fleet, and size limits. Some of these measures suggest a trade off between the catches of bigeye, yellowfin and skipjack tunas and between gear types, and should be adopted taking into consideration the management objectives and the nature of the fishery.

The option of restrictions on use of supply vessels requires further research as it is uncertain at this stage whether supply vessel increase the efficiency and overall catch levels of purse seiners. Such research is currently underway in the Indian Ocean. Restrictions on or banning the transhipment of tuna is a useful measure that facilitates the monitoring of catch relative to quotas, but does not necessarily have much impact on catch levels. Restricting the size of fleets using FADs does not necessarily limit fishing mortality if fishing efficiency is constantly increasing.

Ultimately, FAD based fishing appears to offer a more efficient method for catching tropical tunas than do free school purse seining. However, there are clear risks to fisheries sustainability associated with the use of this method (as indeed there are with any fishing
method). Unless clearly beneficial time-area or other management measures can be implemented to reduce juvenile bigeye and yellowfin mortality that occur as a result of FAD fisheries, continuing use of FADs at the current scale is likely to have a negative impact on stocks of bigeye and yellowfin tuna, and other fisheries that target these species (e.g. longline). The fact that these species are being heavily fished at both ends of the life cycle (juvenile and adults) is of considerable concern to fisheries scientists who fear that this will soon (if not already) lead to stock declines. To add to this concern, the present scientific data and analysis do not allow the long term consequences to the tuna stocks to be accurately estimated.

The immediate objective of fisheries managers and tuna commissions, in relation to FADs, is to reduce mortality of juvenile bigeye and yellowfin tunas. Therefore, they are being required to look at management actions to provide this outcome. Depending on the regional, fishery and stock related factors, these management actions may involve highly prescriptive controls on inputs, or they may be output based to allow fishers to select operational options that avoid capture of juvenile bigeye and yellowfin tunas.
A Review of the Impact of FADs on Tuna Fisheries

Appendix I

IATTC RESOLUTION FOR THE CONSERVATION OF BIGEYE TUNA AND ON THE USE OF FISH-AGGREGATING DEVICES BY THE PURSE-SEINE TUNA FLEET IN THE EASTERN PACIFIC OCEAN, June 1999

The Inter-American Tropical Tuna Commission (IATTC), meeting in Guayaquil, Ecuador, on the occasion of its 63rd Meeting:

Considering the information presented by the scientific staff of the IATTC in the documents on “Estimated Effects of Various Restrictions on the Fishery for Tunas in the Eastern Pacific Ocean” and on “Assessment of Bigeye Tuna in the Eastern Pacific Ocean” and the Report of the Working Group on Bycatch;

Reiterating the need to reduce the incidental catches of juvenile tunas, in particular of yellowfin and bigeye, in the surface fishery in the eastern Pacific Ocean (EPO);

Recalling that the surface fishery on fish-aggregating devices has grown substantially in the last five years, increasing the catch of juvenile bigeye and yellowfin tuna;

Concerned about the reduction in the average size of bigeye tuna caught by the aforementioned surface fishery;

Reaffirming its commitment to the application of the precautionary approach, which establishes that lack of scientific information shall not be used as a reason for not taking management measures for fisheries resources;

Recommends to the Parties and non-parties under whose jurisdiction vessels operate in the eastern Pacific Ocean that they:

1. Taking into account previous resolutions of the Commission on the conservation of bigeye tuna and on the use of fish-aggregating devices, agree to, in addition to the existing measures regarding the use of such devices:

   a) Prohibit the use of tender vessels in support of vessels fishing on fish-aggregating devices in the EPO, without prejudice to activities in other parts of the world;

   b) Prohibit the transhipment of tuna at sea;

   c) Limit the catch of bigeye tunas in the surface fishery in the EPO to 40,000 metric tons in 1999. Once this limit is reached, all sets on floating objects in the EPO shall cease;

   d) Review the status of the bigeye stock at the time of the 2000 Annual Meeting of IATTC, and give consideration to future reductions of the catches of small bigeye tuna commensurate with the scientific advice of the IATTC staff.

With the aim of not exceeding the quota, the IATTC staff shall establish a system for notifying all Parties and non-parties under whose jurisdiction vessels fish in the EPO when three-quarters of the quota has been reached. It shall also notify them at least two weeks in advance of the closure date for the fishery on floating objects, in accordance with the dispos
A Review of the Impact of FADs on Tuna Fisheries

iterations of that same regulation, in order to give them sufficient time to implement this resolution.

2. Establish a scientific working group to carry out comprehensive research, in conjunction with the IATTC staff, to include but not be limited to:

a) The effect on the populations of bigeye and yellowfin of the depth at which the fish-aggregating devices operate;

b) The effects on the catch rates and the size composition of the catch of tunas of the use of bait associated with fish-aggregating devices;

c) Estimates of the natural mortality of the various populations of tunas, in particular bigeye tuna;

d) The establishment of a maximum number of sets on floating objects which the tuna fishery in the EPO can support;

e) The impact of the fishery on floating objects between 130°W and 150°W.

f) Study the impact of permanent and/or temporary closures of areas to the use of fish-aggregating devices, especially in combination with the other regulatory measures set out in this resolution.

g) The impact on the stock of bigeye tuna of catches by small purse-seine vessels (of less that 400 short tons carrying capacity) and longline vessels; and

h) Advise on the feasibility of a program for the placement of observers on small purse seiners, and recommend the appropriate level of observer coverage necessary to obtain reliable scientific information

3. Ask the Director to continue research on the use of gear and/or techniques to reduce the catch of small tunas and other bycatches.

4. Ask the Director to provide the reports concerning this research to the Commission, which may, if appropriate, reconvene the Working Group.
Appendix II

IATTC RESOLUTION ON FISH-AGGREGATING DEVICES, July 1999

The Inter-American Tropical Tuna Commission (IATTC), having responsibility for the tunas and tuna-like fishes of the eastern Pacific Ocean (which for the purposes of this resolution is the area bounded by the coastline of the Americas, the 40°N parallel, the 150°W meridian, and the 40°S parallel) and having maintained since 1950 a continuing scientific program directed toward the study of these resources:

Considering the information presented by the scientific staff of the IATTC in the documents on “Estimated Effects of Various Restrictions on the Fishery for Tunas in the Eastern Pacific Ocean” and on “Assessment of Bigeye Tuna in the Eastern Pacific Ocean” and the Report of the Bycatch Working Group;

Noting that the fishery on fish-aggregating devices (FADs) has grown substantially in the last five years, increasing catches of juvenile tunas, in particular yellowfin and bigeye, in the purse-seine fishery in the eastern Pacific Ocean (EPO);

Concerned about the reduction in the average size of bigeye tuna caught by the purse-seine fishery in the EPO;

Reiterating the need to reduce incidental catches of juvenile bigeye and yellowfin tuna in the purse-seine fishery in the EPO;

Reaffirming its commitment to the application of the precautionary approach, which establishes that lack of scientific evidence should not be used as a reason for not taking management measures for fisheries resources;

Recalling that Resolutions adopted by the IATTC at its 61st and 62nd Meetings contained recommendations that the Parties prohibit the transshipment of tuna at sea, and prohibit the use of tender vessels whose role it is to deploy, repair, pick up, or maintain FADs at sea;

Recommends to the Parties and non-parties under whose jurisdiction vessels operate in the EPO that they:

1. Reaffirm their commitment to prohibit the transshipment of tuna by purse-seine vessels fishing for tuna in the EPO, unless such transshipment takes place in port;

2. Prohibit the use of tender vessels operating in support of vessels fishing on FADs in the EPO, without prejudice to similar activities in other parts of the world;

3. Establish a scientific working group to carry out comprehensive research, in conjunction with the IATTC staff, to include, but not be limited to

(a) The relationship between catches of bigeye and yellowfin tuna and the maximum depth of FADs;

(b) The effect of the use of baited FADs on catch rates and size composition of the catch of tunas;

(c) Estimates of the natural mortality of the various populations of tunas;
A Review of the Impact of FADs on Tuna Fisheries

(d) The establishment of a maximum number of sets on floating objects which the tuna fishery in the EPO can support;

(e) The catches of tunas and associated and dependent species in the fishery on floating objects between 130°W and 150°W;

(f) The impact of permanent or temporary closure of areas to the use of FADs, especially in combination with other regulatory measures being considered by the Commission;

(g) The feasibility of a program to place observers on purse-seine vessels of less than 400 short tons carrying capacity and the appropriate level of observer coverage necessary to obtain reliable scientific information.

Requests that the Director continue research into the use of fishing gear and/or techniques to reduce the catch of small tunas and the bycatch of non-target species and continue to report to the Commission on the results of this research.
Appendix III

ICCAT RECOMMENDATION 98-1 ON CLOSED AREA/SEASON FOR FISHING WITH FADs IN E. TROP. ATLANTIC. YFT & BET

Noting that the Commission’s Standing Committee on Research and Statistics (SCRS) has considered the time/area closures applied voluntarily by vessel owners of the European Community is a very promising approach to reduce catches of juveniles;

Recalling that SCRS has considered that, for this type of measure to be most effective, it should be applied by all purse seiners fishing over floating objects;

Recalling that the strict application of the minimum weight of 3.2 kg for bigeye and yellowfin tunas would entail the loss of very important catches of adult skipjack;

THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THAT:

1 Fishing by purse seiners flying the flag of Contracting Parties and cooperating non-contracting parties, entities and fishing entities over floating objects, shall be prohibited during the period and the area specified in paragraphs 2 and 3 below:

2 The area referred to in paragraph 1 is the following:

-- Southern limit: parallel 4° South latitude
-- Northern limit: parallel 5° North latitude
-- Western limit: meridian 20° West longitude
-- Eastern limit: the African coast

3 The period covered by the prohibition of paragraph 1 will be from 1 November 1999 to 31 January 2000.

4 The prohibition referred to in paragraph 1 includes:

-- Prohibition to launch all floating objects;
-- Prohibition to fish over artificial objects;
-- Prohibition to fish over natural objects;
-- Prohibition to fish with auxiliary vessels;

5 In 2000, SCRS shall analyse the impact of the measure on the stock as well as the area and the dates of this measure and will recommend any change that may be deemed necessary to improve its effectiveness.

6 Contracting Parties shall ensure that all purse seiners concerned by this measure have an observer on board, during the whole duration of the period, who shall observe the respect of the prohibition referred to in paragraphs 1 to 4.
The observers should possess the following skills in order to discharge their duties:

-- sufficient experience to identify species and gear

-- navigational skills

-- a satisfactory knowledge of the ICCAT conservation measures

-- the ability to carry out elementary scientific tasks e.g. collecting samples, as requested and observe and record accurately,

-- a satisfactory knowledge of the language of the flag of the vessel observed.
Appendix IV

ICCAT RECOMMENDATION 99-1 ON THE ESTABLISHMENT OF A CLOSED AREA/SEASON FOR THE USE OF FISH-AGGREGATION DEVICES (FADs)

RECALLING that in 1998 ICCAT adopted a Recommendation Concerning the Establishment of a Closed Area/Season for the Use of Fish Aggregation Devices (FADs) between 1 November 1999 and 31 January 2000;

RECALLING that the strict application of the minimum weight of 3.2 kg for bigeye and yellowfin would entail the loss of very important catches of adult skipjack;

NOTING that the Standing Committee on Research and Statistics (SCRS) has considered that this type of measure can significantly contribute to the reduction of the catches of juvenile bigeye;

NOTING that SCRS has considered that the effect of this measure would be higher if all the surface fleets fishing on FADs participate in this closure;

CONSIDERING that, for the first time in 2000, SCRS will analyse the impact of the measure on the stocks as well as the area and the dates of this measure, and will recommend any change that may be deemed necessary to improve its effectiveness;

CONSIDERING that for this measure to be most effective it has to be applied by all surface fleets fishing on FADs,

THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THAT:

1 Fishing by surface fleets flying the flag of Contracting Parties, Non-Contracting Parties, Entities and Fishing Entities over floating objects, shall be prohibited during the period and the area specified in paragraphs 2 and 3 below:

2 The area referred to in paragraph 1 is the following:

   -- Southern limit: parallel 4º South latitude
   -- Northern limit: parallel 5º North latitude
   -- Western limit: meridian 20º West longitude
   -- Eastern limit: the African coast

3 The period covered by the prohibition of paragraph 1 will be from 1 November of one year to 31 January of the following year.

4 The prohibition referred to in paragraph 1 includes:

   -- Prohibition to launch all floating objects;
   -- Prohibition to fish over artificial objects;
A Review of the Impact of FADs on Tuna Fisheries

-- Prohibition to fish over natural objects;
-- Prohibition to fish with auxiliary vessels;
-- Prohibition to set at sea artificial floating objects with or without buoys;
-- Prohibition to charge buoys in the floating objects found at sea;
-- Prohibition to remove floating objects and to wait that associated fish to the objects will be associated to the boat;
-- Prohibition to tug floating objects outside the zone.

5 The Commission requests SCRS to analyse, for the first time in 2000, the impact of this measure on the stocks and to recommend any change that may be deemed necessary to improve its effectiveness, in order to evaluate the possible modifications to apply to the closure.

6 Contracting Parties, Non-Contracting Parties, Entities and Fishing Entities shall ensure that all surface fleets concerned by this measure have an observer on board, during the whole duration of the period, who shall observe the respect of the prohibition referred to in paragraphs 1 to 4. The biological data collected on the fleet as a whole by these observers should be provided to the SCRS for the purpose of carrying out analyses identified in paragraph 5.

7 Contracting Parties, Non-Contracting Parties, Entities and Fishing Entities will establish internal procedures to penalize surface fleets flying its flag that do not comply with the closure. They will present an annual report on their implementation to the Secretariat. The Executive Secretary will make a report to the Commission.

8 The observers should possess the following skills in order to discharge their duties:

-- Sufficient experience to identify species and gear
-- Navigational skills
-- A satisfactory knowledge of the ICCAT conservation measures
-- The ability to carry out elementary scientific tasks e.g. collecting samples, as requested and observe and record accurately,
-- A satisfactory knowledge of the language of the flag of the vessel observed.
IOTC RESOLUTION 99/01 ON THE MANAGEMENT OF FISHING CAPACITY AND ON THE REDUCTION OF THE CATCH OF JUVENILE BIGEYE TUNA BY VESSELS, INCLUDING FLAG OF CONVENIENCE VESSELS, FISHING FOR TROPICAL TUNAS IN THE IOTC AREA OF COMPETENCE

The Indian Ocean Tuna Commission (IOTC):

Noting that the FAO Code of Conduct for Responsible Fishing provides that States should take measures to prevent or eliminate excessive fishing capacity,

Concerned that the fleets fishing for tropical tunas in the IOTC area of competence continue to increase rapidly, and that current capacity may exceed the level of fishing effort appropriate for sustainable use of the high value tuna resources of the Indian Ocean,

Further concerned that, for example, the biomass of adult bigeye in the Indian Ocean has shown a continual and severe decrease, as reported by the Scientific Committee, as a result of increasing catches by both longliners and purse seiners,

Further concerned that currently about 70% by number of the total bigeye catch is taken by the purse-seine fleet, and consists mainly of juvenile fish, and that 80% of the catch in weight is taken by the longline fleet, and consists mainly of adult fish,

Recalling that in February 1999 the FAO Committee on Fisheries adopted the International Plan of Action for the Management of Fishing Capacity (in application of the Code of Conduct), calling for immediate action to reduce fishing capacity in major international fisheries,

Further recalling that the Rome Declaration on the Implementation of the Code, adopted by the FAO Ministerial Meeting on Fisheries in March 1999, underlines the important role of regional fishery management organizations in respect of the implementation of the Code of Conduct,

Noting that the Scientific Committee has considered that, on the basis of certain indicators, if the catches continue at high levels, the stock of bigeye tuna is likely to become overexploited and, taking account of the precautionary approach, there is a need for immediate management action,

Further noting that the Scientific Committee has recommended that the increase in catches of the stock of bigeye tuna by all gears should be halted immediately, and that the increase in catches of small bigeye tuna associated with floating objects should also be halted,

Recognizing Japan's initiative to implement the FAO Plan of Action by a reduction in the number of long-distance longline vessels by 20% (132 vessels), and the need for possible, concerted and appropriate actions by other States or fishing entities,

Considering that the Scientific Committee concluded that establishing area and seasonal closures of fishing grounds to fishing on floating objects would appear to be the best option to reduce the catches of juvenile bigeye tuna by purse seiners,
A Review of the Impact of FADs on Tuna Fisheries

Recalling the Resolution of the Third Session of IOTC concerning registration and exchange of information on vessels, including flag of convenience vessels, fishing for tropical tunas in the IOTC area of competence,

Very concerned that illegal, unregulated and unreported (IUU) fishing activities by large-scale tuna vessels in the IOTC area of competence have continued to increase, severely diminishing the potential effectiveness of conservation and management measures adopted by IOTC and impeding adequate stock assessment by the Scientific Committee:

1. Undertakes to adopt concerted actions to limit the fishing capacity of the fleet of large-scale vessels fishing for tropical tunas in the IOTC area of competence, to ensure the long-term sustainable exploitation of tuna stocks. As a first step, at its Session in 2000 IOTC will consider, on the basis of the scientific advice referred to in paragraph 3 below, the limitation of the capacity of the fleet of large-scale tuna vessels to the appropriate level.

2. Engages to adopt, at its Session in 2000, a season and area closure of the use of floating objects in the IOTC area of competence, on the basis of the scientific advice referred to in paragraph 3 below.

3. Asks the Scientific Committee to present, at the Session of IOTC in 2000, recommendations on:

   The best estimate, on the basis of existing data and analyses, of the optimum fishing capacity of the fishing fleet which will permit the sustainable exploitation of tropical tunas.

   Precise areas, periods and conditions for a moratorium on the use of floating objects that would bring about a reduction of the fishing mortality of juvenile bigeye. The Scientific Committee should present various options, with estimates of their likely effects on the catch rates of the three species of tropical tunas.

4. Urges Contracting Parties and non-contracting Parties cooperating with IOTC to fulfil their obligations concerning the transmission of the list of vessels fishing for tropical tunas according to the Resolution of the Third Session.

5. Regardless of the full application of this resolution, Contracting Parties will have due regard to the interests of all countries concerned, in conformity with the rights and obligations of those countries under international law and, in particular, to the rights and obligations of developing countries of the Indian Ocean rim with respect to their entry into the high seas fisheries in the IOTC area of competence.
Recalling that in 1997 the Commission urged parties to reduce catches of bigeye tuna to levels below MSY; & Recognising that the Commission has requested that the Standing Committee on Research and Statistics (SCRS) study and present at its 1999 meeting a range of possible stock recovery scenarios; & Considering the importance of establishing interim measures pending the development in 1999 by the Commission of a stock recovery plan;

THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THAT:

1 Each Contracting Party or Cooperating non-Contracting Party, entity or fishing entity shall, in 1999 and thereafter, limit the number of their fishing vessels larger than 24 meters length overall (LOA), with the exclusion of recreational vessels, which will fish for bigeye tuna in the Convention area to the average number of its fishing vessels actually having fished for bigeye tuna in the Convention area for two years of 1991 and 1992. Such limitation of the vessel numbers shall be associated with a limitation of Gross Registered Tonnage (GRT) so as not to increase the total fishing capacity.

2 By August 31, 1999, each Contracting Party or Cooperating non-contracting party, entity or fishing entity shall report to the Commission the limit on the fishing vessel number established pursuant to paragraph 1 above and the basis for calculation. The Commission shall review the appropriateness of such limit and its calculation basis at the 1999 meeting.

3 That paragraphs 1 and 2 above do not apply to Contracting Parties or Cooperating non-contracting parties, entities or fishing entities that catch annually less than 2,000 MT of bigeye tuna on an average of the recent five years. When the annual catch of any of those Parties / entities or fishing entities exceeds 2000 MT before 2001, the Commission should consider and recommend, if appropriate, new conservation measures for bigeye tuna, applicable to them.

4 The Commission will consider in 1999 options of conservation measures to manage by-catch of bigeye tuna by other fisheries targeting tunas and tuna-like fishes.

5 That the Commission shall review, at the 2001 meeting, the effectiveness of this effort control in conjunction with the stock recovery plan.

6 Notwithstanding paragraph 1 above, the Commission shall request Chinese Taipei to limit in 1999 and thereafter catches of Atlantic bigeye tuna to 16,500 MT and the number of their fishing vessels fishing for Atlantic bigeye tuna to 125. Such limitation of the vessel number shall be associated with a limitation of Gross Registered Tonnage (GRT) so as not to increase the total fishing capacity.

7 Without prejudice to the full implementation of this Recommendation, parties should bear in mind the interest of all countries, entities and fishing entities concerned, in accordance with their rights and obligations under international law, particularly those of developing coastal countries in developing their own fisheries. In this regard, the parties recognize that further action may be required, consistent with the need to ensure the sustainability of the fishery resources.
Appendix VII

ICCAT NOVEMBER 2000 RECOMMENDATION ON THE BIGEYE TUNA
CONSERVATION MEASURES

Recalling that in 1997 the Commission urged parties to reduce catches of bigeye tuna to
levels below MSY;

Recognising that in 1998 the Commission requested that the Standing Committee on Research
and Statistics (SCRS) develop stock rebuilding scenarios to levels that support MSY;

Recalling the 1998 Recommendation by ICCAT on the Bigeye Tuna Conservation Measures
for Fishing Vessels Larger Than 24 Meters Overall Length (LOA) limiting the number of the
fishing vessels, which will fish for bigeye tuna in the Convention Area, to the average number
of its fishing vessels actually having fished for bigeye tuna in the Convention area for the two
years of 1991 and 1992;

Considering the importance of establishing interim measures pending the development of a
stock rebuilding plan;

Expressing concern that several states have increased the number of their large-scale tuna
longline fishing vessels and their bigeye catches drastically;

THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC
TUNAS (ICCAT) RECOMMENDS THAT:

1. Each Contracting Party and Cooperating non-Contracting Party, Entity or Fishing Entity
shall, in 2001, limit their catch of Atlantic bigeye tuna to the average catch of bigeye taken by
all their vessels in the two years of 1991 and 1992.

2. Notwithstanding the paragraph above,
   China shall limit, in 2001, its catch of Atlantic bigeye tuna to 4 000 mt. China shall make
every effort to limit the number of its fishing vessels fishing for bigeye tuna to 30, while the
overall number of its vessels registered with the Commission be frozen at 60 for 2001 and
thereafter, unless the Commission decides otherwise. The catch and number of the fishing
vessels of China will be reviewed before the 2001 Commission annual meeting.

The Commission shall request Chinese Taipei to limit, in 2001, its catch of Atlantic bigeye
 tuna to 16 500 mt and the number of its fishing vessels fishing for Atlantic bigeye tuna to 125

The Commission shall request the Philippines to limit, in 2001, and thereafter, the number of
its fishing vessels fishing for Atlantic bigeye tuna to 5.

3. The provision of paragraph 1 will not apply to Contracting Parties, Cooperating non-
Contracting Parties, Entities or Fishing Entities whose reported 1999 catch, as provided to the
SCRS in 2000, was less than 2100 mt.

4. Underages/overages of the 2001 catch limit for bigeye tuna may be added to/must be
subtracted from the 2002 and/or 2003 catch limits for bigeye tuna.
5. The SCRS shall include in its next assessment of the Atlantic bigeye stock, possible recovery scenarios, including specific TAC recommendations, with the goal of rebuilding Atlantic bigeye tuna to biomass levels that will support MSY.
Appendix VIII

IOTC MEMBERS LIST

Membership of IOTC is open to Indian Ocean coastal countries and to countries or regional economic integration organisations which are members of the UN or one of its specialised agencies and are fishing for tunas in this ocean. Current membership includes:

Australia, China, European Community, Eritrea, France, India, Japan, Republic of Korea, Madagascar, Mauritius, Malaysia, Oman, Pakistan, Seychelles, Sudan, Sri Lanka, Thailand and United Kingdom.

Parties qualified to accede to the Commission may do so by depositing with the Director-General of FAO an instrument formally accepting to be bound by the conditions of the IOTC Agreement.

Sessions of the Commission are normally held annually. The officers of the Commission are elected from the delegates or alternates present at Commission meetings and hold office for a biennium.
Appendix IX

ICCAT CONTRACTING PARTIES

The Convention is open for signature, or may be adhered to, by any Government which is a Member of the United Nations or of any specialized agency of the United Nations. Instruments of ratification, approval, or adherence may be deposited with the Director-General of the Food and Agriculture Organization of the United Nations (FAO), and membership is effective on the date of such deposit. Currently, there are 31 contracting parties.

CONTRACTING PARTIES / PARTIES CONTRACTANTES / PARTES CONTRATANTES

<table>
<thead>
<tr>
<th>Party/Partie/Parte</th>
<th>Since/Depuis le/Desde</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITED STATES</td>
<td>1967</td>
</tr>
<tr>
<td>JAPAN</td>
<td>1967</td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>1967</td>
</tr>
<tr>
<td>GHANA</td>
<td>1968</td>
</tr>
<tr>
<td>CANADA</td>
<td>1968</td>
</tr>
<tr>
<td>FRANCE (St-Pierre et Miquelon)</td>
<td>1968</td>
</tr>
<tr>
<td>BRASIL</td>
<td>1969</td>
</tr>
<tr>
<td>MAROC</td>
<td>1969</td>
</tr>
<tr>
<td>KOREA, Rep. of</td>
<td>1970</td>
</tr>
<tr>
<td>CÔTE D'IVOIRE</td>
<td>1972</td>
</tr>
<tr>
<td>ANGOLA</td>
<td>1976</td>
</tr>
<tr>
<td>RUSSIA</td>
<td>1977</td>
</tr>
<tr>
<td>GABON</td>
<td>1977</td>
</tr>
<tr>
<td>CAP-VERT</td>
<td>1979</td>
</tr>
<tr>
<td>URUGUAY</td>
<td>1983</td>
</tr>
<tr>
<td>SÃO TOMÉ E PRINCIPE</td>
<td>1983</td>
</tr>
<tr>
<td>VENEZUELA</td>
<td>1983</td>
</tr>
<tr>
<td>GUINEA ECUATORIAL</td>
<td>1987</td>
</tr>
<tr>
<td>GUINÉE-CONAKRY</td>
<td>1991</td>
</tr>
<tr>
<td>UNITED KINGDOM (Bermuda)</td>
<td>1995</td>
</tr>
<tr>
<td>LIBYA</td>
<td>1995</td>
</tr>
<tr>
<td>CHINA, People's Rep. of</td>
<td>1996</td>
</tr>
<tr>
<td>CROATIA</td>
<td>1997</td>
</tr>
<tr>
<td>COMMUNAUTÉ EUROPÉENNE</td>
<td>1997</td>
</tr>
</tbody>
</table>
### A Review of the Impact of FADs on Tuna Fisheries

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUNISIE</td>
<td>1997</td>
</tr>
<tr>
<td>PANAMA</td>
<td>1998</td>
</tr>
<tr>
<td>TRINIDAD &amp; TOBAGO</td>
<td>1999</td>
</tr>
<tr>
<td>NAMIBIE</td>
<td>1999</td>
</tr>
<tr>
<td>BARBADOS</td>
<td>2000</td>
</tr>
<tr>
<td>HONDURAS</td>
<td>2001</td>
</tr>
<tr>
<td>ALGÉRIE</td>
<td>2001</td>
</tr>
</tbody>
</table>

Note 1: SENEGAL was a member of the Commission from 25-VIII-1971 to 31-XII-1988. CUBA was a member of the Commission from 15-I-1975 to 31-XII-1991. BENIN was a member of the Commission from 9-I-1978 to 31-XII-1994. Note 2: FRANCE (member since 7-XI-1968), SPAIN (member since 21-III-1969), PORTUGAL (member since 3-IX-1969), the U.K.* (member since 10-XI-1995) and ITALY (member since 6-VIII-1997) withdrew from the Commission following the access of the European Community on 14-XI-1997. However, FRANCE retains membership as of 24-XII-97 and the UNITED KINGDOM as of 19-I-1998 on behalf of their overseas territories not covered by the Treaty of Rome.* As concerns the United Kingdom of Great Britain and Northern Ireland, Anguilla, Bermuda, St. Helena, Turks and Caicos.
Appendix X

THE IATTC MEMBER COUNTRIES

The IATTC Member Countries are: Costa Rica, Guatemala, Panama, Ecuador, Japan, United States, El Salvador, Mexico, Vanuatu, France, Nicaragua, Venezuela.
Appendix XI

Sources of Data used in this Report

Indian Ocean Data
IOTC (Indian Ocean Tuna Commission) dataset; ‘Tuna Catches in the Indian Ocean, 1950-1998’

IOTC Website (WWW.SEYCHELLES.NET/IOTC/English/TechInfo/Edatabases.htm#online)

Western and Central Pacific Ocean Data
SPC (Secretariat of the Pacific Community) website http://www.spc.org.nc/oceanfish/
Dataset: ‘WCPO Tuna Capture 1950-1999’

Eastern Pacific Ocean Data
IATTC (Inter-American Tropical Tuna Commission) online database: ‘World Catches of tuna 1970-2000’

IATTC (Inter-American tropical Tuna Commission) dataset: ‘Purse Seine Set Types 1987-2000’

From IATTC Website: http://www.iattc.org/HomeENG.htm

Also IATTC Annual Report for 2000 (in preparation), including published and unpublished data from the National Research Institute of Far Seas Fisheries (NRIFSF), Shimizu, Japan; Institute of Oceanography, National Taiwan University, Taipei, Taiwan; and National Fisheries Research and Development Agency, Republic of Korea. The data were converted from numbers of fish to weight in metric tonne by IATTC staff.

Atlantic Ocean Data

ICCAT online Database: www.iccat.es
References


A Review of the Impact of FADs on Tuna Fisheries


A Review of the Impact of FADs on Tuna Fisheries


Cayre, P. (1991) Behavior of yellowfin tuna (Thunnus albacares) and skipjack tuna (Katsuwonus pelamis) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging. Aquat. Living Resour. 4, 1-12.


Fonteneau, A., Gaertner, D., Nordstrom, V. (2001) An overview of problems in the catch per unit of effort and abundance relationship for the tropical purse seine fisheries. 14th Meeting of the Standing Committee on Tuna and Billfish (SCTB); Noumea, New Caledonia.


A Review of the Impact of FADs on Tuna Fisheries


A Review of the Impact of FADs on Tuna Fisheries


A Review of the Impact of FADs on Tuna Fisheries


A Review of the Impact of FADs on Tuna Fisheries


