TECHNICAL AND COMPLIANCE COMMITTEE
Tenth Regular Session
25 - 30 September 2014
Pohnpei, Federated States of Micronesia

FAD MARKING AND MANAGEMENT DISCUSSION PAPER (PARA 38 OF CMM 2013-01)

WCPFC-TCC10-2014-19
29 August 2014

1. At WCPFC10 in adopting CMM 2013-01 the Secretariat was tasked with preparing a report for consideration by the SC, TCC and Commission in 2014.

Paragraph 38 of CMM 2013-01 says:

38. The Commission Secretariat will prepare a report on additional FAD management options for consideration by the Scientific Committee, the Technical & Compliance Committee and the Commission in 2014, including:
a. Marking and identification of FADs;
b. Electronic monitoring of FADs;
c. Registration and reporting of position information from FAD-associated buoys; and
d. Limits to the number of FADs deployed or number of FAD sets made.

2. As a response to this tasking, on 23 July 2014 the Secretariat sent out WCPFC Circular 2014/60 (attached).

3. TCC10 is invited to discuss and as appropriate provide recommendations and technical advice.

TO ALL COMMISSION MEMBERS, COOPERATING NON-MEMBERS AND PARTICIPATING TERRITORIES

Circular No.: 2014/60
Date: 23 July 2014
No. pages: 187

FAD Marking and Management: Information paper for SC and TCC as Requested

Dear All,

At WCPFC10 in adopting CMM2013-01, the Commission asked members fishing on the highseas to submit FAD Management Plans before 1 July 2014.

37. By 1 July 2014, CCMs fishing on the high seas shall submit to the Commission Management Plans for the use of FADs by their vessels on the high seas, if they have not done so. These Plans shall include strategies to limit the capture of small big-eye and yellowfin tuna associated with fishing on FADs, including implementation of the FAD closure pursuant to paragraphs 14 – 18. The Plans shall at a minimum meet the Suggested Guidelines for Preparation for FAD Management Plans for each CCM (Attachment E).

The Commission also tasked the Secretariat to:

38. The Commission Secretariat will prepare a report on additional FAD management options for consideration by the Scientific Committee, the Technical & Compliance Committee and the Commission in 2014, including:
a. Marking and identification of FADs;
b. Electronic monitoring of FADs;
c. Registration and reporting of position information from FAD-associated buoys; and
d. Limits to the number of FADs deployed or number of FAD sets made.

This request under paragraph is exactly the same as the request made under CMM 2008-01 that the Secretariat responded to by when they prepared and submitted WCPFC-TCC5 2009/22 on FAD Management and Planning. The Secretariat also produced a paper that was adopted at TCC5; 2009/28 *"Minimum data fields for Purse Seine FAD Monitoring"*. A review of the record of TCC5 gives little indication of what happened with the paper 2009/22 (paras 338 to 348 of the TCC report apply) there is in para 340 of an alternative proposal from the Solomon Islands for additional work to be undertaken on FADS including marking:

340. With regard to FAD management and monitoring, the Solomon Islands, on behalf of FFA members, stated that more progress is needed on FAD management, including a market study, and the identification and tracking of FADs and other electronic equipment related to fishing. A proposal for this study was tabled as WCPFC-TCC5-2009/DP-21.

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However no decision is recorded in the text of the meeting report indicating where this went. So it appears that the Secretariat has provided this paper and information and it was discussed at TCC5 but what happened to it at those discussions appears lost in the midst of time. I also checked the annual meeting report for 2009 on the adoption of the TCC Report and there is no further consideration of this issue there either. Therefore it is arguable that the Secretariat has done its job in presenting you with this paper as requested what we lack is any further direction, however, arguing that line while tempting, will not help us move this issue forward.

To try to move the issue forward for you, I have spoken to the PNA about the FAD work they are doing, and they have given approval for me to attach one of their information papers on FAD tracking, attached also is the US paper on FADs presented last year and also copied for you the amended requirements for FAD Management plans that are part of 2013-01. Also attached for your reference is the original paper on this issue as prepared by the Secretariat and a good report on FAD use internationally prepared for the WTPO by MRAG UK.

In some ways to me the fundamental question is……what is it that we are trying to achieve or what are our objectives with FAD Marking and Tracking? When we get the information what do we want to do with it? I can understand why the PNA wants to do it but am unsure of what our overall goal is? I understand we have the information we require on FAD usage from a scientific perspective.

Issues

1. Paragraph 37 of 2013-01 refers to the development of FAD management plans by member countries fishing on the high seas. However para 38 appears to apply to all FADs and if that is so then a number of the issues raised in 38 are being addressed by the PNA, are in the original paper or are improved by the changes made to Attachment E of 2013-01.
2. In relation to (a) marking and identification of FADs, Attachment E of 2013-01 makes this a flag state responsibility. The question this is do you want this to change and have consistence in FAD marking and identification for the WCPFC and if so we would need to develop a paper on FAD marking and identification guidelines and these would need to consider electronic signatures that are on all FADs with buoys attached so they can be tracked by industry.
3. For (b) above this requires information on electronic monitoring of FADs. This is mentioned to a degree in the Secretariat paper but a lot more information is included in a good paper prepared by the PNA for their Ministers "Feasibility Study-PNA FAD Tracking and Management 2013". I have asked PNA for permission to share this paper with you and it is attached for your information. This paper is complimented by a 2014 PNA paper on FADs as well.
4. Registration and reporting of position information from FAD-associated buoys is required under part (c) and again this has been covered in detail by PNA and developments and papers prepared by them for their members are directly relevant to discussion that you need to have on these issues in the Commission; and
5. Part (d) is about FAD limits. We know with some certainty, that for the vessels fishing in the PNA waters, a vessel sets around 100 FADs per boat per year. This may be higher or lower for some flags but this is a round the average. What seems very hard to determine is the level of FAD usage in the Philippines and in Indonesian waters. In 2013-01 Attachment A provides information on actual FAD sets and limits for FAD sets 2014 onwards as it considers what will be allowed for FAD sets. This table in a way deals with Part (d) of this request. What needs to be determined is how to monitor and limit FAD sets in Indonesian and the Philippines waters.

What has changed since 2009?

There are a number of changes since 2009 that we would need to consider in how we approach the four issues above that differ from 2009/22:

1. The number of purse seine vessels in the commercial fishery has increased to some 300 vessels in the fishery in 2014.
2. The known FAD numbers are around 30,000 and roughly the same (PNA) but what is unknown is the level of FAD use in Philippines and Indonesia.
3. The FAD technology has changed and boats can now fish on FADs with some certainty of catching fish through the increased usage of sonar buoys. This technology allows boats to cherry pick the FAD on which they fish and actually changes the game in a major way.
4. Vessels are using more FADs as fish schools become scarcer.
5. This technology will continue to improve as we move forward.
6. The FAD closures are set to extend from 4-6 months so therefore tracking and monitoring will become very important to ensure vessels stay within their limits.

Moving Forward

It is recommended that the Commission.

1. Appoint a small working group of members, the PNA and industry and the SPC under a proactive chair preferably from industry to review the papers included with this report including the FFA and US papers submitted to Commission meetings, the PNA papers and approaches and to recommend a way forward for the Commission on three (3) main issues.
   a. FAD marking, and identification, and use of electronic signatures
   b. FAD monitoring, tracking and control to prevent FADs becoming marine debris; and
   c. Appropriate limits to FAD deployment;
2. Until other decision are made in relation to FADs to limits FAD sets to the table at Attachment 1 of 2013-01;
3. Limit FADs and buoys per vessel to no more than 100 until the work of the small working group is completed; and
4. Commission a paper to be completed by an external consultant to analyses the commercial implications of FAD usage in order to inform a sensible debate on FAD limits and controls.

Thanks,

Professor Glenn Hurry
Executive Director

Feasibility Study – PNA FAD Tracking and Management

October 2013

Summary

The use of fish aggregating devices (FADs) in PNA waters has grown extensively over the last 30 years. While FADs make purse seining more efficient, the continued uncontrolled use poses serious threats to the sustainable management of the tuna resources in PNA waters. Currently it is estimated that over 30,000 drifting and anchored FADs are active in PNA waters, with numbers increasing and no controls in place.

According to the definition of "fishing" in PNA national-level legislation as well as the WCPFC, a drifting FAD is technically "fishing" during its entire time at sea. While currently there are no strict controls on this fishing activity, there are grounds for PNA to take control of FAD fishing to ensure it occurs in line with coastal state standards for management and accountability. One way to do this is to track all the FADs in PNA waters so that members know the actual fishing effort that is occurring in the EEZs while giving PNA members the ability to better manage the fishery and track compliance with conservation measures and the MTCs.

The PNA Ministers discussed the concept of FAD tracking at the 2009 Ministerial, and endorsed FAD tracking in 2011. Building on this progress, the Pew Charitable Trusts and the PNA Office developed a FAD tracking trial with Quick Access Computing (QAC), beginning in 2012. The scope of the trial was to determine if FADs in PNA waters could be tracked using the technology already utilized by purse seine operators. If so, the next step was to further develop the Fisheries Management Information System (FIMS) so it could track FADs as an additional "asset".

The trial was successful in proving that all major brands of satellite buoys attached to FADs could be tracked by the PNAO. Doing so simply requires buoy owners (vessels or companies) to authorize dual reporting of their buoys. The trial was also successful in enhancing the FIMS so it can track FADs automatically, much the same as it tracks vessels and other assets in the system.

While currently little is known about the biggest fishing effort in PNA waters (drifting FADs), the tools have now been developed to turn this around. FAD tracking will enable PNA to:

- Track and control all "fishing" in PNA waters;
- Share data from drifting FADs with scientists to better understand the dynamics and impacts of FADs on tropical tunas and the broader ecosystem;
- Generate revenue from licensing FADs (FAD VDS);
- Monitor compliance in PNA waters with FAD measures (set limits and FAD closures);
- Automate verification of "free-school" sets;
- Ensure industry accountability for FADs that are abandoned or wash up on reefs; and
- Eliminate IUU activity related to FAD fishing.

Background

The wide-spread use of fish aggregating devices (FADs) in industrial tuna fisheries is a growing global concern due to the high levels of by-catch, the lack of regulation on FAD numbers, and the impact on marine litter. To date, PNA has managed FADs through high seas and EEZ FAD closures, but evidence suggests that significantly more drifting FADs are being deployed in the non-closed period. As a result, the benefits of PNA and WCPFC conservation initiatives are being negated, and PNA countries are missing out on an opportunity to take control over the most important fishing gear in the region.

As additional FAD closures are being proposed for the purpose of bigeye conservation, PNA members whose fisheries are more FAD-dependent are rightfully concerned over the potential loss of VDS revenues if their zones are closed beyond the current FAD closure. This leverage is used to the detriment of the Parties by fleets that are highly FAD-dependent; meanwhile the DWFNs continue to refuse any compensatory mechanisms to PNA nations for the adverse impact of the FAD closures.

To put control of the FAD fishery squarely in PNA hands, a system must be developed that is more sophisticated that the blunt FAD closures, and it must compensates PNA members based on the amount of FAD fishing that occurs in their waters. To do this, PNA members need to address the unregulated, unreported, and untracked FAD fishing that occurs daily in PNA waters.

According to national laws of the countries that fish in the WCPO, a FAD that is drifting along is actively “fishing”, however, this fishing effort is not tracked or recorded, even when it occurs in EEZs. The US recently fined a Spanish fishing company $5 million when it was discovered that they deployed FADs in US waters without a license. PNA countries all have similar definitions in national legislation, but no system in place to properly track and manage the large number of FADs in the region.

It is estimated that over 30,000 FADs are currently fishing in PNA waters. The vast majority of these FADs are being monitored by fishing companies who pay about $1,000 per tracking buoy, plus airtime each month. While the industry is well aware when buoys are fishing illegally (in closed areas, territorial waters, MPAs, etc), the coastal state that is responsible for managing fishing in its waters is left unaware. To take control of this activity, PNA ministers agreed that FADs needed to be tracked and managed in PNA waters back in 2010. In collaboration with the Pew Charitable Trusts, the PNAO undertook a FAD tracking trial in 2012 to determine the feasibility of tracking drifting FADs given the current technology used in the FAD fishery.

FAD Tracking Trial

In August 2012, the PNA Office and the Pew Charitable Trusts developed an agreement with Quick Access Computing (QAC) to undertake the FAD tracking trial to determine if FADs could be tracked using the same system used to monitor the VDS. QAC purchased satellite buoys from the major FAD buoy suppliers (GeoEye, Zunibal, and SatLink) and had them deployed in PNA waters.

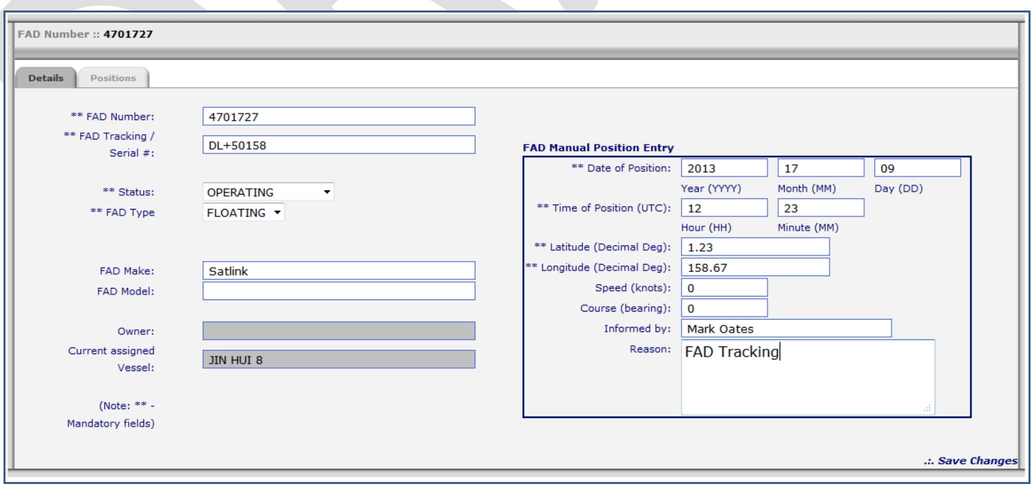
QAC determined that all buoys operated on systems similar to VMS. Buoys can be programed to send regular reports (i.e. every 12 hours) with their unique FAD identification, location, time, water temperature, and biomass from sonar. The buoys can also report this information whenever they are "called" by buoy owner.

More importantly, it was discovered that buoys can report simultaneously to multiple destinations. This provided the assurance that the fishing vessels and the PNA FIMS could have joint access to this information, without additional cost. Without altering the current technology used in the fishery, or incurring increased costs on industry, it is possible to track FADs in PNA waters, but access to the FAD data would need to be granted, and there would need to be a tracking system in place to effectively manage FADs.

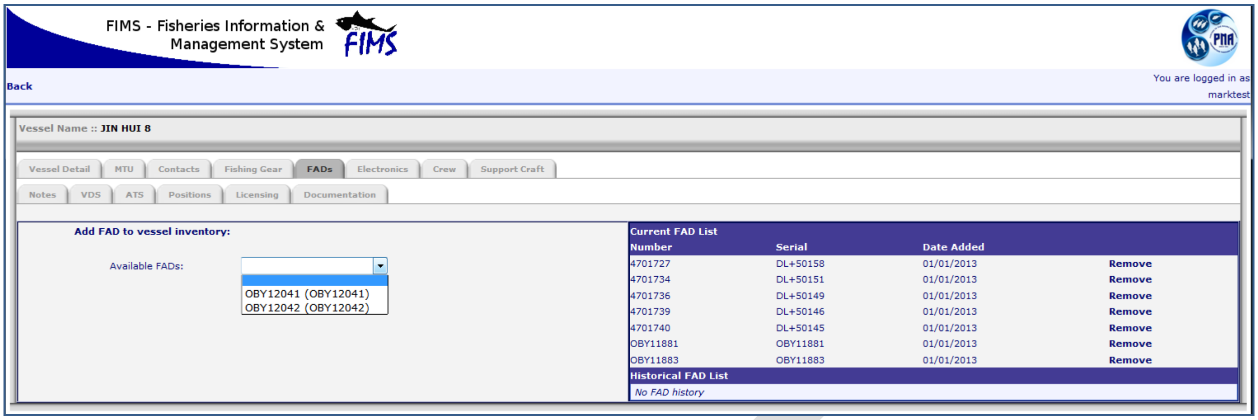
The next phase of the trial was to determine if FADs could be tracked using the Fisheries Information Management System (FIMS) which the PNAO already uses to monitor the VDS and track other "assets", such as observers, in PNA waters. Ultimately, QAC was able to fully integrate FAD tracking capabilities into the FIMS. As long as users register their FADs in the system, they can be tracked, much like vessels, and their tracks can be overlayed onto Google Earth. Additionally, FADs can be grouped to a single vessel or client (group of vessels) for ease of viewing and display in Google Earth.

Due to the success of the trial and the development of the FIMS FAD tracking module, QAC agreed to update the FIMS User Manual with the following sections:

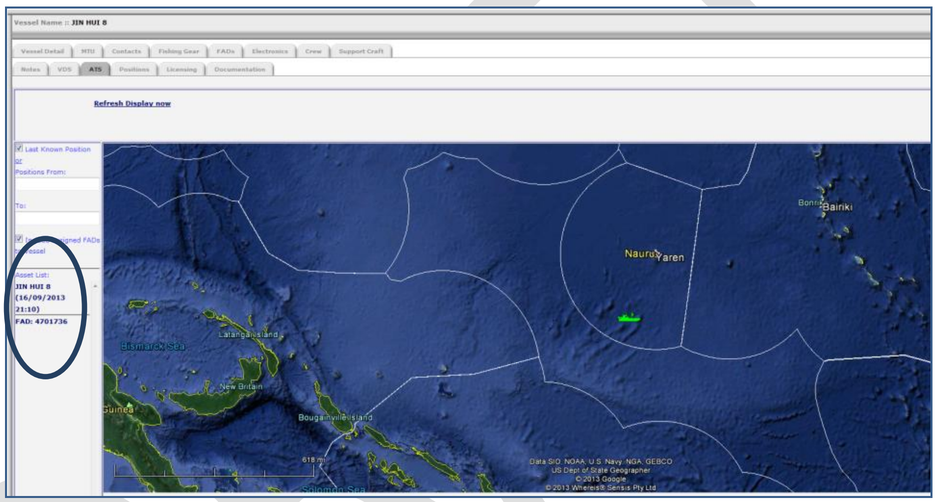
- Making a New FAD
- Search for a FAD
- Edit FAD Details
- Enter FAD Manual Positions
- Assign a FAD to a Vessel
- Assign a FAD to a Client
- View FADs and Vessels on Google Earth



FIMS Screenshot 1: FAD data entry can be viewed and updated as needed.



FIMS Screenshot 2: Floating FADs can be assigned to a Vessel or to a Client (group of Vessels) for ease of viewing and display on Google Earth.



FIMS Screenshot 3: FADs assigned to a vessel can be viewed in the Vessel ATS tab.

Overall, the FAD tracking trial and FIMS integration were quite successful. In QAC's words: *The trial has been a resounding success and proved beyond a doubt that FAD tracking for the region, by way of a second feed from the FAD Buoy Suppliers, is both a functional and cost effective way to receive the FAD Buoy data and tracking the FAD Buoys within the region.*

FAD Tracking Opportunities

1. Take Control of FAD fishing in PNA waters

Consistent with the FFA paper recently submitted to the WCPFC TCC (WCPFC-TCC9_DP08 – Special Requirements of Small Island Developing States), PNA seeks to develop more control, in the form of rights, to the fishing activities. Such arrangements provide the best prospect to manage the resources in ways that achieve sustainability, support development, and avoid disproportionate burden. Taking control of the FAD fishery offers PNA the opportunity to do this.

Concept: PNA FAD Tracking and Management
(Presented to 2013 PNA Ministers and Officials Meeting)

What We Learned from the FAD Tracking Trial

- **FIMS is capable of tracking FAD buoys on the same platform as vessel VMS tracks. By overlaying the vessel activity on FAD tracks, specific FAD sets can be monitored.**
- **The FIMS platform also can count FAD days in each EEZ and non-PNA waters, in the same ways as vessel fishing days. There would be no exception of TS, AW or NFD claims.**

Concept

- **All vessels shall carry only PNA type approved satellite tracking buoys, as a mandatory term of registration and good standing. [Based on trial, every brand in use by industry can meet this parallel reporting requirement as demonstrated.]**
- **Only type approved buoys may be registered and will be mandatory for tracking.**
- **For most vessels this does not represent an additional cost as this is already their prime means of tracking FADs.**
- **Companies shall be required to pre-register each buoy and designate the vessel or vessels associated with its use in the FIMS. These shall be registered prior to use, and registry is valid for the calendar year.**
- **Each buoy, upon activation, shall parallel report to the company/vessel and PNA FIMS.**
- **Any instruction to deactivate a buoy shall be provided to PNA FIMS. PNA shall reserve the right to continue to track abandoned buoys for research, but shall not assume ownership.**
- **Protocols shall be developed covering mandatory requirements to use only registered buoys as prime tracking mechanism.**
- **FAD buoy registry would give PNA options to cap and regulate FAD deployments/sets, both under anchored and drifting FAD management. This may be consistent with 2012/01, but in PNA hands.**
- **In-zone measures implemented now would require the WCPFC to implement compatible measures in high seas and non-PNA waters.**

Scheme

- **All buoys used shall meet PNA type approval and shall be registered before use.**
- **Registration fees are proposed at $1,200/year per buoy for distant water vessels.**
- **FSMA and domestic vessels shall register buoys on FADs, but shall pay a discounted registry of $200/year per buoy.**
- **Using these values, the yield would be more than $30 million per year for PNA.**
- **PNA FIMS shall count total buoy VDS days in each Party zone and other areas for the periods each buoy is active. [Until reporting stops or is stopped.]**
- **Registration fees shall be collected annually. Both full and discounted fees shall be held in an account and shall be distributed annually based on days per zone or other areas as a fraction of total days logged.**
- **Days in high seas, or outside PNA waters if tracked, could go to PNAO to cover costs**

associated with hardware, programmes, maintenance, etc., with the remaining dividends going to the Parties.

PNA FAD Tracking and Management (con't)

Although primarily for drifting FADs, there is merit in making it tracking anchored FADs under the same scheme. Although anchored FADs are not drifting, the tracking would verify anchored FAD positions, monitor oceanic conditions and biomass at anchored FADs, and enhance domestic anchored FAD management plans under national laws.

<u>Summary</u>

- **PNA IA would make FAD buoy registration mandatory, with phase in over six months. All buoys to be required to be registered in advance and to parallel report to FIMS as a term of vessel good standing (at no additional cost to industry).**
- **No capital investment by PNA is required in buoys or airtime to track them by making satellite buoys mandatory for industry. Pew has funded buoy tracking trials and basic programming upgrade of the FIMS platform to track and count FAD buoy days under the VDS platform.**
- **There will be a need for hardware and data feed upgrades for FIMS to handle all the FAD data. This is being factored into budgets to upgrade hardware. Pew and others have expressed interest to provide on-going financial support for this and workshops if required.**
- **Alerts can be developed for when a buoy fails to report, becomes disabled, or is set upon during a FAD closure. Such options would enhance the value of the scheme as a management tool.**

2. Improve Scientific Information on Tropical Tuna Fishery

Each data report from a FAD buoy includes information on oceanographic conditions, and many buoys also provide data on the biomass of fish underneath them. With over 30,000 FADs in the region, there is a great opportunity for scientists to use the oceanographic and biomass data to enhance the understanding of the western and central Pacific tuna fishery.

If PNA moves ahead on FAD tracking, it would be beneficial to also have a data sharing arrangement with SPC. These data would improve future stock assessments and other SPC analyses on the dynamics of the WCPO tuna fisheries. In addition, partnering with scientists would show PNA's continued commitment to science-based management.

3. Promote Accountability - Recover lost and abandoned FADs

Several thousand FADs are lost or abandoned every year in the region. Some wash up on beaches, some get caught on coral reefs, and others drift at sea and contribute to the ever-growing Pacific garbage patch. In practice, FADs can become abandoned by drifting out of the productive fishing grounds, making it too expensive for the fishing vessel to recover, or FAD buoys could become disabled, making them impossible to find again. In both cases, a FAD tracking and management system could be used to minimize losses and incentivize industry to be more accountable for the FADs they deploy in PNA waters.

In cases where FADs wash up on reefs or beaches, it is possible that the buoy would still function and send reports. In these cases, FADs would repeatedly send reports from the same location. Given that each FAD would have a unique electronic signature, it would be simple to determine the owner of the FAD and determine the appropriate course of action (i.e. charge clean-up fee).

In cases where FADs are simply not recovered because they are too far away, or are not holding fish, it is possible for PNA to limit losses by instituting FAD limits per vessel. For instance, vessels may only be allowed to have 30 FADs each for a given year. This makes each FAD a valuable asset which vessels would place in the water more strategically to ensure a maximum number remain active and accessible to set on.

Instead of vessels having hundreds of FADs, vessels would transition to using fewer FADs, but more responsibly. A vessel that has 500 FADs has spent at least $500,000 for the equipment and monitoring. A vessel with only 30 FADs would have FAD costs of only around $30,000. In this example, the $470,000 in savings could go towards FAD licensing fees and the recovery all FADs. In addition, by reducing the overall number of FADs, and in particular abandoned FADs, PNA would take a leadership role in the responsible stewardship of the marine environment.   Again, this is at no additional cost to the industry, but puts more control in PNA hands and results in a lighter environmental footprint.

4. Confirmation of free school sets

FAD tracking could act as a primary or secondary verification of free-school caught tuna. Alerts can be developed to notify vessels when they are within 1 mile of a FAD. Such information would be useful for compliance with WCPFC CMMs and PNA FAD closures. This information could also be used to automatically confirm catches as “FAD free” for the PNA MSC certification.

5. Detect and Deter IUU FAD Activities

FAD tracking would enable PNA members to more accurately assess alleged cases of IUU fishing when it comes to FADs. Given that drifting FADs are actively “fishing” under national legislation, FADs that drift into closed areas or territorial waters could be considered IUU. FAD tracking would allow PNA members to answer important questions regarding potential IUU activities, such as:

- Was a FAD placed illegally in a closed area?
- Was a FAD placed immediately adjacent to a closed area, where prevailing currents would carry it through?
- Was a FAD stolen or tampered with in violation of national legislation?

WCPFC10

Tenth Regular Session

2th December – 6th December 2013

Cairns, AUSTRALIA

CONSERVATION AND MANAGEMENT MEASURE FOR THE COLLECTION AND ANALYSES OF DATA ON FISH AGGREGATING DEVICES

WCPFC10-2013-DP05
5 November 2013

Proposal by the United States of America

Conservation and Management Measure
for the Collection and Analyses of Data on Fish Aggregating Devices

Proposal by the United States of America
to the Tenth Regular Session of the Commission

November 1, 2013

The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (the Commission);

In accordance with the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (the Convention):

Taking into account the best available scientific information on the status of the bigeye, yellowfin and skipjack stocks;

Committed to the long term conservation and sustainable exploitation of fisheries in the western and central Pacific Ocean (WCPO);

Understanding that all fishing gears, including fish aggregating devices (FADs), have an effect on the stocks and the pelagic ecosystem in the WCPO and that such effects should be fully understood by members of the Commission;

Agreeing that to accurately provide the advice necessary to effectively manage tuna fisheries in the WCPO, it is necessary for the Commission's scientific and technical experts to have access to and analyze the relevant data regarding such fisheries and gears and for Commission members to put in place measures as needed to collect such information in their fisheries;

Committed to ensuring that such advice is taken into account in the development of the Commission's conservation and management measures concerning fishing for tunas;

Acknowledging that the Commission has adopted measures and information reporting requirements related to FAD management and FAD data collection;

Recognizing that these measures need to be expanded and improved upon to ensure that the effects of the use of FADs on highly migratory fish stocks, along with non-target, associated and dependent species, are fully understood and that the Commission can receive the best available scientific advice concerning mitigation of any negative effects;

Recalling that, in accordance with the management measure previously adopted by the Commission at WCPFC6, all national, sub-regional and regional observer providers authorized under the Regional Observer Programme (ROP) shall require that all observers employed by them and deployed on purse seine vessels pursuant to the ROP collect and report the *Minimum Standard Data Fields for Purse-Seine FAD Monitoring*; and

Noting that improved FAD designs may help to reduce the incidence of entanglements with sharks, marine turtles, coral reefs, and other species.

ADOPTS, in accordance with the provisions of Articles 5 and 10 of the Convention, the following conservation and management measure to be applicable to the entire Convention Area, as defined in Article 3 of the Convention:

Section 1. General Rules of Application

1. Unless otherwise stated, nothing in this measure shall prejudice the legitimate rights and obligations of small island developing State (SIDS) Members and Participating Territories in the Convention Area seeking to develop their own domestic fisheries. No exemptions or derogations from the provisions of this measure will be allowed unless a SIDS Member or Participating Territory provides in writing to the Commission's Executive Director the reasons why the exemptions or derogations are necessary for the legitimate development needs and aspirations of the SIDS Member or Participating Territory.

2. This measure shall not impinge on the sovereign rights of coastal States to apply additional measures for FAD management in their waters.

3. This measure shall apply to purse seine vessels that fish for tropical tunas in the Convention Area between 20 degrees North latitude and 20 degrees South latitude.

4. For the purposes of this measure, the term FAD means any unanchored man-made device, or natural object, that is capable of aggregating fish, including any object or group of objects, of any size, that has or has not been deployed, that is living or non-living, including but not limited to buoys, floats, netting, webbing, plastics, bamboo, logs and whale sharks floating on or near the surface of the water that fish may associate with.

Section 2. FAD Data Collection and Analyses

5. In 2014, the Secretariat will develop and shall present to the Scientific Committee (SC) and the Technical and Compliance Committee (TCC) a report on additional FAD data collection and management options, including: marking and identification of FADs; electronic monitoring of FADs; and registration and reporting of position information from FAD-associated buoys.

6. Based on the information provided by the Secretariat, the TCC shall develop specific recommendations for a FAD identification scheme for consideration and adoption by the Commission at the Commission's regular annual session in 2014.

7. No later than [1 July 2015], CCMs shall require the owners and operators of their flagged purse seine fishing vessels fishing for tuna in the WCPO, to identify all FADs deployed or modified by such vessels in accordance with the Commission FAD identification scheme. The scheme developed should be consistent with any FAD identification scheme adopted by the IATTC.

8. The TCC and Commission should consider, at a minimum, including the following elements in the FAD identification scheme:
   a. All FADs shall have a unique identification number with a specific numbering system and format to be adopted by the Commission.
   b. The identification should be easy to apply to the FAD and should be applied in such a manner that it will permit its identification and should not become unreadable or disassociated from the FAD.

9. Based on the SC's recommendations at SC9, the SC and TCC shall develop specific recommendations for a *Vessel FAD Data Reporting Log* to be submitted by purse seine vessel operators, for consideration and adoption by the Commission at the Commission's regular annual session in [2014].

10. No later than [2015], the Commission's scientific experts (i.e., those experts engaged pursuant to Article 13 of the Convention) shall present the results of their analyses of the data on FADs collected by

observers through the *Minimum Standard Data Fields for Purse-Seine FAD Monitoring* to the SC and the TCC, and shall also review the existing elements and may recommend additional elements for data collection, as well as specific reporting formats, necessary to allow the SC to evaluate the impact of the use of FADs on the ecosystem of the WCPO fishery.

11. The SC and the TCC shall make recommendations for the Commission's consideration at its regular annual session in [2017] for the monitoring and management of FADs, including possible effects of FADs in the tuna fishery in the WCPO. The Commission shall consider adopting management measures based on those recommendations, including a region wide FAD management plan, and which may include, inter-alia, recommendations regarding FAD deployments and FAD sets, the use of biodegradable materials in new and improved FADs and the gradual phasing out of the use of FADs that do not mitigate the entanglement of sharks, marine turtles and other species.

12. The SC shall also formulate recommendations for management advice and implications on stocks for presentation to the Commission, on the basis of the results of the analyses of the collected FAD information. Such recommendations shall include methods for limiting the capture of small bigeye and yellowfin tuna associated with fishing on FADs.

13. Data collected pursuant to this measure shall be considered non-public domain data, and shall be governed by the provisions for handling data set forth in the Commission's "Rules and Procedures for the Protection, Access to, and Dissemination of Data Compiled by the Commission."

Section 3. Non-entangling FADs

14. To reduce the entanglement of sharks, marine turtles or any other species, and impacts to coral reefs, the design and deployment of FADs should be based on the principles set out in Annex I.

15. If recommended by the SC, the Commission shall adopt measures for the use of non-entangling FADs.

Section 4. Regional Observer Programme Data

16. CCMs and the Secretariat shall work together to ensure that all data included in the *Minimum Standard Data Fields for Purse-Seine FAD Monitoring* collected by observers are entered into the ROP database as soon as possible and in any event no later than 110 days of observer disembarkation from the vessel.

17. A detailed report on the status of the FAD data collected under the ROP should be presented by the Secretariat at each regular annual session of the TCC and the SC for their review and consideration.

Annex I
Principles for design and deployment of FADs

1. If a flat raft is used as a FAD, the surface structure should not be covered, or only covered with non-entangling material.

2. Any subsurface component of the FAD should be constructed in a manner designed to avoid entangling marine life.

3. To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials (such as hessian canvas, hemp ropes, etc.) for drifting FADs should be promoted.

Attachment E: Preparation of FAD Management Plans

To support obligations in respect of FADs[15] in CMM-2013-01, the FAD Management Plan (FADMP) for a CCM purse seine fleet to be submitted to the Commission shall include:

• An objective

• Scope:

- Description of its application with respect to:
  - Vessel-types and support and tender vessels,
  - FAD types [anchored (AFAD) AND drifting (DFAD)],
  - maximum FAD numbers permitted to be deployed [per purse seine or ring net vessel per FAD type],
  - reporting procedures for AFAD and DFAD deployment,
  - catch reporting from FAD sets (consistent with the Commission's Standards for the Provision of Operational Catch and Effort Data),
  - minimum distance between AFADs,
  - incidental by-catch reduction and utilization policy,
  - consideration of interaction with other gear types,
  - statement or policy on "FAD ownership".

• Institutional arrangements for management of the FAD Management Plans

- Institutional responsibilities,
- Application processes for FAD deployment approval,
- Obligations of vessel owners and masters in respect of FAD deployment and use,
- FAD replacement policy,
- Reporting obligations,
- Observer acceptance obligations,
- Relationship to Catch Retention Plans,
- Conflict resolution policy in respect of FADs.

• FAD construction specifications and requirements

- FAD design characteristics (a description),
- FAD markings and identifiers,
- Lighting requirements,
- radar reflectors,
- visible distance,
- radio buoys [requirement for serial numbers],
- satellite transceivers [requirement for serial numbers].

• Applicable areas

- Details of any closed areas or periods e.g. territorial waters, shipping lanes, proximity to artisanal fisheries, etc.

[15] Fish aggregating devices (FAD) are drifting or anchored floating or submerged objects deployed by vessels for the purpose of aggregating target tuna species for purse seine or ring-net fishing operations

- Applicable period for the FAD-MP
- Means for monitoring and reviewing implementation of the FAD-MP.
- Means for reporting to the Commission

TECHNICAL AND COMPLIANCE COMMITTEE
Fifth Regular Session
1-6 October 2009
Pohnpei, Federated States of Micronesia

FFA PROPOSAL ON FAD IDENTIFICATION AND TRACKING

WCPFC-TCC5-2009/DP-21
5 October 2009

1. FFA Members appreciate the information in the Working Paper. Clearly the advice from the Scientific Committee on the status of the bigeye stock and the projected shortfall in effectiveness of CMM 2008-01 means that more will have to be done on FAD management.

2. Following the discussion in the Scientific Committee on the scientific value of information from identification and tracking of FADs and building on the information in the paper, FFA Members are interested in getting further information on the feasibility and value of FAD identification and tracking for scientific, compliance and management purposes.

3. Therefore, FFA Members request the secretariat to have a feasibility study undertaken on the marking, identification and tracking of FADs and associated electronic devices, including a simple assessment of the use and value of information from FAD identification and tracking. The study should also take into account factors such as:

   i) the nature of materials used in FAD construction,
   ii) deployment of FADs by vessels other than fishing vessels,
   iii) use of FADs by groups of vessels,
   iv) sub-surface FADs,
   v) need for FAD marking to be read by observers,
   vi) scope for tracking FAD electronic devices with VMS,
   vii) maritime safety and liability,
   viii) MARPOL requirements,
   ix) national legislative requirements for marking of fishing gear,
   x) ownership of FADs by parties other than fishing vessel operators and
   xi) costs.

FAD Management

A study of the impacts of fish aggregating devices (FADs) and the development of effective management strategies for their responsible use by industrial tuna fishing fleets

A report prepared for the WTPO

MRAG

June 2009

This report has been prepared by MRAG Ltd for WTPO. It should not be circulated without the permission of the WTPO Chairman.

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Checked/Approved by:	RM; CCM

Contents

Glossary / Abbreviations

Abbreviation / Term	Description
ASPIC	
B	Biomass
$B_{Current}$	Current biomass
BET	Bigeye tuna (*Thunnus obesus*)
B_{MSY}	Biomass at maximum sustainable yield
BRP	Biological Reference Point
CPUE	Catch per unit effort
DWFN	Distant water fishing nation
EPO	Eastern Pacific Ocean
F	Fishing effort
FAD	"Fish aggregating device" -
FADIO	The name of a project looking at FADs in the Indian Ocean
FAO	Food and Agriculture Organisation (of the United Nations)
$F_{Current}$	Current fishing effort
F_{MSY}	Fishing effort at maximum sustainable yield
F_{xxxx}	Fishing effort in year (xxxx)
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
MADE	Mitigating ADverse Ecological impacts of open ocean fisheries, project title.
MSY	Maximum Sustainable Yield
Overexploited	In this report 'overexploited' is taken to have the same meaning as 'overfished'
Overfished	A stock is considered 'overfished' when exploited beyond an explicit limit beyond which its abundance is considered 'too low' to ensure safe reproduction. In many fisheries fora, the term is used when biomass has been estimated to be below a limit biological reference point that is used as the signpost defining an "overfished condition" [The limit biological reference point used in this report is B_{MSY}].
RFMO	Regional Fisheries Management Organisation
SCAA	Statistical Catch-at-Age Analysis
SCRS	Standing Committee on Research and Statistics (ICCAT)
SKJ	Skipjack tuna (*Katsuwonus pelamis*)
SPC	South Pacific Community
SSB	Spawning Stock Biomass
TAC	Total Allowable Catch
VPA	Virtual Population Analysis
WCPFC	Western and Central Pacific Fisheries Commission
YFT	Yellowfin tuna (*Thunnus albacares*)

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Executive Summary

Background: As a responsible tuna fishing organisation, the World Tuna Purse Seine Organisation (WTPO) privately commissioned this independent review by MRAG Ltd as part of their ongoing sustainability work, to specifically consider the impact of purse seine and fish aggregation device (FAD) fishing and to explore best management practice and mitigation. The report aggregates and analyses publicly-available data from Regional Fisheries Management Organisations (RFMOs) and other sources to provide a global overview of tuna fishing, with specific reference to purse seine catches. It has looked specifically at the use of fish aggregating devices (FADs) by purse seine vessels.

Development of the FAD fishery: The development of the FAD fishery has been rapid, and there have been significant technological advances to the design of FADs making them more efficient over time (Section 2). Global catches of yellowfin, skipjack and bigeye tunas have been rapidly increasing since the 1970s and have only in the last ten years shown signs of slowing down. The increase in the use of FADs and their development to enhance the catches of tuna fisheries since the 1980s has significantly increased the purse seine catch where other fishing methods have remained relatively stable. The principle target species of purse seiners deploying FADs is skipjack tuna. Yellowfin tend to predominate in free schools.

Tuna resource status: Stock assessments on the principle market species of albacore, bigeye, skipjack and yellowfin tunas that have been undertaken by RFMOs are presented (Section 3). The status of skipjack tuna stocks is generally considered to be healthy. Bigeye and yellowfin tuna stocks are largely fully exploited or overexploited and uncertainty exists in some of the assessments. Albacore are fully exploited, but are not the focus of purse seine fisheries, generally being taken by pole and line vessels.

Ecological impacts of FADs: The ecological impacts of FAD fisheries on target species and on incidentally caught species are explored on both target fish species and incidentally caught species (Section 4). Impacts include removal of juveniles, potential changes to behaviour and ecology, and bycatch of non target species. For the target fisheries, whilst FADs primarily target skipjack, incidental catches of juvenile bigeye and yellowfin tuna are also taken that may affect long term stock sustainability.

Aggregation around floating objects is a natural phenomenon in tuna populations, and whilst their potential negative impacts are described in the literature, little is understood about the ecological advantages they may confer. The behaviour of tunas in free schools and those more dispersed in the ocean, and the impact of FADs upon their ecology and behaviour is not fully understood. Effects studied have included schooling behaviour, migration and movements, feeding behaviour (diet and condition of fish) and related effects on natural mortality. These factors are all interrelated with fish migrating in search of food. Diet therefore plays an important role in the dynamics of FAD associated populations and residence times under FADs are correlated with abundance of prey species. Examining these factors together there is currently a lack of consensus within the scientific community as to whether FADs act to trap fish with negative consequences, or whether, as argued by others FADs have no detrimental effects on tuna growth. There is therefore a need for additional research looking both at free swimming fish and FAD associated fish to address this important question. Furthermore, a disproportionate amount of the research available relates to fixed FADs although more recently some large scale projects related to drifting FADs have been undertaken and should contribute to this debate as the results become increasingly available.

In terms of bycatch, purse seine fisheries are amongst the 'cleanest' and relative to the weight of tuna caught bycatch represents up to around 5% compared to 22% for tuna longlines. The proportion is less for sets around free schools, but FADs result in greater bycatch than free schools. By ocean the proportion of bycatch associated with purse seine and FAD fisheries is similar, but, 70% of the volume of bycatch derives from the Pacific where the greatest tuna catches are taken (Table 1).

Table 1: A summary of the catches of the 4 principle market species of tuna (skipjack, yellowfin, bigeye and albacore) in 2006[1] by all gears, and for purse seiners, showing the catch and proportion estimated to be attributed to FAD or Free school sets, and the corresponding proportion of bycatch[2] by ocean.

a) Tunas

Ocean	FAD		FREE		Total Purse seine		ALL Gears
	Catch (t)	% of PS Catch	Catch (t)	% of PS Catch	Catch (t)	% All gears	Catch (t)
Pacific Ocean	1,320,586.8	62.4%	795,621.2	37.6%	2,116,208.0	76.0%	2,784,281
Atlantic Ocean	84,097.5	54.7%	69,767.4	45.3%	153,864.9	40.0%	384,273
Indian Ocean	315,845.2	71.0%	129,285.5	29.0%	445,130.7	38.9%	1,144,376
Total	1,720,529.5	63.4%	994,674.1	36.6%	2,715,203.6	63.0%	4,312,930

b) Bycatch

Ocean	FAD		FREE		Total bycatch
	Bycatch (t)	Bycatch as % of PS Catch	Bycatch (t)	Bycatch as % of PS Catch	Bycatch (t)
Pacific Ocean	45533	3.5%	3860	0.50%	49393
Atlantic Ocean	1497	1.8%	755	1.1%	2250
Indian Ocean	11157-17329	2.7%-4.1%	326-464	0.2%-0.3%	11485-17793
Total bycactch	58,187-64,359	3.4%-3.7%	4,941-5,079	0.5%-0.51%	63,128-69,436 (2.32%-2.56% of total PS catch)

Source: Section 4.2.2 of this document, compiled from various sources fully cited in that section.

Effects of FADs on stock assessments and stock vulnerability: Next we describe the effects of the FAD fishery on tuna stock assessments (Section 5) and their effects on stock vulnerability (Section 6). There are major problems with the estimation of accurate catch rate indices for stock assessments further complicated by the spatial dynamic resulting from the deployment of multiple FADs in a given area. FADs also result in changing

[1] At the time of writing, the IATTC database is only available up to 2006 (http://www.iattc.org/DataENG.htm).
[2] Bycatch is composed mostly of non target fin-fish species, some sharks and rays and negligible numbers of turtles though these can be released. Marine mammals are also no longer an issue due to mitigation methods.

catchability of different species to fishing (juveniles of bigeye and yellowfin tuna around FADs). More complex assessment models can accommodate this problem but require accurate estimates of growth and mortality which are often poorly defined and there is also a possibility that FADs result in the introduction of bias in their estimation. Improved data collection related to FAD fisheries would help significantly.

The question of vulnerability relates particularly to stocks of yellowfin and bigeye in relation to increased catches of juveniles under FADs. If juvenile mortality is low, then FADs will have a significant impact on the stocks, but if it is high, then FADs will have negligible impact compared to natural mortality. To date estimates of natural mortality from tagging studies have only been obtained from SPC/WCPFC for the western Pacific, where it is low, and from IOTC using tag data from their own studies. This leaves a major uncertainty surrounding stock assessments amongst the different RFMOs, particularly since the mortality rates used by different RFMOs are so different. This highlights the need for further research into estimation of mortality and also fleet interactions to examine the question of whether juvenile mortality under FADs has a significant impact on resource sustainability.

Management and mitigation measures for FAD fisheries: Potential management and mitigation measures are described and the measures currently adopted by the tuna RFMOs are given (Section 7).

Tunas of different species aggregate together in different size classes, areas and depths, and different relative proportions of the different species are caught in sets on free schools or FAD associated schools. Thus fisheries for tuna are multi-species, but targeting through a combination of location, depth and fishing method can affect the species caught. RFMOs address the complex issues related to management of multi-species tuna stocks which include the need to protect the most vulnerable species (bigeye and yellowfin) whilst at the same time permitting exploitation on stocks that are considered to be healthy (skipjack). Management issues also include mitigating the impacts of different fishing methods on incidentally caught species, and on juveniles of target species. Amongst the wider management issues are those that could be focussed on the management of FAD associated fisheries, and it is this aspect that is explored in the current document.

Management and mitigation methods include two broad categories: the modification of fishing effort (and catch) and avoidance of bycatch; and, modification of fishing gear and fishing practices. Within these broad categories management measures that RFMOs have applied (or are planned) with specific reference to FADs include:

- spatio-temporal closures;
- to date there have been no effort limits applied directly to FADs but RFMOs have put in place mechanisms to gather more data, to explore the question of fishing capacity, and to seek proposals for future management plans related to FADs
- full catch retention rules (i.e. discard bans)
- a variety of measures related to modification of fishing practices (e.g. avoid sets on turtles) and gear (e.g. escape panels)

Management controls on FADs require careful consideration. Controlling fishing on FADs has complex biological (e.g. target switching from skipjack to potentially more vulnerable species), social (e.g. employment, the benefits to coastal states), and economic (e.g. purse seining is highly efficient compared to alternative methods that may be proposed) implications. The current review has focussed primarily on the biology, assessment and management of FAD associated fisheries and has not explored the social and economic impacts that would also need to be taken into account in management decisions.

Overall there is currently limited management of FAD fisheries and a combination of approaches is likely to be most appropriate. There is a need to develop guidelines for best management practice for FAD fisheries. There is also is significant need for better and more data to inform management decisions.

Knowledge gaps and future research: Fisheries science should have as its ultimate aim the improved management of fish stocks in order to ensure their long term sustainability within an ecosystems based approach that considers also the impacts of fishing on non target species. Research should aim to underpin that goal. Together with WTPO's focus on management to address issues surrounding FADs, this goal is foremost in defining the proposed prioritisation of future FAD research in combination with the analysis of what areas have already been addressed. The ultimate aim will be to develop guidelines for best management practice related to FADs.

Seven broad areas of research to address knowledge gaps have been identified through the analysis of literature reviewed in this report. Looking at recently completed and current research projects (Section 9) it is clear that new research has already begun to address some of those gaps, and in particular there has been a focus on developing a better understanding of ecosystems and behaviour of tunas as they relate to FADs. Nevertheless a significant amount of work remains to be done in particular in relation to floating FADs. A limited amount of research has also been undertaken in relation to advances in gear technology and changes in fishing practice but this is a potentially very important area of research and more needs to be done. This review has not identified socio-economic issues and so that is an area that needs to be explored. The areas where the biggest knowledge gap exists are related to research to inform stock assessments, to inform management decisions, and in the generation of data to support FAD research generally. A suggested prioritisation (A-F) of future research is provided in Section 9 where specific research topics are also identified. The details are briefly summarised in Table 2 and below.

Table 2: A summary of the FAD related research priorities for each ocean of concern.

Research Priorities	Eastern Pacific Ocean	Western Central Pacific Ocean	Atlantic Ocean	Indian Ocean
Priority A: Stimulate additional research funding:	**√**	**√**	**√**	**√**
Priority B: Address the paucity of FAD related data: Data needed on FAD use and deployment; incidentally caught species and juveniles of target species	**√**	**√**	**√**	**√**
Data for locating spatio-temporal closures.	√ some information already available on closed areas	√ some information already available on closed areas	**√** some data exists	**√**
Priority C: Undertake research to inform management decisions: fleet interactions and particularly the impact of juvenile mortality under FADS on resource sustainability.	√ Some data on fleet interactions / mortality	**√**	**√**	**√** Priority now that new estimates of M available
Simulation of spatio-temporal closures	√	√	**√**	**√**
Evaluate the sustainability of bycatch species / ecological risk assessments	**√**	**√**	**√**	**√**
Mitigation measures/improved gear technology (globally applicable)	**√**	**√** (esp PET spp)	**√**	**√**
Priority D: Undertake research to improve stock assessments: accurate estimates of parameters, such as growth and mortality, needed to parameterise models.	**√**	√ (existing SPC tagging programme)	**√**	√ (existing IO Tagging Programme)
Bias in estimates from tagging needs to be established to improve stock assessments.		**√**		**√**
Obtaining a better index of abundance for FAD caught tuna on different types of FAD and spatial effects.	**√** (some spatial work)	**√** (some spatial work)	**√**	**√**
Priority E: Research on the social and economic impacts of FADs: This study has not examined socioeconomic impacts, and it will be important to understand them as they will influence management decisions.	**√**	**√**	**√**	**√**
Priority F: Further research into the ecology and behaviour of fish associated with FADs: Management implications of the research findings of existing projects to be made available and to highlight new research needs.		√ (existing SPC tagging programme)	√ (MADE / GAP1)	√ (IO tagging; FADIO/MADE)

√ = applicable
√ = some work already done, but more research useful
Blank = not yet applicable

RESEARCH GOAL: to develop guidelines for best management practice related to FADs leading to the improved management of fish stocks in order to ensure their long term sustainability within an ecosystems based management approach.

Priority A: Stimulate additional research: It is necessary to stimulate significant additional funding of FAD related research, particularly for floating FADs. In this context communication of the issues raised in this review and the research areas identified will be important in order to further mobilise the international research effort.

Priority B: Address the paucity of FAD related data: There is a need for a more comprehensive database of FAD use and deployment to contribute to better stock assessments. It is also important to get comprehensive data on incidentally caught species and juveniles of target species to better inform assessments and management decisions. RFMOs should take the lead in this but industry support will be important if this is to be successful. Better data is also needed to inform management, specifically for locating spatio-temporal closures. This will require review of existing data but may also need additional field research. The existing ecological field studies may provide relevant information.

Priority C: Undertake research to inform management decisions: The question of fleet interactions and particularly the impact of juvenile mortality under FADS on resource sustainability is a priority as results from existing work are ambiguous (see Section 6). Research focussed on simulation of spatio-temporal closures, recognised as a suitable management control to protect vulnerable parts of the tuna stocks and limit bycatch, is also important. Such research will also effectively also address questions such as effort and catch controls. Work to evaluate the sustainability of bycatch species whilst important may be hampered by a lack of data, and first ecological risk assessments should be undertaken to prioritise where to focus effort on bycatch species. The latter is thus a priority.

Mitigation measures are part of the manager's tool box and must also take priority. Thus whilst some work has been undertaken already, further work is warranted on improved gear technology and the modification of fishing practices. Industry is well placed to take the lead here.

Priority D: Undertake research to improve stock assessments: It is important to obtain accurate estimates of the parameters, such as growth and as a priority, mortality, needed to parameterise models. Whilst the Pacific (SPC) and Indian Ocean Tuna Tagging Programmes aimed to do this there may be bias in the estimates derived, and research to evaluate the level of that bias needs to be undertaken to improve stock assessments. Obtaining a better index of abundance for FAD caught tuna is also required and this requires analysis of information on different types of FAD, and the establishment of methods for deriving abundance indices including looking at spatial effects.

Priority E: Research on the social and economic impacts of FADs: The present study has not examined socioeconomic impacts, and research to understand them will be important as they will influence management decisions.

Priority F: Further research into the ecology and behaviour of fish associated with floating FADs: A number of recent research projects have already begun to address this area and consequently it is now of a lower priority for new research. The priority is for the outcomes of these projects to be made available as soon as possible. In particular, the management implications of the research findings need to be described as a priority outcome (e.g. does the release of large numbers of FADs have serious ecological consequences suggesting the need for management actions? Do FADs affect the biology of target species reducing spawning stock biomass related to poor diet and fish health?). The existing projects may also highlight other potentially useful areas of study for the longer term. Any ecological advantages that aggregation around FADs may confer, and whether that may influence management should be derived. Finally, research aimed at wider ecosystem modelling may prove valuable but until adequate data is available on the range of species involved this remains a lower priority than some of the previously defined topics in other research areas.

Concluding remarks and Communication to achieve a way forward: This report was commissioned by the WTPO as a body representing the fishing industry with the aim of moving towards responsible best management approaches for tuna fisheries based on FADs. The tuna industry is significant. Approximately 4 million tonnes of the principal market species of tuna are caught annually and purse seine vessels account for approximately 60%. Being highly migratory species managed through international RFMOs located in each of the world's major oceans there are a significant number of stakeholders involved. It is necessary to inform those stakeholders of the findings of this research to bring the findings to their attention and to engage them in future research and management activities described. There are opportunities for different stakeholders (fishers, producers, retailers, research scientists, managers, NGOs) to be involved in different aspects of the future requirements, whether they be addressing the gaps in knowledge or implementing appropriate best management controls. Whilst WTPO have envisaged a two phased approach to this research, the current review being Phase 1, the future research requirement is significant and will require substantial global effort.

Communicating the numerous and complex messages contained in this review, and defining the next steps will require careful consideration of the process to achieve mobilisation of resources for the development and implementation of best FAD management practice. Whilst WTPO could fund elements of the research needed it is also appropriate to consider the big picture.

To address the big picture, a ***Research Programme*** (Framework) must be established with the research areas identified in this report representing the different ***Objectives*** to be addressed. Achievement of those objectives will lead to delivery of the ***Goal***. Under each objective a number of ***research projects*** have been identified and must be undertaken. It will be necessary to adopt a coordinated approach to the implementation of any research programme amongst all the various actors to avoid duplication of effort.

1. Introduction

1.1. Background for this report

This report has been commissioned by the World Tuna Purse Seine Organisation (WTPO), as part of their ongoing sustainability work, to specifically consider the impact of purse seine and FAD fishing and to explore best management practice and mitigation measures. The report aggregates and analyses publicly-available data from Regional Fisheries Management Organisations (RFMOs) and other sources to provide a global overview of tuna fishing, with specific reference to purse seine catches. This report represents the output of the first phase of the study and highlights gaps in the existing knowledge base and recommends areas for future research that could be addressed the next phase of research.

The report, possibly summarised into working papers, will in due course be shared with stakeholders in RFMOs and potentially more widely in order to promote science-based initiatives to maintain tuna populations and their ecosystems at sustainable levels of abundance. The aim is to further dialogue on issues related to responsible and best fishing practices amongst the tuna industry, and further to explore the influence that WTPO may have beyond that of the Regional Marine Fisheries Organisations.

1.2. About MRAG Ltd

MRAG Ltd is an independent consulting company, commissioned to provide impartial and independent scientific advice to WTPO due to their specialist knowledge, expertise and involvement in ongoing fisheries management programmes.

Detailed information on MRAG's experience and capabilities is available at www.mrag.co.uk.

1.3. Research methodology

This report uses publicly-available information to analyse tuna catches in the Atlantic, Indian and Pacific Oceans, including an analysis of bycatch. We have developed a bibliography of FAD fisheries and undertaken a literature review. Additional sources of data used in this report are available from the Regional Fisheries Management Organisations (RFMOs) responsible for the management of tuna fisheries in these oceans:

- **IATTC**: The Inter-American Tropical Tuna Commission, responsible for the conservation and management of fisheries for tunas and other species taken by tuna-fishing vessels in the eastern Pacific Ocean;
- **ICCAT**: The International Commission for the Conservation of Atlantic Tunas, responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and its adjacent seas;
- **IOTC:** The Indian Ocean Tuna Commission, which is mandated to manage tuna and tuna-like species in the Indian Ocean and adjacent seas; and
- **WCPFC**: Western and Central Pacific Fisheries Commission, responsible for the management of tuna fishing in the Western and Central Pacific Ocean.

There has been a recent review of the impacts FAD fisheries (Bromhead et al 2003) and another that explores gaps in current knowledge and future directions for ecological studies related to FADs (Dempster and Taquet, 2004). In this study therefore we have aimed to provide new knowledge since 2003/04 and we provide summary details with analysis highlighting the implications (e.g. of particular ecological impacts of FADs) or outcomes (e.g. of management actions) related to the points reviewed. Where possible we have provided quantitative information. We have also aimed to provide an analysis of the gaps in knowledge, and particular have extended this to look at stock assessment and management strategy simulation needs.

2. Summary of the development of the FAD fishery and its effects on catches.

2.1. Summary

Table 3 presents a summary of the key issues relating to FAD catches, their impacts and outcomes in the four main ocean regions.

Table 3: Summary of FAD fisheries by ocean region and the related impacts and outcomes.

Ocean Region	Issue	Impacts	Outcomes
Eastern Pacific	Increasing catches from FADs from approx 20% in early 1990s to now approx 40% as vessels stop fishing on dolphin associated sets	Potential impact on juveniles particularly bigeye tuna (catch risen from 5000t to 60000t from FADs) Shift from dolphin associated sets.	High reduction in dolphin mortality associated with purse seine fishing. Potential problem with juvenile mortality of bigeye tuna. IATTC Ban on support vessels operating with FAD fishery to reduce numbers of active FADs in the EPO. The application of management measures including catch limits (1998) FAD 'closures' (1999) and fleet capacity limits (2000; 2002)
Western Pacific	Long-term high level of catches from FAD related fisheries from available data, typically on logs.	Potential very high impact on juveniles of larger tunas. High potential impact on bycatch and PET species.	WCPFC created to ensure management of high seas areas.
Atlantic	Stable level of FAD catches 20 – 40%. Concern over level of juvenile catches.	Impacts highest in area around the Gulf of Guinea.	Closed area management with respect to FADs initiated by industry and followed up formally by ICCAT to minimise impacts on juveniles.
Indian	Very high level of FAD catches, though decreasing towards 40-50% at present.	Concern of level of juvenile catches and the impact on the stocks of yellowfin and bigeye tuna	No direct limit on FAD catches although these have been proposed for the Indian Ocean.
Global	FAD catches generally increasing to approx 60% in 2006.	Concern of level of juvenile catches and the impact on the stocks of yellowfin and bigeye tuna Concern of potential impact on bycatch and PET species.	Shift to FADs in EPO reduced dolphin mortality. Some management measures introduced such as closed areas, restrictions on support vessels. Concern in stock assessment over the level of juveniles in the catch.

2.2. Overall

Historically, the concept of using floating structures to enhance catches of fish dates back thousands of years. The oldest surviving written record of the use of fish aggregating devices in the Mediterranean when fishing for dolphinfish (*Coryphaena hippurus*), when the Greek author Oppian who wrote a major treatise on sea fishing, the "*Halieulica"* around 2000AD.

The development of fixed FADs to fish for a wide variety of species including tuna has been detailed in Bromhead *et al.* (2003) in great detail. In this section we concentrate on the purse seine fishing fleets that noting the success of this method, and after developing fishing methods of setting nets around natural logs and debris that act as FADs, started deploying large numbers of drifting man-made fish aggregating devices (FADs). FADs are now widely distributed throughout the world's tropical and subtropical oceans (Fonteneau *et al*. 2000).

Global catches of yellowfin, skipjack and bigeye tunas have been rapidly increasing since the 1970s and have only in the last ten years shown signs of slowing down (See Figure 1 in terms of catches by gear and Figure 2 in terms of ocean region). The increase in the use of FADs and their development to enhance the catches of tuna fisheries since the 1980s has significantly increased the purse seine catch where other fishing methods have remained relatively stable.

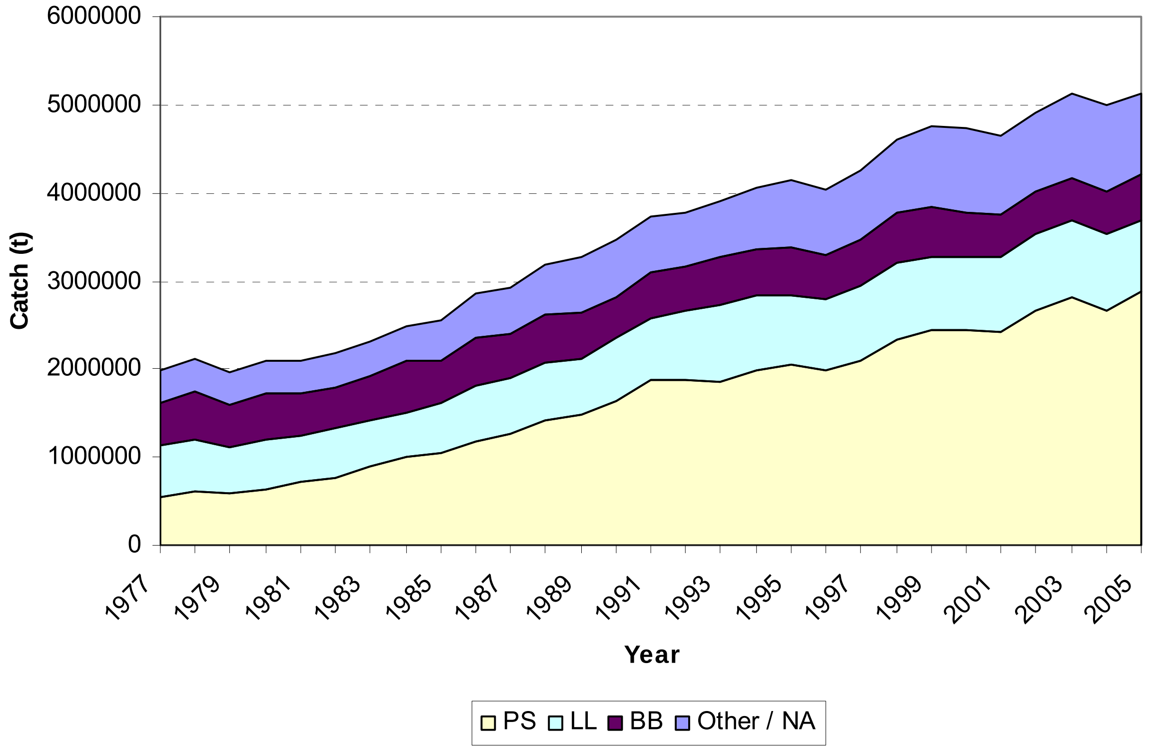

Figure 1 Global tuna catches by gear type (1977 to 2006) [3]

[3] Catch data are presented for all ocean regions between 1977 and 2006. ICCAT, IOTC and WCPFC are currently available until 2007, but IATTC is only available up to 2006 currently (http://www.iattc.org/DataENG.htm). All graphs are therefore presented for the years 1997 to 2006 only.

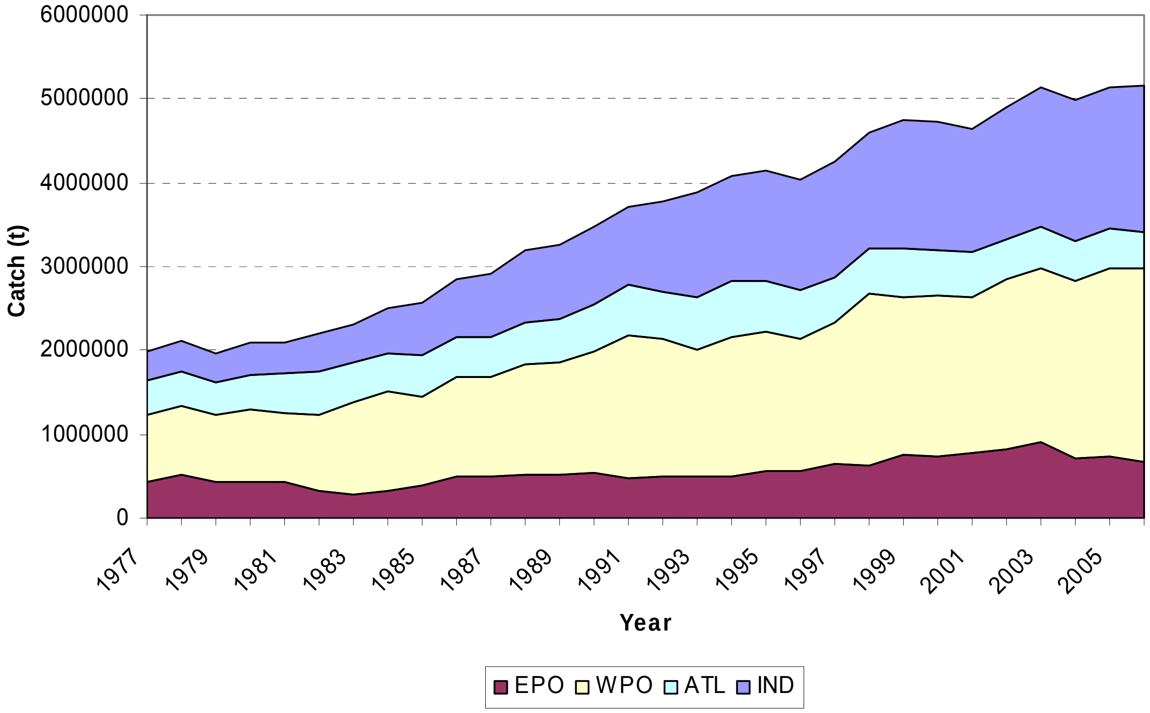

Figure 2 Global tuna catches by ocean region (1977 to 2006)

A large proportion of the increase in purse seine catch over the past thirty years can be attributed to the rise in FAD catches. This is clearly shown in Figure 3. The early rises in the 1980s seen in Figure 2 can be attributed to the increased use globally of drifting FADs in the Atlantic, Indian, Eastern and Western Pacific, with the reduction in fishing on dolphin associated sets in the Eastern Pacific. The gradual increase in the FAD catch proportion in the 1990s and early 2000s shows the gradual technological improvements in FAD fishing.

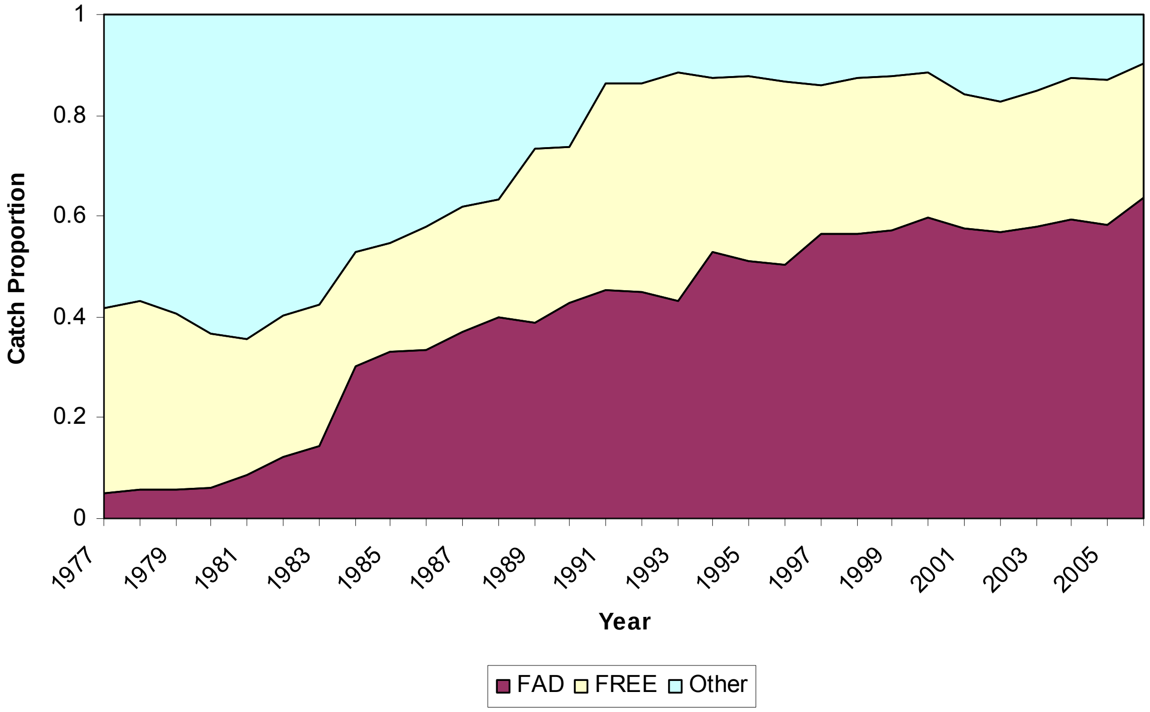

Figure 3 Global proportion of tuna catches (FAD vs FREE vs Other) 1977 - 2006

2.3. Eastern Pacific Ocean

Purse seining for tuna had already been occurring in the Eastern Pacific Ocean since the 1960s but the expansion into other methods of fishing including FADs occurred first in the 1970s when the US purse seine tuna fleet began to fish around natural occurring FADs consisting of drifting logs in 1976 (Marcille,1979). The yellowfin tuna catch in this Eastern Pacific was mainly attributable to dolphin associated sets, as well as upon floating objects and some free-school sets. The modification by the fishing fleets to incorporate more environmentally aware dolphin safe fishing practices in the 1990s increased the FAD proportion of the catch.

Between 1980 and 1990, catches were dominated by yellowfin tuna associated with dolphins with skipjack and bigeye tunas were taken in roughly equal numbers from floating objects and free-schools in the late 1980s. Since then there has been an increase in FAD fishing in the Eastern Pacific Ocean and the proportion of the Eastern Pacific Ocean catch has increased from approximately 20% in 1992 to over 50% in 2006 (See Figure 4). The main effect of this change in fishing pattern is that catches of bigeye tuna from FADs having increased from less than 5,000t to over 60,000t, and a high proportion of this as juveniles) and skipjack catches have increased from 50,000t to around 150,000t to 200,000t per year (1999-2006) (See Figure 5).

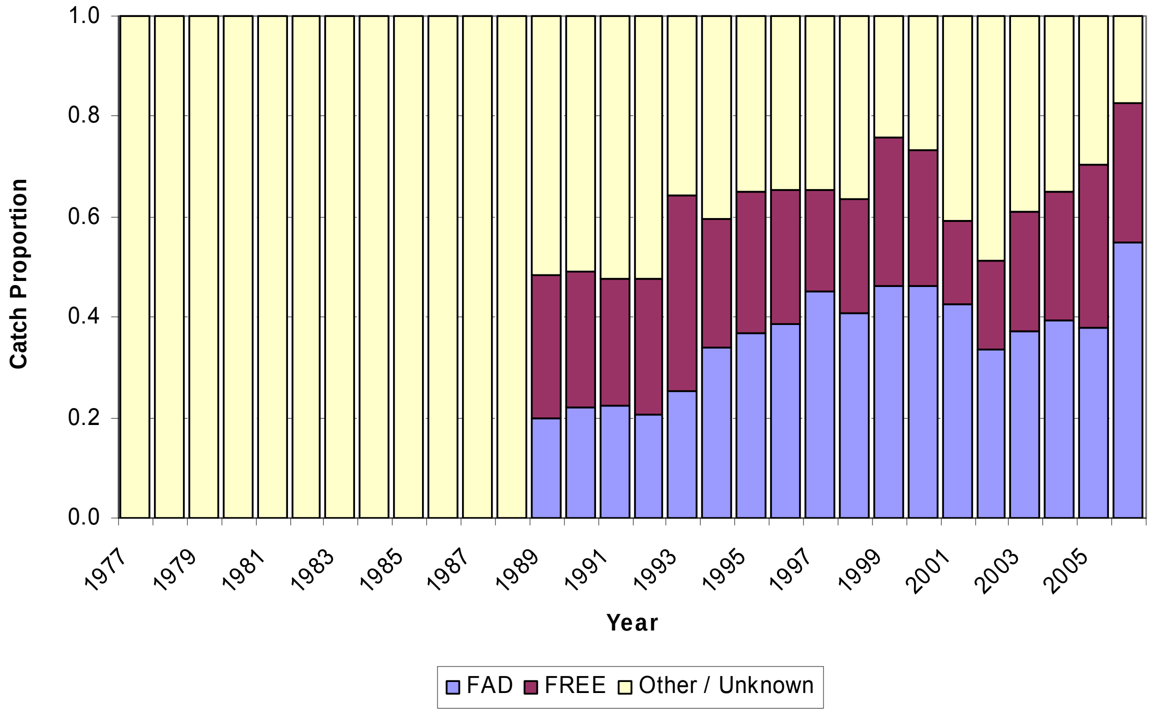

Figure 4 Catch proportions FAD vs FREE Eastern Pacific Ocean (1977 - 2006)

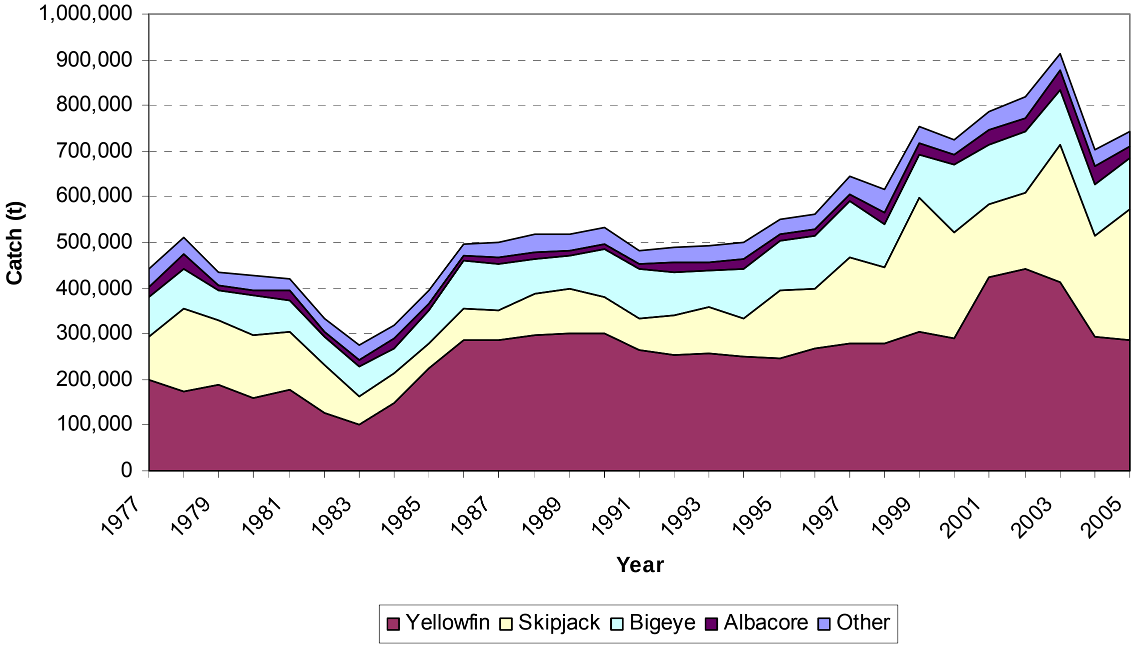

Figure 5 Purse seine catches by species in the Eastern Pacific Ocean (1977 – 2006)

2.4. Western Pacific Ocean

The purse seine fishery in the Western Pacific Ocean started in the late 1960s. The fishery started with most vessels setting on natural FADs but over time as the fishery developed in size the variety of types of set made included sets on logs, anchored FADs, marine animals (both whales and whale sharks have been identified), drifting FADs and free schools. However the catch is still dominated by catches from floating objects of various types.

SPC data on purse seine activity defines clearly the type of set made although and Bromhead et al. (2003) analysed the changes in species composition over time (See Figure 6). The latest figures from WCPFC show that the overall purse seine catches have continued to increase, although a full breakdown by set type is not available with the public data.

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.

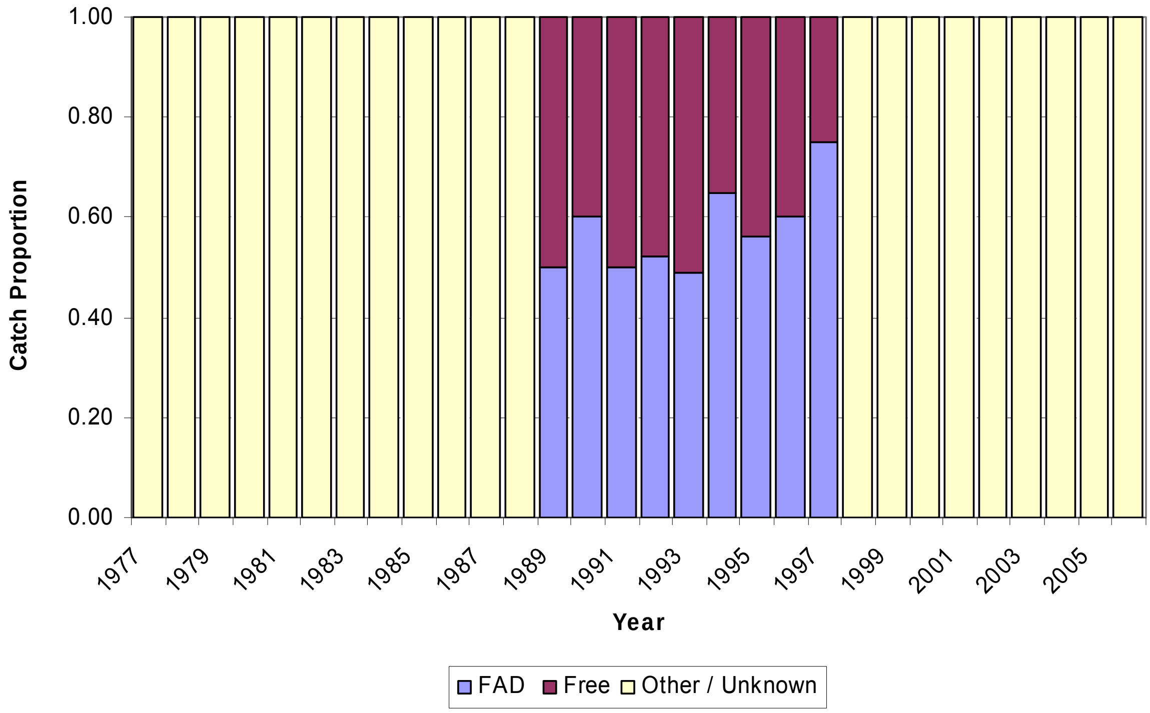

Figure 6 Catch Proportion FAD vs Free (1989-2006)
Source: WCPFC Fisheries Yearbook & Catch proportions from Bromhead *et al.* (2003).
Note: Pre-1989 and post-1997 FAD and free proportions are set as unknown as detailed data are not available.

2.5. Atlantic Ocean

Fishing with FADs in the Atlantic Ocean started in the 1960s but due to the lack of the defined logbook settings to record set types by the purse seiners no detailed records of the FAD catches are available prior to 1988 though Ariz Telleria *et al*. (1999) noted that 15% of purse seine catches in the region were taken from floating object (natural log) sets.

Since the late 1980s the use of FADs increased to a peak of about 45% of the catch proportion in 1995 and 1996 (See Figure 7). The decline in FAD catch proportion between 1997 and 1998 is in part due to the adoption of voluntary time-area closure agreed in the "Agreement of the Community Producers of Frozen Tuna for the Protection of Tunas in the Atlantic Ocean" was initiated by the European purse seine fleets (from November to January) for each season between 1997 and 1998. During 1998, ICCAT adopted a recommendation [98-01] effective from November 1st 1999 to January 31st 2000 and applicable to purse seiners flying the flags of Contracting Parties, and non-Contracting Parties, Entities or Fishing Entities. This measure was extended in 1999 [99-01] to include all the surface fleets. These combined measures closed off the main season and area that would be susceptible to juvenile bigeye tuna catches through the use of FADs, although the overall level of FAD catches outside of this season did increase during 1999 and 2000. Since 2000 the level of the catch proportion from FADs has continued to remain relatively constant, although overall purse seine catch levels have dropped slightly (See Figure 8).

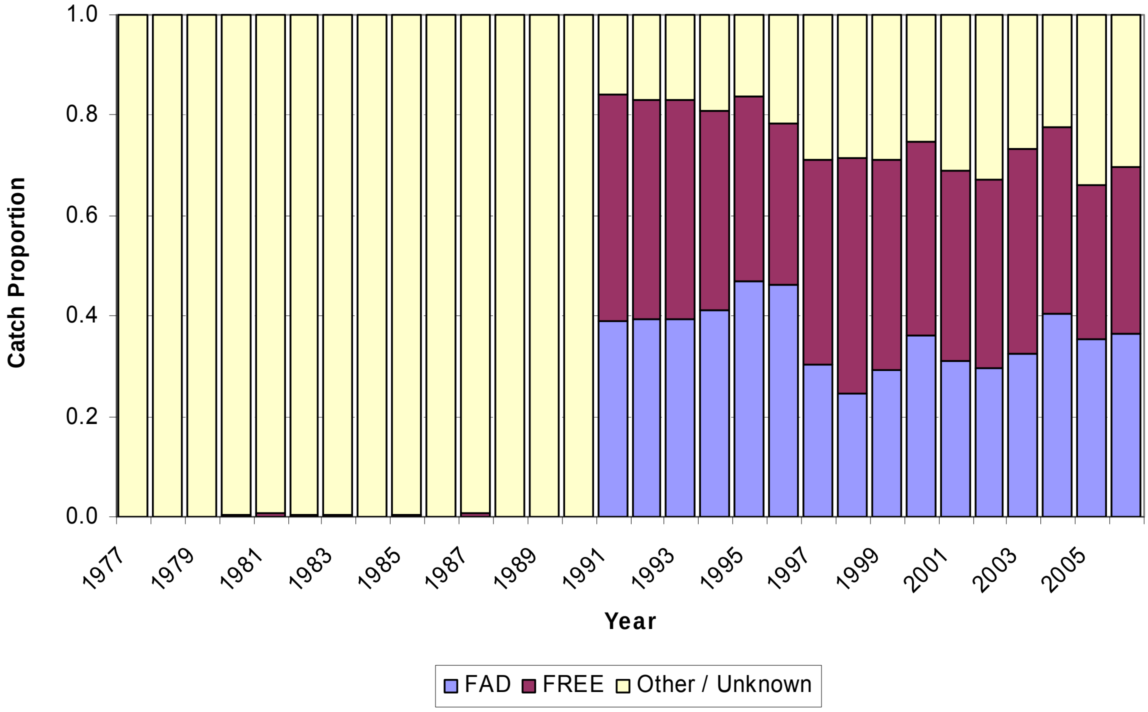

Figure 7 Purse Seine Catch Proportion (FAD vs Free) Atlantic Ocean 1977-2006

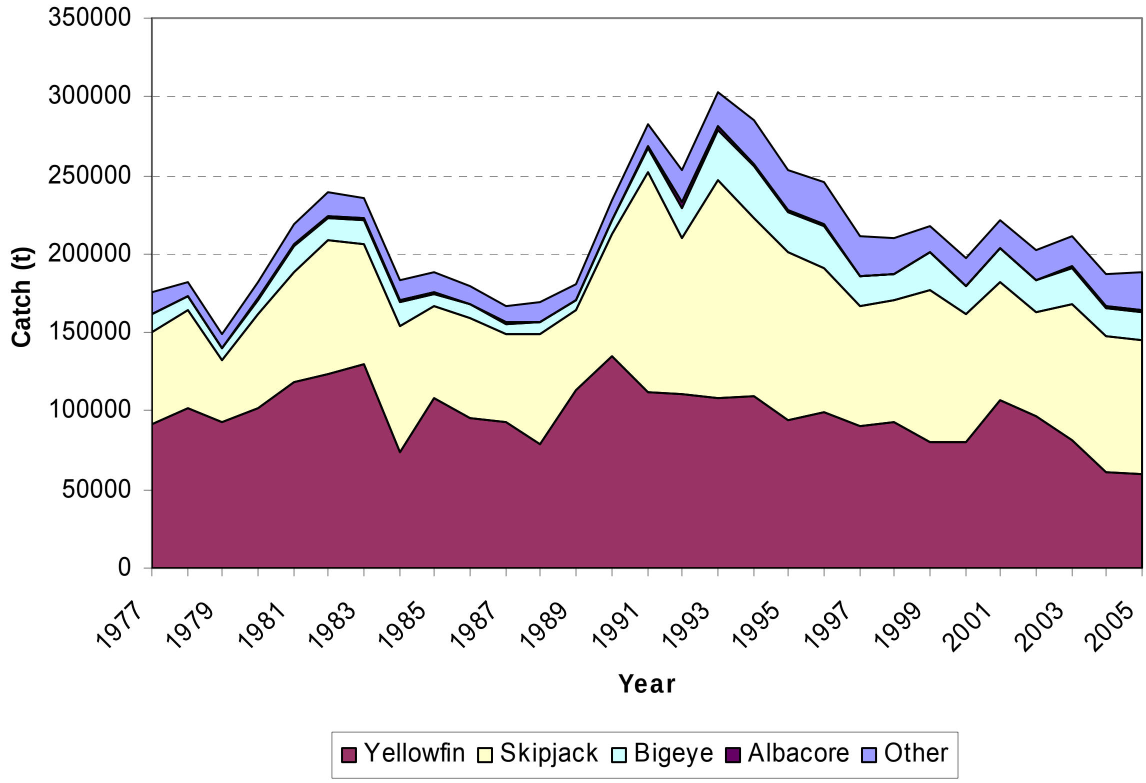

Figure 8 Purse Seine Catches by Species in the Atlantic Ocean (1977 - 2006)
Source: ICCAT Catch and Effort Database

In contrast to the increasing catch levels observed in the Indian, Eastern and Western Pacific Ocean regions, where a general trend of increasing catches of FAD-associated skipjack and bigeye have occurred in the 1990s and 2000s, overall catches in the Atlantic of species have experienced a decline.

2.6. Indian Ocean

The purse seine fishery for tuna in the Indian Ocean started to rapidly expand in the early 1980s (Hallier and Parajua, 1999), as a natural expansion by the European purse seine fleets from the Atlantic Ocean. The use of FADs by the European fleets increased in the 1980's and early 1990's (See Figure 9) with the peak in the catches from FADs occurring in 1997 (see Figure 9). The proportion from FADs was higher at the start of exploitation in the Indian Ocean but this is due to the smaller number of vessels in the fishery at the time.

The catch with FADs of skipjack with catches of juvenile yellowfin and bigeye has continued to increase. Recently catches from FADs have decreased.

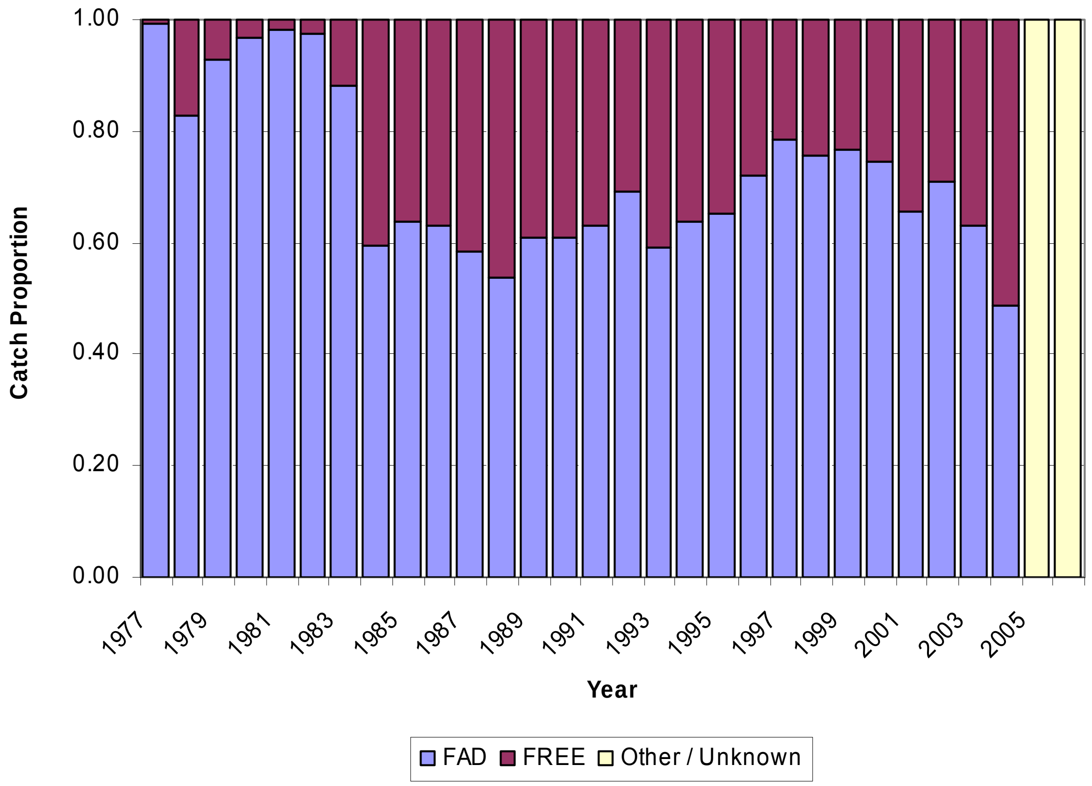

Figure 9 Catch proportions FAD vs FREE Indian Ocean (1977 - 2006)
Source: IOTC dataset. (http://www.iotc.org/English/data/databases.php)

2.7. Development in the Type of FADs used

In parallel to the geographical distribution of FADS there has also been a development over time in the type of FADs used by the purse seine fishing fleets globally.

- **Natural FADS** – Naturally occurring floating objects in the water, such as logs, naturally forming aggregations of flotsam. Earliest forms of naturally forming fish aggregations.

- **Marine mammal and sharks** – Aggregations of tuna occurring associated with other highly visible large marine fauna, including dead whales, oceanic whitetip sharks, whale sharks and dolphins.

- **Fixed FADs** – Artificial FADs created using similar materials to natural FADs, anchored in inshore areas to aggregate fish for artisanal fishers to exploit. Fishing on fixed FADs has expanded in recent years into more industrialised fisheries with larger fixed FADs further offshore to exploit offshore tuna resources, often in conjunction with naturally occurring features such as seamounts that act in a similar way. (See Figure 10).

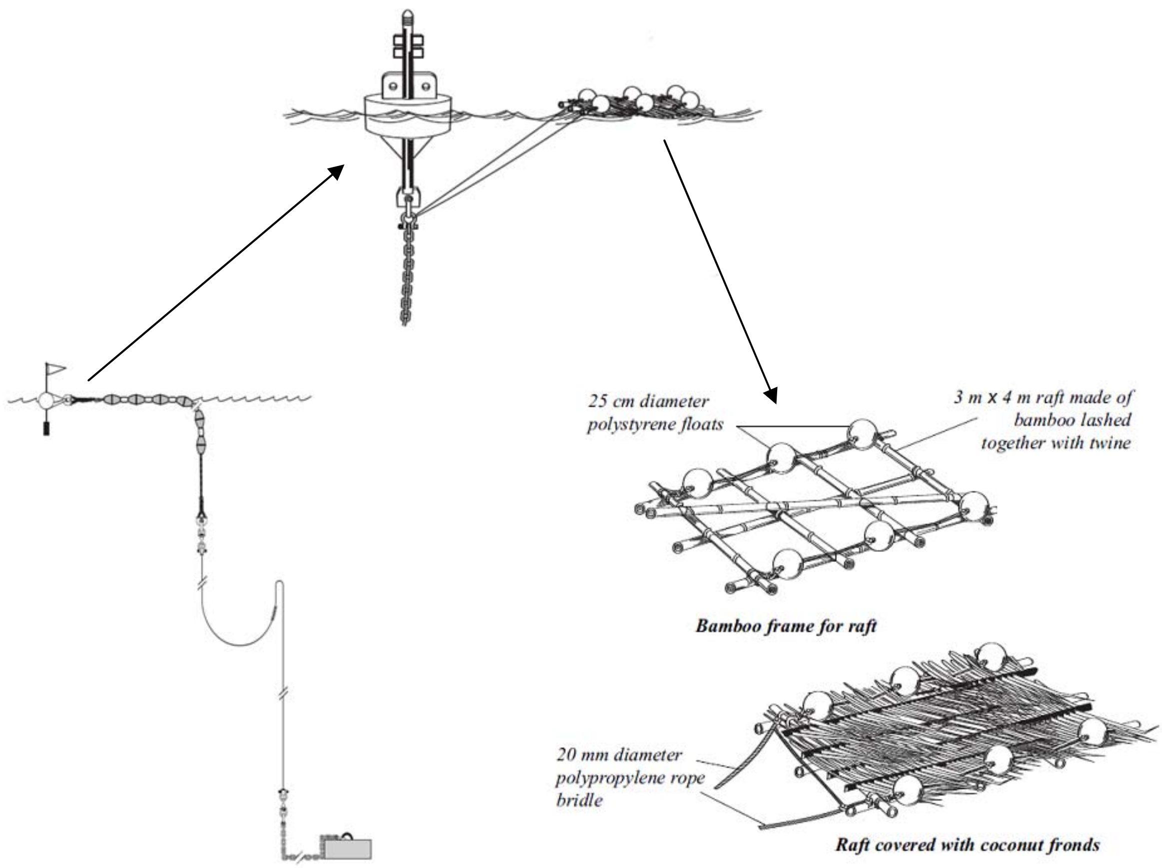

Figure 10 Traditional fixed FAD design from the Pacific. (Images adapted from Chapman et al. (2005))

Artificial Drifting FADs

- **Artificial Drifting FADs**– Artificial FAD created to mimic naturally occurring FADs to increase the level of overall aggregation of tuna. Over time these have become larger and better constructed to increase the longevity of the FAD. (See Figure 11 and Figure 12). They have also had various additional electronic devices fitted:

Figure 11 Drifting FAD deployed in the water (Image from http://www.fadio.ird.fr/)

Figure 12 Drifting FAD deployed in the water viewed from underwater (Image from http://www.fadio.ird.fr/)

- **Artificial Drifting FADS + radio transponders**– As above but with radio transponder fitted to allow vessels to locate FADs in the local area. Allows for more efficient searching and locating of FADs by reducing the time between sets. Radio transponders are reasonably expensive pieces of equipment and therefore FAD structures have increased integrity and longevity.

- **Artificial Drifting FADS + satellite transponders** – As above but with satellite transponder fitted instead of radio transponders to allow vessels to locate FADs at all times. More expensive but allows for much more efficient searching and locating of FADs by reducing the time between sets.

- **Artificial Drifting FADS + satellite transponders + sonar buoys**– As above but sonar buoys attached to the satellite transponder that signal the presence and biomass of tuna aggregations beneath the FADs (Fonteneau, 2000). Minimise the time between sets for a fleet of vessels operating together as when a FAD reaches the appropriate trigger level the nearest vessel can be tasked with harvesting that FAD. (See Figure 13).

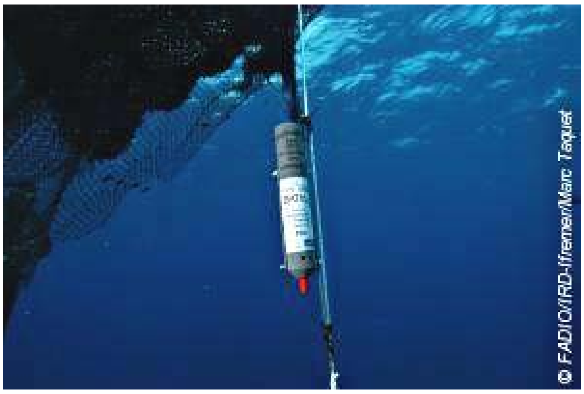

Figure 13 **Drifting FAD with detection / acoustic equipment deployed. (Image from http://www.fadio.ird.fr/)**

2.7.1. Support / Supply Vessels

In parallel to the increase in the number and complexity of drifting FADs has been the increasing use of supply / support vessels that are employed to deploy, monitor and recover the FADs (to ensure optimal placement in the fishery). These developments in FAD structure and patterns of use have probably increased the catch rates or catch per unit effort (CPUE). However there is a severe lack of empirical data on these assumptions and recreating a full historical pattern of FAD development and deployment will not be an easy task. The effects of FADs on catch and CPUE has been flagged by various tuna RFMOs and has been given a high priority in recent years with the ESTHER project (Efficiency of the Tuna Purse Seiners and Effective Efforts) (Gaertner and Pallares, 2001) detailing the potential effects of various parameters of purse seiners on their fishing effort.

In the Eastern Pacific Ocean, IATTC introduced a resolution limiting the use of fish aggregating devices in 1999. Amongst a number of other measures to restrict and further investigate the use of FADs in the EPO, one element of this resolution was to prohibit the use of “tender” vessels operating in support of vessels fishing on FADs in the EPO. Support vessels are not currently restricted in the other three ocean regions.

2.7.2. Cooperative fishing between purse seiners and pole and line fisheries.

In some areas where pole and line (baitboat) fisheries can operate (i.e. when they are close enough to sources of bait and local ports and the thermocline is shallow) there is a degree of cooperative fishing between the purse seine fleet and the pole and line fleet. Two such examples are the fisheries in Ghana and Venezuela, where the baitboats use live anchovy or small sardinellas as bait which is kept live in tanks on board until used. The cooperative element has been introduced as the baitboats now also utilise FADs to help in aggregating fish to enable higher catch rates to be achieved. The baitboat itself also acts as a FAD and the chumming with live bait helps to maintain the population of tuna under the baitboat.

2.8. Summary of the implications of the development of FAD fisheries

Table 4 summarises the information given by major ocean in the preceding sections, and illustrates the development and importance of FAD fisheries over time within each ocean. Table 5 summarises the issues related to the development of fishing with FADs that are further explored in the following sections of this report.

Table 4: A summary of proportion of tuna catch by ocean region taken on FADs, free schools or by another or unknown method.

Year	Eastern Pacific			Western Pacific			Atlantic			Indian		
	FAD	FREE	Other / Unknown	FAD	FREE	Other / Unknown	FAD	FREE	Other / Unknown	FAD	FREE	Other / Unknown
1977	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.06%	99.94%	99.17%	0.83%	0.00%
1978	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.02%	99.98%	82.83%	17.17%	0.00%
1979	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.12%	99.88%	92.89%	7.11%	0.00%
1980	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.25%	99.75%	96.72%	3.28%	0.00%
1981	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.83%	99.17%	98.35%	1.65%	0.00%
1982	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.49%	99.51%	97.52%	2.48%	0.00%
1983	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.28%	99.72%	88.07%	11.93%	0.00%
1984	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.17%	99.83%	59.67%	40.33%	0.00%
1985	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.36%	99.64%	63.91%	36.09%	0.00%
1986	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.13%	99.87%	63.18%	36.82%	0.00%
1987	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.57%	99.43%	58.42%	41.58%	0.00%
1988	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.11%	99.89%	53.90%	46.10%	0.00%
1989	19.89%	28.54%	51.57%	50.00%	50.00%	0.00%	0.00%	0.00%	100.00%	61.02%	38.98%	0.00%
1990	21.85%	27.14%	51.01%	60.00%	40.00%	0.00%	0.00%	0.00%	100.00%	60.76%	39.24%	0.00%
1991	22.55%	24.96%	52.49%	50.00%	50.00%	0.00%	39.15%	44.96%	15.89%	63.07%	36.93%	0.00%
1992	20.72%	27.06%	52.23%	52.00%	48.00%	0.00%	39.25%	43.77%	16.99%	69.08%	30.92%	0.00%
1993	25.17%	39.20%	35.64%	49.00%	51.00%	0.00%	39.51%	43.41%	17.09%	59.27%	40.73%	0.00%
1994	33.80%	25.86%	40.34%	65.00%	35.00%	0.00%	41.27%	39.59%	19.15%	63.82%	36.18%	0.00%
1995	36.88%	28.24%	34.88%	56.00%	44.00%	0.00%	47.04%	36.66%	16.30%	65.24%	34.76%	0.00%
1996	38.58%	26.69%	34.73%	60.00%	40.00%	0.00%	46.21%	32.11%	21.68%	72.13%	27.87%	0.00%
1997	45.29%	20.04%	34.67%	75.00%	25.00%	0.00%	30.47%	40.73%	28.81%	78.53%	21.47%	0.00%
1998	40.68%	22.95%	36.36%	0.00%	0.00%	100.00%	24.37%	47.13%	28.50%	75.76%	24.24%	0.00%
1999	46.07%	29.57%	24.36%	0.00%	0.00%	100.00%	29.30%	41.92%	28.78%	76.88%	23.12%	0.00%
2000	46.04%	27.22%	26.73%	0.00%	0.00%	100.00%	36.14%	38.63%	25.22%	74.43%	25.57%	0.00%
2001	42.51%	16.65%	40.84%	0.00%	0.00%	100.00%	31.19%	37.69%	31.13%	65.61%	34.39%	0.00%
2002	33.75%	17.38%	48.87%	0.00%	0.00%	100.00%	29.56%	37.75%	32.69%	70.93%	29.07%	0.00%
2003	37.15%	23.71%	39.14%	0.00%	0.00%	100.00%	32.32%	41.02%	26.67%	63.24%	36.76%	0.00%
2004	39.42%	25.73%	34.85%	0.00%	0.00%	100.00%	40.48%	37.21%	22.31%	48.89%	51.11%	0.00%
2005	37.78%	32.69%	29.53%	0.00%	0.00%	100.00%	35.43%	30.63%	33.94%	0.00%	0.00%	100.00%
2006	54.92%	27.85%	17.24%	0.00%	0.00%	100.00%	36.39%	33.42%	30.19%	0.00%	0.00%	100.00%

Table 5: A summary of the issues related to FAD development, their potential impacts and the outcomes of that impact.

Issue	Data Sources	Impacts	Outcomes
Increased catch	RFMO databases show increased purse seine catches over the last thirty years over and above the expected levels from the increase in the number and tonnage of the fleets.	Higher catches and in particular increased catch of juvenile bigeye and yellowfin tunas	Potential overfishing
Change in catch per unit effort		Increase in the catch per unit effort	Potential overfishing, increased difficulty in stock assessment as CPUE series needs standardisation.
Change in catch composition leads to change in catch value.		Catches from free schools dominated by adult yellowfin and skipjack tunas. Catches from FADs dominated by adult skipjack and juvenile yellowfin and bigeye	Possible higher more stable volume of catch but lower value.
Expansion of area covered	Fonteneau (2007)	Different areas can be exploited using FADs that may not be fished on free schooling tuna	
Increased utilisation of juvenile areas		Smaller size classes of tuna are exploited in areas where juveniles are found.	Potential for increased juvenile mortality.
Measurement of effort	Gaertner and Pallares, (2001)	Difficult to estimate "true" levels of effort Standardisation of effort over time for stock assessment. This is a complex issue as standardisation is not just a FAD issue but is also linked to a general increase in fleet efficiency over time.	Projects like ESTHER to estimate efficiency of purse seiners. IATTC work on standardisation of purse seine effort (Watters and Deriso, 2000)
Use of supply vessels		Impact on level of effort used. Lack of observer coverage, and vessels may not be covered by logbook systems	Effort changes not recorded, leading to errors or higher levels of uncertainty in stock assessment.

3. Summary status of tuna stocks

3.1. Published stock status summaries

The following summarises the details shown in Table 7 - Table 9, which relate to published stock assessments available on RFMO websites. However, there is often a time lag between assessments by RFMO working parties and their review by the Commissions and posting on websites. A summary of the latest stock assessments is given in Table 6.

Table 6: A summary of selected tuna stocks status.

Ocean	Skipjack tuna	Yellowfin tuna	Bigeye tuna
Eastern Pacific	Moderately to fully exploited	Fully exploited	Overexploited and overfishing occurring
Western Pacific	Moderate fishing pressure, high stock levels	Fully exploited, overfishing likely	Overfishing occurring, stock not currently overexploited
Atlantic	Unlikely to be overexploited	Overfishing occurring, stock may be overexploited	Fully exploited
Indian	Moderately to fully exploited	Overfishing likely, stock may be overexploited	Fully exploited

Note: See 3.1 for data sources.

3.1.1. Skipjack tuna

Pacific: Eastern: Moderately exploited. Biomass, recruitment and exploitation have been increasing over the last 20 years. The main concern is the increasing exploitation rate, though no adverse effects of this have been detected. High uncertainties with stock levels, but CPUE trends encouraging; Western: Moderate fishing pressure and high stock levels. The stock has remained stable in recent years with stock assessments since 2002 giving consistent indicators of stock status.

Atlantic: It is unlikely that overfishing is occurring for both East and West Atlantic skipjack and the stocks are unlikely to be overfished. No management recommendations are made explicitly though catches should not exceed MSY. Both fisheries have been relatively stable in recent years.

Indian: Moderately to fully exploited. Increasing catch rates with increasing effort historically have historically been interpreted as indications of a healthy stock. However catches have declined in 2007 and potentially 2008 as well.

3.1.2. Yellowfin tuna

Pacific: Eastern: Fully exploited. Uncertainty in the stock assessment. The stock has been relatively stable in recent years. F has been decreasing in recent years and in 2008 $F_{current}$ dropped below F_{MSY}; Western Fully exploited. Overfishing quite likely (probability 47%) with a small possibility (6.2%) of the stock being overexploited. Biomass has been declining gradually in recent years with increasing fishing pressure.

Atlantic: Fully exploited. Uncertainty exists on the stock status. Declining stock levels a possibility. Catches have been declining since 2001, and in 2005 and 2006 reached the lowest catch levels since 1974. Two stock assessments undertaken most recently suggest that overfishing has occurred in recent years. The most pessimistic stock assessment suggested the stock is currently overfished, though overfishing had not occurred in 2006. In comparison, the other stock assessment implied that overfishing did not occur in 2006 and the stock is not currently over-fished. Overall there is a 60 % chance that the stock status does not conform to ICCAT's convention objectives. The stock has improved in recent years, with declining trends of catches and effort also occurring.

Indian: Overfishing is likely to be currently occurring and the stock is likely to be close to, or perhaps already, overfished. The current degree of over-fishing is lower than for the 2003-2006. Prior to 2002 yields were below MSY.

3.1.3. Bigeye tuna

Pacific: Eastern: Overexploited. The last 2 assessments have indicated overfishing is likely to be taking place. Current fishing effort levels will suppress B to the lowest levels observed (in 2004); Western: Overfishing is taking place, though the stock is not currently over exploited. Biomass has been declining steadily since 2004 and fishing mortality is currently showing annual declines.

Atlantic: Fully exploited. Current fishing levels will allow the stock B to recover further. The SCRS highlighted concerns over the accuracy of estimations of unreported catches. Catches have been declining since 1994 and reached a historical low in 2006.

Indian: Fully exploited. Current catch levels will cause decline of SSB to approx. SSBmsy. Fishing mortality and biomass have been increasing and decreasing, respectively, since the 1970s.

Table 7: Skipjack tuna (*Katsuwonus pelamis*) stock status estimates

Stock	Latest Stock Assessment	Fishing method (% of catches)	Current Yield	MSY	B_{2006}/B_{MSY}	F/F_{MSY}	Management Advice	State of Exploitation
Eastern Pacific Ocean	2006 (IATTC, 2008b)*	PS = 99.1 % BB = 0.1 LL = 0.4 in 2007 (IATTC Catch by Species, Flag and Gear)	220,665 (2007)	n/a	n/a (SSB_{2004} /SSB_0 = 0.61)	n/a (F_{2006} ~ 0.85)	IATTC is continuing to develop their assessment of skipjack stocks.	Moderately to fully exploited. High uncertainties with stock levels, but CPUE trends encouraging.
Western Pacific Ocean	2008 (WCPFC, 2008a)*	PS = 84.9 % BB = 11.2 LL = 0.3 in 2006 (WCPFC, 2007b)	1,726,702 (2007)	1,280,000	2.99	0.26	2007 catches have reached a historical high. Sustainable unless recruitment persistently falls below long-term average	Moderate fishing pressure and high stock levels.
East Atlantic Ocean	2008 (ICCAT, 2009)*	PS = 57.0 % BB = 37.5 LL = 0.1 in 2006	125,400 (2007)	143,000 – 170,000 t	B_{2006}/B_{MSY} most likely > 1	F_{2006}/F_{MSY} most likely < 1	Closure of surface fishery in Gulf of Guinea in November (Recommendation. 04-01). Catches should not exceed MSY.	Unlikely to be overexploited.
West Atlantic Ocean	2008 (ICCAT, 2009)*	PS = 7.9 % BB = 90.0 LL = 1.1 in 2006	25,400t (2007)	30,000 – 36,000t	B_{2006}/B_{MSY} most likely > 1	F_{2006}/F_{MSY} most likely < 1	Catches should not exceed MSY.	Unlikely to be overexploited.
Indian Ocean	n/a	PS = 49.7% FAD, 9.8% FS in 2007	447,100t in 2006 (IOTC, 2008b)	n/a	n/a	n/a	Skipjack assumed resilient to overfishing, regular monitoring recommended	Moderately to fully exploited. Increasing catches with increasing effort suggest healthy stock.

*This reference applies to the table row unless otherwise stated

Table 8: Yellowfin tuna (*Thunnus albacares*) stock status estimates

Stock	Latest Stock Assessment	Fishing method	Current Yield	MSY	B/B_{MSY}	F/F_{MSY}	Management Advice	State of Exploitation
Eastern Pacific Ocean	2008 (IATTC, 2008b)*	PS = 97.4 % BB = 0.5 LL = 1.4 in 2007 (IATTC Catch by Species, Flag and Gear)	173,413t (2007)	281,902	0.96 (B_{2007}/B_{msy})	$F < F_{MSY}$	In line with IATTC Resolution C-04-09; • Restrictions on Purse-seine effort and longline catches. • 6 week closures during 3rd or 4th quarter of year for purse seiners. • Longline catches not to exceed 2001 levels. (Maunder, 2006)	Fully exploited though uncertainty in the stock assessment.
Western Pacific Ocean	2007 (WCPFC, 2007a)*	PS = 55.1 % BB = 3.6 LL = 17.4 in 2006 (WCPFC, 2007b)	431,814 t (2007)	n/a	1.10	0.95	• Fishery can be considered fully exploited. A reduction in fishing mortality rate required to reduce risk of overfishing.	Fully exploited. Overfishing quite likely (probability 47%) with a small possibility (6.2%) of the stock being overexploited.
Atlantic Ocean	2008 (ICCAT, 2009)*	PS = 58.9 % BB = 12.9 LL = 18.3 in 2006	108,160t (2006)	130,600t or 146,600t.	B_{2006} / B_{MSY} = 0.96	$F_{current} / F_{MSY}$ = 0.86	• Closure of surface fishery in Gulf of Guinea in November (Recommendation. 04-01). • No 1993 commission recommended no increase in the effective level of fishing effort in 1992. (Recommendation 93-04)	Overfishing currently taking place. The stock may also be in an overexploited state.
Indian Ocean	2008 (IOTC, 2008b)*	PS = 31.0 FAD, 38.1 % FS LL = 4.7 in 2007	316,700t in 2007	250,000 – 360,000 t	B_{2007}/B_{MSY} 1.13 – 0.93	F_{2007}/F_{MSY} 0.9 – 1.60	Recent catches have likely exceeded MSY, catch recommended to drop to pre-2003 levels.	Overfishing likely to be currently occurring. The stock is likely to be close to, or perhaps already, overexploited.

*This reference applies to the table row unless otherwise stated

Table 9: Bigeye tuna (*Thunnus obesus*) stock status estimates

Stock	Latest Stock Assessment	Fishing method	Current Yield	MSY	B/B_{MSY}	F/F_{MSY}	Management Advice	State of Exploitation
Eastern Pacific Ocean	2008 (IATTC, 2008b)*	PS = 68.3 % LL = 31.7 in 2007 (IATTC Catch by Species, Flag and Gear)	88,208 (2007)	78,150 - 81,350t	0.74 - 1.15 (B_{2008}/B_{MSY})	~1.2	In line with IATTC Resolution C-04-09; • Restrictions on Purse-seine effort and longline catches. • 6 week closures during 3rd or 4th quarter of year for purse seiners. • Longline catches not to exceed 2001 levels. (Aires-da-Silva & Maunder, 2006)	Overexploited. Overfishing currently occurring. Current fishing effort levels will suppress B to the lowest levels observed (in 2004).
Western and Central Pacific Ocean	2008 (WCPFC, 2008d)*	PS = 21.7 % BB = 5.4 LL = 60.5 in 2006 (WCPFC, 2007b)	143,059 (2007)	64,600 (range 56,800 – 65,520)	1.37 (range 1.02 – 1.37)	1.44 (range 1.33 – 2.09)	Recommendation of a 30% reduction in fishing mortality to return to F_{MSY}.	Overfishing is taking place, though the stock is not over exploited.
Atlantic Ocean	2007 (ICCAT, 2008c)*	PS = 25.0% BB = 22.7 LL = 50.0 in 2006	67,172 t (2007)	90,000t – 93,000t	B_{2006}/B_{MSY} 0.92 (0.85 -107) 80% CI	F_{2005}/F_{MSY} 0.87 (0.70 – 1.24	TAC = 90,000t Vessel no's limited plus area closures.	Fully exploited. Current fishing levels will allow the stock B to recover further
Indian Ocean	2006 (IOTC, 2007a)*	PS = 46.9% FAD, 14.7% FS LL = 38.4 in 2007	117,900 t (2006)	111,200t (95,000 – 128,000t)	1.34 SSB_{2004}/SSB_{MSY} (1.040-1 .64)	0.81 F_{2004}/F_{MSY} (0.54 – 1.08)	Recommended catches should not exceed MSY and effort should stay below 2004 levels.	Fully exploited. Current catch levels will cause decline of SSB to approx. SSB_{msy}.

*This reference applies to the table row unless otherwise stated

4. Ecological impacts of FADS

FADs have become the basis of major commercial tuna fisheries around the world (see Section 22). The use of these structures has increased catches through a combination of attraction of fish to the FAD, and enabling fishermen to better locate aggregated fish schools. For the purpose of this review we have addressed the ecological impacts separately for tuna (target) species (Section 4.1) and other (non-target) species (Section 4.2).

4.1. On target fisheries (Tunas)

The ecological impacts on tuna stocks resulting from the use of FADs are still poorly understood despite more than three decades of associated research (Dempster and Taquet, 2005). The key concerns are that the number of FADs currently distributed throughout the world's ocean may give rise to considerable changes in tuna behaviour and ecology (e.g. schooling, feeding, and migration patterns) and that fisheries associated with them have shifted the exploited size structure of the stock to smaller age classes. The number of FADs used by the commercial fishing fleet currently accounts for over 50% of all floating objects over the world's oceans (Freon and Dagorn, 2000). In 1998 it was estimated that the number of FADs fitted with radio transmitters used by a fleet of around 45 purse seiners operating off the Gulf of Guinea, exceeded 3000 (Bromhead, 2003).Consequently, the extent of their use has lead to rising international concerns regarding the sustainability of tuna fisheries in general.

Tuna are known to associate with drifting structures such as drifting man-made FADs (Fonteneau et al., 2000) and rubbish or natural debris (Riera et al., 1999), as well as fixed structures such as moored FADs (Freon and Dagorn, 2000), oil platforms in the Gulf of Mexico (Franks, 2000) and coastal sea-cage fish farms (Dempster et al., 2002). A number of different theories have been proposed to explain the evolutionary mechanisms which drive the attraction of fish to floating structures and the evidence for these has been reviewed comprehensively by Freon and Dagorn (2000) and Castro et al. (2002). Theories primarily corresponding with large/adult tuna include the 'meeting-point', 'reference-point' and 'indicator-log' hypotheses; whilst those more related to small/juvenile fish include protection from predators and enhanced feeding opportunities. However, these theories have been difficult to test experimentally due to the timescales over which studies are feasible (Dempster and Taquet, 2005); most data has been collected over ecological rather than evolutionary timescales.

Fixed structures are suggested to provide a spatial reference point from which and to which tuna navigate in order to carry out their natural migrations (Fonteneau, 1991; Holland *et al*., 1999). Drifting FADs are proposed to provide 'meeting-points' for tuna, increasing the encounter rate between animals of the same species, thus allowing conservation of energy for other activities such as foraging which would otherwise be used for searching for other individuals or schools (Freon and Dagorn, 2000; Castro *et al*., 2002). However, there is controversy regarding this theory as it fails to explain why tuna would search for FADs rather than searching for tuna schools in first place (Castro *et al.*, 2002). The same authors have suggested that drifting FADs may also act as 'indicator-logs' for convergence zones or oceanic fronts where productivity and consequently food availability is higher, as would naturally occurring drifting objects following ocean currents. However, this theory is also debated, as drifting FADs are seeded in unproductive offshore equatorial currents, which do not necessarily correspond with convergence areas, and may divert fish from their natural poleward migrations (Marsac et al., 2000).

Although debate continues as to the mechanisms by which tuna are drawn to either fixed or drifting FADs, there is consensus that alterations to the distribution and abundance of FADs may lead to changes in the way fish are distributed in the ocean and subsequently have broader consequences for certain exploited fish stocks and the wider pelagic ecosystem. The ecological impact of FADs on the tuna stocks can therefore be divided into three over-arching categories: impacts on individual stocks (abundance, migration behaviour, etc.); impacts upon interaction between different species (competition, etc.); impacts on the wider pelagic ecosystem (including prey species).

Two major reviews exist in the literature, which deal directly with the ecological impacts of FADS. Bromhead et al (2003) reviewed the impact of FADs on tuna fisheries in general but provide detail on the aspects of tuna biology which are relevant to FADs, the resultant impact on tuna behaviour and ecology of FADs and subsequently what the potential impacts are on the sustainability of fisheries associated with FADs. Dempster and Taquet (2005) reviewed literature dealing with FADs (407 references from 1978-2003) to determine areas of research deficiency. Based primarily on these two major reviews (plus additional references published subsequently), Table 10 summarises the key literature dealing with ecological impacts on target species and additional detail on these impacts is provided in the following sub-sections. Table 11 provides geographical locations with respect to the RFMO in which research detailed in Table 10 was carried out.

Table 10 Summary of the literature review on FAD research.

(I) Vulnerability to gear by species size and age and removal of juveniles			
Impact identification	**Assessment of the problem**	**Source**	**Conclusions**
Large scale commercial FAD-associated fisheries contribute to high levels of exploitation on juvenile and smaller species of tuna which associate more readily to FADs than adults or larger species.	Evidence exists for alterations in the size structure of tuna populations, due to large quantities of juvenile yellowfin and bigeye tuna being caught around FADs. Recruitment overfishing' has contributed to a reduction in the spawning stock biomass of some stocks, namely skipjack tuna in the Eastern Atlantic Ocean (i) and to yellowfin in the Eastern Pacific Ocean (ii). The long-term effect of sustained use of drifting FADs may have similar effects in other areas of the world (i and ii).	**(i) Fonteneau et al., 2000** **(ii) IATTC conference Mexico, 2007**	Quantitative evidence exists for removal of juveniles around FADs. The extensive use of FADs coupled with the current level of fishing effort may therefore affect the fishery's long term sustainability. Further work is required to determine the global extent to which juveniles of larger tuna species are caught in FAD-associated fisheries.

(II) Major ecological impacts related to the use of FADs in commercial tuna fisheries			
Impact identification	**Assessment of the problem**	**Source**	**Conclusions**
Widespread use of FADs in large scale commercial fisheries has potential to impact on tuna populations due to removal of some species or size classes of tuna and to changes in their ecology by altering their natural behaviour.	Notable impacts on tuna stocks were observed as a result of the use of FADs as a current practice in large scale commercial fishing, namely on: - feeding biology (i) - schooling behaviour (ii & iii) - migratory movements (iii)	**(i) Essington et al., 2002** **(ii) Fonteneau et al., 2000** **(iii) Marsac et al., 2000**	Some quantitative information exists for alterations to tuna schooling behaviour as a result of FADs, e.g. fewer free swimming schools reported since FAD introduction and school species composition. However, further research is often suggested in conclusions of studies. There has also been a disproportionate amount of research related to impacts and dynamics of fixed FADs, with few studies into impacts of drifting FADs. This is primarily due to difficulties in studying large mobile fish around drifting objects in the open ocean.

(III) Ecological Traps and behavioural impacts			
Impact identification	**Assessment of the problem**	**Source**	**Conclusions**
Impacts on predator-prey relationships: potential for increased fishing effort on drifting FADs lead to cascading predator–prey effects on the pelagic ecosystem. Fish associated with moored FADs have demonstrated prey switching.	The most notorious predator-prey effects are: - increases in cannibalism in fish communities associated with FADs (i) (no records of this behaviour in free-swimming shoals) - shifts in diet towards species with lower nutritional value e.g. invertebrate prey from deep in the water column (ii) & (iii).	**(i) Essington et al., 2002** **(ii) Takahashi et al., 1988** **(iii) Poitier et al., 2001**	Quantitative evidence exists for increased cannibalism amongst tuna associated with FADs, contributing to an increase in natural mortality. Prey switching to a nutritionally lower value species may affect tuna growth.

IMPACT IDENTIFICATION	ASSESSMENT OF THE PROBLEM	SOURCE	CONCLUSIONS
(A) DRIFTING FADS			
Tuna associated with FADs may be in poorer condition (lower weight to length ratio) than their free-swimming counterparts. Tuna associated with FADs may become “trapped” in unproductive areas. Increased rates of cannibalism around FADs contribute to increasing tuna’s natural mortality.	Observations exist of tuna being associated with FADs located in low productivity areas where food is scarce. Evidence of the poorer condition of tuna associated to FADs located in unproductive areas has been well documented. Affects on growth and condition of tuna ultimately result in higher rates of natural mortality (i and ii). Some studies suggest that juvenile tuna may associate with drifting FADs or bait boats for several months (iii). There is potential for the great increase in numbers of drifting FADs in the ocean, distributed unnaturally to act as ‘ecological traps’ for juvenile tuna. Other studies suggest the bigeye tuna is not ecologically trapped by drifting FADs as they spend a limited period of time associated with these structures (iv; xi).	**(i) Marsac et al., 2000** **(ii) Hallier and Molina, 2000** **(iii) Schaefer and Fuller, 2002** **(iv) Menard et al., 2000** **(v) Poitier et al., 2001** **(vi) Marsac et al., 2000** **(vii) Delmendo, 1991** **(viii) Holland et al., 1990** **(ix) Freon and Dagorn, 2000** **(x) Dempster and Taquet, 2005** **(xi) Leroy et al., 2007**	Dietary studies provide evidence to suggest that FADs act as ecological traps. Information on the ecology of pelagic fish at moored FADs cannot be readily extrapolated and used to understand the ecological processes associated to drifting FADs as pelagic fish behaves very differently around both types of structures (ix , x and xi). Further research is required to assess actual reductions in SSB due to the suggested poor dietary regimes of tuna associated with drifting FADs.
(B) FIXED FADS			
Evidence exists for these structures having the potential to modify residence times of pelagic fish in a given area, feeding ecology, migratory pathways and susceptibility to fishing (I to vi).	Cannibalism is known to occur in areas under the influence of fixed FADs, especially amongst yellowfin tuna (i). Other studies suggest that FAD networks located off islands may concentrate fish within the network area, but at meso-scales, they may not ‘trap’ fish more than the island would do in their absence (v). Differential species specific effects also reported with to residence time at inshore/offshore natural and/or man-made FADs (vi)	**(i) Buckley and Miller, 1994** **(ii) Brock, 1985** **(iii) Franks, 2000** **(iv) Dempster et al., 2002** **(v) Dagorn et al., 2007** **(vi) Itano & Holland, 2000**	The presence of moored structures might have similar effects of other naturally occurring structures and therefore the overall impact may not be as detrimental as initially thought.

Table 11 Relevant RFMO location of research referred to in Table 10.

Impact	IATTC	WCPFC	ICCAT	IOTC
Vulnerability to gear				
By species	- IATTC, 2007		- Fonteneau, 2000	
By age/size	- Schaeffer & Fuller, 2002 (drifting)?? - IATTC, 2007		- Fonteneau et al., 2000 - Menard et al., 2000b	
Behavioural impacts				
Schooling	- Schaeffer & Fuller, 2002 (drifting)?? - Schaeffer & Fuller, 2005 (drifting)	- Josse et al., 1999 - Josse, 2000 - Fonteneau et al, 2000 - Dagorn et al., 2007 (fixed) - Leroy et al., 2007 (fixed & floating) Itano & Holland, 2000	- Fonteneau, et al., 2000	
Feeding	- Essington et al., 2000 (drifting) - Schaeffer & Fuller, 2002 (drifting)	- Holland et al., 1990	- Menard et al., 2000b (drifting) - Hallier and Molina, 2000	- Poitier et al., 2000 (drifting) - Delmondo, 1991

4.1.1. Vulnerability to gear by species, size and age

Tuna caught under both fixed and drifting FADs are on average smaller and from earlier age classes than those caught in free-schools in the open ocean (Edwards and Perkins, 1998). It has been suggested that juvenile tuna associate with FADs in order to shelter from predators, and as they grow larger they tend to disperse further into open waters (Bromhead, 2003). All tuna species are known to be caught near FADs but some species are more vulnerable than others. Juveniles of large-sized tuna (bigeye and yellowfin) and adults of smaller tuna species (skipjack) are commonly associated with FADs and therefore more vulnerable to fishing around them. Juvenile individuals of large tuna species are vulnerable to being caught near FADs, primarily because they are often caught in conjunction with adult individuals of considerably smaller species of tuna such as skipjack which are being targeted (Marsac *et al*., 2000). Larger individuals are more vulnerable to bait boat, pole and line (skipjack and yellowfin), and long line (bigeye tuna) fishing.

Menard et al. (2000) also suggests that the FAD fishery may have a wide-ranging effect on tuna migration in general and on the productivity of the skipjack population in particular.

A better understanding is required of the vulnerability of each species to fishing gear by age; how removal of juveniles affects the stock and what the behavioural impact on each individual species in the presence or absence of others is.

4.1.1.1. Removal of Juveniles

The use of FADs is known to increase the vulnerability of small tunas, particularly juveniles of larger species such as big eye and yellowfin. Research off the west African coast in the Equatorial Atlantic area indicated that the mean individual weight of skipjack caught decreased between 1991 and 1997 (Menard *et al.*, 2000) and since then has stabilised (ICCAT, 2007). The same has also been observed for the yellowfin tuna caught in the EPO in recent years (IATTC doc 76/06, 2007). Comparisons made by Fonteneau et al., (2007) between species composition of purse seine catches made on FAD and free swimming schools in the Western Indian Ocean during the period 1990-2006, indicated that up to 20% of the catch around FADs could be juvenile tunas (including 12.9% bigeye and 6.6% yellowfin) compared to 2.4% on free schools (including 1.8% bigeye, 0.6% yellowfin).

The removal of juvenile tuna is a problem in fisheries that target predominately smaller tuna species (<7kg per individual) where by-catch and discards of small tuna and other pelagic species associated with the FADs are known to occur. The general consensus is that smaller size range tuna tend to aggregate under floating objects, where they become less active and therefore more vulnerable to being caught.

Obtaining an accurate estimate of the total mortality of undersized or juvenile tuna caught worldwide is difficult, as discards of small tuna and whether these are dead or alive, is often not reported. However, the latest report of the 2007 IATTC meeting in Mexico, provides a total estimate for discards of some tuna species caught in the EPO region of over 27,200 mt. Further data on discards in tuna fisheries are required to quantify the problem globally; and additional investment into observer programmes may be a solution to acquiring such data. Discards and bycatch from FAD fisheries are also covered in more detail in Section 4.2

4.1.2. Behavioural impacts and 'ecological traps'

There is growing concern that areas seeded with high concentrations of FADs may disrupt natural migratory movements of tunas, 'trapping them in these regions (Bromhead et al., 2000). An 'ecological trap' is when population growth is reduced as a consequence of individuals making sudden maladaptive habitat choices (Hallier and Gaertner, 2008). The 'ecological trap' hypothesis relating to tuna states that because smaller tuna quickly aggregate to drifting FADs, maintain strong associations for extended periods, FADs seeded in tropical currents may lead tunas away from their natural foraging grounds to areas where productivity is lower, resulting in reduced growth and condition, and increased natural mortality (Bromhead et al., 2000).

A lack of consensus remains within the scientific community as to whether or not FADs act as true ecological traps; some reporting high retention rates of tuna around FADs in prey-poor waters and others arguing that FADs have no overall detrimental effects on tuna growth (e.g. moored FADs acting as reference points have a similar role to a natural occurring feature such as a sea mount, reef etc.). Nonetheless, there seems to be a general acknowledgment that residence time for each species varies widely, depending on both physical and biological factors which are *per se* exceedingly variable (Dempster and Taquet, 2005).

Behavioural impacts of FADs relating to the ecological trap hypothesis may be separated into several categories:

i. the effects on tuna's schooling behaviour
ii. the effects upon the feeding behaviour and diet
iii. effects on natural mortality
iv. the effects upon tuna migration and movements

Each of these is described in more detail below.

i. Effects of FADs upon tuna schooling behaviour

Schooling behaviour is a crucial survival mechanism for pelagic species, as it contributes to increased protection from predators, improved opportunities for successful reproduction and increased foraging efficiency.

The extensive deployment of FADs has contributed to reducing the abundance of free-schools of tuna (Fonteneau et al. 2000; Marsac et al. 2000). Furthermore, their presence has created differences in age and size composition between free and FAD-associated tuna schools (Menard et al. 2000b; Freon and Dagorn, 2000) as well as changing school movement and migration patterns (Menard et al. 2000; Josse et al. 1999; Josse, 2000). Tuna associate to or gather so successfully under FADs that the average biomass under them is often observed to be greater than that of free-schooling aggregations (Fonteneau, 1992). Indeed, it has been observed that larger FADs attract larger schools and FADs in the vicinity of other FADs have smaller schools (Bromhead, 2003).

Three types of tuna aggregations have been identified underneath fixed FADs:

- Shallow water schools – comprising of smaller, closely spaced individuals
- Intermediate – larger individuals, sparsely packed individuals
- Deep scattered – large tuna widely scattered

Tuna schools have been reported to remain associated to a particular FAD for up to a year (Takahashi et al., 1988; Hallier and Molina, 2000). There are accounts of skipjack, yellowfin and bigeye tuna remaining associated to bait boats for several months. Of these three species, bigeye is reported to remain associated for the longest periods, and yellowfin for the shortest periods. Present research suggests that the residence time for each species depends on the abundance of prey in the vicinity of the FADs; shorter residence times appear be correlated to low abundance of prey species in surrounding waters (Dagorn *et al.*, 2000). Diet, therefore, plays an important role in the dynamics of FAD associated populations.

ii. Effects upon the feeding behaviour, diet and condition & iii. related effects on natural mortality

There is growing evidence that feeding ecology of tuna associated to FADs differs significantly to that of free-schooling or non-FAD associated tuna. These feeding dynamics can vary further depending on whether tuna are associated to fixed or drifting FADs. Differences between feeding dynamics were found to occur with respect to feeding time and diet composition (Marsac et al, 2000; Menard et al., 2000; Poitier et al., 2001). Drifting FADs may also offer some larger tuna predatory (and cannibalistic) opportunities (Poitier et al., 2001). Diets of tuna caught on fixed FADs comprise a more varied diet, likely to be a result of the other fish species with which they naturally interact under these structures. Table 12 summarises differences in feeding between species within drifting FAD associated and free schools.

Table 12: Observed feeding differences for tuna caught in sets on FAD and free schools (Marsac et al., 2000; Menard et al., 2000b; Poitier et al., 2001).

Drifting FADs	Vs.	Free schooling
FAD associated schools comprised of smaller tuna species (skipjack) and juvenile individuals of larger species (yellowfin and bigeye).		Free-schools tend to be formed by large tuna species (yellowfin, skipjack and bigeye).
85% of tuna stomachs empty.[4]		25% of tuna stomachs empty.
Skipjack tuna associated with FADs reported to have low condition factors.		Free-swimming skipjack reported to have higher condition factors.
Large tunas prey on smaller tuna and juveniles of their own species. Association		Cannibalism has not been reported in

[4] The opposite has been found for fixed FADs (Buckley and Miller, 1994)

Drifting FADs	Vs.	Free schooling
of large tuna to FADs may be motivated by prey availability.		free-schooling tuna
FAD-associated skipjack tends to feed mostly on smaller fish and crustaceans.		n/a

Marsac et al. (2000) compared condition factors between FAD-associated and free swimming schools of skipjack tuna caught north of 5ºN in the eastern Atlantic. Condition factors were calculated as body width as a function of fork length, and were higher for free swimming skipjack than for FAD-associated skipjack (Marsac et al., 2000). Bard (1986) and Menard *et al.* (2000a) have also provided evidence for decreases in the mean weight of skipjack tuna caught around FADs in the Gulf of Guinea since 1991 and Menard *et al.* (2000a) suggested that the lower mean weights could be due to growth overfishing or might reflect a change in growth resulting from residence in warm waters of poor trophic conditions. Menard et al. (2000b) also reported a much higher percentage of small tuna associated with FADS with empty stomachs (85%) than those in free swimming schools (25%). However, these authors also reported more mixed fish species diets for larger tuna in free swimming schools compared to diets of similar sized tuna associated with FADS, which fed exclusively on frigate tuna and skipjack. These observations highlight a potential difference in behavioural drivers of FAD association for different sized/aged tuna, i.e. no trophic function for small FAD associated tunas, while association in larger tuna may reflect predatory behaviour (Menard et al., 2000).

Studies exploring diurnal movement of tuna away from FADs have provided additional information related to foraging patterns in tuna associated with FADs. Observations on tagged bigeye and yellowfin tuna associated with fixed FADs off Hawaii illustrated that the tunas left the FADs at night to forage and spent the daytime tightly associated to the FADs (Holland at al, 1990). Similar observations have been reported for yellowfin and skipjack in other parts of the Pacific (Chabane, 1991; Cillauren, 1994). More recent research in the eastern Pacific has indicated differing vertical movements between tunas associated with fixed and floating objects (Schaefer and Fuller, 2005). All bigeye and skipjack tagged in the study, occupied significantly deeper depths by night than by day, but bigeye depth distributions were deeper (during both the day and night) than skipjack when associated with a moored buoy, and shallower (by day and night) when associated with the drifting vessel (Schaefer and Fuller, 2005). Variations in diurnal vertical movements observed for yellowfin in the northeast Pacific, have been linked with seasonal differences in the deep scattering layer in which the tuna forage (Schaefer et al., 2007).

Further research is clearly required to determine at what scales these observations apply to tuna populations in general. Impacts of FADs on tuna condition might have far reaching effects, with the potential to lead to reduced yield-per-recruit of species such as bigeye and yellowfin (Ariz *et al.*, 1993). Similarly, greater natural mortality due to cannibalism only adds to the potential for recruitment overexploitation caused by catches of juvenile bycatch species. Conversely, research results to date have highlighted differences in behavioural impacts of FADs by species and by size and/ or age within species, and also by the context in which the FADs occur, e.g. fixed or drifting or whether they are positioned inshore or offshore or in networks; providing snapshots of what impacts might be.

iii. The effects upon tuna migration and movements

Evidence that the extensive use of FADs could lead to significant changes in migration patterns of several tuna species and consequently affect its geographical distribution is growing. Opposing theories have, nonetheless, been put forward. The work carried out by

Doray *et al.* (2004) suggested that there is no conclusive evidence of a long-term association of tuna (blackfin) with moored FADs in the western Central Atlantic. Their results show that fish seem to associate to FADs for only a short period of time until attaining a certain size, after which they move on to different areas (Marsac *et al.* 2000). These authors therefore suggest that FADs do not act as an ecological trap for this particular species. Other research has highlighted how the geographical context in which FADs occur can affect the influence they might have on tuna movements at varied spatial scales (Dagorn et al., 2007). Data on the number of FADS at which fishing took place between 2003 and 2006 also illustrates that although large numbers of FAD existed and were deployed during this time, fishing only took place on between 24% and 36% of these (Sarralde et al., 2006), indicating that residence of fish under FADS might be lower than predicted.

4.1.3. Future research/Gaps in current knowledge

Dempster and Taquet's (2004) review of FAD research literature dated between 1978 and 2003, revealed that only 17% tested specific hypotheses or reported the results of manipulative experiments, with the remaining studies being descriptive. The same authors also reported that around 77% of the published work on FADs relates to moored FADs; drifting FADs have received comparatively little attention. Furthermore, the majority of the studies carried out are short (<1yr) to medium-term (1 to 5 yrs). Long-term studies for both drifting and moored FADs typically constituted syntheses of fisheries dependent data on FAD-based fisheries.

Dempster and Taquet (2004) therefore concluded that further research was required utilising manipulative studies, primarily addressing ecological impacts of drifting FADs, despite the associated difficulties in tackling this field. Research into this topic is expensive and extremely time consuming, exceeding by at least one order of magnitude the cost of carrying out similar studies on fixed FADs. However, it is widely recognised within science and industry that the amount of funding directed at research into their impacts on tuna populations is disproportionate to the overall revenues arising from these fisheries. Fishing on drifting FADs produced 1.2 million tons of tuna in 2003 with a market value of over 720 million Euros; mean while only 12% of funding has been directed towards understanding the impacts of drifting FADs (Dempster and Taquet, 2004).

Bromhead et al (2000) also recommended a need for further research into the associative behaviour of juveniles with FADs and research to determine the extent and impacts of ecological traps in tuna populations related to FADs. Very little is known about the underlying evolutionary mechanisms and sensory processes causing attraction of fish to FADs. Detailed physiological studies are required to address this information gap. The great level of uncertainty surrounding the impacts of FADs on migration patterns in tuna emphasises the need for further research in this area, particularly with respect to drifting FADs. Recent developments in tagging and acoustic technology have allowed this area to begin to be addressed and should continue to be developed (see Section 8) making comparisons with behaviour of free-swimming tuna schools.

Additional gaps include the effects of prey availability on the duration of a tunas' association with FADs; the effects of oceanographic variability in tuna schooling behaviour; and differences in ontogenetic and species specific feeding patterns between fish associated with FADs and free-swimming counterparts.

Summary of information outstanding:

1. Underlying sensory processes leading the fish to be attracted to FADs
    a. sound
    b. smell
    c. sensitivity to electro-magnetic field
    d. vision

2. Ecological consequences of tuna aggregations on FADs (e.g. comparison of growth rates and diets of FAD-associated and un-associated tuna by species and size/age; extent of cannibalism in FAD associated tuna; association of juveniles to FADs, etc)
3. Effects of drifting FADs on large-scale migration patterns (utilising tagging, acoustic techniques and remote data collecting)
4. Extent to which drifting FADs are populated by tuna and residence times of associated species where major purse seine fisheries operate
5. Determination of diurnal vertical movements of different species and sizes of tuna under drifting FADS to aid development of more selective fishing methods targeting these structures.
6. Detailed species and size composition data of both catch and discards from drifting FAD fisheries.

4.2. Bycatch (non target species)

4.2.1. Summary of the literature

A summary table of available information of bycatch rates for purse seine tuna fisheries, by ocean area, is included in Table 13.

Table 13: A summary of available information on bycatch rates of tuna purse seine fisheries in 2006 (Total catch refers to the 4 principle species only).

Ocean	Total catch	% PS	FAD		Free	
			% of PS	% Bycatch	% of PS	% Bycatch
Pacific	2,784,281	76.0	62.4	3.45	37.6	0.49
Atlantic	384,273	37.7	**54.6**	1.8	45.4	1.1 – 10.2*
Indian	1,144,376	38.7	75.5	2.7	24.5	0.2

Note: See section 4.2.2 for data sources.
* Note that the higher estimate of 10.2% bycatch on free schools reported by Bannerman (2000) is inconsistent with other observations and may be an outlier related to particular local conditions. This study related to purse seine vessels fishing within Ghanaian waters and they may not be typical of most industrial purse seine vessels. The data is nevertheless reported in this section, but has been excluded from the executive summary.

4.2.1.1. Estimates of bycatch rates

There are currently no publicly available bycatch datasets or databases for RFMOs with competency over tuna fisheries, consequently complete bycatch datasets do not exist for any of the RFMOs in question. However, a number of detailed studies of bycatch levels have been conducted. In the context of this report, the bycatch studies of interest are those that contain estimates of bycatch for purse seine vessels, disaggregated by FAD and free school association. A summary of available information by RFMO is included in Table 13.

Discard rates of non-target species for the Eastern Pacific Ocean are included in IATTC Fishery Status reports for large purse seine vessels. These rates are split between FAD and free school associated sets as well as dolphin associated sets. IATTC Fishery Status report no. 5 (IATTC, 2008a) was used to provide the discard data, in the absence of available bycatch data at the same degree of detail. Species specific discard rates were in general higher for FAD associated sets in comparison to free school associated sets, with the exception of sailfish, manta rays and sting rays.

Bannerman (2000), Gaertner *et al.* (2002) and Chassot *et al.* (2008) are three of the latest attempts to estimate purse seine bycatch in tuna fisheries in the Atlantic Ocean. These three studies rely heavily on observer programs to provide the data required to conduct the analysis. A more detailed description of each paper follows. Bannerman (2000) presents bycatch rates for free school associated purse seine sets during the ICCAT recommended FAD moratorium implemented in Ghana from November 1999 to January 2000. Scientific observers onboard the five participating vessels recorded bycatch quantities. Gaertner *et al.* (2002) estimated billfish bycatch rates of the European purse seine fleet operating in the tropical tuna fishery in the Eastern Atlantic Ocean. Data from 62 observer trips between June 1997 and May 1999 were used in the analysis. The effects of the temporary FAD moratorium adopted by the fleet during the observer program were also analysed. Chassot *et al*. (2008) conducted the most recent attempt at estimating purse seine bycatch in the Atlantic Ocean. Data collected by observers on board French purse seine vessel from 2005 to 2008 were used to estimate species specific bycatch rates for FAD and free school associated sets. The study highlighted the fact that the vast majority of bycatch was retained on board rather than discarded. Two whale sharks were observed to be caught in the purse seine but escaped before the set was hauled. In general, bycatch was observed more frequently and in greater volumes in FAD associated sets compared to free school.

Romanov (2002) and Amandè *et al*. (2008a) are two key sources of bycatch estimates for tuna purse seine fisheries in the Indian Ocean. Romanov (2002) estimated bycatch rates in the Indian Ocean tuna purse seine fishery for FAD and free school associated sets, as well as whale associated sets. Data from scientific observers on board Soviet vessels from 1986 to 1992 were used. The study highlighted the importance of scientific observer programmes in order to provide high quality data with which to analyse the full impact of tuna purse seine fisheries on Indian Ocean ecosystems. Amandè *et al.* (2008a) present bycatch estimates for the European purse seine fishery in the Indian Ocean using data collected through observer programs from 2003 to 2007. Previous studies contained estimates of bycatch rates using data from the same observer programme (*e.g.* Delgado de Molina *et al.*, 2005a). However Amandè *et al.* (2008a) is the first, and currently only, study to estimate bycatch rates using all available observer programme data up until 2007. Bycatch levels per set were approximately 10 times higher for FAD associated sets compared to free school associated sets and approximately 5 times higher including tuna discards. FAD associated bycatch rates for finfish were particularly high in comparison to free school associated sets. The study commented on the large uncertainties associated with the bycatch estimates presented in the paper.

There are no publicly available bycatch estimates for purse seine tuna fisheries in the Western Central Pacific Ocean, disaggregated by FAD and free school association.

4.2.1.2. Management of the impacts of fishing activities on bycatch species

In general FAD associated sets have a greater diversity of bycatch species present and have a greater volume of bycatch compared to free school associated sets (*e.g.* Romanov, 2002; Amandè *et al.*, 2008; Chassot *et al.*, 2008). Finfish and billfish have high discard mortality rates whereas turtles have comparatively low discard mortality rates. However various endangered species of turtles are vulnerable to interactions with fishing gear. There is little information available on seabird bycatch and mortality rates for purse seine vessels split be FAD or free school association.

In general stock assessments are only carried out for bycatch species of purse seine tuna fleets if they are targeted or caught in large amounts in other fisheries *e.g.* swordfish and marlin species caught in longline fisheries. This is mainly due to the lack of data required with which to carry out stock assessments for bycatch species, which correspondingly makes it difficult to accurately quantify the impact of fishing activities on them. Instead, efforts have been made to reduce bycatch rates for species that are deemed vulnerable *e.g.*

turtles, seabirds and sharks. In some instances the at-risk bycatch species have been identified using Ecological Risk Assessments (WCPFC, 2008d).

Summaries, by RFMO, are included below of measures taken and recommendations made to assess and manage the impacts of fishing activities on bycatch species. Note that juvenile tuna catches and tuna discards are dealt with in Section 4.1.1.1.

IATTC have developed a model of the pelagic ecosystem in the Eastern Pacific Ocean to examine the impacts of fishing and environmental factors on middle and upper trophic levels (Olson & Watters, 2003). The model takes in to account discards and landings by fishing gear, with purse seine catches further broken down in to FAD, free school and dolphin associated sets. Striped and blue marlin and swordfish are caught as bycatch in the Eastern Pacific Ocean's tuna purse seine fisheries. IATTC conducts stock assessments on these stocks and can take in to account mortality rates on the species from the purse seine fishery in order to analyse the impact of bycatch on these stocks. Stock assessments of blue shark in the Eastern Pacific have also been undertaken. However there are no stock assessments available for any of the other bycatch species and the IATTC acknowledges that the impacts of fishing on these species are unknown (IATTC, 2008a). IATTC have implemented resolutions to mitigate the impacts on bycatch species (*e.g.* Resolution C-04-07 and C-04-05). There is an emphasis on data collection on bycatch species in order to more fully understand the effects of fishing activities on the species concerned.

ICCAT manage stocks of billfishes (marlin species, sailfish spearfish) and small tunas that can be present as bycatch in the tuna purse seine fishery. Stock assessments are carried out where possible for these species. Management measures have been implemented as a consequence of the stock assessments result (*e.g.* ICCAT Recommendation 02-13 restricting purse seine catches of blue marlin). Recommendations have been made by the Commission for data to be provided on the catches of various bycatch species (*e.g.* sailfish, spearfish). The levels of data available on bycatch species are dependent on the magnitude of catches in most cases, though in some cases the availability of historical catch data is poor or non-existent (*e.g.* some species of small tunas). ICCAT recommendations and resolutions have been implemented on a species specific basis to protect at-risk bycatch species (*e.g.* ICCAT Resolution 2003-11 for turtles).

The IOTC Working Party on Ecosystems and Bycatch has stressed the importance of scientific observer programmes in the provision of quality data required to examine bycatch issues and strongly recommended that IOTC Recommendation 05/07, requiring vessels to carry scientific observers if necessary, be made binding. IOTC resolutions have requested member states and cooperating parties to provide reports on bycatch of seabirds, turtles or other bycatch species to the IOTC secretariat. However to date no official reports have been provided (IOTC, 2008a). The Working party on Ecosystems and Bycatch are also particularly keen for an Ecological Risk Assessment on bycatch monitoring and assessment to be undertaken for the Indian Ocean, a tool which has proven useful at identifying at-risk bycatch species in other RFMOs. Insufficient information is available for reliable stock assessments to be made for any of the bycatch species in Indian Ocean tuna purse seine fisheries.

Stock assessments of various stocks of swordfish and marlin species are undertaken by the Science Committee of the WCPFC (WCPFC, 2008d). Stock assessments of other bycatch species are not carried out. The Scientific Committee recognised the importance of the Ecological Risk Assessment in identifying at-risk bycatch species. Furthermore, the Scientific Committee recommends that further research be undertaken on these bycatch species. Shark, turtle and seabird bycatch rate information was provided to the Scientific Committee in 11, 7 and 7 part I annual reports respectively, out of a total 26 reports received by the Scientific Committee.

4.2.2. Bycatch quantification

There are currently no publicly available bycatch datasets or databases for RFMOs with competency over tuna fisheries, consequently complete bycatch datasets do not exist for any of the RFMOs in question. However, a number of studies of bycatch levels for particular fleet segments do exist and for each ocean region there are estimates available for bycatch for purse seine sets on both FAD and free school associated schools.

Estimates of bycatch rates and volumes for purse seine vessels were calculated for the Atlantic, Indian and Pacific Oceans, split by FAD and free school associated sets. Best estimates of bycatch rates were obtained using available information and applied to 2006 purse seine catches, the most recent year where purse seine catches and FAD and free school associated set percentages are currently available.

Species, or species group specific bycatch rates are expressed as the weight in tonnes of bycatch per tonne of total tuna catch. An exception to this is for turtles where bycatch rates are sometimes presented as the number of individuals caught as bycatch per tonne of total tuna catch. Purse seine catches by species in 2006 were taken from official catch statistics for each of the ocean areas (Table 14, Table 19 and Table 25). Available information on the percentage of purse seine catch attributable to FAD and free school associated sets, by species, was used to disaggregate the total purse seine catches into FAD and free school associated catches. Known FAD and free school catch ratios for a particular ocean area and species, were applied for instances where portions of the purse seine catch were not known to be attributable to FAD or free schools through a lack of available information (Table 15, Table 20 and Table 26). The estimated ocean and species specific bycatch rates for FAD and free school associated purse seine sets are then raised by the estimated total FAD or free school purse seine catch in 2006 for the ocean area in question, giving the estimated bycatch volume in tonnes. The bycatch rates and volumes for different species groups are summarised in Table 16,
Table 21, Table 27, Table 28.

FAD/free school associated purse seine set data and discard data for the Eastern Pacific Ocean were assumed to be indicative for the Pacific Ocean as a whole in the absence of available information for the Western Pacific Ocean. Discard data for 2006 presented in IATTC Fishery Status Report No. 5 (IATTC, 2008a) was used instead of discard data for 2007 available in IATTC Fishery Status Report No. 6 (IATTC, 2008b) to maintain consistency with the usage of 2006 catch data.

It is important to note that bycatch and discard rates do not necessarily correspond to mortality rates for all species groups. Bycatch can often be retained on board for sale if financially viable or used for food for the crew of the fishing vessel. Amandè *et al.* (2008a) calculated that 7% and 33% of billfish and ray bycatch, respectively, is discarded alive and more than 90% of fish bycatch by number is discarded dead. In contrast 90% of turtle bycatch are discarded alive.

4.2.2.1. Pacific Ocean

Table 14: Total catch and purse seine catch for the main tuna species in the Pacific Ocean in 2006, with the percentage of purse seine catch attributable to FAD, free school and unknown associated sets.

Species	% FAD	% FREE	% Unknown	Purse Seine (t)	All Gears (t)
Skipjack tuna	63	35	2	1,628,010	1,860,117
Yellowfin tuna	21	25	53	389,779	581,074
Bigeye tuna	98	2	0	98,419	217,569
Albacore	na	na	na	0	125,521
Others	na	na	na	na	na

Source: IATTC (2008a) used to calculate % FAD and %Free of purse seine catches. WCPFC (2007b) used to calculate the catch figures.
Note: It is assumed that the FAD/free percentages taken from IATTC (2008a) for the Eastern Pacific Ocean are indicative of those for the Pacific Ocean as a whole.

Table 15: Total Pacific Ocean Purse Seine catch in 2006 by species and FAD or free school associated sets assuming the 'unknown' portion has the same FAD/free school proportions as the known catches.

Species	FAD	FREE	Total
Skipjack tuna	1045293.8	582716.2	**1628010.0**
Yellowfin tuna	179128.7	210650.3	**389779.0**
Bigeye tuna	96164.3	2254.7	**98419.0**
Albacore	na	na	**0**
Others	na	na	**na**
TOTAL	**1320586.8**	**795621.2**	**2116208.0**

Source: IATTC (2008a) used to calculate % FAD and %Free of purse seine catches. WCPFC (2007b) used to calculate the catch figures.
Note: It is assumed that the FAD/free percentages taken from IATTC (2008a) for the Eastern Pacific Ocean are indicative of those for the Pacific Ocean as a whole.

Table 16: Summary estimates of discard rates and estimated volumes (tonnes) in 2006 in the Pacific Ocean for purse seiners, separated by FAD and free school associated sets.

Species	Estimated raised total bycatch (mt)			Bycatch as a proportion of the total landed catch from:	
	FAD	FREE	TOTAL	FAD	FREE
Other fish	43510.2	3480.6	**46991**	3.29%	0.44%
Sharks and rays	2022.5	379.4	**2402**	0.15%	0.05%
Turtles (mortality)*	25.2	5.5	**31**	0.00%	0.00%
Birds	na	na	**na**	na	na
Marine Mammals	na	na	**na**	na	na
Total**	**45532.7**	**3860.0**	**49392.7**	**3.45%**	**0.49%**

Source: Bycatch data taken from IATTC (2008a). This data for the Eastern Pacific Ocean is assumed to be indicative of bycatch rates for the Pacific Ocean.
* Turtle bycatch rates and volumes are numbers of individuals.
** Totals excluding turtle bycatch.

Table 17: Discard rates and estimated volumes (tonnes) for free school associated purse seine sets in the Pacific Ocean.

Species Group	Percentage by Weight	Raised to Pacific Ocean 2006 catches
PS Catch 2006 (mt)	Free school	795621
Other fish	Billfish = 0.00738 %	58.8
	Unidentified tunas = 0.226 %	1801.0
	Frigate fish and bullet tuna = 0.121 %	959.2
	Other fish = 0.0832 %	661.6
Sharks and rays	Aggregated species = 0.0397 %	315.5
	Rays = 0.00803 %	63.9
Turtles (mortality)*	Aggregated species = 0.00069 %	5.5
Birds	na	na
Marine Mammals	na	na
Total**	**Total = 0.49%**	**3860.0**

Source: IATTC (2008a). This data, for the Eastern Pacific Ocean, is assumed to be applicable for the Western Pacific Ocean.
* Turtle bycatch rates and volumes are numbers of individuals.
** Totals excluding turtle bycatch.

Table 18: Discard rates and estimated volumes (tonnes) for FAD associated purse seine sets in the Pacific Ocean.

Species Group	Percentage by Weight	Raised to Pacific Ocean 2006 catches
PS Catch 2006 (mt)	FAD	1320587
Other fish	Billfish = 0.0494 %	653.0
	Unidentified tunas = 2.405 %	31756.5
	Frigate fish and bullet tuna = 0.204 %	2698.8
	Other fish = 0.636 %	8401.8
Sharks and rays	Aggregated species = 0.153 %	2016.2
	Rays = 0.000482 %	6.4
Turtles (mortality)*	Aggregated species = 0.00191%	25.2
Birds	na	na
Marine Mammals	na	na
Total**	**Total = 3.45%**	**45532.7**

Source: IATTC (2008a). This data, for the Eastern Pacific Ocean, is assumed to be applicable for the Western Pacific Ocean.
* Turtle bycatch rates and volumes are numbers of individuals.
** Totals excluding turtle bycatch.

4.2.2.2. *Atlantic Ocean*

Table 19: Total catch and purse seine catch for the main tuna species in the Atlantic Ocean in 2006, with the percentage of purse seine catch attributable to FAD, free school and unknown associated sets.

Species	% FAD	% FREE	% Unknown	Purse Seine (t)	All Gears (t)
Skipjack tuna	64.2	10.7	25.1	71215	142177
Yellowfin tuna	17.7	67.2	15.2	62761	108087
Bigeye tuna	41.6	26.9	31.5	16457	66575
Albacore	0.0	14.8	85.2	3432	67434
Others	0.0	11.2	88.8	20356	78408

Source: ICCAT CATDIS database used to calculate % FAD and %Free of purse seine catches. ICCAT nominal catch database provided catch statistics.

Table 20: Total Atlantic Ocean Purse Seine catch in 2006 by species and FAD or free school associated sets assuming the 'unknown' portion has the same FAD/free school proportions as the known catches.

Species	FAD	FREE	Total
Skipjack tuna	61028.2	10186.4	**71214.6**
Yellowfin tuna	13061.6	49699.5	**62761.1**
Bigeye tuna	10001.1	6456.2	**16457.3**
Albacore	6.6	3425.3	**3431.9**
Others	0.0	203.6	**203.6**
TOTAL	**84097.5**	**69970.9**	**154068.4**

Source: ICCAT CATDIS database used to calculate % FAD and %Free of purse seine catches. ICCAT nominal catch database provided catch statistics.

Table 21: Summary estimates of bycatch rates and estimated volumes (tonnes) in 2006 in the Atlantic Ocean for purse seiners, separated by FAD and free school associated sets.

Species	Estimated raised total bycatch (mt)					Bycatch as a proportion of the total landed catch		
	FAD[1]	FREE[1]	FREE[2]	TOTAL[1]	TOTAL[1,2]	FAD[1]	FREE[1]	FREE[2]
Other fish	988.9	311.0	7004.1	**1300**	**7993.0**	1.2%	0.4%	10.0%
Sharks and rays	505.8	444.5	98.0	**950**	**603.8**	0.6%	0.6%	0.1%
Turtles	4.4	6.7	0.1	**11**	**4.6**	0.0%	0.0%	0.0%
Birds	na	na	na	**na**	**na**	0.0%	0.0%	na
Marine Mammals	0.0	0.0	na	**0**	**na**	0.0%	0.0%	na
Total	**1494.7**	**755.5**	**7102.1**	**2250.3**	**8596.8**	**1.8%**	**1.1%**	**10.2%**

Source: [1] Chassot *et al.* (2008)
[2] Bannerman (2000)

* Bycatch rates and volumes are numbers of individuals.

** Totals excluding turtle bycatch.

Table 22: Bycatch rates and estimated volumes (tonnes) for free-school associated purse seine sets in the Atlantic Ocean in 2006.

Species Group	Percentage by Weight	Raised to Atlantic Ocean 2006 catches (t)
PS catch 2006	Free school	69971
Other fish	Rainbow runner = 4.50%	3149
	Kingfish = 1.91%	1336
	Dolphin fish = 2.06%	1441
	Black Triggerfish = 0.28%	196
	Blue runner = 0.28%	196
	Ocean sunfish = 0.03%	21
	Blue marlin = 0.20%	140
	Black marlin = 0.14%	98
	Cotton mouth jack = 0.08%	56
	Guinean amberjack = 0.36%	252
	Atlantic sailfish = 0.17%	119
Sharks and rays	Aggregated shark species = 0.06%	42
	Atlantic manta = 0.08%	56
Turtles	Aggregated species = <0.01%	0
Birds	na	na
Marine Mammals	na	na
Total	**Total = 10.24%**	**7102**

Source: Bannerman (2000)

Table 23: Bycatch rates and estimated volumes (tonnes) for free-school associated purse seine sets in the Atlantic Ocean in 2006.

Species Group	Percentage by Weight	Raised to Atlantic Ocean 2006 catches (t)
PS catch 2006	Free school	69971
Other fish	Acanthocybium solandri <0.01%	0.8
	Balistes capriscus =<0.01%	4.2
	Canthidermis maculatus =<0.01%	2.1
	Coryphaena hippurus = <0.01%	2.4
	Diodon hystrix = <0.01%	0.1
	Elagatis bipinnulata = <0.01%	2.1
	Lagocephalus lagocephalus = <0.01%	0.1
	Mola mola = 0.02%	12.0
	Ranzania laevis = <0.01%	0.0
	Istiophorus albicans = 0.39%	270.3
	Makaira nigricans = 0.02%	12.5
	Unidentified billfish = 0.01%	4.2
Sharks and rays	Dasyatis violacea = <0.01%	0.0
	Mobula mobula = 0.03%	0.2
	Rhincodion typus = 0.60%	4.2
	Sphyrna zygaena = <0.01%	0.0
Turtles*	Chelonia mydas = <0.01%	0.0
	Lepidochelys kempii = <0.01%	0.0
	Lepidochelys olivacea = <0.01%	0.0
	Unidentified turtles = <0.01%	0.0
Birds	na	na
Marine Mammals	none recorded	0
Total**	**Total = 1.08%**	**315.5**

Source: Chassot *et al.* (2008)
* Turtle bycatch rates and volumes are numbers of individuals.
** Totals excluding turtle bycatch.

Table 24: Bycatch rates and estimated volumes (tonnes) for FAD associated purse seine sets in the Atlantic Ocean.

Species Group	Percentage by Weight	Raised to Atlantic Ocean 2006 catches (t)
PS catch 2006	FAD	84097
Other fish	Acanthocybium solandri = 0.21%	178.7
	Aluterus monoceros = <0.01%	0.6
	Balistes capriscus = 0.06%	53.5
	Balistes punctatus = 0.09%	74.7
	Balistidae sp. = <0.01%	0.1
	Canthidermis maculatus = 0.02%	19.4
	Caranx crysos = <0.01%	1.1
	Coryphaena hippurus = 0.06%	53.5
	Echeneidae sp. = <0.01%	0.1
	Elagatis bipinnulata = 0.46%	383.9
	Kyphosus sectator = <0.01%	0.8
	Kyphosus sp. = <0.01%	0.5
	Lobotes surinamensis = 0.04%	35.0
	Mola mola = <0.01%	1.4
	Sphyraena barracuda = 0.03%	26.4
	Uraspis secunda = 0.05%	46.0
	Istiophorus albicans = 0.03%	25.6
	Makaira indica = 0.01%	9.2
	Makaira nigricans = 0.09%	78.6
Sharks and rays	Carcharhinus falciformis = 0.03%	25.2
	Carcharhinus longimanus = 0.01%	4.8
	Manta birostris = 0.01%	9.2
	Rhincodion typus = 0.55%	459.8
	Sphyrna zygaena = <0.01%	2.2
	Unidentified sharks = 0.01%	4.6
Turtles*	Chelonia mydas = <0.01%	1.1
	Lepidochelys kempii = <0.01%	2.1
	Lepidochelys olivacea = <0.01%	1.1
Birds	na	na
Marine Mammals	none observed	0.0
Total**	**Total = 1.78%**	**1494.7**

Source: Chassot et al. (2008).
* Turtle bycatch rates and volumes are numbers of individuals.
** Totals excluding turtle bycatch.

4.2.2.3. Indian Ocean

Table 25: Total catch and purse seine catch for the main tuna species in the Indian Ocean in 2006, with the percentage of purse seine catch attributable to FAD, free school and unknown associated sets.

Species	% FAD	% FREE	% Unknown	Purse Seine (t)	All Gears (t)
Skipjack tuna	85.9	14.1	0.0	258,582	605,979
Yellowfin tuna	46.3	53.7	0.0	160,113	402,234
Bigeye tuna	73.5	26.5	0.0	24,888	112,097
Albacore	89.6	10.4	0.0	1,548	24,066
Others	4.5	0.3	95.2	110,794	292,228

Source: IOTC catch and effort database used to calculate % FAD and %Free of purse seine catches. IOTC nominal catch database used to calculate the catch figures.

Table 26: Total Indian Ocean Purse Seine catch in 2006 by species and FAD or free school associated sets assuming the 'unknown' portion has the same FAD/free school proportions as the known catches.

Species	FAD	FREE	Total
Skipjack tuna	222033.7	36548.4	**258582.0**
Yellowfin tuna	74121.0	85991.8	**160112.9**
Bigeye tuna	18303.5	6584.5	**24888.0**
Albacore	1387.0	160.8	**1547.8**
Others	103601.7	7192.0	**110793.7**
TOTAL	**419446.9**	**136477.5**	**555924.4**

Source: IOTC catch and effort database used to calculate % FAD and %Free of purse seine catches. IOTC nominal catch database used to calculate the catch figures.

Table 27: Summary estimates of bycatch rates and estimated volumes (tonnes) in 2006 in the Indian Ocean for purse seiners, separated by FAD and free school associated sets.

Species	Estimated raised total bycatch (mt)			Bycatch as a proportion of the total landed catch from:	
	FAD	**FREE**	**TOTAL**	**FAD**	**FREE**
Other fish	8556.7	259.3	**8816**	2.0%	0.2%
Sharks and rays	2600.6	68.2	**2669**	0.6%	0.1%
Turtles	na	na	**na**	na	na
Birds	na	na	**na**	na	na
Marine Mammals	na	na	**na**	na	na
Total	**11157.3**	**327.5**	**11484.8**	**2.7%**	**0.2%**

Source: Amandè *et al.* (2008a).

Table 28: Summary estimates of bycatch rates and estimated volumes (tonnes) in 2006 in the Indian Ocean for purse seiners, separated by FAD and free school associated sets.

Species	Estimated raised total bycatch (mt)			Bycatch as a proportion of the total landed catch from:	
	FAD	**FREE**	**TOTAL**	**FAD**	**FREE**
Other fish	12978.1	133.2	**13111**	3.1%	0.10%
Sharks and rays	3948.7	330.8	**4279**	0.9%	0.24%
Turtles	10.5	0.0	**10**	0.0%	0.00%
Birds	0	0	**0**	0	0
Marine Mammals	na	na	**na**	na	na
Other bycatch	401.8	0.3	**402**	0.1%	0.00%
Total	**17328.6**	**464.3**	**17792.9**	**4.13%**	**0.34%**

Source: Romanov (2002).

Table 29: Bycatch rates and estimated volumes (tonnes) for free school associated purse seine sets in the Indian Ocean.

Species Group	Percentage by Weight	Raised to Indian Ocean 2006 catches
PS Catch 2006 (mt)	Free school	136478
Other fish	Aggregated species = 0.19%	259.3
Sharks and rays	Aggregated species = 0.05%	68.2
Turtles	na	na
Birds	na	na
Marine Mammals	na	na
Total	**Total = 0.24%**	**327.5**

Source: Amandè *et al.* (2008a).

Table 30: Bycatch rates and estimated volumes (tonnes) for FAD associated purse seine sets in the Indian Ocean.

Species Group	Percentage by Weight	Raised to Indian Ocean 2006 catches
PS Catch 2006 (mt)	FAD	419447
Other fish	Aggregated species = 2.04%	8556.7
Sharks and rays	Aggregated species = 0.62%	2600.6
Turtles	na	na
Birds	na	na
Marine Mammals	na	na
Total	**Total = 2.66%**	**11157.3**

Source: Amandè *et al.* (2008a).

Table 31: Bycatch rates and estimated volumes (tonnes) for free school associated purse seine sets in the Indian Ocean.

Species Group	Percentage by Weight	Raised to Indian Ocean 2006 catches
PS Catch 2006 (mt)	Free school	136478
Other fish	Billfish = 0.090%	122.1
	Rainbow Runner = 0.005%	7.4
	Dolphinfish = 0.003%	3.7
Sharks and rays	Sharks = 0.130%	176.9
	Mantas and mobulas = 0.113%	153.9
Sea turtles	Sea turtles = 0.000%	0.0
Birds	None recorded	0.0
Marine mammals	na	na
Other bycatch	Other bycatch = 0.000%	0.3
Total	**Total = 0.34%**	**464.3**

Source: Romanov (2002).

Table 32: Bycatch rates and estimated volumes (tonnes) for FAD associated purse seine sets in the Indian Ocean.

Species Group	Percentage by Weight	Raised to Indian Ocean 2006 catches
PS Catch 2006 (mt)	FAD	419447
Other fish	Billfish = 0.101%	422.8
	Wahoo = 0.162%	679.9
	Rainbow Runner = 1.031%	4326.2
	Dolphinfish = 1.010%	4235.6
	Barracuda = 0.013%	55.4
	Triggerfish = 0.728%	3052.3
	Mackerel scad = 0.049%	205.9
Sharks and rays	Sharks = 0.929%	3895.8
	Mantas and mobulas = 0.013%	52.9
Sea turtles	Sea turtles = 0.003%	10.5
Birds	None recorded	0.0
Marine mammals	na	na
Other bycatch	Other bycatch = 0.096%	401.8
Total	**Total = 4.13%**	**17328.6**

Source: Romanov (2002).

4.2.3. Gaps in knowledge on bycatch

There are a variety of studies available providing bycatch estimates of purse seine vessels operating in tuna fisheries, split by FAD and free school associated sets, covering the majority of the worlds ocean. However there is large uncertainty in the estimates. More bycatch data is required in order to increase the levels of information available and reduce the uncertainty in bycatch estimates. Various RFMOs have requested bycatch reports at a national level from member states and cooperating parties, however in general little has been provided, if any at all. The levels of data provided could be greatly increased if the provision of such data was made mandatory. Additionally, the impacts of FAD and free school associated purse seine fishing on bycatch species has not been quantitatively analysed for the majority of bycatch species across the globe. This is primarily due to insufficient information being available to conduct stock assessments. Stock assessments and models are vital in examining the status of bycatch stocks and the impacts of FAD and free school associated purse seine fishing upon them, but require detailed understanding of the bycatch species and catches. Ecological Risk Assessments have proved a useful tool in identifying at-risk bycatch species in tuna fisheries and are likely to do so for RFMOs that have not yet carried out such an assessment, data permitting. Ecosystem approaches to modelling have been used by the IATTC to examine the impacts of fishing on middle and upper trophic level species and the collection of more data should help calibrate the models parameters. Thus it is clear that more data on bycatch species and associated catch rates is required to fully appreciate the impacts of purse seine fishing on FADS. This information has usually been provided by scientific observer programmes.

5. Effect of FADs on stock assessment

As described in previous sections of this report, the expanding use of FADs in the tuna purse seine fisheries of the world has led to dramatically increased catches of skipjack, yellowfin and bigeye. This increased pressure on exploited populations makes it important that stock assessment scientists are able to accurately reconstruct biodynamics of a particular fishery, so as to inform management. Unfortunately the changing technological face of the fishery (including the widespread deployment of FADs) has made stock assessment increasingly problematic. Here we outline the reasons for this, alongside a description of current methods used by each RFMO, and their limitations.

Table 33. Summary table of assessment problems including those associated with the use of FADs

Data limitations	***Problem***	***RFMO's affected***
Species composition of catches	Species split of catches from the Purse seine fleet are estimated from port sampling and observer programs. This is an uncertain process that is becoming increasingly important since the catches of bigeye and yellowfin by purse seine fleets has increased through the use of FADs.	This is particular problem for the WCPFC/SPC, since catch sampling coverage is less comprehensive.
Catch rate	Changes in effective fishing effort through the introduction of FADs have led to the undermining of CPUE as an index of abundance.	This is a generic problem for all RFMO's.
Spatial considerations	Changes in the spatial distribution of effort as a result of FAD use has undermined the reliability of catch rate as an index of abundance and assumptions of a continuous biologically homogeneous stock that underpin assessments.	This is a generic problem for all RFMO's.
Population modelling	***Problem***	***RFMO's affected***
Growth	This is an important parameter that has proved difficult to estimate due to the lack of suitable data, particularly for skipjack. The use of FADs has introduced additional problems by allowing the fishing of spatially disaggregated populations with potentially different growth parameters. FADs may also have	This is a generic problem for all RFMO's.

	undermined estimation of the growth curve from tagging data due to the introduction of changing selectivity patterns.	
Natural mortality	This is an important parameter that has proved difficult to estimate due to the lack of suitable tagging data. The use of FADs has not contributed to this problem.	No direct estimates have been attempted by the IATTC or ICCAT. Reliable estimates have been obtained by the SPC and suitable data may allow similar estimates from the IOTC.
Indicators and reference points	Reference points output by the assessment have become increasingly uncertain as assessments have been undermined by FAD use. Thus management advice has also become increasingly uncertain.	This is a generic problem for all RFMO's.

5.1. Species composition of catches

The tropical tunas are primarily caught by three different gear types, namely longline, pole-and-line (also known as baitboat, in the Atlantic) and purse-seine. Purse-seine fleets set on free-schools, artificial FADs or other floating material. Pole and line fleets mainly set on free-schools. In the Atlantic baitboats sometime set on FADs, use the vessel itself as an aggregating device, and act as a FAD for purse-seine vessels [ICCAT SCRS-2008-016]. Each of these gear types target different species. Specifically, the longlines target large yellowfin and bigeye, whilst the purse-seine and pole-and-line fleets tend to target skipjack and yellowfin. Adult yellowfin and bigeye usually school as a single species and are easily distinguished. Thus catches of these species are recorded separately by the longline fleets. The purse-seine and pole-and-line fleets on the other hand, although they do target single species schools of yellowfin, can catch a mixture of all three species when setting on FADs. Due to their difference in commercial value, skipjack and yellowfin are generally distinguished in such catches. However small yellowfin and bigeye destined for the canneries have the same market value [Lawson, 2003, SCTB16-SWG6] and are thus not distinguished in purse-seine logbooks. It is therefore necessary to estimate the species split of catches using observer [Lawson, 2003, SCTB16-SWG6] or port sampling records [e.g. Tomlinson, 2002, IATTC SAR2]. This empirical data is used to estimate the species split by time, area and fishery. Total catches from each time/area/fishery strata are then used to estimate the total catch per species. For yellowfin and bigeye, juvenile catches are an important component of fishing mortality that needs to be included in the stock assessment, with major implications for the predicted state of the stock.

Species composition data are collected from Purse seiners in the Atlantic, Indian and Eastern Pacific Oceans through comprehensive port sampling programmes. In contrast, for fleets in the Western and Central Pacific Ocean, data is generally collected on an opportunistic basis through observer and port sampling programmes. Port sampling in this region was found to substantially underestimate the proportion of yellowfin and bigeye in the catch, so that precedence should be given to observer sampling data [Lawson, 2008, WCPFC-SC4-2008/ST-WP-3]. Whether such biases exist in the port sampling schemes for other oceans has yet to be evaluated, although it has been discounted as a major uncertainty in the Atlantic [Fonteneau, 2008, ICCAT SCRS/2008/162]. Nevertheless the precision of the catch estimation procedure remains a major source of uncertainty, given the spatial and technological dynamics of the fishery. This includes the introduction of FADs, which have changed the species composition of purse seine catches [Fonteneau, 2000, IOTC WPTT-00-15].

5.2. Catch rate

The catch rate is an important index of abundance for most of the tuna fisheries, however it is notoriously unreliable. This is particularly the case for the purse-seine and pole-and-line fisheries that provide catch rate data on skipjack. They rarely provide catch rate indices for yellowfin and bigeye, with some assessments done by ICCAT [e.g. ICCAT CVSP 56(2): 443-527, 2004; ICCAT CVSP 62(1): 97-239] and the IATTC [e.g. Maunder and Watters, 2001, IATTC SAR1] being the exception. This is despite the fact that purse-seines are often responsible for a substantial proportion of the yellowfin catch [e.g. Western central Pacific Ocean purse-seine review 2006].

In both the purse-seine and pole-and-line fisheries the increasing number and technological advancement of FADs has increased the vulnerability of skipjack schools in the world's oceans. Over 90% of purse seine sets on FADs are successful, compared to only 50% of sets on free-schools [Fonteneau, 2000, IOTC WPTT-00-15]. The FAD fishery has also led to marked changes in the spatial distribution of fishing. For example, FADs have led to an expansion of the West African purse-seine fishery across the Atlantic [ICCAT,1999, SCRS/99/21], and allowed establishment of a viable purse-seine skipjack fishery in the Eastern regions of the Western central Pacific Ocean [Langley, 2004, SPC SCTB17 SA-5]. Such spatial changes will have a marked impact on catch rates that have proven difficult to accommodate in stock assessment models.

Changing catchability prevents the catch rate being used as an index of abundance, unless it can be modelled through a process of 'standardisation'. Standardisation aims to extract a biomass abundance index by removing the effect of changing catchability on the catch rate. The essential problem is how to measure the effective fishing effort exerted by a particular fishery (i.e. an effort measure which is proportional to fishing mortality). Effective effort is likely to be increasing even if nominal effort is constant, due in part to the technological and spatial changes referred to above. The nominal catch rate will thus also increase, giving the misleading impression of an increasing biomass density.

For the purse-seine fishery, effort can be measured as search time, which has traditionally been spent searching at random for schooling aggregations of fish. However, search time could now refer to time devoted to random search and encounter of free-school and time devoted to targeting beacon tracked FADs. Unfortunately purse-seine logbooks rarely distinguish between the two types of effort. Thus fisheries scientists, attempting to come up with other more appropriate indices of local abundance, have suggested the catch-per-set on FADs, or the catch-per-areal unit fished, which attempt to account for technological and spatial changes to the fishery respectively. These have been used as indicators of skipjack stock status by ICCAT [ICCAT SCRS-99-21; ICCAT CVSP 62(2):2008] and the SPC [Langley, 2004, SPC SCTB17 SA-5]. The need to account for the use of FADs is the more pressing issue, but the problem with using the catch-per-set is that the number of FADs deployed in a particular area will influence the expected catch: the number of tuna under each FAD will decrease as the number of FADs increases (for a given biomass per area) [Fonteneau, 2000, IOTC-WPTT-00-15]. This problem has barred the widespread use of catch per set as an indicator of abundance and led to the development of more complicated measures of effective effort [e.g. Watters and Maunder, 2001, IATTC SAR1], with an increased dependence on data quality.

FADs themselves are not identical and there is very little technical documentation on the drifting FADs used by seiners. They are generally deployed and financed by the fishermen themselves, and a degree of secrecy surrounding FAD 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, 2000, IOTC-WPTT-00-15]. Other technologies increasingly being adopted and used include bird radar, sonar, echo-sounders, more powerful winches and larger nets, all of which would need to be accounted for during standardisation. In reality, the effective fishing effort is increasing in a way that is difficult to quantify.

Behavioural changes adopted by fishing fleets can also complicate standardisation. In the West African and Maldivian skipjack fisheries, the baitboat fleets also use FADs. In West Africa they cooperate with the purse-seine fishery by themselves aggregating fish on which the purse-seine can set. Both the purse-seine and baitboat fleets also use supply vessels. These can not only help to deploy FADs but allow fishing vessels to exert greater effort searching for and catching fish. For baitboat fisheries, the use of supply vessels can allow particular boats to remain with a single aggregation of fish for the entire season, routinely offloading catch to the supply vessel. Finally, the purse-seine and baitboat fleets can target either skipjack (by setting on FADs) or yellowfin (by setting on free-schools). Since both species are caught by both fishing practices with different likely yields, the catch rate will depend on which species is being targeted. Thus, the relative market value of these two species is an important influence on their catch rates [Fonteneau 2003, IOTC-WPTT-03-02].

Economics is also an important consideration for data from the longline fleets, the majority of which now target bigeye, due to its higher commercial value. The catch rate data from the longline fleet is generally considered to be more reliable. Although they have also achieved substantial technological advancements, these are less than the changes introduced by FADs in the purse-seine fishery. Furthermore, there is generally less ambiguity concerning the species split of catch.

The longline catch rate data provide a valuable index for assessment of the worlds yellowfin and bigeye stocks. Unfortunately similar data from purse-seine and baitboat fleets, however reliable, has proven extremely difficult to utilise, primarily due to the technological changes described above. If appropriate standardisation methods were devised it could provide valuable information for a skipjack stock assessment and, perhaps more importantly, an index of abundance for the smaller yellowfin and bigeye also being caught.

5.3. Spatial considerations

As noted above, spatial changes have been facilitated by the use of FADS which have opened new oceanic fishing zones for skipjack (notably the central Atlantic and Pacific Oceans). These are likely to have important implications for the catch rates reported by a particular fishery. However there are also spatially dependent biological parameters that can cause problems for tuna stock assessments. Skipjack for example have a highly variable and environmentally dependent growth rate, which varies spatially and has proven extremely difficult to estimate with any certainty. This can make stock assessment difficult, particularly if the model is attempting to integrate over an entire ocean, which may contain multiple sub-populations with different growth rates. This spatial variation has undermined attempts to build reliable stock assessment models of skipjack by the ICCAT and IOTC. A similar problem exists for the larger and more valuable tuna species (yellowfin and bigeye). However these are more mobile with recruitment and growth that is less dependent on environmental conditions, facilitating the construction of representative stock assessment models.

5.4. Stock assessment models

A variety of models have been applied to assess the status of tropical tuna stocks in the Atlantic, Pacific and Indian Oceans. These can broadly be divided into cohort-based and biomass production models. The biomass production models (e.g. the Pella-Tomlinson model [IATTC Bulletin, Vol. 13, No. 3, 1969]) consider the overall intrinsic growth of the population as a function of its total biomass. The simplicity of these models is useful in that they are easy to implement, have low data requirements and produce credible results [e.g. Sibert, 2004, SPC SCTB17 MWG-4]. They are easily fitted to catch rate and/or tag data (providing it is internally consistent, see [Hillary, 2007, IOTC-WPTT-2007-27]), although usually require some prior information on the intrinsic growth rate.

Cohort-based analysis is so-called because it tracks the movement of age- or length-based cohorts as they progress through the population. Such models applied to tuna are universally age-based, which provides a more intuitive framework for model development. The advantage of these models is that they allow estimation of mortality, from the proportion of individuals that survive from one cohort to the next, as well as trends in abundance. Fishing and natural mortality, and the balance between the two, are key parameters used to describe the status of the stock.

Two approaches to estimation are commonly taken, namely Virtual Population Analysis (VPA) and Statistical Catch-at-Age Analysis (SCAA), both of which make use of catch-at-age data and trends in abundance indices. Three important differences distinguish the two approaches. First, VPA makes the assumption that observed data are exact (i.e. with negligible error) and second, it requires the catch-at-age data to be available for all the years covered by the assessment. This places limitations on the time frame over which populations can be assessed and does not allow a formal statistical treatment of observation errors in the data. SCAA is not only more robust statistically but it does not require that catch-at-age data are available for every year covered by the assessment. For both these reasons it can therefore be more inclusive in its data requirements. Third, VPA does not incorporate a stock-recruitment relationship. Instead, a stock-recruitment curve is fitted using regression methods to the output of the VPA (estimated number of recruits per cohort), and then used to predict future recruitment. SCAA methods on the other hand allow estimation of the stock-recruitment curve within the model framework in a statistically consistent manner. This is not only a more coherent approach but importantly facilitates estimation of temporal deviations in recruitment that can have important implications for predicting how the population will respond to future management measures.

To fit SCAA and VPA models information is required on catch-at-age. The predicted catch-at-age can then be fitted directly to observed values. This approach has been implemented, for example, in SCAA assessments of bigeye [Hillary, 2006, IOTC-2006-WPTT-15] and yellowfin [Nishida, 2007, IOTC-2007-WPTT-12] by the IOTC. Since only the length of fish caught is usually recorded, empirical data on catch-at-age are themselves estimated quantities. In species for which age data are directly available (in yellowfin and bigeye, but not skipjack, age can be measured from seasonal depositions in hard body parts such as otoliths) an empirical age-length matrix can be used to convert catch-at-length to catch-at-age. However an alternative approach is to use the growth curve, estimated either within the stock assessment model itself or as a separate analysis. This can be used to predict the length distribution for a given age cohort, catches from which can then be fitted to observed length-frequency data within a statistical catch-at-length (SCAL) model.

5.4.1. Growth

Growth is of central importance to assessments in predicting the biomass of the stock. The growth curve can be estimated from otolith and tagging data, and also by tracking identifiable cohorts of fish from modes in the length-frequency data of a SCAL model. In the SPC and IATTC, where SCAL models are routinely used, a variety of approaches have been adopted. In SPC assessments of yellowfin for example, the growth curve was previously estimated directly from tagging and otolith data [Lehodey, 1999, SPC SCBT99 WPYFT-2]. However it is currently estimated within MULTIFAN-CL [Hampton, 2004, SPC SCTB17 SA-1]. In the Eastern Pacific Ocean, the growth curve estimated from otoliths and tagging data provide a prior, with the growth curve itself estimated as a set of parameters within the yellowfin and bigeye stock assessments [Da Silva, 2007, IATTC SAR8; Maunder, 2007, IATTC SAR8]. However for all these models, growth represents one of the primary uncertainties, particularly for skipjack. This is partly due to spatial heterogeneities that result from variability in environmental conditions, and which undermine assumptions of homogeneous growth across a particular ocean. In IOTC assessments of skipjack for example, growth is estimated from tagging studies conducted in the Maldivian fishery. Whether this is valid for the entire Indian Ocean population is unclear. In the Atlantic such heterogeneities have undermined the fitting of an age-based cohort model to length-frequency data for skipjack [ICCAT SCRS/99/21; ICCAT SCRS/2008/16]. Notably, some success has been reported in the Pacific [Maunder, 2005, IATTC SAR5], largely due to the availability of adequate skipjack tagging data. For yellowfin and bigeye, an additional problem is that standard models of growth do not appear to provide a good representation of the data, particularly with regard to the growth of small individuals [e.g. Maunder, 2007, IATTC SAR7]. This poor fit is largely unresolved in the assessments, although some attempts have been made to increase parameterisation of the growth model to accommodate the observed discrepancy [e.g. Hampton, 2004, SPC SCTB17 SA-1].

5.4.2. Natural mortality

Growth, mortality and recruitment are the three determinants of stock biomass, and are thus crucial to management related assessments of the resource, including estimations of yield-per-recruit and MSY. Besides growth, natural mortality and recruitment represent substantial uncertainties. Recruitment is usually either fixed [e.g. Hillary, 2006, IOTC-2006-WPTT-15] or assumed independent of biomass with stochastic fluctuations around a mean value [e.g. Maunder, 2003, IATTC Bull. Vol. 22 No. 5]. Similarly, natural mortality remains one of the most elusive parameters in attempts to model tuna population dynamics using SCAA and SCAL models [Fonteneau, 2005, ICCAT CVSP 57(2):127-141]. Its importance stems from its relation to population recruitment and ability to withstand exploitation. High natural mortality (M) values suggest a more productive population (since higher recruitment would be required to sustain a population at equilibrium), and vice versa.

Natural mortality is often fixed during model fits because it is difficult to estimate within the assessment model. In ICCAT assessments for example M was fixed in 1984 [ICCAT 1984 CVSP 21(1): 1-289] and has remained largely unchanged in subsequent assessments. A hypothetical value of 0.8 was chosen for skipjack, constant across all ages. This was also used for small yellowfin and bigeye based on their tendency to school together, the logic being that if of a similar size and exposed to similar environmental conditions they are likely to have similar M values. Older than two years yellowfin and bigeye school separately from skipjack and were allocated constant M values of 0.6 and 0.4 respectively, again on an arbitrary basis. The assumed relationship between size and natural mortality across species is currently unsubstantiated but appears at least to be biologically valid [Fonteneau, 2005, ICCAT CVSP 57(2):127-141]. The arbitrary nature of the assigned mortality values used is however clearly unsatisfactory. For bigeye tuna these were used in VPA assessments of the resource. Some work has recently been done to estimate M for bigeye tuna in the Atlantic using tagging data with a dedicated attrition model [Gaertner, 2003, ICCAT CVSP 55(5):1868-1879] and within MULTIFAN-CL [ICCAT 2005 CVSP 57(2): 177-200]. In both cases it was found that M was lower than previously assumed. For the attrition model, M was around 0.65 for juveniles and 0.3 for adults. In the MULTIFAN-CL analysis, it was found that M was around 0.4 for fish younger than five years, declining to 0.13 by age ten and then staying relatively constant until age 20, after which there is a slight increase. These values are clearly inconsistent with those assumed in previous VPA assessments, implying lower productivity levels. Furthermore sensitivity analyses show that estimating M values within MULTIFAN-CL results in a markedly different biomass trajectory compared to the situation where M is fixed at the previously used values [ICCAT 2007 CVSP 62(1): 97-239]. These results have however yet to be fully accepted by the working group, which currently regard simple production model analyses as providing the best representation of stock status [ICCAT 2007 CVSP 62(1): 97-239]. Some progress has also been reported for estimations of M for yellowfin in the Western Atlantic using tagging data within MULTIFAN-CL [ICCAT SCRS/2008/016]. A constant M across ages was estimated at 1.28. Although still preliminary these are much higher than previously assumed, and suggested the stock was in a more healthy state. For skipjack, attempts to estimate M within MULTIFAN-CL have been unsuccessful [ICCAT SCRS/2008/016].

The IOTC assessments have tended to borrow natural mortality vectors from the other oceans, although the regional tuna tagging program (RTTP-IO) is starting to allow attempts at direct estimation of M for the three species. For bigeye assessments, natural mortality is fixed at values used by the ICCAT [Fonteneau, 2005, ICCAT CVSP 57(2): 127-141; Nishida, 2006, IOTC-2006-WPTT-22; Shono, 2006, IOTC-2006-WPTT-18]. The justification for this is limited, with there being some evidence that it provides a better fit to the data than mortality vectors from the SPC [IOTC-2004-WPTT]. Recent analyses of data from the RTTP-IO suggests bigeye M to be less than that assumed in these assessments (M(0,1,2+) = 0.70,0.70,0.35) [Hillary, 2008, IOTC-2008-WPTT-14], although these results have yet to integrated into a model of stock dynamics. The yellowfin ASPM assessment has been conducted using a variety of M vectors borrowed from the ICCAT, SPC and IATTC [e.g. Nishada, 2005, IOTC-WPTT-2005-09]. A hybrid M vector had been agreed upon by the working group [IOTC-WPTT-2005 Appendix IV] although this has not been applied. Currently a vector based on that from ICCAT is used in SCAA assessments [Shono, 2008, IOTC-2008-WPTT-21; Nishada, 2008, IOTC-2008-WPTT-28]. A mortality vector from the Pacific has also been used in MULTIFAN-CL assessments of Indian Ocean yellowfin, with some success [Langley, 2008, IOTC-2008-WPTT-10]. Preliminary results from the RTTP-IO data indicate that M may be higher for this species (M(0,1+ = 1.6,1.2) [Hillary, 2008, IOTC-2008-13]. There is insufficient information on the population to conduct a formal stock assessment of skipjack [IOTC-WPTT-2003] so that M has yet be agreed upon. Tag based estimates of M for skipjack seem unusually low and may be unreliable [Hillary, 2008, IOTC-2008-15].

In the Eastern Pacific Ocean, estimates of natural mortality for bigeye [Da Silva, 2007, IATTC SAR8], yellowfin [Maunder, 2007, IATTC SAR8] and skipjack [Maunder, 2003, IATTC SAR5] are based on those obtained for the Western central Pacific Ocean, where it has been estimated using tagging data [Hampton 2000, Canadian J of Fish Acq Sci 57: 1002-1010], but taking into account the proportions of females at age and maturity at age specific to the Eastern Pacific. The mortality vector for bigeye [Watters, 2001, IATTC SAR1] and yellowfin [Maunder, 2001, IATTC SAR1] has a characteristic shape, being highest for juveniles, decreasing for pre-mature adults but then increasing again as individuals enter sexual maturity. At older ages mortality declines to pre-mature adult levels. The M vector used for both species is a composite of M values for males and females, which differ between the sexes due to an assumed higher energy expenditure of females during spawning. This leads to the increase in M at intermediate ages, and subsequent decline as the proportion of females decreases in the older age classes. It has been shown for bigeye that including a vector of this shape has a large influence (compared to a constant mortality vector) on estimated absolute biomass levels and stock indicators such as the average maximum sustainable yield [Watters, 2001, IATTC SAR1]. Additional sensitivity analyses have been conducted to examine the effect of bigeye juvenile mortality on stock assessment estimates, which were found to be insensitive [Harley, 2005, IATTC SAR5]. For skipjack SCAL assessments [Maunder, 2005, SAR5], mortality at age is assumed similar to that for the SPC, but with constant M for older ages. However it is regarded as particularly unreliable. A poor quantification of M, along with other difficulties in estimating life history parameters for the species, has meant that approaches based on SCAL models have been superseded by more simple indicator-based approaches that make fewer biological assumptions, but nevertheless make use of estimated annual survival rates [Maunder, 2008, SAR8; Maunder, 2009, SAR9].

In the Western and Central Pacific Ocean, tagging data from the Pacific Tuna Tagging Program (PTTP- now in its second phase) is included in the stock assessment model MULTIFAN-CL to estimate natural mortality during the fitting process [e.g. Hampton 2000, SPC SCTB SA-1]. Indeed, the ability to estimate natural mortality underpins the more advanced stage of model development in the Pacific compared to other regions. Because estimation takes place within the statistically consistent framework provided by MULTFAN-CL uncertainty in estimates of M are transmitted through the model to estimates of other management related quantities. The estimated M vector for bigeye [Hampton, 2004, SCTB17-SA2] and yellowfin [Hampton, 2004, SCTB17-SA1] is of a similar shape to that assumed by the IATTC. However simulation analyses have indicated that some of this variation may be an artefact of sampling [Labelle, 2004, Fisheries Research]. Sensitivity analyses have therefore been conducted using the M vector assumed in the Eastern Pacific Ocean. Overall, however, this was found to have little influence on the results [Hampton, 2004, SCTB17-SA2]. A similar situation exists for yellowfin [Hampton, 2004, SCTB17-SA1], however in this case use of the EPO M vector led to a more pessimistic result. The skipjack assessment is also conducted within MULTIFAN-CL [Hampton, 2002, SCTB15 SKJ1]. In this case the M vector is U-shaped, being higher for the young and old age classes. This result is biologically feasible, although there are currently no estimates of M for skipjack in the other oceans, to which it could be compared.

Table 34. Natural mortality rates for each RFMO and species. Age 0 refers to the age of recruitment to the fishery. MF-CL: MULTIFAN-CL; Ext: estimated externally from the assessment model fit. Data from the SPC/WCPFC and IATTC were kindly provided by Simon Hoyle and Mark Maunder respectively.

RFMO	Tuna species	Natural Mortality at age (year)						Estimation	Uncertainty assessed during stock assessment
		0	1	2	3	4	5		
ICCAT	BET	0.8	0.8	0.4	0.4	0.4	0.4	None	Yes
	YFT	0.8	0.8	0.6	0.6	0.6	0.6	None	Yes
	SKJ	0.8	0.8	0.8	0.8	0.8	0.8	None	No
SPC / WCPFC	BET	0.60	0.40	0.40	0.41	0.44	0.46	MF-CL	Yes
	YFT	1.64	0.86	0.85	1.15	1.07	0.86	MF-CL	Yes
	SKJ	2.07	0.96	1.07	2.01	-	-	MF-CL	Yes
IATTC	BET	0.75	0.40	0.40	0.40	0.43	0.45	Ext	Yes
	YFT	2.24	1.16	0.90	1.13	1.00	0.88	Ext	No
	SKJ	2.76	1.91	1.97	1.97	1.97	1.97	Ext	No
IOTC	BET	0.8	0.8	0.4	0.4	0.4	0.4	None	No
	YFT	0.8	0.6	0.6	0.6	0.6	0.6	None	No
	SKJ	-	-	-	-	-	-	-	-

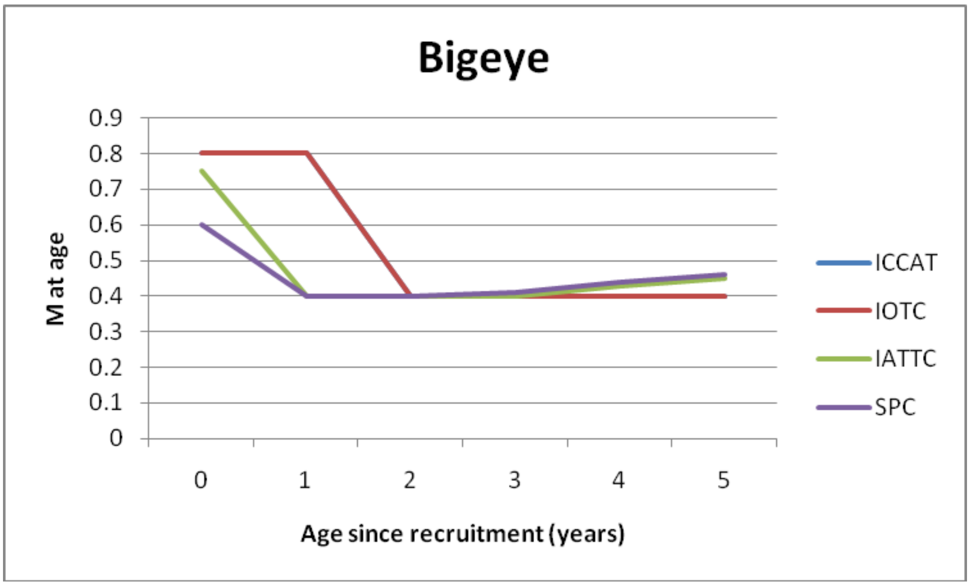

Figure 14. Bigeye natural mortality rates for each RFMO

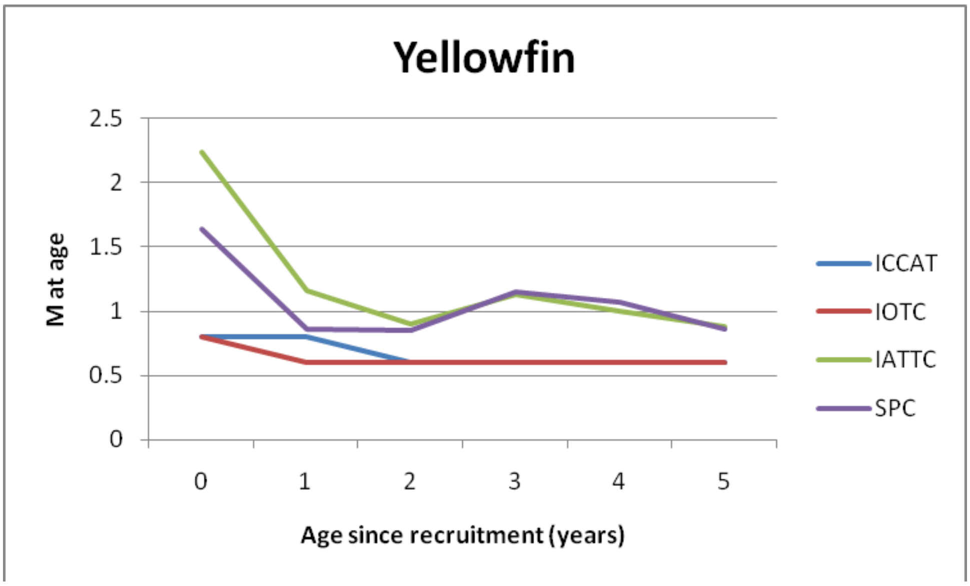

Figure 15. Yellowfin natural mortality rates for each RFMO

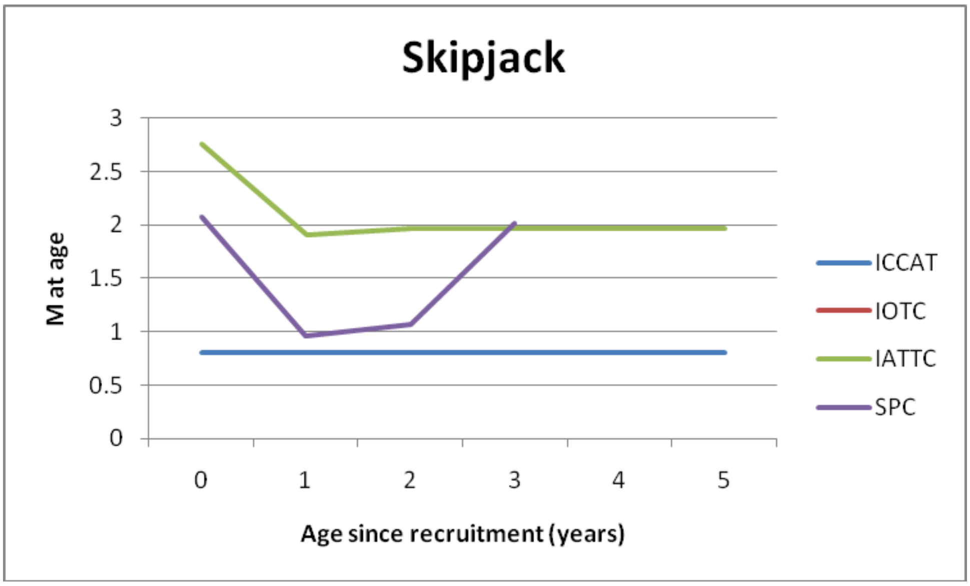

Figure 16. Skipjack natural mortality rates for each RFMO. Note that natural mortality is not used in IOTC assessments.

5.4.3. Stock indicators

Fishing mortality and biomass provide the indicators on which management advice is based. For situations in which sufficient information on the stock is available, reference points can be constructed to assess the position of the population relative to the desired management goal. Two commonly used reference points are fishing mortality at MSY (F_{MSY}) and biomass at MSY (B_{MSY}), which are used as indicators of overfishing and of being in an overfished state respectively (see Section 3). As examples, the IATTC uses the fishing mortality and spawning biomass at MSY as reference points for the status of a stock, whilst the SPC in addition use the ratio of exploitable biomass to the expected exploitable biomass with zero fishing mortality. A useful analysis for situations in which information on absolute stock biomass is unavailable or unreliable is yield-per-recruit analysis, which calculates the biomass yield for every recruit to the fishery based on estimated rates of natural and fishing mortality-at-age [Maunder, 2001, IATTC SAR1]. One of the objectives of fisheries management is to maximise the yield-per-recruit, which is similar to achieving the MSY. Yield-per-recruit analysis predicts an optimum age, and therefore weight, to harvest fish. Thus the average weight of fish relative to the optimum, calculated from the predicted length frequency data (output by the SCAA model), can be used as a measure of the performance of a fishery [Maunder, 2001, IATTC SAR1]. Additional stock indicators for situations in which absolute biomass values are uncertain, include trends in the average weight (which is indicative of stock biomass [Maunder, 2007, IATTC SAR8]) and total catches (which when considered alongside trends in the CPUE can provide a good indication of overexploitation). This variety of stock indicators is summarised for each RFMO in Section 5.5.5.

5.5. Current stock assessment methods

5.5.1. IATTC

Tunas are caught in the Eastern Pacific Ocean by a number of different methods, including purse-seine, longline, and pole-and-line. Prior to the 1960s pole-and-line fishing vessels were responsible for the majority of the catch. This method has since been superseded by the longline and purse-seine fisheries, with the purse-seine fleet responsible for a majority of the landings. A variety of fishing methods are employed by purse-seiners, including fishing on tunas associated with dolphins, fishing on FADs (introduced in 1993), and fishing on free-schools [IATTC, 2008, Fishery status report 6]. Dolphin and free-school sets land a high proportion of yellowfin and some skipjack, primarily from regions north of the equator and close to the coast of South America. FAD associated sets on the other hand land skipjack, and are concentrated in offshore regions south of the equator. This FAD fishery is primarily responsible for landings of small yellowfin and bigeye within the purse-seine fishery. Longline catches consist mainly of bigeye, but significant catches of yellowfin are also taken. Pole-and-line vessels have been important historically, but currently take only a small proportion of the total catch.

Recently, an age-structured, SCAL model has been developed by the IATTC and applied to the stocks of skipjack, yellowfin and bigeye. In each case, catch, effort and length-frequency data is aggregated according to different fisheries. These fisheries are defined on the basis of gear, the spatial distribution of vessels and similarities in size selectivity. This allows many of the changing characteristics of the fishery as a whole to be accommodated in the model framework, under the assumption of a single stock. In particular, the purse-seine fleet is segregated by time, space and whether sets are made on free-schools, dolphins or FADs. This specifically allows for spatio-temporal changes in FAD use. For each fishery, fishing mortality rates are separated into an age-specific effect (selectivity) and a temporal effect (catchability). It is assumed that selectivity is constant over time. Thus, if there is evidence that selectivity has changed over time, two fisheries are defined so that there can be different selectivity curves for the two time periods. In the assessment of bigeye, for example, there are two purse-seine fisheries that catch on free-school sets. These fisheries are separated on a temporal basis because the size composition of the catches for this set type has changed over time. Changing catchability is estimated within the assessment model for each fishery to take account of changes in fishing technology and the behaviour of fishermen, any environmental effects, a seasonal effect and deficiencies in model structure (process error). This estimation of catchability within the stock assessment model is equivalent to the more standard practice of statistical modelling of the catch rate index (standardisation) prior to its input in the assessment model, although some standardisation of the effort series is in fact used, to remove spatial dependent changes in effective effort for the longline time series [Watters, 2000, IATTC Bull. 21(2)]. For the purse-seine fleet, total effort in days for each fishery is estimated from log-book data prior to being input into the assessment model [Watters 2001, IATTC SAR1], effectively segregating the effort between FAD and free-school sets.

A SCAL model has been applied to all the tuna species in the Eastern Pacific Ocean. For skipjack however, a great deal of uncertainty around the model fit remains. Skipjack tuna is notoriously difficult to assess. Due to skipjack's high and variable productivity (i.e. annual recruitment is a large proportion of total biomass), it is difficult to detect the effect of fishing on the population with standard fisheries data and stock assessment methods. This is particularly true for the stock of the Eastern Pacific Ocean, due to a paucity of age-frequency and tagging data [Maunder, 2007, IATTC SAR8]. The most recent assessment of skipjack [Maunder, 2005, IATTC SAR5] is considered preliminary because it is not known whether catch-per-day fished for purse-seine fisheries is proportional to abundance. Few skipjack are caught in the longline fisheries or dolphin-associated purse-seine fisheries, so CPUE data from these cannot be used. Within a single trip free-school purse-seine sets are generally mixed with FAD or dolphin sets, complicating the CPUE calculations. Currently, there is no index of relative abundance that is considered to be reliable for skipjack in the Eastern Pacific Ocean. Therefore less data intensive quantitative indicators of stock status have been investigated, such as the average annual weight of the fish caught. These have been shown to provide an indication of trends in stock status that may be useful for management [Maunder, 2007, IATTC SAR8].

For yellowfin and bigeye the stock status is better defined. The yellowfin and bigeye stocks themselves are intrinsically easier to model due to their life history characteristics (slower growth, lower rates of natural mortality and higher levels of mixing) so that the data requirements are less. The models for yellowfin and bigeye are fitted to catch and length-frequency data from a number of fisheries (including the purse-seine fleet setting on FADs and free-schools). Each fishery is allowed a different selectivity, so that their impact on different aged fish is accommodated. Problems exist with the inclusion of the purse-seine effort series, since again it is unclear that time measured in days fishing is an accurate measure of fishing effort. It is retained nevertheless. Importantly, the impact of the fisheries on juvenile yellowfin and bigeye are accurately modelled through changes in selectivity and catchability. Model fits are generally good, although difficulty was encountered when attempting to estimate growth rate parameters for both species [Maunder and Watters, 2003], thus the models are not completely satisfactory but require further development, likely including additional data.

5.5.2. SPC / WCPFC

Since the 1980s the Western and Central Pacific Ocean fishery has been dominated by the purse-seine fleet, which has effectively taken over from the still declining pole-and-line fishery. In 2003, the purse-seine fishery accounted for 60% of the total catch, whilst the pole-and-line fishery took 15% and the longline fishery 11%. The remainder (13%) was taken by a variety of other gear types including an artisanal fishery in Indonesia and the Philippines.

The purse-seine fishery is essentially a skipjack fishery, unlike the Eastern Pacific Ocean and Atlantic fisheries, with skipjack accounting for 70-85% of the purse-seine catch. Yellowfin account for 15-30% and bigeye only a small proportion of the purse-seine catch. As the fleet has expanded, there have been dramatic increases in skipjack catch. FADs were introduced in 1996 that led to an increase in bigeye catches. However in contrast to other fisheries, the number of sets on FADs has remained in the minority, accounting for only about 20% of the total skipjack catch in 2006 [SPC Review of the purse-seine fishery 2006]. The combined proportion of associated sets (on FADs and drifting logs) has remained around 40% since the 1990s, despite the introduction of FADs in 1996, suggesting that the number of FAD sets is related to the availability of logs. FAD use is also dependent on the distribution of fishing effort, itself dependent on the Southern Oscillation (*El Nino*). FADs are generally deployed in the eastern Western central Pacific Ocean (particularly by the US fleet), which is fished more during an *El Nino* year. A reduction in FAD use in recent years is associated with a shift in fishing effort to the west, were free swimming and log associated schools are more available. As for other fisheries, the yellowfin catch differs for associated and unassociated sets. Specifically, associated sets generally yield higher catch rates for skipjack than unassociated sets, and *vice versa* for yellowfin. There is also a spatial component, with yellowfin being more available in the eastern Western central Pacific Ocean, therefore accounting for a higher proportion of the overall purse-seine catch during *El Nino* years [SPC Review of the purse-seine fishery 2006].

The stocks of skipjack, yellowfin and bigeye in the Western central Pacific Ocean are generally considered to be distinct from those in the Eastern Pacific Ocean. However Pacific-wide stock assessments have been carried out for bigeye, using MULTIFAN-CL, through collaborations between the SPC, IATTC and NRIFSF of Japan [Hampton et al. 2003, SCTB-16- BET1] . A Pacific-wide assessment is possible due to the availability of relatively robust assessment data for this species, and is desirable due to its more migratory nature. Results from the Western central Pacific and the Pacific-wide assessments are comparable, however the same is not true for the Eastern Pacific assessment carried out by IATTC, and the Pacific wide assessment [Hampton and Maunder, 2005, WCPFC–SC1 SA

WP–2−SUP]. The precise reasons for this are unclear and are likely related to the fact that the IATTC assessment is based on a different model (see Table 35), with different underlying assumptions [Hampton and Maunder, 2005, WCPFC–SC1 SA WP–2−SUP]. There are substantial implications for the status and management of the Eastern Pacific stock, yet it is still uncertain to what extent the modelling and management should be carried out on a Pacific-wide basis or separately for the Western Central and Eastern Pacific substocks. Nevertheless it is clear from the distribution of catch data that the current East-West division is arbitrary with respect to the biology and population dynamics of bigeye tuna, making this an important area of future research.

Bigeye, yellowfin and skipjack are all assessed using the SCAL model MULTIFAN-CL and are believed to be in a reasonably healthy state. They are considered as a single Western and Central Pacific stock with data aggregated according to five sub-regions. Sub-region 2 is most relevant to the subsequent discussion since it encompasses the activities of the Indonesian and Filipino domestic fishing fleets. The activity of these fleets is a source of substantial uncertainty. For yellowfin, there is a sizeable but poorly determined catch from the Indonesian and Filipino fleet in sub-region 2, which has increased substantially since 1990 and targets very small fish (smaller than those caught by the purse-seine fleet on FADs). This selectivity means that it has a pronounced impact on the stock, despite only moderate levels of catch and restriction to a relatively small tropical area. The impact of the Indonesian fleet is particularly severe and accounts for over half the overall reduction in stock biomass in the Western central Pacific Ocean [Hampton, 2004, SPC SCTB17 SA-1]. For bigeye, the Filipino and Indonesian fleet also catches small fish, but the impact of this fishery on the stock is restricted to sub-region 2 only [Hampton, 2004, SPC SCTB17 SA-2]. It can be concluded that reductions in catches of juvenile bigeye and yellowfin would have significant benefits for the overall stocks and the longline fishery (see Section 6.1).

For yellowfin and bigeye, the MULTIFAN-CL assessment model is fitted to the Japanese longline catch using standardised effort series. Effort is standardised by either GLM or by using a statistical/deterministic habitat standardised model. Mortality at age is either estimated or fixed; similarly for the catchability of the longline fleet, although attempts to estimate this catchability have been largely unsuccessful. A major uncertainty is in the steepness of the stock recruitment relationship. For yellowfin, a more relaxed prior distribution on this parameter leads to a much more pessimistic assessment of the resource. Overall levels of recruitment for both bigeye and yellowfin have been estimated as increasing since the 1970s. It is this increase that is responsible for current opinion that the stocks are not being overexploited. However the possibility has been raised that it is an artefact of increased juvenile catches and an increased or stable longline catch rate in sub-region 2. To maintain a high catch rate at high levels of juvenile fishing mortality, recruitment must also be high. However as previously mentioned, considerable uncertainty surrounds the estimated catch being taken from this sub-region.

5.5.3. ICCAT

A variety of different methods have been applied to assess the status of tropical tuna stocks in the Atlantic, namely biomass production models (e.g. ASPIC or the Bayesian Surplus Production model), VPA (ADAPT-VPA) and SCAL models (MULTIFAN-CL), with mixed results.

Skipjack are considered as two stocks, a smaller Western Atlantic stock is fished off the coast of the USA, the Caribbean and Argentina, and an Eastern stock off the coast of West Africa. The purse-seine fishery in the West Atlantic is relatively small with limited FAD use. In contrast it accounted for ~70% of the catch in the East Atlantic fishery in 2007. The use of FADs is therefore a more important consideration for the stock assessment in the East Atlantic. Independent assessments for each stock are conducted using biomass production models (although some success in using MULTIFAN-CL has been reported for the Western stock). The only indices of abundance currently used in the skipjack assessment are catch rate data from each of the fishing fleets (excluding longliners). For the purse-seine fleet, a number of catch rate indices have been proposed, including catch per day, catch per set, catch per grid visited and the number of sets per day [ICCAT, 1999, SCRS/99/21]. A major problem for assessment is defining an adequate index of fishing effort for both the purse-seine and baitboat fleets. In the most recent stock assessment report [ICCAT, 2008, SCRS/2008/016], changes to the purse-seine fishery (including the introduction of FADs) were accounted for by estimating an annual increase in fishing efficiency since 1969, measuring effort by the number of days fished. This makes no distinction between FAD and non-FAD sets. Furthermore, no account was made for changes in the baitboat fishery which can also use FADs and has increased its fishing efficiency alongside the purse-seine fleet through the use of supply boats.

Due to the wide geographical coverage of each stock, some of the catch rate indices show contradictory trends (as a result of local variations in fishing pressure and biological characteristics), which lead to problems in model convergence [ICCAT, 2008, SCRS/2008/016]. As a result the current status of these skipjack stocks in unclear. The complexity of the fishery means that unless further data are made available the stock assessment is unlikely to improve. Tagging data have been collected for the East Atlantic stock that could be very beneficial to include in production model development.

In contrast to skipjack, the Atlantic yellowfin population is considered as a single stock. Both production models and VPA have been applied during assessments, fitting in both cases to the available multi-fleet catch rate data [ICCAT, 2003, CVSP 56(2): 443-527]. The yellowfin stock is targeted by purse-seine, longline and baitboat fleets. The longline catch rate series is the most reliable, although targeting is still a concern for estimations of effort. There have been considerable changes in technology and fishing practice for the purse-seine and baitboat fleets, primarily through the use of FADs and supply vessels, associated with a change in spatial distribution, as described above. In the case of skipjack the increasing fishing efficiency has led to increased pressure on the stocks. For yellowfin however, the greatest proportion of the catch still comes from purse-seine sets on free-schools, so that the expanding FAD fishery has only led to a small increase in fishing pressure. However the primary concern is with the changing selectivity of the fishery, since the increasing use of FADs leads to a higher catch of juveniles. This change can only be adequately accounted for by an age- or length-structured model, which allows for the differential application of fishing mortality to each age/length cohort. A biomass production model is inadequate, unless the intrinsic growth rate is allowed to vary with time (this has not been attempted in the assessments thus far). Catch-at-age data is available for the different fleets for use in the assessment, but catches from free-schools and FADs are not distinguished. This means that independent selectivity curves for each set type, which would be required by a SCAA or SCAL model, could not be supported by the data. However the VPA estimates the mortality per age cohort directly and is therefore sufficiently flexible to accommodate changing selectivity patterns. Whether the data is of a sufficient quality to support such a parameter rich model [Shono, 2003, ICCAT CVSP 56(2):593] is unclear.

An additional concern, as with skipjack, is in regard to the calculation of fishing effort, which is measured in days fishing. This has been adjusted to account for FADs (and other changes) by assuming an annual increase in purse-seine fishing efficiency of 3% since 1981 (essentially allowing a non-linear increase in catchability with time). Whether this adjustment is sufficient is unclear, but model fits to the catch rate data are good.

For the Atlantic bigeye stock the situation is similar but more severe than it is for the yellowfin stock, in that total increase in catches as a consequence of the introduction of FADs has been minimal, but juveniles are now being heavily fished. This is a substantial change from the previous scenario, in which bigeye where caught almost exclusively by longline targeting larger fish. Furthermore, the expansion of the FAD fishing Westward from the East Atlantic has led to catches of bigeye in regions where they were not previously caught. Combined with increased longline pressure, and a declining CPUE, the result has been an urgent need for an accurate stock assessment.

Standardised fishery dependent catch rate indices are used in the assessment. For the purse-seine fishery only catch rate data from sets on FADs are included, since these sets catch 80% of the purse-seine catch of bigeye. This catch rate index used the set as the unit of effort. An additional step, not included in the assessments for yellowfin and skipjack was to consider the Ghanaian baitboat and purse-seine fleets as a single entity, accounting for the fact that there is an increasing level of cooperation between the two (with purse-seine vessels setting on baitboat that have aggregated fish).

Again, a suite of models have been applied during bigeye assessments, including various production models, a VPA and statistical catch-at-age. Success with this last model distinguishes the bigeye assessment. Catch-at-age data were split between different fleets when estimating parameters with MULTIFAN-CL, allowing FAD based fisheries to have their own selectivity functions. This should adequately account for the expanding use of FADs, again provided the data is of sufficient quality. The MULTIFAN-CL model is also spatial, dividing the Atlantic into three regions, and incorporates tagging data. Thus even though it is preliminary, and considered as a complement to the more simple VPA and production models, the MULTIFAN-CL model has the potential to accurately incorporate FAD use.

5.5.4. IOTC

Tropical tunas in the Indian Ocean are exploited primarily by pole-and-line (skipjack and yellowfin), purse-seine (skipjack, yellowfin and bigeye) and longline (bigeye and yellowfin). The data quality from these fisheries is considered to be reasonable. However there are still uncertainties surrounding total catch and catch and effort due to the operation of poorly monitored vessels, notably a sizeable gillnet fishery (skipjack and yellowfin) and IUU vessels. The high number of non-reporting fleets operating in the Indian Ocean since the mid-1980s has led to large increases in the number of catches that need to be estimated from the results of various monitoring operations. This reduces confidence in the catch estimates for yellowfin and bigeye, and to a lesser extent skipjack [IOTC-2006-WPTT].

The European purse-seine fleet entered into the Indian Ocean from the Atlantic in 1981, adding to the existent Japanese purse-seine fleet. This amounted to a dramatic increase in purse-seine nominal fishing effort, which was located primarily in the Western Indian Ocean and targeted skipjack. Despite subsequent contraction of the Japanese fleet, the overall nominal effort exerted by the purse-seine fleet since then has continued to increase (by 15% between 2003 and 2005). In addition, the European fleet greatly expanded the use of FADs, and a number of supply vessels also operate. This increase in purse-seine effort has lead to steadily increasing catches of skipjack, largely attributable to the use of FADs, which account for 80% of the purse-seine skipjack catch [IOTC-2007-SC-03]. Catches from free-schools on the other hand have been stable.

During its last skipjack assessment in 2003, the WPTT analyzed the information available and considered that the uncertainties in the information were too large to conduct a complete assessment of the Indian Ocean skipjack. As an alternative, the WPTT decided to analyse various fishery indicators (e.g. catch, nominal catch rate, area fished) to gain a general understanding of the state of the stock, considered as a single Indian Ocean population. The range of stock indicators considered do not signal that there are any problems in the fishery currently [IOTC-2007-SC-03]. Thus skipjack are not considered to be in danger of overfishing.

In the case of yellowfin, the most recent round of stock assessments left a high degree of uncertainty as to the status of the stock, nevertheless indicating that it is likely to be being overfished. The yellowfin population is treated as a single stock, for which only two reliable indices of abundance are available, namely the Japanese and Taiwanese longline fleet standardized CPUEs. These indices have dissimilar trends that have prevented a consensus on the assessment being reached. Different levels of exploitation are estimated, depending on which index is used [Hillary, 2007, IOTC-2007-WPTT-27]. Both series indicate a strong downward trend in the early period of the fishery (1960-1980), when catches were still relatively small, with more moderate declines in recent years when catches have been increasing. This additional contradiction within the CPUE series has caused further problems, so that even if only one of the indices is used, model fit is poor unless a changing catchability over time is assumed [IOTC-2007-WPTT]. It is probable that these assessments have not fully taken into account the changing characteristics of the fishery, such as spatial or technological development. Thus attempts to model the population using various production and age- or length- structured population models have been largely unsuccessful. Of particular concern are the recent high catches that have been recorded since 2000, which have had no discernable effect on the CPUE. The most likely explanation is that catchability of the stock has changed. Unless these factors can be accounted for when standardizing the abundance indices, effects on the population of these potentially high levels of exploitation may be masked.

The most recent bigeye assessment is based only on the Japanese longline CPUE series, since the Taiwanese series was unavailable at the time [IOTC-2006-WPTT]. Model fits using both a simple biomass production model [Hillary, 2006, IOTC-2006-WPTT-34] and age- or length- structured models [e.g. Hillary, 2006, IOTC-2006-WPTT-15] are generally good, providing reasonably consistent estimates of MSY. Importantly, the age- and length-structured models take into account the different selectivity patterns of the purse-seine and longline fleets, so that the consequence for bigeye of increasing use of FADs in the Indian Ocean can at least be assessed.

5.5.5. Summary

In the preceding discussion we have outlined the various assessments used by each RFMO and the associated concerns. These are listed in Table 35, alongside the reference points used. There are major problems with the estimation of accurate catch rate indices for the assessments, particularly in the purse-seine and baitboat fisheries which have changed their fishing practices markedly in recent decades. Some progress has been made in producing a standardized index for purse-seine fleets, by considering FAD and free-school sets independently and using the set itself as the unit of effort. A problem with this approach is the need to incorporate the spatial dynamic resulting from deployment of multiple FADs in a given area. This has not yet been attempted. An advantage is that this approach accounts for the use of supply vessels by the purse-seine fleet, which have been used to deploy and locate FADs, thus reducing the search time used by a particular purse-seine vessel and invalidating time as a good measure of fishing effort. However an adequate measure of effort has still not been devised for the baitboat fleet, which also uses supply vessels to offload their catch and therefore allows the baitboat itself to be used as an aggregating device, staying with a particular school of fish for extended periods. Cooperation between purse-seine and baitboat vessels needs also to be considered. These concerns aside, the purse-seine catch rate data provide an important index of abundance for all the stock assessments, providing information on the abundance of juveniles to cohort-based models used in the yellowfin and bigeye assessments, and overall abundance trends for biomass production models of skipjack. It must be emphasised that this purse-seine catch rate data depends on the estimated species split of catches, and efforts should be made to propagate this uncertainty through to the assessment outputs. The yellowfin and bigeye tuna assessments benefit from having more reliable longline catch rate series. In addition tagging and catch-at-age/catch-at-length data provide important information on age-dependent mortality, allowing the development of assessment models for yellowfin and bigeye that can account for changing selectivity patterns in the fishery brought about by the introduction of FADs. However additional problems remain to be addressed, specifically the changing spatial distribution of the fishery, which could have a profound influence on catch rates, and consistency of data within the model framework.

Table 35. Assessments and reference points used by RFMO and species (F: fishing mortality; SB: spawning biomass; B: exploitable biomass; SB_0: current spawning biomass assuming F=0; B_0: current exploitable biomass assuming F=0; Y: yield; H: harvest rate)

RFMO	Tuna species	Assessment method/model	Model classification	Reference points
IATTC	BET	A-SCALA	Age-structured statistical catch at length model	SB/SB_0; SB/SB_{MSY}; B/B_{MSY}; Y/MSY
	YFT	A-SCALA	Age-structured statistical catch at length model	SB/SB_0; SB/SB_{MSY}; B/B_{MSY}; Y/MSY
	SKJ	-	Simple age structured model fitted to CPUE and average weight	Catch; CPUE; Effort; Average weight; Biomass; Recruitment; Exploitation rate
SPC / WCPFC	BET	MULTIFAN-CL	Age-structured statistical catch at length model	SB/SB_0; SB/SB_{MSY}; B/B_0; B/B_{MSY}; F/F_{MSY}; Y/MSY
	YFT	MULTIFAN-CL	Age-structured statistical catch at length model	SB/SB_0; SB/SB_{MSY}; B/B_0; B/B_{MSY}; F/F_{MSY}; Y/MSY
	SKJ	MULTIFAN-CL	Age-structured statistical catch at length model	SB/SB_0; SB/SB_{MSY}; B/B_0; B/B_{MSY}; F/F_{MSY}; Y/MSY
ICCAT	BET	MULTIFAN-CL	Age-structured statistical catch at length model	F/F_{MSY}; SB/SB_{MSY}
		VPA-2BOX	Virtual population analysis	F/F_{MSY}; SB/SB_{MSY}
		PRODFIT; BSP; ASPIC	Pella-Tomlinson biomass production models	B/B_{MSY}; H/H_{MSY}; Y/MSY; B/K
	YFT	ADAPT-VPA	Virtual population analysis	SB/SB_{MSY}; F/F_{MSY}
		ASPIC	Pella-Tomlinson biomass production model	B/B_{MSY}; H/H_{MSY}
	SKJ	PROCEAN; BSP	Pella-Tomlinson biomass production models	B/B_{MSY}; H/H_{MSY}
		Catch only model	Catch is predicted by a Schaefer biomass dynamic model and logistic exploitation model and fitted to catch data using Bayesian methods	B/B_{MSY}; H/H_{MSY}; Probability that Y>MSY
IOTC	BET	CASAL; ASPM; SS2	Age-structured statistical catch at age models	MSY; F/F_{MSY}; SB/SB_{MSY}
		SP Bayes	Bayesian Pella- Tomlinson biomass production model	B/B_{MSY}; Y/Y_{MSY}; H/H_{MSY}
	YFT	CASAL; ASPM; SS2	Age-structured statistical catch at age models	MSY; F/F_{MSY}; SB/SB_{MSY}
		SP Bayes	Bayesian Pella- Tomlinson biomass production model	B/B_{MSY}; Y/Y_{MSY}; H/H_{MSY}
	SKJ	-	-	Catch; CPUE; Effort; Size frequency distribution; Average weight; Spatial distribution of effort

5.6. Limitations

5.6.1. Models

The stock assessment models outlined and applied by each of the RFMO's are diverse in terms of their complexity, related data requirements and underlying assumptions. An expanding FAD fishery creates a variety of problems for these models that they are differentially equipped to deal with. The first is a generic problem and regards the difficulty in quantifying catch rate when the effective effort asserted is continually increasing through technological advancement, including the use of FADs. More accurate catches of yellowfin and bigeye, and more accurate indices of abundance for all three species could both be achieved with enhanced data quality and coverage. As the FAD fishery has increased, the data requirements needed to accommodate this change have also increased, and in many cases are not sufficient.

The second problem introduced by FADs is that of changing selectivity of yellowfin and bigeye catches. This change is appropriately dealt with by the more complex SCAA and SCAL models (e.g. A-SCALA, MULTIFAN-CL and CASAL) that can accommodate fisheries that exploit the age classes differently. Although in this context they are superior to the production models (which may still be usefully applied to skipjack stocks) they are dependent on accurate catch-at-age, or more usually catch-at-length, data. Along with tagging data, this information is used to estimate mortality and growth parameters within the model. These parameters are often poorly defined, so that a higher quality of data would improve estimation. However in contrast to the catch rate and catch estimations which have been complicated by the use of FADs and would benefit directly from improved data quality, and although estimation of stock assessment model parameters would also improve through better quality catch-at-length data, there is an additional more subtle problem introduced by the FAD fishery with respect to estimation.

As previously mentioned, an accurate representation of growth is fundamental to a reliable stock assessment, yet traditional models can fail to accurately reproduce the data. In the Western central Pacific Ocean, lower than expected growth rates for smaller fish have been observed for both immature yellowfin [Lehodey, 1999, SCP SCBT12 YFT-2] and bigeye [Lehodey, 1999, SPC SCTB12 BET-2] (although interestingly not for the Eastern Pacific Ocean [Schaefer, 2006, IATTC Bull. 23(2)]). The reasons for this are unclear. However for yellowfin at least it is possible that it is a result of differential selectivities during capture and re-capture of tags. Broadly speaking there will be bias towards sampling those fish that better match the selectivity of the re-capture fishery. For example if recapture is predominantly from FAD sets, then there will be a bias towards sampling small fish with slower growth rates. Re-capture from free-school or longline sets on the other hand, may preferentially select only the large, faster growing fish. This is less of a problem for skipjack [Maunder, 2001, IATTC Bull. 22(2)], for which uncertainty is better understood in terms of spatial variability in growth due to environmental conditions. Nevertheless the effect of this selectivity bias and its implication for estimation of the growth curve warrants further investigation.

5.6.2. Data

There are serious data limitations in many of the tuna fisheries, particularly with regard to estimates of natural mortality and growth. These limitations are behind the implementation of extensive tagging programs. However there is also a need to provide an accurate abundance index for skipjack, yellowfin and bigeye from purse-seine catches. This is a particular problem for the assessments of skipjack, since the purse-seine catch rate index is the only index of abundance available. However due to the large landings reported by the purse-seine fishery it also causes problems for assessments of yellowfin, and an inability to appropriately standardise effort seriously undermines attempts to model this species. The problem is also apparent for bigeye. However since bigeye catches are themselves an estimated quantity, the development of such an index faces an additional barrier. Nevertheless, if developed into a sufficiently reliable index it would provide an extremely valuable indicator of recruitment, as it would for yellowfin.

As described in Section 5.2, FADs are an obstacle to the derivation of such a purse-seine abundance index since they undermine the use of search time as a measure of fishing effort. An immediate way round this problem would be to use the catch per set, which has the added advantage of circumventing the need for data on supply vessels (which can influence search time) and targeting (since it can be assumed that all FAD sets target skipjack). However this has its own limitations in that the catch per set will be dependent on the number of FADs in the local vicinity. This makes the catch per set a spatially dependent measure of density. It is therefore probable that the collection of appropriate spatial data would allow the catch-per-set to be developed into a reliable measure of abundance. Such data should include, at the very least, the location all purse-seine sets and whether they were made on FADs or free-schools. This could form the basis of a spatially dependent abundance index. It would be useful also to have information on the number and location of unfished FADs, although this is likely to be commercially sensitive and may not be necessary if it is assumed that the number of FAD sets in a particular area is a good measure of the total number of FADs in that area.

Of undoubted importance is the need to develop a categorisation of FADs, so that they can be grouped according to their effectiveness with regard to aggregating fish. This is likely to require some empirical study and would provide valuable information for an abundance index.

Finally it is necessary to accurately record the species split of purse-seine catches. Currently yellowfin and bigeye are often recorded as a single species, so that bigeye catches need to be estimated from observer or port sampling records. This introduces additional uncertainty and a potential bias into estimates of exploitation and establishment of yellowfin and bigeye abundance indices from purse-seine catches. Furthermore, it is unnecessary, since juvenile bigeye and yellowfin are easily distinguished anatomically.

5.7. Further research

5.7.1. Natural mortality

Section 5.4.2 reviewed the values of M used by the stock assessments by each of the RFMO's. There is clearly a marked difference both in the values used and their means of estimation. The most reliable estimates of M are obtained from tagging studies, but these require a great deal of auxiliary information on reporting rates, tag shedding and stock definition. Thus although tagging studies have been conducted by all the RFMO's, they have not all been able to produce reliable estimates of M, which, along with growth, is one of the most important biological parameters related to estimates of biomass dynamics and productivity.

So far only the SPC, and recently the IOTC, have been able to estimate M using tag data from their own studies. This leaves a major uncertainty surrounding stock assessments currently conducted by the IATTC and ICCAT, particularly since the mortality rates used are so different. This difference in itself is clearly grounds for further research, with the intention of first understanding and then resolving limitations in the data that prevent reliable estimations of mortality being made using the available tagging data.

5.7.2. Growth curve estimation

The importance of the growth curve in stock assessments of tuna resources, and the uncertainties surrounding its estimation that have been introduced by changing fishery selectivities, make it a good candidate for further investigation. It is proposed that a simple simulation model will be developed to reproduce tag returns under different selectivity assumptions. This will provide a basis for quantification of the bias that may have been introduced into growth curve estimation as a result of the FAD fishery. The project will concentrate on the yellowfin fishery in the Indian Ocean, due to the availability of data and recognised problems with estimation of growth from tag returns in that region [R. Hillary pers. comm.]. Importantly, identification and quantification of a bias will have beneficial implications for the yellowfin assessment in that region

6. Effect of FADs on stock vulnerability

The previous section outlined some of the problems and limitations inherent in the stock assessment methods as they are currently applied. In many cases these are a consequence of limitations in the data introduced by FADs (i.e. the data requirements and uncertainty in the models has increased through the introduction of FADs) rather than begin a direct consequence of FAD use. In this section we introduce the problem of stock vulnerability: even if a tuna population can be accurately represented by the stock assessment model, does the use of FADs in any way increase its vulnerability to overexploitation?

The question of vulnerability relates primarily to stocks of yellowfin and bigeye which are suffering increased levels of juvenile mortality as a result of FADs. The effect that this will have on the population is dependent on rates of natural mortality. If the juvenile mortality is low, then the massive use of FADs will produce a significant decrease in the yield-per-recruit. Thus for a constant catch biomass, the exploitation experienced by the stock will increase. If on the other hand juvenile mortality is high, the relative increase in overall mortality introduced by FADs will be low, even when large catches are observed. In this case the potential effect of FADs may be small.

6.1. Fleet interactions

The balance between natural and fishing mortality in juvenile segments of the population, how it is changed by FADs, and how this affects the stock productivity have been addressed by RFMOs in the context of fleet interactions. In the case of bigeye for example, it is clear from the preceding discussion that the catch of juvenile bigeye by the purse-seine fleet is likely to have an influence on the sustainability and yield of the longline fishery. Thus quantitative analyses that explore the consequences of reduced mortality imposed by the purse-seine fleet are useful, and can be viewed as investigations into the vulnerability of bigeye stocks to FAD associated mortality.

In the Eastern Pacific Ocean, the fishing mortality exerted on the younger bigeye age classes as a result of FAD use is much higher than that exerted by longlines on older fish [Da Silva, 2007, IATTC SAR8], and a reduction in purse-seine effort is predicted to have benefits for longline catches and mean spawning biomass [Harley, 2005, ICCAT CVSP 57(2): 218]. A similar result has been obtained in the Western central Pacific Ocean, illustrating that juvenile bigeye catches can substantially reduce the yield from older age classes [Hampton, 2005, ICCAT CVSP 57(2): 242]. These analysis conducted by the SPC and IATTC differ in their outcome from the evaluations by the ICCAT and IOTC. In the Indian Ocean an analysis of the effect on bigeye catches of a reduction in juvenile fishing mortality imposed by the purse-seine fleet showed it to have a marginal effect [Pallares, 2003, IOTC-2003-WPTT-12]. A more limited evaluation of this question was performed by ICCAT. In contrast to those performed by other RFMOs it did not make use of simulations but instead assumed an equilibrium population. ICCAT evaluated the relative impact of effective effort restrictions on individual fisheries in terms of yield-per-recruit [ICCAT, 2006, CVSP 59(2): 347-410; ICCAT SCRS/2008/170]. The results of these analyses indicate that only modest gains in yield-per-recruit for yellowfin and bigeye can be obtained by decreasing the surface fleet fishing mortality.

Since the relationship between juvenile fishing mortality and yield is dependent on the rate of natural mortality, it follows that the interaction between fisheries that harvest juvenile and adult segments of the population will also depend on natural mortality. However as previously mentioned, natural mortality is a source of significant uncertainty and is poorly defined by the ICCAT and IOTC. It is worth pointing out that in the Pacific, where natural mortality is best defined from tagging studies, there is a clear impact of purse-seine catches on bigeye productivity, suggesting juvenile morality in this species is sufficiently low for FAD associated mortality to have an impact on the bigeye population, thereby increasing its vulnerability to overexploitation.

6.2. Management measures

Given an assumed impact of FAD fishing on the vulnerability of yellowfin and bigeye stocks, a number of management measure have been proposed to mitigate the effect. These have been addressed in detail in Section 7 of this report and elsewhere [Bromhead, 2003].

6.3. Further research

6.3.1. Reductions in Purse seine fishing effort

The discussion in Section 6.1 illustrates work that has been done in evaluating the consequences of direct reductions in purse-seine fishing effort. Results are ambiguous, but in the Pacific at least suggest that a reduction in purse-seine fishing on FADs will be beneficial to bigeye productivity. Although fleet interactions have been estimated by the IOTC [Pallares, 2003, IOTC-03-12], the recent estimation of mortality in the Indian Ocean [Hillary, 2008, IOTC-WPTT-2008-13; Hillary, 2008, IOTC-WPTT-14; Hillary, 2008, IOTC-WPTT-2008-15] makes it worthwhile to re-address this question. This work will therefore examine the potential consequences of reductions in purse seine fishing effort to the stability and productivity of the bigeye and yellowfin tuna populations. If warranted, this analysis could be extended to other oceans, so that results could be compared and presented within a comprehensive and unified framework.

6.3.2. Time-area closures

An alternative to direct effort controls is spatial management [Fonteneau, 2007, ICCAT CVSP 60(1): 190-223], so that purse-seine effort is re-located to areas where yellowfin and bigeye catch has been empirically demonstrated to be low. This approach differs from traditional considerations of MPAs as refugia from which biomass is exported to other unprotected components of the population. Rather there is a benefit to the entire population that simply results from a reduction in the proportion of juvenile catches, under constant total catch biomass, through a redistribution of fishing effort. The intention is to limit catches from a specific sector of the fished populations, namely juvenile yellowfin and bigeye.

The potential benefits of spatial management measures for yellowfin and bigeye were behind the proposed implementation of areas closed to purse-seine fishing in the East Atlantic, Indian Ocean and Eastern Pacific [reviewed in Bromhead, 2003]. In the East Atlantic at least, empirical data demonstrates that area closures can lead to substantial reductions in juvenile yellowfin and bigeye mortality. However despite its potential as a management tool, there has been limited quantitative evaluation of the benefits. In the East Atlantic, benefits of previous closures have been assessed simply in terms of empirical reductions in purse-seine fishing mortality on juvenile yellowfin and bigeye [ICCAT, 2006, CVSP 59(2): 347-410]. In the Indian Ocean, the IOTC investigated potential benefits through assumed reductions in fishing effort and likely benefits to the yield-per-recruit [IOTC-2003-SC06]. In the Western Central Pacific, Hampton and Langley [Hampton and Langley, 2007, WCPFC-SC3-SA-SWG/WP-04] have quantified the reduction in catches of all three tuna species that would be associated with the closure of various regions. The analysis was able to highlight the fact that closing some areas of national jurisdiction would lead to a large reduction in catches of juvenile bigeye, but with minimal impact on the total skipjack catch. The authors highlight however, the economic consequences for the domestic fleets if such a management option were pursued. Recent work in the Eastern Pacific Ocean has illustrated a potential benefit of time-area closures, demonstrating that a simple redistribution of effort may substantially reduce catches of juvenile bigeye [Harley, 2007, Fish Bull 105:49-61].

The use of marine protected areas in fisheries management is controversial, and they are widely considered to be of limited use in highly mobile species such as tuna. Nevertheless the work done so far (referred to briefly above) illustrates that they may have some benefit due to spatial variations in species catch composition. An obvious next step is to quantitatively evaluate the consequences for the biomass dynamics of the exploited bigeye stock, in each ocean for which suitable data is available. The construction of such an analysis is dependent on the assumption that the bigeye stock is continuous across the region with instantaneous mixing. This means that the effort redistribution will not lead to local depletion and have an overall benefit for the population. It is proposed that such a model is developed in Phase 2 of this investigation. It will concentrate on bigeye, since the biodynamics of this species is better described, and quantitatively evaluate the potential stock benefits of spatial-temporal reductions in purse-seine fishing effort.

7. Review of existing management actions

7.1. Introduction

In this section we first outline potential bycatch mitigation methods that can be applied to purse seine fisheries fishing for tunas with FADS (Section 7.2). We then explore in detail the management actions imposed by the relevant RFMOs in each ocean (Table 36), and in summary compare those actions against the range of potential actions to explore management gaps and options (Section 7.3).

Tunas of different species aggregate together in different size classes, areas and depths, and different relative proportions of the different species are caught in sets on free schools or FAD associated schools (see Sections 4.1.1 and 4.2.2). Thus fisheries for tuna are multi-species, but targeting through a combination of location, depth and fishing method can affect the species caught. RFMOs address the complex issues related to management of multi-species tuna stocks which include the need to protect the most vulnerable species (bigeye and yellowfin) whilst at the same time permitting exploitation on stocks that are considered to be healthy (skipjack). Management issues also include mitigating the impacts of different fishing methods on incidentally caught species, and on juveniles of target species. Amongst the wider management issues are those that could be focussed on the management of FAD associated fisheries, and it is this aspect that is explored in the current document.

Table 36: Summary of Management Actions by ocean region and the related impacts and outcomes.

Ocean Region	Issue	Impacts	Outcomes
Eastern Pacific		FAD effort high after switch from dolphin associated sets	Ban on support vessels operating in IATTC region.
		Experimental fishing and full retention programmes implemented	Experimental fishing conducted, awaiting publishing of results.
		Research required	IATTC WG FADs created
	Impact on turtles	Mitigation and monitoring put in place	IATTC Resolution in force.
Western Pacific	Impact on juvenile tunas.	Research required on interaction	Research and Management Plans required
		Mitigation of impacts in key areas.	Closed areas implemented by WCPFC Resolution
	Impact on turtles	Mitigation and monitoring put in place	WCPFC Resolution in force. Research plans by WCPFC Members required.
Atlantic	Impacts on juvenile tunas.	Monitoring on FAD catches required	ICCAT Members initiate port sampling of purse seine catches in major ports.
		Mitigation and reduction of FAD effort in juveniles required.	Closed area mechanism initiated by industry then followed by ICCAT

Ocean Region	Issue	Impacts	Outcomes
			Recommendations.
	Capacity	Capacity too high and reduction in number of vessels or FAD effort recommended.	ICCAT WG on Capacity
	Impact on turtles	Mitigation and research required	ICCAT Resolution in force.
	Impact on sharks	Mitigation and research required	ICCAT Resolution in force.
Indian	Impacts on juvenile tunas.	Monitoring on FAD catches required	IOTC Members initiate port sampling of purse seine catches in major ports
		Mitigation and reduction of FAD effort in juveniles required.	Closed area mechanism initiated by industry then followed by ICCAT Recommendations.
	Capacity	Capacity too high and reduction in number of vessels or FAD effort recommended.	Reduction in effort recommended but no action
		Number of FADs unknown so gear marking of all FADs required.	IOTC Resolution
	Impact on turtles	Mitigation required	IOTC Resolution in force.

7.2. Summary of management and bycatch mitigation methods

A number of mitigation measures are available, and have been implemented by RFMOs, in order to reduce tuna bycatch. Efforts to reduce tuna bycatch comprise two basic approaches: firstly, through the modification of fishing effort in order to avoid bycatch, and secondly through modifying fishing gear and practices. Examples of measures and strategies for each approach are given in the following sections. Additionally, at the end of this section we reproduce two tables from the Report of the 6th Session of the IOTC Scientific Committee (IOTC, 2003) that indicate the potential effects of different management measures to protect yellowfin and big-eye tuna stocks (Table 37). These do not correspond to all the categories we have indicated below.

7.2.1. Management through modification of fishing effort and avoidance of bycatch

A number of mechanisms are designed to reduce bycatch through the modification of fishing effort to enable increased avoidance of bycatch. Measures range from those based on the behaviour of tuna species or bycatch species (Spatio-Temporal Closures and Marine Reserves) to those directly imposed on the fisheries fleet to reduce effort, such as a cap on the number of vessels.

7.2.1.1. Spatio-Temporal Closures and marine reserves

Spatio-temporal closures are temporary closures of an area (which may or may not be the same area over time) to protect features such as juvenile or spawning aggregations, and may be relevant to migratory tuna stocks. Time area closures can reduce catches of juvenile bigeye and yellowfin by participating fleets, but this benefit may be offset by increased catches by non- participating fleets, and increased effort in areas not closed to the fishery. They could also be applied to protect significant events in the life history of bycatch species. RFMOs have identified spatio-temporal closures as potentially effective measures for controlling bycatch and juvenile tuna catch (Bromhead et al 2003). These measures would effectively close an area for a specified period of time to all fishing or potentially just to FAD fishing with appropriate observer coverage. However more research is required; Harley and Suter (2007) modelled such closures to investigate their impact on protecting big-eye tuna and on target skipjack tuna. They concluded that because the level of bigeye tuna catch reduction was insufficient to address sustainability concerns, future research should be directed toward gear technology solutions.

Nevertheless, tuna RFMOs including ICCAT and IOTC have implemented spatio-temporal closures targeting FAD fishing in the recent past through regulatory mechanisms imposed by the RFMO. Additionally there have been voluntary initiatives by industry.

Spatio-temporal closures are only effective with the full co-operation of all stakeholders in the fishery; thus voluntary closures are especially effective. Regulatory closures usually require the use of observer programmes to monitor and enforce them, and would be recommended where only FAD fishing is to be banned in order to ensure that vessels only set on free schools and not on FADs. Full closure of an area may be implemented and compliance of licensed vessels observed through vessel monitoring systems without the need for full observer coverage.

Marine reserves are a particular type of spatio-temporal closure and are defined as ''areas of the ocean completely protected from all extractive and destructive activities'' (Lubchenco *et al*, 2003). They are potentially a powerful management tool, but are most ideally suited to protecting sedentary species. The use of marine reserves for mobile species is however, supported by Roberts *et al.* (2005) and Norse *et al.* (2005) who state that strategically placed marine reserves can benefit migratory species by protecting aggregation sites like seamounts and essential fish habitats, such as nursery grounds and spawning sites (Kramer & Chapman, 1999). Marine reserves are most effective when implemented in conjunction with other management tools (Roberts *et al.*, 2005). Stefanson and Rosenberg (2005 and 2006) stated that beneficial effects may be obtained from marine reserves if these areas are used in conjunction with direct controls on fishing mortality, such as quotas or effect limits.

Marine reserves have been employed to protect mobile species such as tuna but their effectiveness decreases as species mobility increases, and their implementation can be difficult (Kramer & Chapman, 1999). IOTC data 1980 – 2005 showed that the migration path of yellowfin tuna can vary by up to 600nm between years. Thus tropical yellowfin and skipjack tuna fisheries can be seen to be extremely mobile and as such they are extremely difficult to protect with static marine reserves without closing off excessively large areas of ocean. The application of fixed marine reserves to migratory tuna stocks thus has limited application.

The introduction of new marine reserves therefore would need very careful consideration as a potential management option for tunas within the context of the UN Fish Stocks Agreement "to ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks"[5]. Introducing them requires extensive research to identify the key areas and times where the maximum benefits can be achieved i.e. where bycatch or

[5] Regional Fisheries Management Organisations (RFMO) with responsibility for the management of the stocks have been shown to be the best way to manage straddling and migratory stocks

juvenile catch rates are highest whilst at the same time taking account of their social and economic impacts, particularly for developing coastal states.

7.2.1.2. Catch and effort limits

Catch and effort measures are aimed primarily at controlling fishing directed at the target species (tuna) but will have a proportionate impact on reducing bycatch including juveniles of target species.

Catch limits can be imposed to limit the amount of fish of each particular species that can be safely taken to maintain sustainable catches. At sea these can be difficult to monitor and rely on extensive observer coverage, but are often recoded in logbooks and verified by landings (IOTC, 2003, for example, refer to limitations on the catches of skipjack).

RFMOs have variously applied catch and effort limits (see Sections 7.2.1.2 and 7.2.1.3). The owners of purse seine vessels have also been shown to be pro-active by limiting the number of vessels to ensure that supplies of tuna balance the demand (Joseph, 2003).

7.2.1.3. Limiting fishing effort on FADs

Limiting the fishing effort in terms of the total effort associated with fishing on FADs can be achieved by reducing the absolute number of sets on FADs and/or restricting the number of FADs in use, or restricting the technology associated with them (electronic equipment). However, it is necessary to consider what the impact of limiting FAD fishing might be on the total tuna fishery exploited, and what the primary objective of proposed FAD control would be.

Tuna fisheries are multispecies fisheries and different gear can preferentially target different species. Purse seine fishing on free schools and long line fishing generally target large yellowfin and skipjack tuna. Pole and line and purse seine fishing on FADs target primarily skipjack tunas. Fisheries management strategies applied to multispecies resources often tend to be based on the precautionary principle to protect the most at risk species. For tunas this would be the larger slower growing bigeye tuna. Thus it is necessary to understand to what extent the catch of juvenile yellowfin and bigeye around FADs is affecting their recruitment, in order to define whether controlling FADs is the most appropriate approach for the target fishery.

If controls on FADs were introduced to protect non target species, this would have some impact in reducing bycatch, but it could also lead to a shift in effort towards the more vulnerable species of yellowfin and bigeye tuna. Currently skipjack are the least heavily exploited tuna resource and reducing fishing effort on FADs will reduce the overall catch levels of skipjack tuna. Thus rather than reducing FAD effort, mitigation measures based on gear modifications such as those described in Section 7.2.2 may be more appropriate to achieve the desired balance of limiting effort on vulnerable tuna species and limiting bycatch.

Thus limiting FAD effort is a complex issue with many potential repercussions that need to be carefully considered in the light of the best available scientific evidence.

7.2.1.4. *Support vessel limits*

The use of support vessels (also referred to as supply-vessels) is believed to enable purse seiners to increase their catch. A comparison between the catches from Spanish and French fleets using FADs inferred that the Spanish fleet's higher catch rate could be attributed to the use of supply vessels (IOTC Working Party on Tropical Tunas in 2000). In 2008 with the increasing fuel prices it has been suggested that support vessels are now are being used more and more to deploy, repair and recover FADs, with the fishing vessels concentrating on fishing and maximising their fuel economy.

IATTC introduced a ban on the use of support vessels with respect to fishing on FADs in 1999. (IATTC 99-07).

7.2.1.5. *Discard Ban*

The aim of such a measure would be to encourage bycatch avoidance and better targeted fishing practices. A requirement to retain discards onboard would effectively reduce a vessels hold capacity for commercial fish. However as a consequence it might also lead to fishing practices directed at high value. Bycatch avoidance mechanism would only work in accordance with an observer programme to ensure that the discard ban is being adhered to (Bromhead *et al.* 2003).

7.2.2. Management and mitigation through modification of fishing gear and practices

There are a number of gear modifications and fishing practices that allow a purse seine vessel to minimise the bycatch from a set. These include the working practices on the vessel, which can be verified through inspections of the purse seine nets and by observer programmes. The following analysis shows that mitigation methods such as mesh size limits can be introduced to reduce small bycatch species whilst for larger bycatch species the process of hauling the net in need to be altered to ensure the survival of bycatch species such as turtles and sharks. There are a number of other measures that could be considered best industry practice that may provide incentives for fishers to avoid juveniles (such as price controls – only paying for fish above a certain size). The latter category is not explored here.

7.2.2.1. *Mesh size limits*

Minimum mesh sizes defined for the main body of the net can be specified to allow all fish under a certain size to escape but retaining the target catch of large adult fish. The size of the mesh will need to be set an appropriate level to define the necessary level of escapement for non-target and juvenile fish. These options are not particularly feasible in the purse seine fishery for excluding juvenile yellowfin and bigeye tunas as these are the same size as the target skipjack tuna.

7.2.2.2. *Escape panels*

Minimum mesh sizes for the certain parts of the body of the net can be specified to allow fish under a certain size to escape but retaining large adult fish. As for the mesh size limits the size of the mesh size will need to be set an appropriate level to define the necessary level of escapement for non-target and juvenile fish.

7.2.2.3. *Manual release*

Turtles captured in purse seine nets can be spotted during the closing period of the hauling of the net. They can be removed from the net on hauling and often released unharmed. When combined with observer programmes this provides an ideal opportunity for recording of turtle tagging and biometric information. RFMOs have passed recommendations and resolutions encouraging the release of incidentally caught animals, particularly turtles.

Sharks, skates and rays captured in purse seine nets can be easily spotted in nets. Purse seine fishing methodology from the southern bluefin tuna fishery has been modified to allow the live removal of large predators (sharks and seals) from the net. Techniques have also been developed to allow the live removal of sharks from tow and farm cages (AFMA (2005)). When combined with observer programmes this provides an ideal opportunity for recording of shark tagging and biometric information.

A series of additional technological developments to reduce bycatch, most of which were originated by the fishers in conjunction with the scientists at IATTC, have been crucial in reducing dolphin mortality in the Eastern Pacific Ocean where purse seine fisheries are associated with dolphins (Hall, 1998).

7.2.2.4. *Medina panels*

Acting in the opposite direction to the larger mesh panels, fine meshed medina panels at the top of the purse seine nets can be used to deter entanglements as the fine mesh can be detected by marine mammals (and when combined with backing down (Section 7.2.2.5) can release the marine mammals unharmed) and can reduce entanglements and drowning of turtles (Leadbitter (1999) and Crespi (2001)).

7.2.2.5. *"Back-down" of net*

During hauling the purse seine net can be backed down to allow the escape of marine mammals, sharks and rays that tend to be found in the shallower areas of the net, (tuna often diving to escape from a potential threat). This allows the non-target species to escape through a gap in the purse seine net at the surface, while the tuna are retained in the deeper sections of the net. This requires practice and patience on the part of the crew but can be implemented (Leadbitter (1999) and Warren (1994)).

Hall (unpublished, PowerPoint presentation) has summarised the methods available for reducing by catch and catches of juveniles, which include a combination of avoidance of bycatch and modification of fishing gear and practices (Figure 17).

Figure 17: A summary of the methods available for reducing by catch in purse seine fisheries (reproduced from PowerPoint presentation, Martin Hall, 2009)

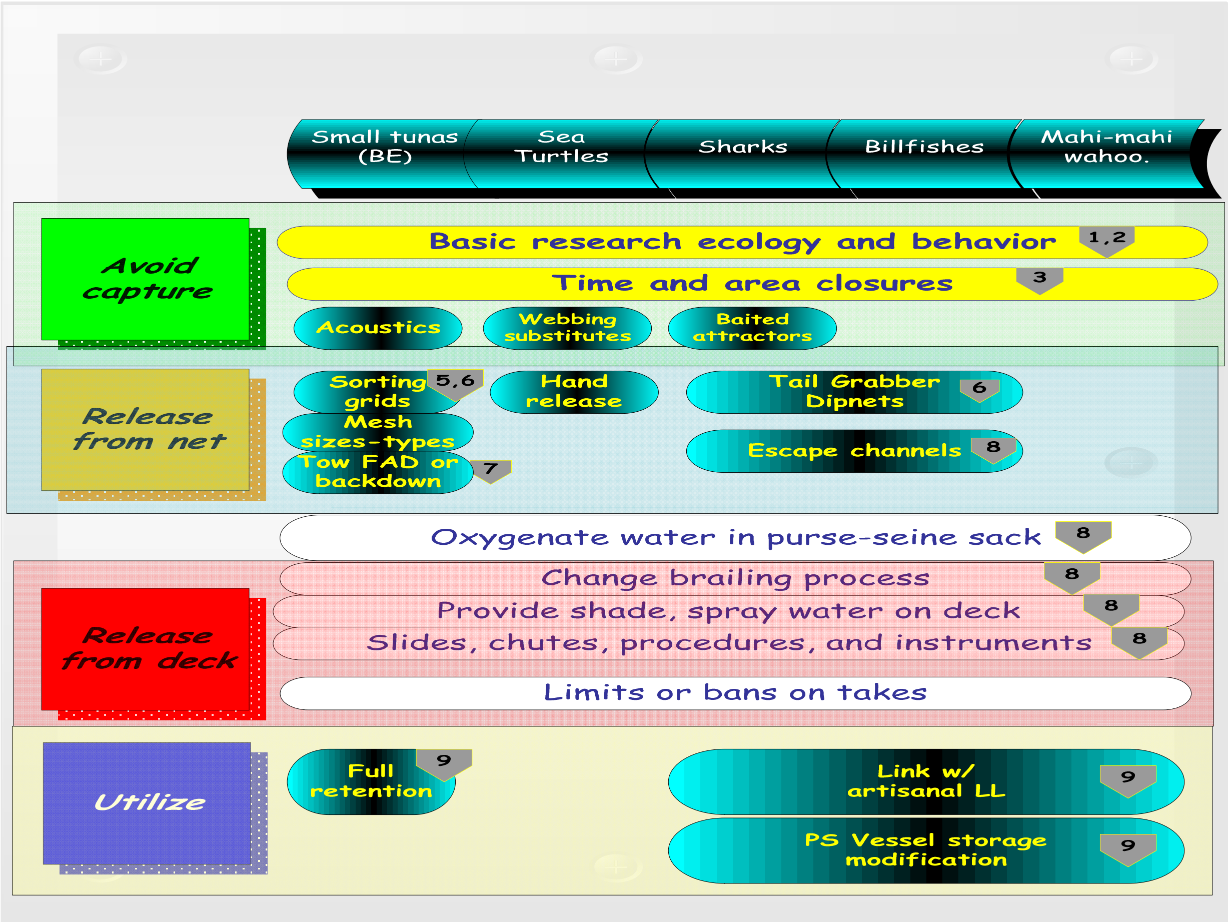

Table 37 : Tables 1 and 2 reproduced directly from the Report of the 6th session of the IOTC scientific committee (IOTC, 2003) indicating the effects of different management measures to protect yellowfin and bigeye tuna stocks.

Table 1. Summary evaluation of potential effects of the management measures considered (see text for details).

Management measure	Comment	Likely effect on juvenile bigeye mortality	Likely effect on juvenile yellowfin mortality	Likely effect on bigeye catches	Likely effect on yellowfin catches	Likely effect on skipjack catches
Time-area closure to purse seine fishing	A spatial-temporal closure has been applied in the Atlantic, and considered by the IOTC in 2000	12-31% reduction depending on scenario	15-38% reduction depending on scenario	Short term: 6000-15000t loss of large BE+YF to PS Long term: 2 - 6% increase in total yield	short term: 6000-15000t loss of large BE+YF to PS long term: not available	20,000- 50,000t reduction
Reduction in overall purse seine effort	Reducing the number of vessels	10% reduction in no. of vessels: 4-18% reduction	10% reduction in no. of vessels: 4-18% reduction	Short term: 10% reduction in no. of vessels: 4-17% reduction Long term: <2.2% increase in overall yield	short term: 10% reduction in no. of vessels: 5-17% reduction in catch long term: not available	10% reduction in no. of vessels: 4-17% reduction in catch
	Increasing days in port when unloading	2-4 days: 5-11% reduction (2nd semester only) 2-4 days: 7-15% reduction (whole year)	2nd semester only, 2-4 days:5-10% reduction whole year, 2-4 days: 7-15% reduction	Short term: 2-4 days:5-11% catch reduction (2nd semester only) 2-4 days: 7-15% catch reduction (whole year) Long term: <3% increase in overall yield	Short term: 2-4 days:4-9% catch reduction (2nd semester only) 2-4 days: 7-15% catch reduction (whole year) Long term: not available	2nd semester only 2-4 days:5-11% reduction in catch whole year 2-4 days: 7-15% reduction in catch
Limitations on the number of FADs and/or their electronic equipment	Should potentially reduce the fishing mortality due to FADs	Reduction; not enough information to quantify	Reduction; not enough information to quantify	Uncertain, but even total ban is unlikely to increase yield by more than 13-24% depending on scenario	Reduction; not enough information to quantify	Reduction, with amount depending on extent of the limitation
Ban of supply vessels	Supply vessels are important only for some PS vessels (9 supply vessels operating)	Reduction; not enough information to quantify	Reduction; not enough information to quantify	Uncertain	Uncertain	Reduction; not enough information to quantify
Limits on skipjack catches by trip for purse seiners	Recommended in 2001 by various tuna boat owner associations in order to improve the SKJ market prices	Reduction; not enough information to quantify	Reduction; not enough information to quantify	Uncertain	Uncertain	Reduction depending on extent of limitation
Size Limit	Such measures have commonly been adopted by various fisheries agencies; used for tunas by ICCAT	Uncertain, depending on success of implementation	Uncertain, depending on success of implementation	Uncertain, depending on success of implementation	Uncertain, depending on success of implementation	Uncertain, depending on success of implementation

Table .2. Summary evaluation of advantages and disadvantages of the management measures considered.

Management measure	Advantages	Disadvantages
Time-area closure to purse seine fishing	• Improve the long-term yield per recruit. (It was noted that, in case of stocks that are heavily exploited a reduction in the catch of juveniles would lead to an increase in yield per recruit and spawning stock size. In the case of yellowfin tuna, the benefits would flow to the purse seine, driftnet and longline fisheries. For bigeye tuna the only beneficiary would be the longline fishery). • Possible decrease in the total discards from the fishery.	• Loss of catch of skipjack to purse seine fleet • Likely difficulties with compliance; lack of compliance would reduce the benefits of the measure • Likely redirection of effort to other areas within the Indian Ocean
Reduction in overall purse seine effort	Reduction in number of vessels: • Could reduce the catches of bigeye and yellowfin taken in association with FADs • Reduced effort cannot be redirected to another area/time within the Indian Ocean	Reduction in number of vessels: • May be difficult to implement • Given the differences in efficiency between vessels, different implementations (choice of vessels to exclude from the fleet) would lead to different levels of effectiveness of this measure
	Increase in the number of days in port: • Could reduce the catches of bigeye and yellowfin taken in association with FADs	Increase in number of days in port: • May be difficult to implement, particularly in case of transshipping at sea
Limitations on the number of FADs and/or their electronic equipment	• Addresses problem directly • Reduction in the number of FAD-associated sets	• Monitoring the number of drifting objects deployed by purse seiners would imply having inspectors on board permanently, including on supply vessels. • At this stage there is no information about the relation between the number of drifting objects deployed and the resulting catches.
Ban of supply vessels	Could lead to a reduction in the number of FAD-associated sets.	• Difficult to quantify at this stage • Only some vessels use supply vessels • May be difficult to implement
Limit on skipjack catches by trip for purse seiners	Could lead to a reduction in the number of FAD-associated sets.	• Difficult to implement • Decrease in catch of skipjack • Possible increase in discards
Size limit	Currently none - cannot be implemented	It is not possible to implement this measure effectively given current technology.

7.3. Summary and management gaps

Annex 1 provides details of the specific management actions taken by RFMOs. The details are taken from the full resolutions and only those elements that relate to FAD fishing have been given. These are separated into those resolutions that make direct reference to FADs or to floating objects, and those resolutions that whilst they do not refer directly to FADs are relevant, e.g. assessment of fishing capacity, resolutions on turtles, etc. A summary of the measures adopted by the different RFMOs is provided in Table 38.

Table 38 Summary of RFMO management measures in relation to mitigating the effect of FAD fisheries.

Management measure	Action take			
	IATTC	WCPFC	ICCAT	IOTC
Mitigation through modification of fishing effort and avoidance of bycatch				
Spatio-Temporal Closures and marine reserves	C-04-09 Implemented 3 year closure in the EPO, defined as the area bounded by the coastline of the Americas, the 40°N parallel, the 150°W meridian, and the 40°S parallel, shall for 2004, 2005 and 2006 be closed from either (1) 0000 hours on 1 August to 2400 hours on 11 September; or (2) from 0000 hours on 20 November to 2400 hours on 31 December.	Closures defined in CMM 2008-01 for 2 months for all purse seine fisheries on FADs between 20°N and 20°S. Observer coverage at all times during this period. High seas closed during this period, unless Member can show full compliance.	98-01, 99-01, 04-01 define closed area in the Gulf of Guinea to FAD operations. 04-01 extended in 08-01 through 2009 and recommendation for analysis of effects of extending the closure in 2010.	Considered but to date no resolution has been applied. A voluntary industry ban on FADs occurred in a defined area in 1998-99
Catch and effort limits (e.g. cap on vessels)	No specific regulations in place, but C-99-07 resolution in place which recommends that parties and non-parties with jurisdiction over vessels operating in the EPO, prohibit transhipment of tuna by purse seine vessels (unless in port) and prohibit the use of tender vessels supporting vessels fishing on FADS in the EPO. Capacity resolution 02/03 is also relevant but again does not refer specifically to FADs	None	93-04 cap on the level of effective fishing effort on Atlantic yellowfin tuna to that observed in 1992. Capacity working group established in 2007 to investigate the problem.	**Effort**: CPCs with more than 50 vessels on the IOTC record of vessels shall limit vessels >24 m to the number registered in 2003. Non members of IOTC who fish for bigeye tuna were requested to reduce their fishing effort in 2002 in relation to 1999 levels **Catch**: CPCs shall limit their catch of bigeye tuna to recent (2005) levels reported by the Scientific Committee (but no subsequent quotas were set)
Effort Limit (FADs)	No specific regulations in place, but C-99-07 resolution in place to	Management plans for FADs to be presented to the	Capacity working group established in 2007 to investigate	None, but since 2008 detailed statistics have been

Management measure	Action take			
	IATTC	**WCPFC**	**ICCAT**	**IOTC**
	establish a scientific working group tasked to establish a maximum number of sets on floating objects which tuna fishing in the EPO can support.	Commission by 01/01/2008. (CMM 2006-01). CMM 2008-01 requests new FAD management plans by 01/07/2009 for use on high seas including strategies to limit capture of small bigeye and yellowfin tunas Secretariat will provide management options on marking and ID of FADs, electronic monitoring, registration and position and limits of FADS deployed or set.	the problem.	gathered on the deployment of FADs
Support vessel limits	Prohibit the use of tender vessels operating in support of vessels fishing on FADs in the EPO	None	None	None
Transhipment vessel limits	None but tuna purse seine vessels do not normally tranship at sea. Transhipment observer programme in place 2008 to date.	None but tuna purse seine vessels do not normally tranship at sea.	None but tuna purse seine vessels do not normally tranship at sea. Transhipment observer programme in place 2007 to date.	None but tuna purse seine vessels do not normally tranship at sea. Transhipment observer programme in place 2009 to date.
Discard Ban	C04-05 (REV2), C-05-05 and C-06-03 define full retention rules. Results from 3 years awaiting publication.	CMM 2008-01 requires full catch retention on board from 01/01/2010 if observer programme implemented.	None	None
Mitigation through modification of fishing gear and practices				
Mesh size limits	None.	CCMs to develop under 2005-04 enhanced mitigation for turtle bycatch and 2006-01 for juvenile tuna mitigation. CMM 2008-01, 3 year program to explore methods to reduce juvenile tuna bycatch	Size limit recommendations in place for bigeye (79-01) and yellowfin 99-01 in place until 2004. These were not implemented through gear (mesh size) controls, however.	No specific resolutions, but a recommendation on turtles and a resolution on sharks apply. Both 'encourage' release of bycatch animals and propose research to explore more selective fishing gear. The onus is on the flag-state and on voluntary action by fishing companies.
Escape panels	C-04-05 IATTC to act on reduction of mortality on juvenile tunas through escape panel technology. C-07-04 specifies arrangements for experimental use of		None	

Management measure	Action take			
	IATTC	WCPFC	ICCAT	IOTC
	flexible grids to allow the escape of small tunas. Device testing in place for 90 days.			
Manual release	C-07-03 take actions to avoid encirclement of tunas, monitor turtle catches and report to the Commission. Rules on release of turtles under C-04-05 (REV 2)	Manual release recommended where possible (2005-04 and 2008-03) . Dip nets to be used.	92-01 encourages release of turtles and collection of data.	

As outlined in this report, management and mitigation methods include two broad categories: the modification of fishing effort (and catch) and avoidance of bycatch; and, modification of fishing gear and fishing practices. Within these broad categories management measures that RFMOs have applied (or are planned) with specific reference to FADs include:

- spatio-temporal closures;
- to date there have been no effort limits applied directly to FADs but RFMOs have put in place mechanisms to gather more data, to explore the question of fishing capacity, and to seek proposals for future management plans related to FADs (WCPFC – CMM 2008-01 Attachment E provides guidelines for the preparation of FAD management plans[6])
- full catch retention rules (i.e. discard bans)
- a variety of measures related to modification of fishing practices (e.g. avoid sets on turtles) and gear (e.g. escape panels)

Management controls on FADs require careful consideration. Controlling fishing on FADs has complex biological (e.g. target switching from skipjack to potentially more vulnerable species), social (e.g. employment, the benefits to coastal states, competition for resources with artisanal fishers in coastal states), and economic (e.g. purse seining is highly efficient compared to alternative methods that may be proposed) implications. The current review has focussed primarily on the biology, assessment and management of FAD associated fisheries and has not explored the social and economic impacts that would also need to be taken into account in management decisions.

Overall there is currently limited management of FAD fisheries and a combination of approaches is likely to be most appropriate. There is a need to develop guidelines for best management practice for FAD fisheries. There is also is significant need for better and more data to inform management decisions.

[6] By 1 July 2009, CCMs fishing on the high seas shall submit to the Commission Management Plans for the use of FADs by their vessels on the high seas. These Plans shall include strategies to limit the capture of small bigeye and yellowfin tuna associated with fishing on FADs, including implementation of the FAD closure pursuant to paragraphs 13 and 19 above. The Plans shall at a minimum meet the Suggested Guidelines for Preparation for FAD Management Plans for each CCM (Attachment E)

8. Existing projects related to FADS

In addition to the information on previous research that has been captured in the literature reviews presented in the earlier sections of this report, there are a number of recently completed and current projects that will provide relevant information on tuna fisheries associated with FADs. Here we provide details of the objectives of those projects as this will contribute to our analysis of the gaps in knowledge and research (Section 9). The projects have been separated according to the focus of their major objective, although in many cases each project may have a number of objectives that fall into different categories.

Most of the current or recently completed projects are focussed on questions that relate to the behaviour and ecology of tunas associated with FADs (Table 39) for which the issues were described in Section 4. Only GAP 1 explicitly indicates that it will investigate the positive effects of FADs on ecosystems in addition to any negative effects. In addition to those projects identified in Table 39, SELAC (Table 40), the Indian Ocean Tuna Tagging project (Table 41) and the Ocean Tracking Network (OTN, Table 42) have elements related to the ecology and behaviour of tunas and are relevant to FAD research. MADE, in addition to looking at tunas explicitly looks at the impacts of FADS on the biology of bycatch species and will focus on silky sharks.

Table 39: Projects which focus on the behaviour and ecology of tunas associated with FADs

Project Title	Project Objectives
FADIO; 2003 - 2006	FADIO I was built around two principal objectives in order to, in the long term, transform FADs into observatories of the pelagic ecosystems: - Development of prototypes: new electronic tags and instrumented buoys to observe fish aggregations around FADs. - Improvement of knowledge on the behaviour of pelagic fish around FADs. http://www.fadio.ird.fr/
EU-MADE. Mitigating adverse ecological impacts of open ocean fisheries	This is an EU regional project and in relation to FADs will link with BIOPS, GAP1, OTN and also SWIOPF which will include FAD work in Seychelles. With respect to FADs MADE will look at options for reducing FAD bycatch. It will address the question: Does the release of large numbers of FADs affect the behaviour and biology of the fish? It will look particularly at silky sharks and mitigation measures to reduce their capture and address the question: Do artificial FADs affect the biology of sharks
GAP1 2008-2009	Current RFMO management practices are such that the scientists from working parties of the RFMOs define hypothesis and methodologies. Whilst the fishing industry provide the required data, that is in turn analysed by scientists. GAP1 redefines this approach with the concept that fisherman should work together to define scientific questions, combining industry's knowledge and "classic" scientific knowledge (3). The purpose of GAP1 is to initiate cooperative research processes that provide the background knowledge and partnerships for preparation and implementation of a stakeholder-science participatory research project (2). The project covers a wide range of issues including that of FADs. The subsequent agreements that were made

	between industry and scientists on the issue of FADs are listed below: - Identify negative (are FADs ecological traps for tunas and other associated species?) and positive effects of FADs on the ecosystems. - How much and how does the amount of juvenile tunas caught around FADs affect the tuna populations? - Can fish behaviour provide indicators of the status and evolution of the ecosystems, and used to predict the changes in the ecosystems and therefore improve the stock assessments? (3) (1) http://www.gap1.eu/ (2) http://www.gap1.eu/Aboutus/Aboutus.htm (3) http://www.gap1.eu/Downloads/GAP_Regionalmeeting1IRD-AZTI.pdf
Pacific Tuna Tagging Programme, SPC Tuna Tagging 2006 - ongoing	The Pacific Tuna Tagging Programme (PTTP) is a joint research project being implemented by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC), the PNG National Fisheries Authority (NFA) and the members and participating non-members of the Western and Central Pacific Fisheries Commission. The goal of the PTTP is to improve stock assessment and management of skipjack, yellowfin and bigeye tuna in the Pacific Ocean. The objectives are: 1. To obtain data that will contribute to, and reduce uncertainty in, WCPO tuna stock assessments. 2. To obtain information on the rates of movement and mixing of tuna in the equatorial WCPO, between this region and other adjacent regions of the Pacific basin, and the impact of FADs on movement at all spatial scales 3. To obtain information on species-specific vertical habitat utilisation by tunas in the tropical WCPO, and the impacts of FADs on vertical behaviour. 4. To obtain information on local exploitation rates and productivity of tuna in various parts of the WCPO. Phase 1 began in PNG and Solomon Islands in 2006 and Phase 2 continued into the Western and Central Pacific. www.spc.int/tagging
IATTC: Regional tagging program for bigeye, skipjack, and yellowfin tuna in the eastern Pacific Ocean, 2010-2012	This is a new proposal for a regional tuna tagging program. The primary objective is to conduct large-scale tagging of the three main commercial species of tunas, bigeye (Thunnus obesus), skipjack (Katsuwonus pelamis), and yellowfin (Thunnus albacares), captured in the purse-seine and longline fisheries of the eastern Pacific Ocean (EPO). The data obtained would improve the scientific basis for estimation of the exploitation, movements, natural mortality, and growth rates of these species in the EPO. There is a particular emphasis on addressing questions related to FADs http://www.iattc.org/PDFFiles2/IATTC-78-08c-Regional-tagging-program.pdf
Pacific tuna Tagging Programme	See below: 'Projects that focus on providing data useful for stock assessments and other purposes'.

Only GAP1 aims to address a question related to improving tuna stock assessments (see Section 5) through looking at changes in the ecosystem as an indicator to improve stock assessment, so the focus remains largely ecological. GAP1 also aims to address a management related question (Section 7): How much does the amount of tuna caught around FADs affect the population. From a management perspective it is necessary to understand how important it is to limit fishing on juveniles.

Improvements in gear technology and modification of fishing practices are additional measures that managers and fishers can employ to mitigate against the adverse effects of fishing on FADS (See Section 7). This area is the focus of two projects (Table 40). Together these projects may help to identify the means of reducing bycatch and/or juveniles of yellowfin and bigeye tuna under FADS through remote identification of the species composition of the fish under a FAD, and also the modification of fishing practices to avoid them. FADIO also looked at technologies for observing fish under FADs.

Table 40: Projects related to gear technology and modification of fishing practices

Pilot Study on purse seining in the Indian Ocean AP – 07/2004 [Apcerco – Oceano Indico] 2004	The overall objective of this project was to obtain information into to the behaviour of the various tuna species around FADs in the Indian Ocean, aiming to improve the FADs selectivity. For this purpose, using acoustic equipment, it was possible to: - differentiate the various tuna species - differentiate the various sizes of each species - study the mechanisms underlying the fish's attraction to floating structures
ABYSS Juvenile bigeye tuna catches by purse seiners according to depth around FADs 2004-2006	The objectives if this project are to investigate: - Catches of juvenile bigeye tuna around FADs according to depth and temperature - Catches according to the type of purse seine net - Catch composition around FADs with each net http://www.ieo.es
SELAC (Research on Acoustic Selectivity on FAD associated tropical purse seine fisheries in the Eastern Pacific Ocean) July 2009	The SELAC project is based on a pilot Project run in the Western Indian Ocean from 15th May – 15th December 2005. The Acoustic selectivity Project utilises two Spanish flag purse Seine vessels. The vessels stay away during monitoring whilst a speed boat with echo sounders monitors the FAD 1-2 hours prior to setting. Monitoring is then carried out again by the purse seiner immediately before setting. The objectives of this project and the methodology used are the following; • Obtain the individual echoes to discriminate by species and sizes of tunas under FADs. • Being able to determine species, biomass and size of tunas concentrated under FADs.. • Behavioural study of tunas under FADs. PowerPoint summary: Borrador SELAC 2008 inglés.ppt (unpublished)

All projects will provide additional useful data but a couple are more focussed on specifically providing information such as growth and mortality parameters, and indices of abundance that will be useful in improving the outputs from stock assessment models (Table 41). GAP 1 also falls into this category as outlined above.

Table 41: Projects that focus on providing data useful for stock assessments and other purposes.

Regional Tuna Tagging Project – Indian Ocean	As a consequence of the increasing capacity of the tuna fishery in the Indian Ocean with the catches now exceeding 700,000 tonnes per annum a tuna tagging project has been implemented in the Indian Ocean (2). The project's objective is to reinforce IOTC's management capacity to encourage a sustainable exploitation of tuna resources. The specific objectives are; • Reinforcing scientific knowledge of tropical tuna stocks • Determining the rate of exploitation, by obtaining the crucial model parameters necessary for stock assessment (2) The tagging programme provides information on the following areas; • Stock structure and migrations • Growth parameters • Natural mortality as a function of age and sex • Interactions between different fisheries • Behaviour of tunas as a function of their environment • Impact of FADs on the resource The last two areas being the most relevant to the current study (2). http://www.rttp-io.org/en/ (2) http://www.rttp-io.org/en/about/
Pacific Tuna Tagging Programme, SPC Tuna Tagging 2006 - ongoing	The Pacific Tuna Tagging Programme (PTTP) is a joint research project being implemented by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC), the PNG National Fisheries Authority (NFA) and the members and participating non-members of the Western and Central Pacific Fisheries Commission. The goal of the PTTP is to improve stock assessment and management of skipjack, yellowfin and bigeye tuna in the Pacific Ocean. The objectives are: 5. To obtain data that will contribute to, and reduce uncertainty in, WCPO tuna stock assessments. 6. To obtain information on the rates of movement and mixing of tuna in the equatorial WCPO, between this region and other adjacent regions of the Pacific basin, and the impact of FADs on movement at all spatial scales 7. To obtain information on species-specific vertical habitat utilisation by tunas in the tropical WCPO, and the impacts of FADs on vertical behaviour. 8. To obtain information on local exploitation rates and productivity of tuna in various parts of the WCPO. Phase 1 began in PNG and Solomon Islands in 2006 and Phase 2 continued into the Western and Central Pacific. www.spc.int/tagging
IATTC: Regional tagging program for bigeye, skipjack,	This is a new proposal for a regional tuna tagging program. The primary objective is to conduct large-scale tagging of the three main commercial species of tunas, bigeye (Thunnus obesus), skipjack (Katsuwonus pelamis), and yellowfin (Thunnus albacares), captured in the purse-seine and longline fisheries of the eastern Pacific Ocean (EPO). The data obtained would improve the scientific basis for estimation of the exploitation, movements, natural mortality, and growth rates of these species in

and yellowfin tuna in the eastern Pacific Ocean, 2010-2012	the EPO.
Study of Tuna Fishing Ground Condition in the Eastern Indian Ocean, 2001 - 2003	The main objectives of the project are: - To investigate the relationship between oceanographic and meteorological parameters and the CPUE of MV. SEAFDEC purse seine operation - To collect continuously long term data for finding out the appropriate index for the abundance of Tuna in the Eastern Indian Ocean http://map.seafdec.org/tuna/index.html

Finally we provide details on a couple of projects that will provide relevant research but which are not directly related to FADs (Table 42). This table is not exhaustive and there will be many others in this category (e.g. CLIOTOP that looks at climate impacts, http://web.pml.ac.uk/globec/structure/regional/cliotop/cliotop.htm). These projects help in understanding the characteristics of water masses where tuna aggregate and are intrinsically linked to research into the behaviour of tunas which will ultimately lead to a better understanding of mechanisms resulting in the attraction of tunas to FADs.

Table 42: Others relevant projects not directly related to FADs

Project Title	Project Objectives
Ocean Tracking network, 2007-	Throughout the years, the abundance of a great variety of commercial fish species has been steadily declining in the world's oceans. The underlying reasons why fisheries resources are becoming increasingly scarce are tightly linked to factors such as overexploitation and pollution, in addition to many other factors that also contribute to this reduction, including climate change, shift in migratory patterns, etc.. Despite extensive scientific effort to collect information and scientific data throughout the last decades, information from beneath the sea's surface is still very limited, constituting a large void into the knowledge of the ecology of marine ecosystems. A far better understanding into this topic is needed as human's future survival is directly linked to the stability of oceanic life. The Ocean Tracking Network (OTN), a $168-million conservation project, will help to close the gap into this knowledge. With it, thousands of marine animals around the world — from fish to birds to polar bears — will be tracked using acoustic sound waves. At the same time, we will be building a record of climate change — data that can be analyzed and then applied http://oceantrackingnetwork.org/index.html
Origin of yellowfin tuna in the Hawaiian Islands using natural markers in otoliths -2008	The current work is a collaborative effort with David Itano of University of Hawaii. The aim of the proposed work is to provide information on the origin of young yellowfin tuna (age-1 and age-2) in the Hawaiian Islands using natural tracers that are linked to ambient physicochemical conditions of the water. Our first step will be to develop a reference library that describes the otolith chemical signatures of age-0 yellowfin from putative spawning/nursery areas in Hawaii and the broader WCPO (i.e. are ambient chemical conditions in regional nurseries sufficient to impart unique signatures in the otoliths of yellowfin?). It has long been assumed that juveniles from the equatorial region are purported to be the main source of recruits to the Hawaii-based fisheries and will therefore be a critical sampling location for the proposed work. Next, we will target age-1 and age-2 (sub-adult to young adult) yellowfin from the Hawaiian Island fisheries to determine their source (natal origin). Three hypotheses will be tested

	using otolith chemistry: H1: chemical signatures in the otoliths of yellowfin from regional nurseries differ, H2: inshore fisheries for yellowfin around the Hawaiian Islands are supported primarily by local recruitment (i.e. resident populations), H3: juveniles from the equatorial region are the main source of the recruits to the Hawaii-based fishery. We will then be able to determine whether residents (versus transients) constitute the primary source of yellowfin recruits to the Hawaii-based fisheries. Collection of yellowfin from the Hawaiian Islands and areas of the broader WCPO are currently underway and preliminary results are expected by summer 2008. http://www.tamug.edu/rooker/pelagic.html

9. Gap analysis and future research needs

The literature review provided in the previous Sections has identified a number of issues that require further research in order to better inform the management of tuna fisheries based on FADs and to mitigate against the negative impacts of FADs that have been described. A previous gap-analysis conducted in 2004 looked at the current knowledge and identified future directions specifically for ecological studies (Dempster and Taquet, 2004). Bromhead *et al* (2003) also identified some potential future research directions. The current review has looked at what has been done since 2003-4, and has also explored in more detail the issues related to stock assessment and management of tuna stocks.

We have identified future research needs that apply to a number of areas: research generally; the impacts of FADS on fish behaviour and ecology, including bycatch species; information to improve stock assessments; informing management decisions; gear technology; and social and economic impacts of FADs that have not been addressed in the current review. Cross cutting all these research areas a common thread has been a significant need for more and better data related to FADs, their deployment and the impacts of fishing around them. The following Sections look at these research areas in more detail examining the issues, research needed to address those issues, and a broad statement on how to address the research, i.e. through new field studies or through desk based studies including literature reviews, assessments and simulation modelling approaches. We also indicate where current research has begun to address some of those issues. Amongst the future requirements there is a significant role for industry to play in collaboration with scientists and the RFMOs.

9.1. FAD research in general

Looking at the research question in general as it relates to FADS, Dempster and Taquet (2004) highlight the low level of FAD related research funding. Since that time there have been a number of FAD related initiatives (see Section 8) but relative to the value of the tuna industry considerably more research is justified. They also indicate that there is a paucity of research based on floating FADs employed in tuna purse seine fisheries, and a paucity of empirical studies to test research hypotheses related to FADs (Table 43).

Table 43: Issues related to FAD research in general (1).

Issue	Research needed	How to address? (Current projects)
1.1. To date most research has been focussed on fixed FADs (Dempster and Taquet 2004)	More research into the effects of drifting FADs is needed making more use of tagging, acoustic techniques and remote data collection.	Field research; (Note that many of the more recent projects referred to in Section 4 relate to floating FADs)
1.2. To date most research has been focussed on observation and descriptive studies (Dempster and Taquet 2004)	More experimental research approaches need to be applied to address the various questions surrounding FADs	Design empirical field studies
1.3. Low level of research funding (Dempster and Taquet 2004)	More funding of FAD research is needed.	Communicate the issues raised in this review, and the research areas identified. Mobilise further international research effort (Note that since 2003a number of new projects have been initiated).

9.2. Research into the impacts of FADS on fish behaviour and ecology

As described in Section 4 there remain a number of questions relating to how and why FADs act to attract fish to them, a better understanding of which may inform management. Currently there is no scientific consensus on the impact of FADs on behaviour and ecology of tunas compared to free swimming fish in similar areas. In particular the hypothesis that FADs trap fish in unproductive areas needs to be further tested against arguments that observed effects are a reflection of naturally occurring differences for fish in different parts of the ocean or stages of their migratory cycle. In addition to such research related to target tuna species, bycatch and discards are an issue that needs further investigation. Wider ecosystem modelling approaches may be relevant, but parameterisation of the models is at an early stage and better data on the characteristics of a wide range of species is required (Table 44).

Table 44: Research into the impacts of FADs on fish behaviour and ecology (2).

Issue	Research needed	How to address? (Current projects)
2.1. It is still not clear why fish aggregate under FADs (meeting points, spatial reference points, feeding points), or what are the underlying sensory processes attracting them	If this was better understood, it is possible that better management / mitigation measures could be identified. This may include understanding the sensory processes leading fish to be attracted to FADs	Field Research - Fish behaviour and ecology. (Relevant projects MADE / FADIO / GAP1/SPC tuna tagging)
2.2. There is conflicting evidence on the ecological consequences of tuna aggregations on FADs	The impact of FADs on growth rates and diets of FAD-associated and un-associated tuna by species and size/age; extent of cannibalism in FAD associated tuna; association of juveniles to FADs; Effects of drifting FADs on large-scale migration patterns (utilising tagging, acoustic techniques and remote data collecting); Extent to which drifting FADs are populated by tuna and residence times of associated species where major purse seine fisheries operate; Determination of diurnal vertical movements of different species and sizes of tuna under drifting FADS to aid development of more selective fishing methods targeting these structures.; and, Considering all the above, what can be deduced on the unresolved question of whether FADs trap fish in unproductive areas or whether currently observed differences are a function of the differences that would be observed in condition of fish in different areas of the ocean anyway .	Field Research - Fish behaviour and ecology. (Relevant projects MADE / FADIO / GAP1/PNG tuna tagging; IO tuna tagging project looked at stock assessment model parameter – growth, mortality etc, SPC Tuna tagging Programme looks at fish movement in addition to growth and mortality; In the Pacific, the proposed IATTC tuna tagging programme will look at movement and mixing rates and factors such as growth and mortality)
2.3. Tunas naturally aggregate under floating objects but the reasons for this are not well understood. The fact that they do so suggests that there must be some natural benefit to the fish populations.	What is the evolutionary benefit that has led to this aggregation behaviour. Can these benefits be harnessed in any way to support the sustainability of fish stocks?	Field research (GAP1 explicitly, but other projects focussed on the ecology and behaviour of tunas may also shed light on this)
2.4. Wider Ecosystem modelling approaches will have relevance although parameterisation of the models is currently at an early stage.	Wider ecosystem modelling	Desk research, but underpinned by a substantial amount of field data. (CLIOTOP?)

9.3. Research to inform stock assessments

Section 5 described the current approaches to tuna stock assessment and the issues that impede reliable assessments particularly related to fishing around FADs. Improved data collection will benefit stock assessments (Section 9.7) but a number of research activities can be identified that would inform the stock assessment process itself (e.g. better characterisation of FADs and their efficiency; understanding potential bias introduced through uncertain growth parameter inputs, Table 45).

Table 45: Stock assessment related research (3)

Issue	Research needed	How to address? (Current Projects)
3.1. A range of different FAD types are deployed. Difference in FAD design and how effectively they aggregate fish will affect their relative fishing power and thus the derivation of abundance indices.	Develop a categorisation of FADs and through empirical studies determine their relative effectiveness in order to standardise effort related to FADs and improve the potential for developing abundance index related to FADs.	Initial desk study building on categorisation of FADs indicated in Section 3. Field research to test the effectiveness of different categories of FADs - work closely with industry.
3.2. Particularly for SKJ that are caught predominantly on FADs, there are significant problems in deriving accurate catch rate indices to undertake stock assessment (YFT and BET benefit from having a more reliable longline time series of cpue)	A method for deriving catch rate indices for FADs needs to be developed. It must account for the spatial dynamic of multiple FADs deployed in an area, their relative efficiency in aggregating fish, and the spatial dynamic of fishing effort.	Desk Study, may require improved data. (ESTHER (Gaertner and Pillares, 2001); MV SEAFDEC, IO tuna tagging)
3.3. SCAA and SCAL models include a growth curve estimated from tagging, otolith and catch at size data. Estimates from tag data may be biased by the selectivity of tag-recapture fisheries. Thus there may be a bias towards sampling slower growing fish where tagged fish are predominantly caught around FADs.	Simulation modelling of tag returns under different selectivity assumptions in order to quantify the level of bias that may have been introduced into growth curve estimation as a result of the FAD fishery. This will lead to improved stock assessments.	Simulation modelling in order to inform better stock assessments
3.4. Catch per set as a measure of effort avoids some problems of defining effort related to FADs, but will be subject to its own limitations related to number of FADs in an area	How does the changing spatial distribution of FADs influence catch rates and how can this be addressed?	Simulation modelling - sensitivity analyses. Better spatial data required.
3.5. Estimating natural mortality accurately. So far only the SPC, and recently the IOTC, have been able to estimate M using tag data from their own studies. This leaves a major uncertainty surrounding stock assessments currently conducted by the IATTC and ICCAT, particularly since the mortality rates used are so different. This difference in itself is clearly grounds for further research,	Research is needed firstly to understand limitations in the tagging data that prevent reliable estimations of mortality being made. Subsequent research will feed into tagging programmes to resolve these issues. This is therefore a priority so that the planned tagging programme in the EPO can benefit. A particular issue is to determine juvenile mortality.	IOTC and SPC tuna tagging programmes.

9.4. Research to inform management decisions

Managers must sustainably manage the multispecies target tuna fisheries whilst at the same time, in relation to fishing on FADs, seeking to minimise the negative impacts of FADs on components of the multispecies stock (i.e. the removal of juveniles of yellowfin and bigeye tuna whilst targeting skipjack tuna) and on incidentally caught species. Whilst ecological studies have identified that removal of juveniles and bycatch is an issue, managers need to understand whether these impacts have a significant detrimental effect on the sustainability of tunas and other species. A range of management controls are available (see Section 7). Management simulations enable alternative management controls to be evaluated in order to determine their likely impact. Table 46 identifies potential research activities to address these management questions.

Table 46: Research to address management questions (4).

Issue	Research needed	How to address? (Current projects)
4.1. With the increased level of fishing on FADS how does the increased juvenile mortality on BET and YFT affect resource sustainability? Results from existing work are ambiguous, but in the Pacific at least suggest that a reduction in purse-seine fishing on FADs will be beneficial to bigeye productivity. Although fleet interactions have been estimated by the IOTC the recent estimation of mortality in the Indian Ocean makes it worthwhile to re-address this question.	Does removal of YFT and BET juveniles lead to overfishing? What are the potential consequences of reductions in purse seine fishing effort on the stability and productivity of the bigeye and yellowfin tuna populations in the Indian Ocean? Simulation studies utilising the improved parameter estimates from the IO tagging programme are now feasible. If warranted, this analysis could be extended to other oceans, so that results could be compared and presented within a comprehensive and unified framework Improved estimation of life history parameters is needed to extend this work further, particularly natural mortality (see 3.5).	Simulation studies to improve on existing investigations in to the impact of FADs on YFT and BET vulnerability to overfishing and the potential impacts of FAD effort changes. In depth review and potential re-estimation of natural mortality rates by Ocean. (GAP1; Tagging programmes)
4.2. There has been limited work undertaken on the impact of exploitation arising from FAD fishing on bycatch species. Often there is insufficient data to undertake stock assessments of those species	Does the removal of Bycatch species have a significant impact on the sustainability of those resources (separate out also by IUCN redlist and other species), Simulation modelling approaches could be applied to look at the sensitivity of different populations to exploitation by FADs	Stock assessments of by catch species. Data poor methodologies will need to be applied. Improved data collection necessary; Simulation modelling.
4.3. There has been limited quantitative evaluation of the potential benefits of spatio-temporal closures and fixed closures for highly migratory tuna stocks.	Simulation modelling to quantitatively evaluate the consequences of closures for the biomass dynamics of exploited tuna stocks.	Management simulations
4.4. Bycatch species include sensitive species (IUCN redlist, sharks, turtles etc) and others of less concern. A clear understanding of the most at risk species from FAD fishing needs to be developed.	Conduct ecological risk assessments of FAD bycatch to identify the most at risk species that should be targeted for improved management / mitigation measures.	Desk Study - may require additional data on bycatch species.
4.5. The balance between natural and fishing mortality and how it is changed by FADs on juvenile and adult parts of the tuna population is critical.	.	Management simulations: (draws on the IOTC Tuna Tagging data and relevant for other tagging programmes looking at juvenile mortality)

9.5. Gear technology related research

Amongst the various management controls Section 7.2.2 described approaches to address the impacts of FADs through the modification of fishing gear and fishing practices. This is an important area of research (Table 47) and should be pursued and implement in conjunction with a range of other management controls.

Table 47: Gear technology related research (5)

Issue	Research needed	How to address? (Current projects)
5.1. The use of FADs increases the bycatch associated with purse seine fisheries compared to fishing on free schools. A range of mitigation measures and modification of fishing practices can reduce the level of bycatch.	Mitigation measures to reduce bycatch species - more research into the various mitigation measures available is required, including modifications to fishing practices to minimise bycatch.	Laboratory research and field research working closely with industry. (REDES / SELAC/ FADIO)
5.2. Gear technology and modification of fishing practices may also offer potential for reducing catches of juveniles of target species.	Mitigation measures to reduce or avoid fishing on juveniles of YFT/BET and enhance targeting on SKJ. (e.g. remote detection of species composition under a FAD prior to fishing).	Laboratory research and field research working closely with industry. (REDES / SELAC/ FADIO)

9.6. Research on the social and economic impacts of FADs

FAD fisheries are now well established and are highly efficient providing a substantial quantity of fish to meet global demand. This report has highlighted a number of issues related to FADs including their potential to result in overfishing, the rapid development of the technology making assessment of FAD based fisheries difficult, and their ecological impacts on both target and incidentally caught species. Controlling fishing on FADs has complex biological (e.g. target switching from skipjack to potentially more vulnerable species), social (e.g. employment, the benefits to coastal states, competition for resources with artisanal fishers in coastal states), and economic (e.g. purse seining is highly efficient compared to alternative methods that may be proposed) implications. The current review has focussed primarily on the biology, assessment and management of FAD associated fisheries and has not explored the social and economic impacts. An additional literature review and analysis of the social and economic impacts of FAD fisheries is justified (research area 6), and would identify other areas of relevant research not covered here.

9.7. Data requirements related to FADs

This review has highlighted the paucity of data available in order to fully characterise and assess FAD fisheries. There is a need to collate comprehensive data across the whole fishery at the level of RFMOs and in order to achieve this it will be necessary for the fishing industry to support RFMOs in this effort. A number of improvements to data collection are indicated in Table 48.

Table 48: Data requirements related to FADs (7)

Issue	Research needed	How to address?
7.1. There is a lack of comprehensive quantitative information on bycatch and discards. Snapshot information is currently available based on limited research and observer programmes.	More comprehensive data collection at level of RFMO of bycatch species numbers, weight and size caught, released alive and discarded dead that may be attributed to FADs	RFMOs with industry support
7.2. Catch per set as a measure of effort avoids some problems of defining effort related to FADs, but will be subject to its own limitations related to number of FADs in an area	Better data on the use and deployment of FADS: Enhanced spatial data related to FAD deployment is needed including the location of all purse seine sets FAD / Free, the number and location of unfished FADs, the total number of FADs deployed in an area.	RFMOs with industry support. IOTC has introduced enhanced data collection on FAD deployments since 2008
7.3. Currently juvenile YFT and BET caught around FADS are recorded as a single species. BET then need to be estimated from observer or port sampling records.	Enhanced data collection and coverage providing better detail on species and size composition (yellowfin or bigeye?) and leading top more accurate indices of abundance.	RFMOs with industry support
7.4. Information necessary to define areas suitable for spatio-temporal closures needs to be more clearly defined.	Better understanding of location and timing of key life cycle events of both target species and sensitive bycatch species in order to define spatio temporal closures.	Desk study: Analysis of existing available spatial data; Field research: New research and observer programmes investigating size and maturity over space and time; (MADE, FADIO, GAP1) Enhanced data collection as described above and analysis.

9.8. A summary and prioritisation of future research requirements

Fisheries science should have as its ultimate aim the improved management of fish stocks in order to ensure their long term sustainability within an ecosystems based approach that also considers the impacts of fishing on non target species. Research should aim to underpin that goal. Such a goal is foremost in defining the proposed prioritisation of future FAD research in combination with the analysis of what areas have already been addressed.

Seven broad areas of research to address knowledge gaps have been identified through the analysis of literature reviewed in this report. Looking at recently completed and current research projects it is clear that new research has already begun to address some of those gaps, and in particular there has been a focus on developing a better understanding of ecosystems and behaviour of tunas as they relate to FADs (research area 2). Nevertheless a huge amount of work remains to be done supporting the finding by Dempster and Taquet (2003) that there is a relatively low level of funding and more needs to be done, and in particular in relation to floating FADs (research area 1). A limited amount of research has also been undertaken in relation to advances in gear technology and changes in fishing practice (research area 5) but this is a potentially very important area of research and more needs to be done. This review has not identified socio-economic issues (research area 6) and so that is an area that needs to be explored. The areas where the biggest knowledge gap exists are related to research to inform stock assessments (area 3), to inform management decisions (area 4), and in the generation of data to support FAD research generally (area 7). A suggested prioritisation of future research follows (the numbering refers to the numbered research topics within each of the tables, Priority is denoted by A-F).

Priority A: Stimulate additional research funding (research area 1): It is necessary to stimulate significant additional funding of FAD related research, particularly for floating FADs. In this context topic 3.1 related to the communication of the issues raised in this review, and the research areas identified is important in order to further mobilise the international research effort.

Priority B: Address the paucity of FAD related data (research area 7): There is a need for a more comprehensive database of FAD use and deployment to contribute to better stock assessments (topic 7.2). It is also important to get comprehensive data on incidentally caught species (7.1) and juveniles of target species (7.3) to better inform assessments and management decisions. RFMOs should take the lead in this but industry support will be important if this is to be successful. Better data is also needed to inform management, specifically for locating spatio-temporal closures (7.4). This will require review of existing data but may also need additional field research. The existing ecological field studies may provide relevant information.

Priority C: Undertake research to inform management decisions (research areas 4 and 5): Topic 4.1 which aims to examine the question of fleet interactions and particularly the impact of juvenile mortality under FADS on resource sustainability is a priority as results from existing work are ambiguous (see Section 6). Topic 4.3 is also important. It is focussed on simulation of spatio-temporal closures which are recognised as a suitable management control to protect vulnerable parts of the tuna stocks and limit bycatch, but will effectively also address questions such as effort and catch controls. Work to evaluate the sustainability of bycatch species (4.2) whilst important may be hampered by a lack of data, and first ecological risk assessments (Topic 4.4) should be undertaken to prioritise where to focus effort on bycatch species. Topic 4.4 is thus a priority.

Mitigation measures are part of the manager's tool box and must also take priority. Thus whilst some work has been undertaken already, further work is warranted on improved gear technology and the modification of fishing practices (Topics 5.1 and 5.2). Industry is well placed to take the lead here.

Priority D: Undertake research to improve stock assessments (research area 3): It is important to obtain accurate estimates of the parameters, such as growth and particularly mortality (Topic 4.5, priority), needed to parameterise models. Whilst SPC and Indian Ocean Tuna Tagging Programmes aimed to do this there may be bias in the estimates derived, and the level of that bias needs to be established to improve stock assessments (topic 3.3). Obtaining a better index of abundance for FAD caught tuna is also required and this requires analysis of information on different types of FAD (topic 3.1) and establishment of methods for deriving abundance indices (3.2) including looking at spatial effects (3.4).

Priority E: Research on the social and economic impacts of FADs (research topic 6): This study has not examined socioeconomic impacts, and it will be important to understand them as they will influence management decisions.

Priority F: Further research into the ecology and behaviour of fish associated with FADs (research topic 2): A number of recent research projects have already begun to address this area and consequently it is now of a lower priority (topics 2.1 and 2.2). The priority is for the outcomes of these projects to be made available as soon as possible. In particular, the management implications of the research findings need to be described as a priority outcome (e.g. does the release of large numbers of FADs have serious ecological consequences suggesting the need for management actions? Do FADs affect the biology of target species reducing spawning stock biomass related to poor diet and fish health?). The existing projects may also highlight other potentially useful areas of study for the longer term (Topic 2.2). Any ecological advantages that aggregation around FADs may confer, and whether that may influence management should be investigated (topic 2.3). Wider ecosystem modelling (2.4) may prove valuable but until adequate data is available on the range of species involved this remains a lower priority than some of the previously defined topics in other research areas.

10. Communication

This report was commissioned by the WTPO as a body representing the fishing industry with the aim of moving towards responsible best management approaches for tuna fisheries based on FADs. The tuna industry is significant. Approximately 4 million tonnes of the principal market species of tuna are caught annually and purse seine vessels account for approximately 60%. Being highly migratory species managed through international RFMOs located in each of the world's major oceans there are a significant number of stakeholders involved. It is necessary to inform those stakeholders of the findings of this research to bring the findings to their attention and to engage them in future research and management activities described. There are opportunities for different stakeholders (fishers, producers, retailers, research scientists, managers, NGOs) to be involved in different aspects of the future requirements, whether they be addressing the gaps in knowledge or implementing appropriate best management controls. Whilst WTPO have envisaged a two phased approach to this research, the current review being Phase 1, the future research requirement is significant and will require substantial global effort.

Communicating the numerous and complex messages contained in this review, and defining the next steps will require careful consideration of the process to achieve mobilisation of resources for the development and implementation of best FAD management practice. Whilst WTPO could fund elements of the research needed it is also appropriate to consider the big picture.

To address the big picture, a ***Research Programme*** (Framework) must be established with the research areas identified in this report representing the different ***Objectives*** to be addressed. Achievement of those objectives will lead to delivery of the ***Goal***. Under each objective a number of ***research projects*** have been identified and must be undertaken. It will be necessary to adopt a coordinated approach to the implementation of any research programme amongst all the various actors to avoid duplication of effort.

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This bibliography accompanies the review:' FAD Management, A study of the impacts of fish aggregating devices (FADs) and the development of effective management strategies for their responsible use by industrial tuna fishing fleets' prepared for the WTPO. In compiling the literature for the review, a large amount of material on FADs was collated. The bibliography represents an additional output to the review that is valuable in its own right, and has therefore been made available in full. All references cited in the review are included in the bibliography. Not necessarily all bibliographic entries have been cited in the review.

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Annex1: Specific management actions taken by RFMOs

1. Inter-American Tropical Tuna Commission

The IATTC, established by international convention in 1950 (http://www.iattc.org/PDFFiles/IATTC_convention_1949.pdf), by Costa Rica and the United States. IATTC is responsible for the conservation and management of fisheries for tunas and other species taken by tuna-fishing vessels in the eastern Pacific Ocean, (as defined in the Antigua Convention the area of concern was between 50°N and 50°S[7] and east of 150°W to the coast of the Americas, See Figure 18). Each member country of the IATTC is represented by up to four Commissioners, appointed by the respective government.

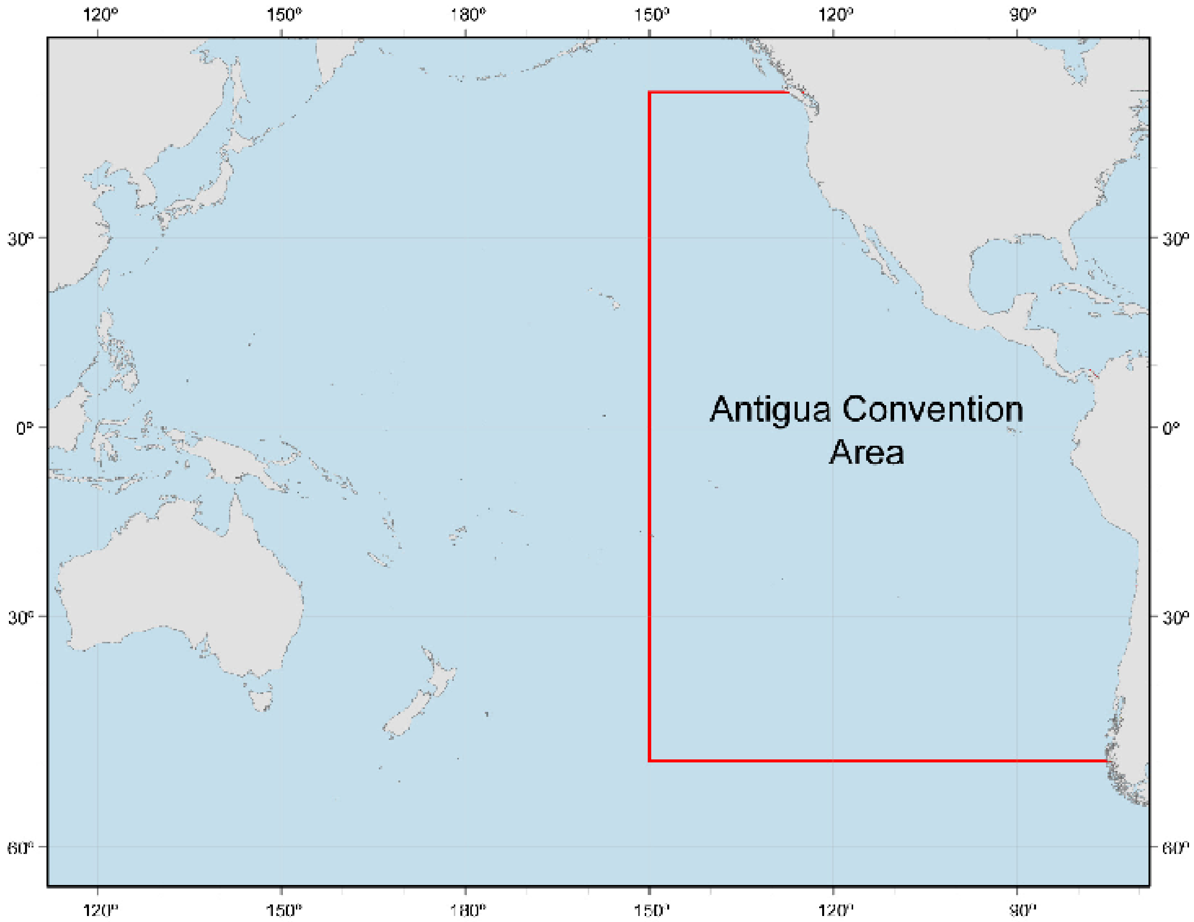

Figure 18 IATTC Area of Concern as defined by the Antigua Convention.
Source: IATTC Website (http://www.iattc.org/EPOmapENG.htm)

The current membership of IATTC is Colombia, Costa Rica, Ecuador, El Salvador, France, Guatemala, Japan, Mexico, Nicaragua, Panama, Peru, Republic of Korea, Spain, United States, Vanuatu and Venezuela. Belize, Canada, China, Cook Islands, the European Union and Chinese Taipei are Cooperating Non Parties or Cooperating Fishing Entities.

[7] This needs to be verified as the coordinates are now 40°N and 40°S

The work of the IATTC staff is divided into two programs, the Tuna-Billfish Program and the Tuna-Dolphin Program.

The principal responsibilities of the Tuna-Billfish Program are:

1. to study the biology of the tunas and related species of the eastern Pacific Ocean with a view to determining the effects that fishing and natural factors have on their abundance;
2. to recommend appropriate conservation measures so that the stocks of fish can be maintained at levels which afford maximum sustainable catches;
3. to collect information on compliance with Commission resolutions.

The principal responsibilities of the Tuna-Dolphin Program are:

1. to monitor the abundance of dolphins and their mortality incidental to purse-seine fishing in the eastern Pacific Ocean;
2. to study the causes of mortality of dolphins during fishing operations and promote the use of fishing techniques and equipment which minimize these mortalities;
3. to study the effects of different modes of fishing on the various fish and other animals of the pelagic ecosystem;
4. to provide a secretariat for the International Dolphin Conservation Program (IDCP).

Table 49 provides details of the IATTC resolutions and recommendations that make specific reference to FADs and/or fishing on floating objects. An indication of the outcome of each resolution or recommendation is also given.

Table 49 IATTC recommendations and resolutions making specific reference to FADs and/or floating objects

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
C-07-03	Resolution to mitigate the impact of tuna fishing vessels on sea turtles	Contracting Parties, cooperating non-Parties, fishing entities and regional economic integration organizations (collectively "CPCs") shall: 1. Implement the FAO Guidelines to reduce the bycatch, injury, and mortality of sea turtles in fishing operations and to ensure the safe handling of all captured sea turtles, in order to improve their survival. 2. Beginning in 2008, report to the IATTC annually by 30 June on the progress of implementation of the FAO Guidelines, including information collected on interactions with sea turtles in fisheries managed under the Convention. 3. Enhance the implementation of their respective sea turtle bycatch, injury, and mortality reduction measures that are already in place (using best scientific information) and collaborate with other CPCs in the exchange of information in this area. 5. Require fishermen on vessels targeting species covered by the Convention to bring aboard, if practicable, any comatose or inactive hard-shell sea turtle as soon as possible and foster recovery, including resuscitation, before returning it to the water. 6. CPCs with purse seine vessels fishing for target species covered by the Convention in the EPO shall: a. Avoid encirclement of sea turtles to the extent practicable. b. Take actions necessary to monitor Fish Aggregating Devices (FADs) for the entanglement of sea turtles, and provide the monitoring results to the Commission as part of the requirement of paragraph.	Resolution in place. Observer database on turtle interactions established (IATTC, 2008)
C-07-04	Resolution on experimental fishing	Notwithstanding the requirements for closure of the purse-seine fishery stipulated in Resolution C-06-02 on the conservation of tuna in the eastern Pacific Ocean in 2007, one purse-seine vessel shall be allowed to fish for purposes of a scientific experiment during the period of closure established by its flag state. The scientific experiment shall be for the purpose of testing gear modifications designed to reduce the catches of small tunas, and shall be elaborated in a proposal submitted to the Director at least two weeks before the expected date of the beginning of the first fishing trip of the vessel, and approved by the Director in consultation with the Commission prior to the trip.	Resolution in place.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		In accordance with the Resolution which establishes the need to seek alternative methods for reducing the catch of juvenile tunas, ECUADOR has designed and built a flexible grid which when installed in purse seine nets, will allow the small tunas to escape, a device that needs to be tested. With the aim of avoiding operative losses to the vessel company that has borne all the costs of building the device and that will also cover 100% of the costs of the test cruise(s), it is requested that: during the 2007 closure for the purse-seine fleet operating in the EPO, a single vessel be allowed to test the device. The experiment will take place from about 05 August and will finish its first phase in about 90 days, making as many trips as conditions permit in the usual fishing areas on FADs and schoolfish. Depending on the initial results, the use of the grid will be continued during 90 more days in order to monitor its real effectiveness and/or make adjustments to the design, allowing at the same time operation in the months in which the oceanographic conditions vary due to seasonal changes, mainly temperature and currents.	
C-06-03	Resolution on Full Retention	To amend "Until January 1 2007" to "Until January 1 2008" in paragraph a. of Section 1 "Reduction of the incidental morality of juvenile tunas" of the Consolidated Resolution on Bycatch (C-04-05). To review compliance with Section 1 of Resolution C-04-05, by flag state, in the Permanent Working Group on Compliance.	Resolution lapsed, awaiting analysis of results of work.
C-05-05	Resolution on Full Retention	To amend "Until January 1 2006" to "Until January 1 2007" in paragraph a. of Section 1 "Reduction of the incidental morality of juvenile tunas" of the Consolidated Resolution on Bycatch (C-04-05). To review compliance with Section 1 of Resolution C-04-05, by flag state, in the Permanent Working Group on Compliance.	Extended in C06-03.
C-04-05 (REV 2)	Consolidated Resolution on bycatch	Contracting Parties, cooperating non-Parties, fishing entities and regional economic integration organizations (collectively "CPCs") shall: 1. Reduction of the incidental mortality of juvenile tunas: a. Until January 1, 2008: i. Implement programs to require all purse-seine vessels to first retain on board and then land all bigeye, skipjack, and yellowfin tuna caught, except fish considered unfit for human consumption for reasons other than size. A single exception shall be the final set of a trip, when there may be insufficient well space remaining to accommodate all the tuna caught in that set.	Extended in C 05-05 (for 2006) and C-06-03 (for 2007)

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		ii. Review annually the effect and effectiveness of this program. b. Support, and seek the necessary funds for, the following future studies and research: i. Develop technology for releasing juvenile tunas, particularly sorting grids. ii. Apply technology for the identification of species and size composition in schools prior to setting, for example acoustic technology. c. Pursue the establishment of mechanisms for communicating information on areas of high concentration of juvenile tunas in real time within the fleet or parts of the fleet, taking account of the importance of ensuring confidentiality of such information. 2. Release of non-target species Require fishermen on purse-seine vessels to promptly release unharmed, to the extent practicable, all sharks, billfishes, rays, dorado, and other non-target species. 3. General: a. Publicize the provisions of the Resolutions, particularly the requirement to promptly release unharmed, to the extent practicable, all sea turtles, sharks, billfishes, rays, dorado and other non-target species. b. Encourage fishermen to develop and use techniques and equipment to facilitate the rapid and safe release of any such animals. c. Urge governments with vessels targeting species covered by the Convention to provide the required bycatch information as soon as possible. 4. Sea turtles: a. Require fishermen on vessels targeting species covered by the Convention to promptly release unharmed, to the extent practicable, all sea turtles. b. Encourage all the CPCs to voluntarily provide the Commission with all data on bycatches of sea turtles in all fisheries targeting species covered by the Convention, recognizing that a comprehensive approach is necessary to deal effectively with sea turtle issues; c. Encourage FAO to address the conservation and management of sea turtles, including the issue of bycatches of sea turtles as part of such a comprehensive approach; d. Implement the following actions: i. Train crews of vessels targeting species covered by the Convention, particularly those without observers, in techniques for handling turtles to improve survival after release. ii. Prohibit vessels targeting species covered by the Convention from disposing of salt bags or any other type of plastic trash at sea.	

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		iii. Encourage the release, when practicable, of sea turtles entangled in FADs and other fishing gear. iv. Foster the recovery of FADs when they are not being used in the fishery. v. Take measures, including providing assistance, necessary to ensure that longline vessels carry on board the necessary equipment (e.g. de-hookers, line cutters and scoop nets) for appropriate release of incidentally caught sea turtles e. Require specific measures for encircled or entangled sea turtles, as follows: i. Whenever a sea turtle is sighted in the net, all reasonable efforts should be made to rescue the turtle before it becomes entangled in the net, including, if necessary, the deployment of a speedboat. ii. If a turtle is entangled in the net, net roll should stop as soon as the turtle comes out of the water and should not start again until the turtle has been disentangled and released. iii. If a turtle is brought aboard the vessel, all appropriate efforts to assist in the recovery of the turtle should be made before returning it to the water. f. Educate fishermen through information dissemination activities, including distributing informational materials and organizing seminars on, inter alia, reducing bycatches of sea turtles and safe handling of incidentally caught sea turtles to improve their survivability. ACTIONS BY IATTC STAFF The Director shall: 5. Reduction of the incidental mortality of juvenile tunas: Seek the necessary funds for the following future studies and research: i. Develop technology for releasing juvenile tunas, particularly sorting grids. ii. Develop technology for the identification of species and size composition in schools prior to setting, for example acoustic technology. 6. Species of large pelagic fish of interest to the artisanal fishery, particularly dorado: Identify areas of high bycatches of these species, and verify the stability in time and space of any such areas. 7. Billfish, sharks and rays: a. Develop techniques and/or equipment to facilitate their release from the deck or from the net. b. Seek the necessary funds to carry out experiments to determine the survival rates of released billfish, sharks and rays. c. Define areas and periods in which any of these species are most likely to be caught. 8. Sea turtles: a. Study and formulate recommendations regarding modifications of the design of FADs to eliminate entanglement of sea turtles, particularly the use of webbing hanging below	

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		FADs. b. Educate fishermen through information dissemination activities, including distributing informational materials and organizing seminars on, inter alia, reducing bycatches of sea turtles and safe handling of incidentally caught sea turtles to improve their survivability. c. Compile manuals produced by the CPCs for safe handling and release of incidentally caught sea turtles by all gear types, and make those manuals available to all the CPCs for their use.	
C 02-05	Resolution on bycatch	3. Regarding the reduction of the incidental mortality of juvenile tunas: a. To pursue the establishment of mechanisms for communicating information on areas of high concentration of juvenile tunas in real time within the fleet or parts of the fleet, taking account of the importance of ensuring confidentiality of such information; b. To support, and seek the necessary funds for, the following future studies and research: 1. Develop technology for releasing juvenile tunas, particularly sorting grids. 2. Apply technology for the identification of species and size composition in schools prior to setting, for example acoustic technology. 4. Regarding sea turtles: a. To encourage all the Parties to voluntarily provide the Commission with all data on incidental catches of sea turtles in all fisheries, mainly those for tunas, recognizing that a comprehensive approach is necessary to deal effectively with sea turtle issues; e. To implement the following actions: 1. Publicize the requirement to release turtles and the other provisions of the Resolutions. 2. Train crews of tuna purse-seine vessels, particularly those without observers, in techniques for handling turtles to improve survival after release, and encourage States to take similar actions for other tuna fisheries. 3. To study and formulate recommendations regarding modifications of the design of FADs to eliminate entanglement of sea turtles, particularly the use of webbing hanging below FADs. 4. To prohibit tuna-fishing vessels disposing of salt bags or any other type of plastic trash at sea. 5. To encourage the release, when practicable, of sea turtles entangled in FADs.	IATTC (2006) details the bycatch levels observed in the purse seine fishery. Turtle actions expanded into C 07-03 and C04-05 and extensions.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		6. To foster the recovery of FADs when they are not being used in the fishery.	
C 01-04	Resolution on bycatch	5. To request that the Director seek the cooperation of vessel owners to explore ways to reduce and, to the extent practicable, eliminate the entanglement of sea turtles in webbing attached to Fish- Aggregating Devices and to provide any information on these efforts to the Working Group on Bycatch at its next meeting	Review of results of full retention requirement in 2001 IATTC 3rd bycatch working group meeting.
C 99-07	Inter-American Tropical Tuna Commission Resolution on fish-aggregating devices	*Recommends to the Parties and non-parties under whose jurisdiction vessels operate in the EPO* that they: 1. Reaffirm their commitment to prohibit the transhipment of tuna by purse-seine vessels fishing for tuna in the EPO, unless such transhipment 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; (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 130ºW and 150ºW; (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.	Resolution in place. Working Group on Fish-Aggregating Devices created and reported in 1998 and 1999.

References

IATTC 2008. ANNUAL REPORT of the Inter-American Tropical Tuna Commission 2006. IATTC. 166pp.

IATTC 2006. ANNUAL REPORT of the Inter-American Tropical Tuna Commission 2004. IATTC. 100pp.

2. Western and Central Pacific Fisheries Commission

The Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean was opened for signature at Honolulu on 5 September 2000 (http://www.wcpfc.int/pdf/text.pdf). The Convention was one of the first regional fisheries agreements to be adopted since the conclusion in 1995 of the UN Fish Stocks Agreement.

The objective of the Convention is to ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks in the western and central Pacific Ocean in accordance with the 1982 United Nations Convention on the Law of the Sea and the 1995 UN Fish Stocks Agreement. The Convention established the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. The Convention applies to all species of highly migratory fish stocks (defined as all fish stocks of the species listed in Annex I of the 1982 Convention occurring in the Convention Area and such other species of fish as the Commission may determine) within the Convention Area, except sauries. Conservation and management measures under the Convention are to be applied throughout the range of the stocks, or to specific areas within the Convention Area, as determined by the Commission.

The following states are currently Members of the Commission: Australia, Canada, China, Cook Islands, the European Community, Federated States of Micronesia, Fiji Islands, France (for French Polynesia, New Caledonia and Wallis and Futuna), Japan, Korea, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Papua New Guinea, Palau, Philippines, Samoa, Solomon Islands, Tonga and Tuvalu, Vanuatu.

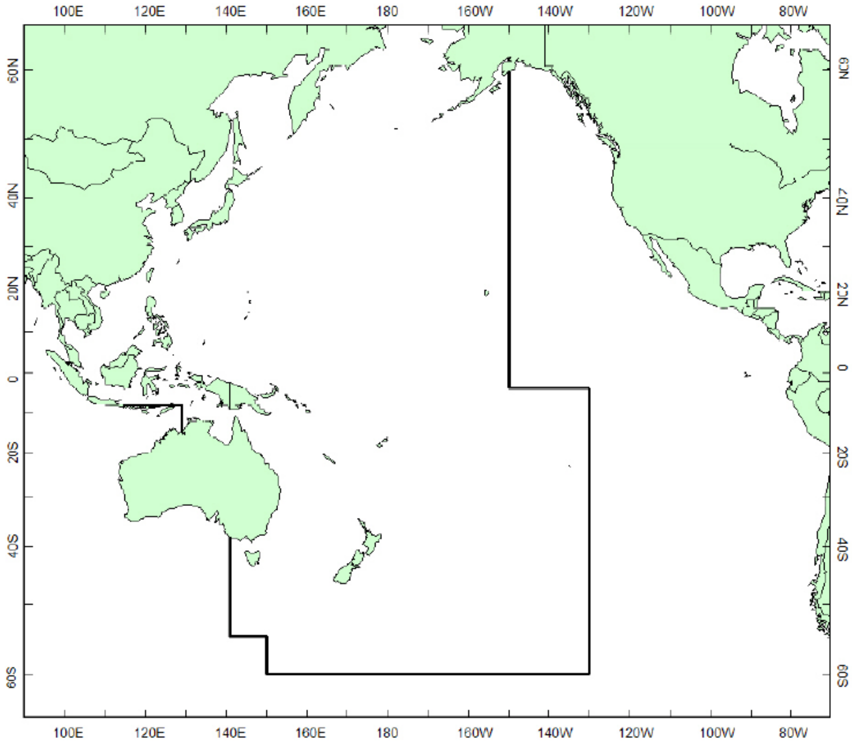

Figure 19 Map of the WCPFC Convention Area

Source: WCPFC (www.wcpfc.int)

To clarify the legal implications of the range of decisions that the WCPFC may take, the Second Meeting of the WCPFC (see WCPFC/Comm2/29 14 December 2005) adopted the following Nomenclature for its decisions.

- Resolutions describe non-binding statements and recommendations addressed to members of the Commission and Cooperating non-members. Such Resolutions are sequentially numbered and include the year of adoption.

- Conservation and Management Measures describe binding decisions relating to conservation and management measures. Such decisions are sequentially numbered and include the year of adoption.

- Other Decisions of the Commission describe all other decisions made by the commission.

Table 50 provides details of the WCPFC resolutions and recommendations that make specific reference to FADs and/or fishing on floating objects, whilst Table 51 provides details of those resolutions that are relevant to FADs but do not explicitly mention them. An indication of the outcome of each resolution or recommendation is also given.

Table 50 WCPFC recommendations and resolutions making specific reference to FADs and/or floating objects

No.	Resolution	Management action / Detail relevant to FADs	Status
2005-01	Conservation and management measures for bigeye and yellowfin tuna In the Western and Central Pacific Ocean	*Control of sets on FADs for the purse seine fishery* 12. For the purposes of these measures, the term Fish Aggregation Device (FAD) means any man-made device, or natural floating object, whether anchored or not, that is capable of aggregating fish. 13. CCMs shall develop management plans for the use of FADs (anchored and drifting) within waters under national jurisdiction which shall be submitted to the Commission. 14. The Commission will work with CCMs to develop methods to reduce catches of juvenile bigeye and yellowfin tuna caught in association with FADs. 15. Beginning in 2006, the Scientific Committee and the Technical and Compliance Committee shall undertake to explore and evaluate mitigation measures for juvenile bigeye and yellowfin taken around FADs, in cooperation with other RFMOs, and present the results annually to the Commission. This work shall continue on an annual basis.	Replaced by CMM 2008-01 [Bigeye and yellowfin tuna]
2005-03	Resolution on non-target fish species	1. Commission Members, Cooperating Non-members and participating Territories (CCMs) shall encourage their vessels operating in fisheries managed under the WCPFC Convention to avoid to the extent practicable, the capture of all non-target fish species that are not to be retained; 2. Any such non-target fish species that are not to be retained, shall, to the extent practicable, be promptly released to the water unharmed	Resolution in place.
2005-04	Resolution to mitigate the impact of fishing for highly migratory fish species on sea turtles	Commission Members, Cooperating non-Members, and participating Territories (called CCMs) shall, as appropriate, implement the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations (the Guidelines) in order to reduce the incidental catch of sea turtles and to ensure the safe handling of all turtles that are captured, in order to improve their survivability. The WCPFC shall encourage CCMs to collect, and provide to the WCPFC, all available information on interactions with sea turtles in fisheries managed under the WCPF Convention. 3. The Commission encourages CCMs to enhance the implementation of their respective turtle mitigation measures that are already in place (using best available scientific information on mitigation techniques) and urges them to foster collaboration with other CCMs in the exchange of information in this area.	Resolution in place.

No.	Resolution	Management action / Detail relevant to FADs	Status
		4. The Commission urges CCMs to require that purse seine vessels flying their flags: i. Avoid encirclement of sea turtles to the extent practicable and, if encircled or entangled, take all practicable measures to safely release sea turtles. ii. Take all reasonable efforts whenever a sea turtle is sighted in the net to rescue the turtle before it becomes entangled in the net, including if necessary, the deployment of a speedboat. iii. Stop net roll, if a turtle is entangled in the net, as soon as the turtle comes out of the water and, to the extent practicable, assist the recovery of the turtle before returning it to the water. iv. Take necessary measures to monitor fish aggregating devices (FADs) to the extent practicable to release any sea turtles that become entangled and consider FAD designs and use that reduce the likelihood of sea turtle entanglement. 8. As the Commission develops its regional observer program and considers improving observer coverage in the Convention Area, existing observer programs should be reviewed to ensure that the appropriate information on sea turtle interactions is being collected (e.g. species identification, fate and condition at release, relevant biological information and gear configuration).	
CMM 2006-01	Conservation and management measures for bigeye and yellowfin tuna In the Western and Central Pacific Ocean	*Purse Seine Fishery* 3. Beginning in 2007, CCMs shall take necessary measures to ensure that the level of purse seine fishing effort by their vessels in areas of the high seas does not exceed 2004 levels or the average of 2001-2004. 4. CCMs whose vessels fish in areas beyond national jurisdiction shall develop management plans for the use of FADs (anchored and drifting) in areas beyond national jurisdiction which shall be submitted to the Commission by 1st January 2008. 5. Management plans for the use of FADs shall include strategies to limit the interaction with juvenile bigeye and yellowfin tuna.	Replaced by CMM 2008-01 [Bigeye and yellowfin tuna]

No.	Resolution	Management action / Detail relevant to FADs	Status
		6. Recognizing the urgent need to reduce fishing mortality of juvenile bigeye and yellowfin tuna from fishing on FADs, the Commission will adopt a measure at its next session to reduce juvenile bigeye and yellowfin mortalities from fishing effort on FADs, taking into account any existing measures. 7. The Commission asks the CCM's to urgently collaborate on research to reduce fishing mortality of juvenile bigeye and yellowfin from fishing on FADs. This research should include collaboration with industry to explore technical and industry based solution to the FAD closures, identify areas with high concentrations of juvenile bigeye and yellowfin tuna, consider areas of closure and determine a regime for observer coverage and reporting for adoption at the next session of the Commission.	
CMM 2008-01	Conservation and Management Measure for bigeye and yellowfin tuna in the Western and Central Pacific Ocean	11. For the members of the FFA who belong to the PNA, this measure will be implemented through their domestic processes and legislation, including the Vessel Day (VDS) Scheme which limits total days fished in the EEZs of PNA members to no greater than 2004 levels (Attachment C). The purse seine fishery in EEZs in the area bounded by 20ºN and 20ºS shall be closed to fishing on FADs between 0000 hours on 1 August and 2400 hours on 30 September. During this period all purse seine vessels required to carry an observer from the Regional Observer Program on board, and without such an observer on board, will cease fishing and return directly to port. During this period, a vessel may only engage in fishing operations if the vessel carries on board an observer from the Regional Observer Program to monitor that at no time does the vessel deploy or service any FAD or associated electronic devices or fish on schools in association with FADs. 12. Other non-PNA CCMs shall implement compatible measures to reduce purse seine fishing mortality on bigeye tuna in their EEZs. 13. The purse seine fishery on the high seas in the area bounded by 20ºN and 20ºS shall be closed to fishing on FADs between 0000 hours on 1 August and 2400 hours on 30 September. During this period all purse seine vessels without an observer from the Regional Observer Program on board will cease fishing and return directly to port. During this period, a vessel may only engage in fishing operations if the vessel carries on board an observer from the Regional Observer Program to monitor that at no time does the vessel deploy or service any FAD or associated electronic devices or fish on schools in association with FADs. 14. Vessels seeking an observer from the Regional Observer Program for the period of the closures identified in paragraphs 12 and 13 above shall notify	Resolution in place, not reported on yet.

No.	Resolution	Management action / Detail relevant to FADs	Status
		the Regional Observer Program Coordinator 21 days in advance. If the lack of an available observer from the Regional Observer Program would prevent a vessel from being able to fish during the period in question, the flag State may place an observer from its national program on the vessel to monitor compliance with these measures with approval from the Regional Observer Program Coordinator and, in respect to fishing in EEZs, the approval of the relevant national authority. High Seas Alternative to Paragraph 13 (Catch Limits) 15. As an alternative to the high seas FAD closure established pursuant to paragraph 13, Members may adopt measures to reduce their catch by weight of bigeye tuna in the purse seine fishery in the area between 20°N and 20°S by a minimum of 10 percent relative to 2001-2004 average levels through a Member-specific catch limit to achieve this goal. This alternative shall only be available to Members identified by the Commission in advance as having demonstrated a functioning capacity to implement such measures in an effective and transparent manner, including through: an established and functioning port monitoring program that allows monitoring of bigeye landings for each trip by each vessel; a commitment to carry on board observers from the Regional Observer Program, including upon return to port so that the observer can view the port monitoring program for each trip; a commitment to provide data for each trip by each vessel to the Commission within 30 days from the completion of the trip; having provided operational catch and effort data at least for the period 2001 to 2004 to substantiate the base level catch and effort; other such conditions as the Commission may determine. Any such program will be open to audit by the Commission to review the effectiveness of the program. 16. Once identified by the Commission as having met the requirements outlined above, the Members in question shall submit the full details of their intended measures and their port monitoring program to the Commission by 31 January 2009. The Commission will review these submissions and take them into account when assessing the effectiveness of the measures. *Measures for 2010-2011* EEZs Waters under the jurisdiction of PNA members	

No.	Resolution	Management action / Detail relevant to FADs	Status
		17. For the members of the FFA who are members of the PNA, this measure will be implemented through their domestic processes and legislation, including: a. the VDS which limits total days fished in the EEZs of PNA members to no greater than 2004 levels (Attachment C); and b. the Third Arrangement Implementing the Nauru Agreement of May 2008 which comprises a 3 month FAD closure period in the EEZs of the PNA member countries from 0000 hours on 1 July each year until 2400 hours on 30 September each year; full catch retention and other conditions for the purse seine fleet in national waters. Waters under the jurisdiction of non-PNA members 18. Other non-PNA CCMs shall implement compatible measures to reduce purse seine fishing mortality on bigeye tuna in their EEZs. *High Seas* 19. The purse seine fishery on the high seas in the area bounded by 20ºN and 20ºS shall be closed to fishing on FADs between 0000 hours on 1 July and 2400 hours on 30 September. During this period all purse seine vessels without an observer from the Regional Observer Program on board will cease fishing and return directly to port. During this period, a vessel may only engage in fishing operations if the vessel carries on board an observer from the Regional Observer Program to monitor that at no time does the vessel deploy or service any FAD or associated electronic devices or fish on schools in association with FADs. 20. Alternative measures may be set to reduce bigeye catch by a further 20% as a result of the review by the Commission of the 2009 alternative measure. 21. The Commission shall consider the development of a high seas vessel day scheme (HS VDS) to be compatible with the PNA VDS to provide a common currency for managing purse seine effort. Based on the advice and recommendations of the SC and TCC, the Commission shall consider such a scheme at its annual session in 2009 with a view to adoption at its annual session in 2010 with a view to ensuring that reductions in fishing effort on the high seas and in adjacent EEZs are compatible. 22. The high seas pockets indicated in Attachment D will be closed effective	

No.	Resolution	Management action / Detail relevant to FADs	Status
		from 1 January 2010 unless the Commission decides otherwise at its 6th annual meeting in December 2009. At this meeting the Commission will also consider the closure of all high seas pockets in the Convention Area between 20 north and 20 south. *FAD Management Plans* 23. By 1 July 2009, CCMs fishing on the high seas shall submit to the Commission Management Plans for the use of FADs by their vessels on the high seas. These Plans shall include strategies to limit the capture of small bigeye and yellowfin tuna associated with fishing on FADs, including implementation of the FAD closure pursuant to paragraphs. 13 and 18 above. The Plans shall at a minimum meet the Suggested Guidelines for Preparation for FAD Management Plans for each CCM (Attachment E). 24. The Commission Secretariat will prepare a report on additional FAD management options for consideration by the Scientific Committee, the Technical & Compliance Committee and the Commission in 2009 including: a. Marking and identification of FADs; b. Electronic monitoring of FADs c. Registration and reporting of position information from FAD-associated buoys; and d. Limits to the number of FADs deployed or number of FAD sets made. *Juvenile Tuna Catch Mitigation Research* 25. The Commission will work with CCMs, regional tuna commissions and industry to develop and implement a 3 year program to explore methods to reduce catches of juvenile bigeye and yellowfin tuna caught in association with FADs. 26. CCMs, working independently or collaboratively with industry, and reporting through the Scientific Committee and the Technical and Compliance Committee at each regular session, shall explore and evaluate mitigation measures for juvenile bigeye and yellowfin taken around FADs and present the results annually to the Commission.	

No.	Resolution	Management action / Detail relevant to FADs	Status
		Catch Retention 27. In order to create a disincentive to the capture of small fish and to encourage the development of technologies and fishing strategies designed to avoid the capture of small bigeye and yellowfin tuna, CCMs shall require their purse seine vessels fishing in EEZs and on the high seas within the area bounded by 20ºN and 20ºS from 1 January 2010, subject to the Commission implementing the program in Paragraph 28 for 100 percent coverage on purse seine vessels by the observers from the Regional Observer Program, to retain on board and then land or tranship at port all bigeye, skipjack and yellowfin tuna. The provisions of this paragraph shall not prevent the PNA from implementing the catch retention requirement in their EEZs in accordance with the Third Implementing Agreement. The only exceptions shall be: a) when, in the final set of a trip, there is insufficient well space to accommodate all fish caught in that set noting that excess fish taken in the last set may be transferred to and retained on board another purse seine vessel provided this is not prohibited under applicable national law; or b) when the fish are unfit for human consumption for reasons other than size; or c) when serious malfunction of equipment occurs. *Monitoring* 28. Purse seine vessels fishing within the area bounded by 200N and 200S exclusively on the high seas, on the high seas and in waters under the jurisdiction of one or more coastal States, or vessels fishing in waters under the jurisdiction of two or more coastal States, shall carry effective 1 January 2010, an observer from the Commission's Regional Observer Programme. 29. In 2009 vessels fishing in the area described above will carry observers compliant with licensing arrangements and on the high seas will have a minimum of 20% observer coverage drawn from the Regional Observer Program. The level of coverage achieved will be monitored and reported through TCC. The Secretariat, in conjunction with the Inter-American Tropical Tuna Commission (IATTC), will develop a cross-endorsement arrangement in order to allow vessels operating within IATTC and Commission areas on the	

No.	Resolution	Management action / Detail relevant to FADs	Status
		same fishing trip to use the same observer. *Other Considerations for Purse Seine Measures* 30. Developing skipjack purse seine fisheries, between 20ºN and 20ºS that can provide verifiable evidence of minimal yellowfin and bigeye by-catch (cumulative <2%), with 100% observer coverage, and with a legitimate development plan, will be exempted. Any such plan shall restrict the use of FADs and implement other such management measures necessary to minimize impacts on bigeye and yellowfin tunas. These measures must be supported by adequate monitoring, control and surveillance to ensure their effective implementation. Existing plans shall be tabled at the Commission for information. The Commission is to be given the opportunity to comment on the plan before its approval. This measure does not apply to the domestic purse seine fisheries of small island developing states. This Measure replaces CMM 2005-01 and CMM 2006-01.	
2008-03	Conservation and Management of Sea Turtles	5. CCMs with purse seine vessels that fish for species covered by the Convention shall: a. Ensure that operators of such vessels, while fishing in the Convention Area: i. To the extent practicable, avoid encirclement of sea turtles, and if a sea turtle is encircled or entangled, take practicable measures to safely release the turtle. ii. To the extent practicable, release all sea turtles observed entangled in fish aggregating devices (FADs) or other fishing gear. iii. If a sea turtle is entangled in the net, stop net roll as soon as the turtle comes out of the water; disentangle the turtle without injuring it before resuming the net roll; and to the extent practicable, assist the recovery of the turtle before returning it to the water. iv. Carry and employ dip nets, when appropriate, to handle turtles. b. Require that operators of such vessels record all incidents involving sea turtles during fishing operations and report such incidents to the appropriate authorities of the CCM. c. Provide the results of the reporting under paragraph 5(b) to the Commission as part of the reporting requirement of paragraph 2. d. Provide to the Commission the results of any research related to the	

No.	Resolution	Management action / Detail relevant to FADs	Status
		development of modified FAD designs to reduce sea turtle entanglement and take measures to encourage the use of designs found to be successful at such reduction.	

Table 51 WCPFC Resolutions not making specific reference to FADs but of indirect relevance

No.	Resolution	Management action / Detail relevant to FADs	Status
2005-03	Resolution on non-target fish species.	1. Commission Members, Cooperating Non-members and participating Territories (CCMs) shall encourage their vessels operating in fisheries managed under the WCPFC Convention to avoid to the extent practicable, the capture of all non-target fish species that are not to be retained; 2. Any such non-target fish species that are not to be retained, shall, to the extent practicable, be promptly released to the water unharmed.	Resolution in place.

3. International Commission for the Conservation of Atlantic Tunas

The International Commission for the Conservation of Atlantic Tunas is responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and adjacent seas (See Figure 20). The organization was established at a Conference of Plenipotentiaries, which prepared and adopted the International Convention for the Conservation of Atlantic Tunas, signed in Rio de Janeiro, Brazil, in 1966. After a ratification process, the Convention entered formally into force in 1969.

ICCAT is mandated to cover about 30 tuna and tuna like species are including Atlantic bluefin (*Thunnus thynnus thynnus*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*); swordfish (*Xiphias gladius*); billfishes such as white marlin (*Tetrapturus albidus*), blue marlin (*Makaira nigricans*), sailfish (*Istiophorus albicans*) and spearfish (Tetrapturus *pfluegeri)*; and other small tunas.

The structure of ICCAT is the Commission composed of Contracting Party Delegations[8], a Standing Committee on Finance and Administration (STACFAD), a Standing Committee on Research and Statistics (SCRS). ICCAT has four panels that are responsible for keeping under review a species, group of species, or geographic area and for collecting scientific and other information relating thereto. Based on investigations from the SCRS, Panels may propose to the Commission recommendations for joint action by the Contracting Parties. The current panels and responsibilities are as follows;

Panel 1: Tropical tunas (yellowfin, bigeye and skipjack)
Panel 2: Northern temperate tunas (albacore and Atlantic bluefin)
Panel 3: Southern temperate tunas (albacore and southern bluefin)
Panel 4: Other species (swordfish, billfishes, small tunas)

Panel 1 is the panel with responsibility for the review of the tropical purse seine fishery. [9]

ICCAT also has Conservation and Management Measures Compliance Committee, a Permanent Working for the Improvement of ICCAT Statistics and Conservation Measures (PWG) and the Commission may convene other Working Groups as required such as the current Working Group on Fishing Capacity.

The ICCAT Secretariat based in Madrid performs the administration and coordination functions for the Commission.

[8] Current ICCAT Membership (Albania, Algeria, Angola, Barbados, Belize, Brazil, Canada, Cap-Vert, China, People's Rep of, Communauté Européenne, Côte D'Ivoire, Croatia, Egypt, France (St-Pierre Et Miquelon), Gabon, Ghana, Guatemala, Guinea Equatorial, Honduras, Iceland, Japan, Korea, Rep Of, Libya, Maroc, Mexico, Namibie, Nicaragua, Nigeria, Norway, Panama, Philippines, République De Guinée, Russia, Saint Vincent And The Grenadines, São Tomé E Principe, Sénegal, South Africa, Syria, Trinidad & Tobago, Tunisie, Turkey, United Kingdom (for Overseas Territories), United States, Uruguay, Vanuatu, Venezuela). The following three countries have been given the status of Cooperating Non-Contracting Parties: Chinese Taipei, Guyana and Netherlands Antilles.

[9] See http://www.iccat.int/Documents/Commission/panel_members.pdf for panel membership lists.

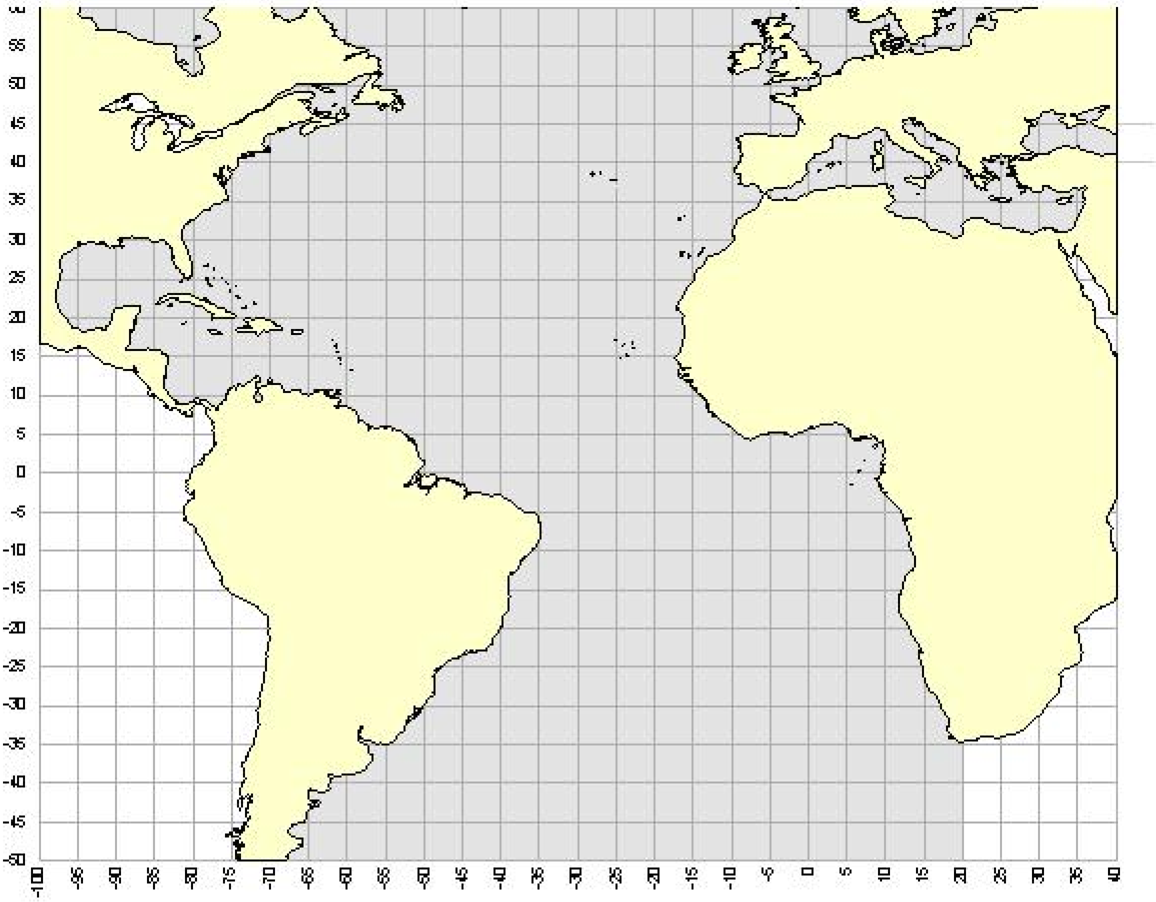

Figure 20 ICCAT Regulatory Area

Table 52 provides details of the resolutions and recommendations that make specific reference to FADs and/or fishing on floating objects, whilst Table 53 provides details of those resolutions that are relevant to FADs but do not explicitly mention them. An indication of the outcome of each resolution or recommendation is also given.

Table 52 ICCAT recommendations and resolutions making specific reference to FADs and/or floating objects

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
96-01	Recommendation by ICCAT on Bigeye and Yellowfin Tunas	*DEPLORING* the inadequacy of scientific knowledge relative to bigeye tuna and to the effects of the fishing techniques with fish aggregating devices (FADs) on the multi-species fisheries of tropical tunas; *CONVINCED* of the urgent need to improve knowledge and the scientific basis for these subjects, *AWARE* of the danger that the large increase in bigeye tuna catches and juvenile catches observed, could present to the stock of Atlantic bigeye tuna. *DETERMINED* to do everything possible to improve, as quickly as possible, this scientific basis, indispensable for better knowledge and good management of this stock which is of the greatest economic importance, particularly for longline fleets as concerns bigeye tuna, *EQUALLY DETERMINED* to adopt adequate, viable and efficient management measures which will be proposed by the SCRS on the basis of improved scientific information. THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THE CONTRACTING PARTIES CONCERNED:	
		FIRST: That in order to contribute to the rapid acquisition of information, a national observer program for longliners, purse seiners and baitboats be established according to the provisions to be decided by an *ad hoc* working group of the SCRS: a) on 25%of vessels fishing with fish aggregating devices (FADs), mainly in order to determine in which time/area strata juvenile tunas could be most associated with FADs. b) on 5%of vessels fishing using other methods in order to obtain data on the composition of the catches, particularly those of spawners, relative to the fishing areas and seasons.	Observer programmes on EU purse seine fleet during 2000-2003.Data presented to ICCAT SCRS. Sampling programmes in major Atlantic ports, to determine species compositions and length frequency distributions by time, area and fleet strata.
		SECOND: To supplement the study carried out by the observer program with a survey of the vessels that use FADs.	

		THIRD: Based on the results of these investigations and in order to assure the taking of precautionary measures: a) to present, during the Commission Meeting in November, 1997, the results of studies undertaken in accordance with the FIRST paragraph and on this basis, consider during that meeting, the necessary measures to assure maintaining the stock of tropical tunas, mainly as concerns the regulation of the use of FADs; b) to respect the SCRS recommendations relative, on the one hand, to the bigeye tuna catches in reference to MSY and to the catches of juveniles, and on the other hand, with the yellowfin catches, in reference to fishing mortality.	

98-01	Recommendation by ICCAT Concerning the Establishment of a Closed Area/Season for the Use of Fish Aggregation Devices (FADs)	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 analyze 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. 7 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.	Closed area in operation.

99-01	Recommendation by ICCAT on the Establishment of a Closed Area/Season for the Use of Fish-Aggregation Devices (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; -- 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 analyze, 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	Repealed in 2001 by 04-01 as part of the multi-year plan for the management of the bigeye tuna fishery. SCRS 2000 analyse impact on stocks. Deemed by latest reports to have not been effective in reducing the catch of small bigeye tuna. (see 04-01)

01-04	Resolution by ICCAT for evaluating alternatives to reduce catches of juveniles or dead discards of swordfish	Para 1: Contracting Parties, Cooperating Non-Contracting Parties, Entities, and Fishing Entities should evaluate any long-term time-area closures implemented within the Convention Area for vessels flying their flag for the purpose of reducing the mortality of undersized swordfish and present such evaluation in the form of a scientific paper to the SCRS for consideration.	**Check SWO**
04-01	*Recommendation by ICCAT on a multi-year conservation and management program for bigeye tuna*	*Area/Season closure* 8 In order to protect the stock, in particular juvenile fish, fishing by purse seiners and baitboats flying a CPC flag, shall be prohibited during the period and in the area specified in paragraphs 9 and 10 below; 9 The area referred to in paragraph 8 is the following: – Southern limit: parallel 0° South latitude – Northern limit: parallel 5° North latitude – Western limit: meridian 20° West longitude – Eastern limit: meridian 10° West longitude. 10 The period covered by the prohibition of paragraph 8 will be from 1 November to 30 November of each year. 11 The SCRS shall examine in 2005 the impact on stocks of this measure, and shall recommend the necessary modifications that would improve its effectiveness and review possible modifications to be applied to the closure. 16 This recommendation replaces the *Recommendation by ICCAT on a Bigeye Tuna Size Limit* [Rec. 79-01] and the *Recommendation by ICCAT on the Establishment of a Closed Area/Season for the Use of Fish-Aggregation Devices (FADs)* [Rec. 99-01].	*04-01* sets a number of regulations for 2005-2008 including an overall TAC for major countries set at 90,000 t as well as a specific limit for the number of vessels for several countries. The SCRS examined the percentages of the small bigeye based on the catch-at-size information created at the time of 2007 assessment. The percentage of small bigeye is at about 70% in terms of the number of fish and there is a general increasing trend. Considering that the new closed area is much smaller in time and area than the previous moratorium time/area, and is located in an area which historically has lower effort anyway, this regulation is likely to be less effective in reducing the overall catches of small bigeye by the surface fishery. This expectation is supported by an analysis of 1994-2007 purse seine catches which was presented to the Committee, confirming that the new closure has been less effective than previous moratoria in reducing the proportional catch of small bigeye. The Committee stressed that, if time/area closures were to be effective in reducing small fish harvests and growth overfishing, such a closure should be expanded in time and space and focused in locations with optimal potential benefit. New measures to expand the closure were proposed at the 2008 meeting with Recommendation 08-01 (below) the output.

08-01	Recommendation by ICCAT to amend the recommendation by ICCAT on a multi-year conservation and management program for bigeye tuna	The International Commission for the Conservation of Atlantic Tunas (ICCAT) recommends that: 1. The terms of the 2004 *Recommendation by ICCAT on a Multi-Year Conservation and Management Program for Bigeye Tuna* [Rec. 04-01] are extended through 2009. 4. The Commission requests the SCRS to evaluate before the Regular meeting of 2009: − the existing port sampling programmes aimed at collecting fishery data for bigeye, yellowfin, and skipjack tuna that are caught by purse seine and baitboat fisheries in the Gulf of Guinea, − the closure contained in the proposal from Ghana and Côte d'Ivoire, and any alternative closure, taking into account the need to reduce the catch of juvenile fish and make appropriate recommendations to improve the sampling programme and the closure so that they are implemented by 2010.	New resolution agreed in 2008, no progress reported so far. This recommendation will delay the implementation of any expansion of the closed area / season in the Gulf of Guinea.

Table 53 ICCAT Resolutions not making specific reference to FADs but of indirect relevance

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
93-04	Recommendation by ICCAT on supplemental regulatory measures for the management of Atlantic yellowfin tuna	Para 1: No increase in the level of effective fishing effort exerted on Atlantic yellowfin tuna, over the level observed in 1992. *i.e. and accurate measure of the level of effort in 1992, currently and historically needs to be developed. The use of FADs and support vessels needs to be considered in this measure of effort.*	Active. Assessment of fishing capacity in relation to ICCAT managed stocks for has highlighted continued problems with reporting and inconsistency in vessel information[10]. Recommendation for all CPCs to utilize the appropriate reporting formats to submit data to ICCAT.
[03-11]	Resolution by ICCAT on sea turtles	Para 1: To encourage Contracting Parties, Cooperating non-Contracting Parties, Entities or Fishing Entities to collect and provide SCRS with all available information on interactions with sea turtles in ICCAT fisheries, including incidental catches and other impacts on sea turtles in the Convention area, such as the deterioration of nesting sites and swallowing of marine debris. Para 2: To encourage the release of marine turtles that are incidentally	Active Recording, but no papers presented to ICCAT.

[10] ICCAT (2008) Report of the 2nd Meeting of the Working Group on Capacity. PLE-101/2008.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		caught alive, and share all available information such as technical measures to reduce the incidental catch of turtles and to ensure the safe handling of all turtles that are released, in order to improve their survivability. Para 3: To seek, through the appropriate ICCAT body, the development of data collection and reporting methods for the incidental by-catch of sea turtles in tuna and tuna-like species fisheries. Para 4: To support efforts by FAO to address the conservation and management of sea turtles, through a holistic approach	
[04-10]	Recommendation by ICCAT concerning the conservation of sharks caught in association with fisheries managed by ICCAT	Para 1: Contracting Parties, Cooperating non-Contracting Parties, Entities or Fishing Entities (CPCs) shall annually report Task I and Task II data for catches of sharks, in accordance with ICCAT data reporting procedures, including available historical data. Para 8: CPCs shall, where possible, undertake research to identify ways to make fishing gears more selective.	CPCs reporting Task I and Task II data for sharks in varying rates. Shark catches are low from purse seine, but more research is needed. Purse seine gear selectivity for sharks not reported to ICCAT. Total of 27 papers but nearly all longline fishery with occasional driftnet paper.
[06-19]	Resolution by ICCAT to Establish a Capacity Working Group	1. A Capacity Working Group is established and will meet as early as possible in 2007 at a place to be determined by the Commission. The Working Group has the following terms of reference: a) to determine by fishery the availability of the data required to assess fishing capacity and appropriate methodologies to measure fishing capacity based on available data; b) to review and assess the level of fishing capacity for ICCAT managed species by country/ fleet/gear/fishery in light of the status of the resources, as indicated in SCRS assessments with a priority focus on bluefin tuna, including caging activities; c) to review the CPUE data and other relevant information in order to evaluate the relationship between capacity levels and available fishing possibilities. d) In light of the outcomes of points 1(a)-(c) above, the Working Group may, if necessary, develop guidelines for managing fishing capacity in ICCAT fisheries for consideration by the Commission, *inter alia,* taking into account the needs of developing countries while ensuring the sustainable and equitable use of tuna and tuna-like resources; 2. Prior to the first meeting of the Working Group, CPCs shall submit to the Secretariat available information to be used in an assessment of fishing	The ICCAT Working Group on Capacity has met twice in 2007 and 2008. Assessment of fishing capacity in relation to ICCAT managed stocks for has highlighted continued problems with reporting and inconsistency in vessel information. Recommendation for all CPCs to utilize the appropriate reporting formats to submit data to ICCAT.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
		capacity including, but not limited to, the following: a) Inputs in terms of numbers of vessels, vessel characteristics, fishing operational characteristics, and any other relevant information; b) Information on the types of measures and approaches used by the CPCs to manage fishing capacity; 3. At the 2007 annual meeting, the Working Group will report the progress of deliberations and, as appropriate, present proposals for next steps to the Commission. 4. The SCRS should provide the Working Group with relevant information on short- and long-term stock conditions and harvest levels in ICCAT fisheries for the most recent year(s) available, and data on effort and CPUE by flag, gear, season and area, in advance of the 2007 Working Group meeting to assist deliberations. 5. The Working Group should be supported by the ICCAT Secretariat staff. Broad representation from ICCAT's CPCs is encouraged, including by relevant experts in the field. 6. The Working Group could also draw upon the technical work (and expertise) of relevant intergovernmental organizations as well as the work of other regional fisheries management organizations (RFMOs). The results of the joint tuna RFMO meeting in January 2007 should also be taken into account.	
79-01	Recommendation by ICCAT on a Bigeye Tuna Size Limit (Entered into force: September 7, 1980; Extended for indefinite period in 1984)	The Commission RECOMMENDS: THAT the Contracting Parties take the necessary measures to prohibit any taking and landing of bigeye tuna (*Thunnus obesus*) weighing less than 3.2 kg until December 31, 1983. NOTWITHSTANDING the above regulations, the Contracting Parties may grant tolerances to boats which have incidentally captured bigeye tuna weighing less than 3.2 kg with the condition that this incidental catch should not exceed 15 percent of the number of fish per landing of the total bigeye catch of said boats. At the Commission Meeting immediately prior to the expiration date of the regulatory measures	Repealed in 2001 by 04-01 as part of the multi-year plan for the management of the bigeye tuna fishery.
05-01	RECOMMENDATION BY ICCAT ON YELLOWFIN SIZE LIMIT	*TAKING INTO ACCOUNT* the concern expressed by the SCRS on the inapplicability of the minimum size for yellowfin due to the characteristics of this fishery, THE INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS (ICCAT) RECOMMENDS THAT: The 1972 *Recommendation by ICCAT on a Yellowfin Size Limit* [Rec. 72-01] is repealed.	Repeals 72-01.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
72-01	*Recommendation by ICCAT on a Yellowfin Size Limit* (Entered into force: July 1, 1973; Repealed by 05-01).	*REFERRING* to Item 13 of the Proceedings of the Second Regular Meeting of the Commission, held in Madrid in 1971, authorizing the Council to recommend to the Contracting States to take regulatory measures regarding yellowfin, The Council: *RECOMMENDS* that the Contracting States take the necessary measures to prohibit any taking and landing of yellowfin tuna weighing less than 3.2 kg. *NOTWITHSTANDING* the above regulation, the Contracting States may grant tolerances to boats which have incidentally captured yellowfin weighing less than 3.2 kg, with the condition that this incidental catch should not exceed 15 percent of the number of fish per landing of the total yellowfin catch of said boats."	In force between 1973 and 2005, but deemed inapplicable and repealed by 05-01 (above).

4. Indian Ocean Tuna Commission

The Agreement for the Establishment of the Indian Ocean Tuna Commission was adopted by the FAO Council on 25 November 1993 and entered into force on the accession of the tenth Member on 27 March 1996 (see http://www.iotc.org/). IOTC is an intergovernmental organization mandated to manage sixteen tuna and tuna-like species in the Indian Ocean and adjacent seas (Figure 21). Its objective is to promote cooperation among its Members with a view to ensuring, through appropriate management, the conservation and optimum utilisation of stocks and encouraging sustainable development of fisheries based on such stocks.

IOTC recommendations concerning conservation and management of the stocks for furthering these objectives need only be adopted by a simple majority of its Members. Conservation and management measures binding on all Members of the Commission must be adopted by a two-thirds majority. These take the form of Resolutions. If objections to a measure are made by more than one-third of the Members, the other Members are not bound by that measure, but this does not preclude any or all of them from taking effect.

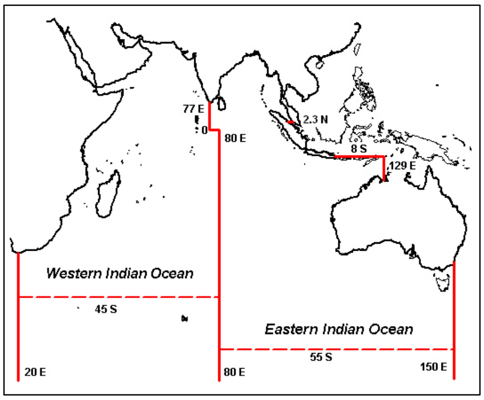

Figure 21 IOTC area of competence - the Indian Ocean (FAO statistical areas 51 and 57) and adjacent seas, north of the Antarctic Convergence, insofar as it is necessary to for the purpose of conserving and managing migratory stocks.

The structure of IOTC is the Commission; Sub-commissions; three standing committees being a Scientific Committee, a Compliance Committee and a Standing Committee on Administration and Finance (SCAF); and, Working parties. The Commission is administered by a full time Secretariat located in Seychelles. 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[11]. Sub-commissions will be open to those Contracting Parties which are coastal States lying on the migratory path of the stocks concerned in the sub-commission or are States whose vessels participate in the fisheries of these stocks. No sub commissions have been constituted to date. The Scientific Committee advises the Commission on research and data collection, on the status of stocks and on management issues. Working parties report to the Scientific Committee and analyse in more detail problems related to the management

[11] Current members: Australia, Belize, China, Comoros, Eritrea, European Community, France, Guinea, India, Indonesia, Islamic Republic of Iran, Japan, Kenya, Republic of Korea, Madagascar, Malaysia, Mauritius, Sultanate of Oman , Pakistan, Philippines, Seychelles, Sri Lanka, Sudan, Tanzania, Thailand, United Kingdom and Vanuatu. The following parties have been given Cooperating Non-Contracting Party status: Senegal, South Africa and Uruguay.

goals of the Commission. The Compliance Committee develops resolutions defining management measures of the Commission, and deals with IUU issues. The SCAF defines the Work Programme and Budget of the Secretariat.

It is the responsibility of the National Authorities to ensure that action is taken under their own fisheries legislation to implement those measures which become binding on them. This does not preclude any unilateral management actions. The current study focuses only on the resolutions and recommendations agreed by IOTC and does not attempt to look into the fisheries legislation of Member states and cooperating non contracting parties.

Table 54 and Table 55 provide details of the resolutions and recommendations that make specific reference to FADs and/or fishing on floating objects, whilst Table 56 provides details of those resolutions that are relevant to FADs but do not explicitly mention them. An indication of the outcome of each resolution or recommendation is also given.

In addition to the IOTC adopted resolutions, the three European organizations of frozen tuna producers (ANABAC-OPTUC, OPAGAC and ORTHONGEL) adopted an agreement in September 1998 banning the use of FADs for fishing tuna in the area delimited by 5º South - 10º North in latitude and 53º East – African coast in longitude. The ban was in place from 15 November 1998 till 15 January 1999 (Artetxe 1999).

Table 54 IOTC Resolutions making specific reference to FADs and/or floating objects

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
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	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.	No new resolutions adopted in 2000 or subsequently.
		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.	No resolution to this effect in 2000 or subsequently.
		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.	The 1999 and 2000 SC reports are unavailable on IOTC website. The WPTT report in 1999 recommended quotas for BET around FADS; restrictions on the use of supply vessels; minimum sizes for BET; area and seasonal closures of fishing grounds to log fishing (yet to be defined). The WPTT Report in 2000 expanded on recommendations for area and seasonal closures (http://www.iotc.org/files/proceedings/2000/wptt/IOTC-2000-WPTT-R[EN].pdf) . Three areas were considered (Mozambique Channel, West Seychelles and Somalia). Somalia was considered by far the most suitable for an area closure for a limited time period. Two possible areas within this region were examined further and 5 options for time closures were given. Note that recent Pirate activity off Somalia means that no vessels are fishing within 300nm of Somalia so there is defacto an unofficial closed area. The fishing capacity debate began to be explored by SC in 2008.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
01/02	Relating to control of fishing activities.	This resolution requires that flag states (of CPCs) shall only authorize the use of vessels in IOTC area where it is able to ensure that those vessels will comply with IOTC resolutions. It specifies details relating to documentation on board, marking of fishing vessels, and: 4c. Fish aggregating devices shall be clearly marked at all time with the letter(s) and / or number(s) of the vessel to which they belong	Resolution in force.
02/08	On the conservation of Bigeye and Yellowfin tuna in the Indian ocean	RESOLVES to seek technical advice from the Scientific Committee for the next session of the Commission on: ▪ Potential management measures designed to reduce the fishing mortality on juvenile bigeye and yellowfin tuna. The measures to be investigated should include, but not be restricted to, time and/or area closures on purse seine fishing on floating objects, and other forms of effort reduction or alternative fishing strategies. ▪ Other potential management measures aimed at maintaining or reducing the effective fishing effort and catches of yellowfin and bigeye tunas by all gears. ▪ The likely effect of these measures on the future productivity of the stocks of bigeye and yellowfin tunas and their consequences on catches of skipjack tuna. On the basis of the updated scientific advice, the Commission will seek to adopt appropriate measures to address the recommendations of the Scientific Committee at the 2003 Session of the Commission.	The SC report in 2002 provided technical advice in response to this resolution (http://www.iotc.org/files/proceedings/2003/sc/IOTC-2003-SC06-R[EN].pdf) No corresponding measures adopted in 2003 or subsequently.

No.	Resolution	Management action / Detail relevant to FADs	Status / Outcome
08/01	Mandatory statistical requirements for IOTC members and cooperating non contracting parties	1. CPC's shall provide the following information to the IOTC Secretariat according to the timelines specified in paragraph 6: **2. Nominal catch data:** Estimates of the total annual catch by species and gear for all species under the IOTC mandate. **3. Catch and effort data:** (a) **For surface fisheries:** catch weight by species and fishing effort shall be provided by 1° grid area and month strata. Purse seine fishery data shall be stratified by fishing mode (e.g. free swimming schools or schools in association with floating objects). The data shall be extrapolated to the total national monthly catches for each gear. Documents describing the extrapolation procedures (including raising factors corresponding to the logbook coverage) shall also be submitted routinely. These provisions, applicable to tuna and tuna-like species, shall also be applicable to the most commonly caught shark species and, where possible, to the less common shark species. CPC's are also encouraged to record and provide data on species other than sharks and tunas taken as bycatch. **4. Size data:** Size data shall be provided for all gears and for all species covered by the IOTC mandate according to the guidelines set out by the IOTC Scientific Committee. Size sampling shall be run under strict and well described random sampling schemes which are necessary to provide unbiased figures of the sizes taken. Length data by species, including the total number of fish measured, shall be submitted by a 5° grid area by month, by gear and fishing mode (e.g. free swimming schools or schools in association with floating objects for the purse seiners). **5.** Given that the activities of supply vessels and the use of **Fish Aggregating Devices** (FAD) are an integral part of the fishing effort exerted by the purse seine fleet, the following data shall be provided: (a) The number and characteristics of supply vessels: (i) operating under their flag, (ii) assisting purse seine vessels operating under their flag, or (iii) licensed to operate in their exclusive economic zones, and that have been present in the IOTC Area. (b) Number of days at sea by supply vessels by 1° grid area and month to be reported by the flag state of the supply vessel. (c) The total number and type of FADs set by the supply vessel and purse seine fleet per quarter. Types of FADs are defined as 1) drifting log or debris, 2) drifting raft or FAD with a net, 3) drifting raft or FAD without a net, 4) other (e.g. Payao, dead animal etc). All types monitored by a tracking system. These data would be for the exclusive use of IOTC scientists, subject to the approval of the data owners and Resolution 98/02 *Data confidentiality policy and procedures*, and should be provided in a timely fashion.	Resolution in force. No statistics have yet fed through into the deliberations of the working parties or Scientific Committee.

Table 55 IOTC Recommendations making specific reference to FADs and/or floating objects

No.	Recommendation	Management action / Recommendation relevant to FADs	Status
05/08	On sea turtles	1. The Commission encourages Contracting Parties and Cooperating non-Contracting Parties (hereinafter referred to as "CPCs") to implement the Guidelines, *inter alia,* the necessary measures for vessels fishing for tuna and tuna-like species in the IOTC Area to mitigate the impact of fishing operations on sea turtles: **A. General** i) Requirements for appropriate handling, including resuscitation or prompt release of all bycaught or incidentally caught (hooked or entangled) sea turtles. ii) Retention and use of necessary equipment for appropriate release of bycaught or incidentally caught sea turtles. **B. Purse seine** i) Avoid encirclement of sea turtles to the extent practical. ii) Develop and implement appropriate gear specifications to minimize bycatch of sea turtles. iii) If encircled or entangled, take all possible measures to safely release sea turtles. iv) For fish aggregating devices (FADs) that may entangle sea turtles, take necessary measures to monitor FADs and release entangled sea turtles, and recover these FADs when not in use. 2. The Commission encourages CPCs to collect and voluntarily provide the Scientific Committee with all available information on interactions with sea turtles in fisheries targeting the species covered by the IOTC Agreement, including successful mitigation measures, incidental catches and other impacts on sea turtles in the IOTC Area, such as the deterioration of nesting sites and swallowing of marine debris.	Working Party on Ecosystems and Bycatch examines all available information. Problems identified in 2008 include: • Recording of basic data on incidentally caught turtles (e.g. location, carapace size, species ID if possible), with a view to enhancing knowledge of the juvenile life stage. • Estimate the levels of sea turtle mortality due to various fishing methods, including long line, gillnets and purse seine. http://www.iotc.org/files/proceedings/2008/wpeb/IOTC-2008-WPEB-R[E].pdf

Table 56: IOTC Resolutions not making specific reference to FADs but of indirect relevance

No.	Resolution	Management action / Detail relevant to FADs	Status
01/01	Concerning the national observer programmes for tuna fishing in the Indian Ocean.	Contracting parties and Cooperating non contracting parties (CPCs) are encouraged to present national observer programmes that have been put into effect to observe the application and compliance with IOTC measures, including details of the type of fishing gear and species caught	A limited number of national observer programmes exist, but are not currently coordinated through IOTC
01/04	On limitation of fishing effort of non members of IOTC whose vessels fish Bigeye Tuna.	This resolution requests non members of IOTC who fish for bigeye tuna to reduce their fishing effort in 2002 in relation to 1999 levels	Unknown
03/01	On the limitation of fishing capacity of Contracting Parties and Cooperating on-Contracting Parties	CPCs with more than 50 vessels on the IOTC record of vessels shall limit vessels >24 m to the number registered in 2003.	Resolution in force
05/01	On Conservation and Management Measures for Bigeye Tuna	CPCs shall limit their catch of bigeye tuna to recent levels reported by the Scientific Committee; at the 10th session (i.e. next, 2006) the Commission shall establish catch levels that apply for 3 years for CPCs catching more than 1000t bigeye tuna. A quota mechanism will be established. Advice was sought from the Scientific Committee on (amongst others) the evaluation of the impact of different levels of catch reduction by the main gear types.	No resolution in 2006 or subsequently that establishes catch levels or quota for CPCs catching more than 1000t BET. SC in 2006 did not report on the impacts of catch reduction by gear type.
05/05	Concerning the conservation of sharks caught in association with fisheries managed by IOTC	Various controls on shark fishing, including, 'In fisheries that are not directed at sharks, CPCs shall encourage the release of live sharks, especially juveniles and pregnant sharks, to the extent possible, that are caught incidentally and are not used for food and/or subsistence.' 'CPCs shall where possible undertake research to identify ways to make fishing gears more selective'	Resolution in force. The ban on shark fining means that animals must be retained whole which takes up valuable hold space. Therefore there is an incentive to release sharks where possible.
07/03	Concerning the recording of catch by fishing vessels in the IOTC area.	Sets minimum logbook requirements for purse seine vessels. Includes recording association with natural logs etc, and observations on catch by natural / artificial logs (FADS) (see also 08/01)	Resolution in force
07/04	Concerning registration and exchange of information on vessels fishing for tunas and swordfish in the IOTC area.	This establishes the IOTC 'white' list of CPC vessels authorized to fish in the IOTC area. Amongst the details collected are gear(s) used. (Resolution 02/04 relates to a 'black' list of vessels from non CPCs that have carried out IUU activities in the IOTC area)	Resolution in force