2nd MEETING OF THE FAD MANAGEMENT OPTIONS INTERSESSIONAL WORKING GROUP

Pohnpei, Federated States of Micronesia

28 – 30 September 2016

ISSF FAD RELATED RESEARCH AND THE FAD IWG RESEARCH PLAN

WCPFC-2016-FADMgmtOptionsIWG02-OP02

19 September 2016

International Seafood Sustainability Foundation (ISSF)

ISSF FAD Related Research and the WCPFC FAD IWG Research Plan

Presented by the International Seafood Sustainability Foundation (ISSF)
September, 2016

Executive Summary

The purpose of this paper is to help guide the development of the WCPFC FAD Research plan. The table below provides an executive summary of the details contained in the rest of the paper. For full details on the research, please refer directly to the peer reviewed papers referenced on the last page or links provided throughout the document.

WCPFC Research Plan	ISSF Research – Key Results / Outcomes	References / Further Information

FAD Design	Non-entangling and biodegradable FADS:
	• Industry and scientists designed and tested FADs to demonstrate those that have low or no entanglement risk. Key recommendations on FAD design provide four categories:
	  o highest entanglement risk (use of any netting material, known to entangle sharks and turtles)
	  o lower entanglement risk (small mesh <7 cm may be present, tightly wrapped, underwater structure can be tightly bundled netting or weighted panels)
	  o non-entangling FADs (no netting in construction, subsurface structure of ropes or non-entangling material)
	  o biodegradable non-entangling FADs (only natural and/or biodegradable materials used).
	ISSF is supporting two studies to test biodegradable FADs, this research is ongoing:
	• Hawaii – testing large diameter rope and small square mesh made of coconut husk. Further required with finer time sampling
	• Maldives – cotton, cotton+sisal and cotton+linen+sisal ropes tested. Further trials with industry on dFADs
	Precautionary approach is the adoption of non-engagement and biodegradable FAD designs to minimise the impact on bycatch and the ecosystem.
		Guide to Non-Entangling FADs
		2015-12: Report of the 2015 ISSF Workshop on Non-Entangling FADs
		2016-08: Advances in the Use of Entanglement-Reducing Drifting FADs in Tuna Purse Seiners

	ISSF's bycatch reduction efforts have also looked at options for the live release of non-target catch from the net and handling and release of non-target catch from the deck. Also critical are studies on post-release survival verified with satellite PAT tags to determine the likelihood that released bycatch species survive the fishing interaction and at what point in the fishing operation to concentrate release efforts.	Itano et al. 2012; Itano et al. 2016b; Sancristobal 2016. Hutchinson, et al. 2015
Tuna Behaviour	ISSF research on tuna and non-target species behaviour has focused on residence times and vertical migration associated with dFADs. Key results: • In general, tunas, sharks and bycatch species were documented to remain associated with drifting FADs on a near-	Forget et al. 2015; Itano et al. 2016[a]; Restrepo et al. 2015 (for a summary)

	continuous basis for weeks or even months at a time before departing
	• Bigeye and yellowfin tuna generally have relatively long residence times at dFADs ; while skipjack and silky shark remained for short periods. Rainbow runner and oceanic triggerfish were recorded as intermediate in residence times
	• At residence times of less than 24hours:
	  o distinct diel FAD associative patterns were observed with interesting differences noted between ocean areas and diel behaviour data for target and non-target species will be useful in interpreting remotely monitored acoustic date from echo sounder buoys
	  o silky shark behavior mirrored the associative pattern of the target tuna species, particularly skipjack, being at the FAD during daytime, departing in early evening and returning around 3am.
	  o bigeye tuna were observed to be less present at the FAD in the early evening but this also coincided with a departure of the primary target species (skipjack and yellowfin tuna)
	  o overall, there is no specific change in fishing time that could mitigate the vulnerability of silky shark, finfish bycatch or bigeye tuna without significant reduction in target catch.
	• Acoustic tags show that all species have shallower night time versus deeper daytime behaviour when FAD associated, this is particularly true in the pre-dawn hours when all species were observed to rise to their shallowest depth, including bigeye tuna.
	  o these findings suggest that shallowing purse seine net depth will not be a viable or practical solution to mitigate bigeye fishing mortality on floating object sets.
	• In relation to silky sharks specifically, research continues to understand their behavior on FADs using electronic tagging and PAT tags in the Atlantic Ocean.
	ISSF Scientists recommend that the FAD IWG expand their focus on this research priority to include the non-target species in addition to skipjack, yellowfin and bigeye tuna.
	
	In the 2011 field research,10 experiments were undertaken to monitor simultaneous behavior of SKJ, BET, and YFT associated with large dFADs in multi-species aggregations in the equatorial EPO. Key results:
	• Documented spatial and temporal differences in the schooling behavior of the three tuna species were detected, but the differences do not appear sufficient such that modifications in purse-seine fishing practices could effectively avoid the capture of small bigeye and yellowfin tunas, while optimizing the capture of skipjack tuna in purse-seine sets on FADs.
		Filmalter et al. 2015 (for silky sharks)
		
		Schaefer and Fuller 2013

Hotspot Analysis	The ISSF does not have any specific research projects pertaining to this Research Plan priority as it does not have access to the operational-level data that would be required. However, ISSF is highly supportive of this important work and research priority.	nil
Acoustic FADs	• Key goal of the research is to differentiate tunas from non-target species by identifying the size and species of tuna under FADs. The research involves testing three eco-sounders operating simultaneously at 3 different frequencies (38 kHz, 120 kHz and 200 kHz). • Key results include: o Identification of target strength measurements specific to SKJ and BET	Towards acoustic discrimination of tuna species at FADs Sancristobal et al. 2014;

	○ Confirmation of the potential of using multiple frequencies to discriminate skipjack from yellowfin and bigeye tuna. • Further research focusing on differentiating between yellowfin and bigeye tuna, i.e. being able to remotely identify the size and abundance of bigeye tuna with echo sounder.	2016
	Tuna-X-Ray research is being undertaken to complement understanding of how species specific differences in anatomy and morphology influence acoustic discrimination. This research involves X-Raying YFT to capture dorsal and lateral images of the swim bladder. Further research will try to capture images of BET. Future Research on target strength measurements is critical to the acoustic research, but required obtaining acoustic tests of single species tuna schools. This has yet to occur for YFT. To address this, ISSF in collaboration with IATTC will seek to address this.	Sancristobal et al. 2014
Fleet Behaviour	It is clear that: • the adoption of echo sounder buoys has brought about dramatic changes in fishing strategy and planned or prospected fishing areas. • the rapid adoption of echo sounder equipped GPS buoys by advanced purse seine fleets with high catch rates offers strong empirical evidence of their value. **Understanding how fishing technology and increases in FAD-related effort creep influence purse seine CPUE and fleet dynamics would seem to be a very important aspect of this research priority.**	The use of echo-sounder buoys in purse seine fleets fishing with DFADs in the eastern Pacific Ocean. Moreno et al. 2016[b]; Lopez, et al. 2014
	Although not a research priority, ISSF notes that supply vessel activities related to dFADs increases the efficiency of the purse seiner by reducing the time needed by the purse seiner to search for and/or maintain FADs. Greater data collection is needed regarding supply/tender vessels, as well as regulation and monitoring. Key aspects include: • The number and use of supply vessels, including identifying which particular purse seine vessels each support, and the number of FADs being deployed and serviced by such vessels. • What activities supply vessels are engaged in, whether they are working as bait boats, servicing FADs, or engaging in fishing and make this information available on the RFV. • Observer coverage requirements apply to supply vessels so data from these fishing activities are collected and reported.	http://iss-foundation.org/download-monitor-demo/download-info/issf-technical-report-2016-11-issf-survey-paper-on-the-treatment-of-supply-vessels/

1 Introduction

One of the primary focus areas of the International Seafood Sustainability Foundation (ISSF) concentrates on bycatch reduction and improved targeting in tropical tuna fisheries. These efforts are coordinated by the ISSF Bycatch Steering Committee (Committee) lead by Dr. Laurent Dagorn. The ISSF Scientific Advisory Committee provides advice and oversight to the Committee through SAC Chair, Dr. Victor Restrepo. The Committee has concentrated on bycatch issues related to tuna purse seine fishing on floating objects but improvements to longline fisheries are also considered. Even though bigeye tuna is technically a retained, target catch of this fishery, ways to mitigate the harvest of bigeye tuna remain a primary objective of the ISSF due to its depressed stock condition in some major fishing areas. The reduction in fishing mortality of oceanic sharks is another focus area of the program as well as ways to minimize impacts to marine turtles and FAD associated finfish species. It is hoped that these research examples will assist the WCPFC FAD Intersessional Working Group (FAD IWG) to focus and address research priorities and objectives.

The group concentrates on the identification and testing of practical, technical solutions to bycatch reduction within a scientific framework. Potential solutions are developed in consultation with the tuna industry and tested in all tropical oceans, recognizing that oceanographic conditions will cause regional differences that may influence potential mitigation efforts. Industry input and feedback is maintained through ISSF coordinated Skippers Workshops that put scientists and fishermen in the same room to discuss and critique potential or tested bycatch methods and ideas. Committee members have expertise in the biology, physiology and movement of tunas and oceanic sharks, FAD dynamics, hydro-acoustics, gear technology, advanced tagging technologies and additional experience useful for bycatch mitigation.

The program conducts applied research through at-sea research cruises, tanks studies and laboratory research. In addition to the Skippers Workshops, ISSF supports the production and translation of publications, guides, infographics and videos that promote best practices for the safe handling and live release of bycatch or endangered/threatened/protected species that may encounter tuna fishing gear.

At-sea research cruises on commercial purse seine vessels provide scientists with a unique opportunity to observe and document the behavior of tuna and non-target species on FADs, in the net and during all stages of commercial fishing operations. Research cruises have also chartered non-commercial, non-fishing vessels which allow scientists to dictate the amount of time spent on FADs for tagging and controlled experiments. The ISSF, in conjunction with the tuna industry has engaged in 14 research cruises since 2011 in the Indian, Atlantic, Eastern Pacific and Western/Central Pacific Ocean purse seine fishing grounds. Cruises range from chartered arrangements to ISSF scientists joining fishing vessels on an opportunistic basis through industry collaboration. Research efforts focus on mitigating bycatch in four stages of the purse seine process:

- Passive techniques before arriving at a FAD;
- Avoidance of bycatch after arriving at the FAD but before setting;
- Live release of non-target catch from the net;
- Handling and release of non-target catch from the deck.

A summary of completed at-sea research has been compiled by Restrepo et al. (2016) see ISSF At-Sea Bycatch Mitigation Research. This research is depicted and summarized in the infographic: ISSF Research on FADs and blog: Blog - On FADs and FAD Management.

These efforts are parallel to many of the Research Priorities and stated objectives of the FAD IWG (ST-WP-06). Examples of ISSF research, papers and ongoing efforts will be described below as they relate to the FAD IWG's research priorities.

2 WCPFC Research Plan priority: **FAD Design – what works and what doesn't**

2.1 Promotion of non-entangling and bio-degradable FADs

Observations made on ISSF research cruises in the western Indian Ocean and other EU funded cruises were combined with pop-off satellite archival tag (PAT) data from silky sharks (*Carcharhinus falciformis*) to document high shark entanglement rates with drifting FADs in the Indian Ocean (Filmalter et al. 2013). It was recognized that large-mesh nylon webbing hung below drifting FADs (dFADs) in this area and at that time (pre-2013) was the main problem that caused high entanglement rates for sharks and posed a potential entanglement threat to sea turtles and other finfish. Awareness of this problem has contributed to efforts by industry and scientists to design and test FADs that have low or no entanglement risk. ISSF has compiled a large body of information on the design and style of FADs used by all fleets through their Skippers Workshops. This information was used with other experience to develop the ISSF Guide For Non-Entangling FADs.

The Guide describes industrial dFADs into four categories:

- Highest Entanglement Risk (use of any netting material, known to entangle sharks and turtles)
- Lower Entanglement Risk (small mesh <7 cm may be present, tightly wrapped, underwater structure can be tightly bundled netting or weighted panels)
- Non-Entangling FADs (No netting in construction, subsurface structure of ropes or non-entangling material)
- Biodegradable Non-Entangling FADs (only natural and/or biodegradable materials used)

The IATTC, IOTC and ICCAT have all adopted resolutions that contain regulations and recommendations supporting the use of non-entangling FADs by purse seine fleets and in some cases recommendations for the use of biodegradable materials. The WCPFC should be encouraged to adopt similar or compatible measures.

2.1.1 **Additional ISSF Non-Entangling FAD design resources:**

ISSF research cruises on purse seine vessels and on non-fishing vessels on the purse seine grounds are unique in that ISSF scientists often conduct snorkel and SCUBA dives on drifting FADs and inside the purse seine net to observe and document (film and video) tuna and bycatch behavior. While diving on drifting FADs, the scientists conduct underwater visual census and observations of bycatch behavior and also make notes on FAD design and entanglements of sharks or bycatch species. These observations are described in Restrepo et al. 2016. FADs removed from the water by the purse seiner are also inspected as to design and any entangled organisms.

Some additional ISSF reports relating to the use and promotion of non-entangling FADs are included in:

2015-12: Report of the 2015 ISSF Workshop on Non-Entangling FADs

2016-08: Advances in the Use of Entanglement-Reducing Drifting FADs in Tuna Purse Seiners

2.2 **Ongoing research: Biodegradable materials**

Drifting FADs or anchored FADs that break free from the substrate can wash ashore and negatively impact shorelines, reefs and cause entanglements with vessels. FADs constructed of synthetic materials (nylon, polypropylene, plastic) can cause permanent damage to sensitive coral reef ecosystems. Biodegradable FAD materials should be promoted but they need to be tested for reasonable longevity, strength and confirmed ability to aggregate tuna. ISSF is supporting two studies to test biodegradable materials in the ocean environment.

2.2.1 **Hawaii**

Large diameter rope (approximately 80 mm) and small square mesh (approximately 10 mm) made of coconut husk fiber was attached under an anchored FAD offshore of windward Oahu, Hawaii and in Kaneohe Bay near the Hawaii Institute of Marine Biology. Breaking strength was tested at intervals up to 97d when materials were found to be significantly degraded. Further testing is required with finer scale time sampling and with different diameter test materials. No evidence of colonization by fouling organisms or grazing by herbivorous fishes was noted.

2.2.2 **Maldives**

Ropes of 16 – 20.6 mm diameter of cotton, cotton+sisal and cotton+linen+sisal are being tested in Maniyafushi Island, Maldives. Bundles of test rope have been suspended from the mooring of an offshore FAD and in the lagoon with control ropes stored on the deck of a vessel. The breaking strain of ropes will be measured after different immersion periods. Subsequent trials will be conducted on drifting FADs through cooperation with industry.

2.3 ISSF/IATTC investigation of differences in the tuna species catch composition among shallow versus normal draft FADs in the equatorial EPO purse-seine fishery

The objective of this study is to evaluate the performance of non-entangling shallow draft (NESD) drifting FADs in attracting tuna aggregations, relative to typical design and depth FADs in the same time/area strata, specifically to compare bigeye tuna catch composition between the two FAD types. Lennert-Cody et al (2008) reported that the depth of drifting FADs was a significant factor in their modeling of the effects of gear characteristics on bigeye tuna catch in the eastern Pacific Ocean. Long standing opinions and questions regarding the performance of shallow depth FADs, including whether they will attract comparable size tuna aggregations with lower proportions of bigeye tuna to that of normal depth FADs, are being assessed in this study.

ISSF and the IATTC made arrangements for this field experiment to be undertaken in collaboration with Negocios Industriales Real S.A. (NIRSA), a large diverse seafood company located in Posorja, Ecuador, with a fleet of 11 tuna purse-seine vessels.

Bamboo FAD rafts of 50 shallow and 50 normal depth FADs were constructed with similar dimensions and construction materials for the study. The appendages hung beneath the normal depth FADs (37m) consisted of 2 coils of twisted and tied scrap tuna or sardine netting weighted with chain. The appendages hung beneath the shallow depth FADs (5m) consisted of 4 ropes (1-2” dia) with coconut palm fronds tightly laced, attached to a split bamboo frame weighted with chain. Marine Instruments M3i echo-sounder buoys were attached to each of the 100 FADs.

The normal and shallow depth FADs were deployed simultaneously in pairs along 7 transects in productive fishing areas of the eastern Pacific in June and July of 2015. Each deployment was recorded on a data form created specifically for this project which included data fields for FAD type, deployment position and date, buoy number and unique ID numbers assigned and painted on each buoy. In addition, the IATTC observer aboard monitored and recorded each of the deployments so as to independently verify the FAD types with the buoy ID numbers. Deployment and fishing activity forms specific to this project were provided to all 11 NIRSA fishing vessels to be completed when conducting any fishing activity around the 100 experimental FADs.

To date we have obtained catch information from NIRSA vessels for sets on 16 of the shallow depth and 21 of the normal depth FADs in this experiment. We are planning to continue this experiment as long as possible, so as to obtain adequate catch data from about 50 sets on each FAD type. That appears to be a minimum number of sets required for conducting a valid statistical analyses of the data from this experiment using a general linear model or other appropriate model, to evaluate whether FAD depth is a significant variable with respect to bigeye catch, relative to other variables to be included in the model.

Note that the timing of this experiment was not optimal since it occurred during anomalous oceanographic conditions, one of the strongest El Nino-Southern Oscillation (ENSO) events in history. A transition to ENSO-neutral, borderline La Nina conditions, has occurred in the equatorial EPO in 2016 and expected to persist. In January 2017 NIRSA vessels will deploy another 100 NESD and 100 normal draft FADs in the equatorial EPO to continue with this collaborative ongoing field experiment. Those new FAD deployments coupled with the resulting data from the previous deployments should substantially increase the number of sets on shallow and normal depth FADs and enable an appropriate statistical test of the null hypothesis under variable oceanographic conditions in the equatorial EPO.

3 WCPFC Research Plan priority**: Tuna Behavior – how different tunas behave under FADs**

The ISSF has been involved in several studies in all oceans that examine the behavior of target tuna species and the non-target species commonly associated with FADs. **It is recommended that the FAD IWG expand their focus on this research priority to include the non-target species in addition to skipjack, yellowfin and**

bigeye tuna. Understanding how the entire FAD aggregation behaves throughout the 24-hour cycle is key to interpreting acoustic data and developing better bycatch mitigation and targeting strategies.

3.1 The behavior of tuna and non-target species on FADs

The ISSF with guidance from their Bycatch Committee has devoted considerable resources to investigate the residence times and diurnal vertical behavior of tuna and non-target species associated with drifting FADs using acoustic telemetry. In these studies, FADs with a diverse aggregation of tuna and non-target species are equipped with an acoustic receiver that can process data from acoustic tags inside the fish and transmit the data via satellite to the researchers over an extended period. Skipjack, yellowfin and bigeye tuna, silky sharks, rainbow runner (*Elegatis bipinnulata*) and oceanic triggerfish (*Canthidermis maculata*) are captured for the study with hook and line gear and implanted with acoustic tags that report presence/absence and fine-scale depth data when the fish is associated (within range, approx. 700m) of the FAD mounted receiver. The study has been replicated in the Indian Ocean (Forget et al. 2015), the Atlantic Ocean (Itano et al. 2016[a]) and the Central and Western Pacific. A summary of these studies, including those conducted in the Central and Western Pacific Ocean are included in Restrepo et al. 2015. The study has been repeated in all oceans to investigate the possibility of regional differences in aggregative behavior useful for bycatch mitigation.

In general, tunas, sharks and bycatch species were documented to remain associated with drifting FADs on a near-continuous basis for weeks or even months at a time before departing for unknown reasons. For example, at scales of greater than 24 hours, they did not stay FAD-associated for three days, leave for two, return for six, depart for five, etc. Bigeye and yellowfin tuna were generally seen to have relatively long residence times at dFADs while skipjack and silky shark remained for short periods. Rainbow runner and oceanic triggerfish were recorded as intermediate in residence times (Itano et al. 2016[a]).

At residence scales of less than 24 hours, distinct diel FAD associative patterns were observed with interesting differences noted between ocean areas. Rainbow runner and oceanic triggerfish were more closely associated with FADs during the night in the Indian ocean while they were noted to be almost evenly and constantly associated day and night with Atlantic FADs making them difficult to avoid by adjusting set time. Some avoidance of these species might be achieved by attempting daytime sets in the Indian Ocean. However, silky sharks in all areas were found to be more closely associated with FADs during the daytime, and avoidance of silky sharks is a priority objective of bycatch mitigation efforts.

In addition, silky shark behavior mirrored the associative pattern of the target tuna species, particularly skipjack, being at the FAD during daytime, departing in early evening and returning around 3am. Bigeye tuna were observed to be less present at the FAD in the early evening but this also coincided with a departure of the primary target species (skipjack and yellowfin tuna). In other words, no specific change in fishing time could mitigate the vulnerability of silky shark, finfish bycatch or bigeye tuna without significant reduction in target catch (Forget et al. 2015).

The acoustic tags also provided detailed depth data, characterizing the vertical behavior of skipjack, yellowfin bigeye, silky shark, rainbow runner and oceanic triggerfish on drifting FADs in all oceans. All species indicated shallow night time versus deeper daytime behavior when FAD associated. Unfortunately, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net useful in that region. This is particularly true in the pre-dawn hours when all species were observed to rise to their shallowest depth, including bigeye tuna. However, information obtained on the diurnal residence and depth distributions of these species will be useful to improve the interpretation of echo sounder and echo sounder buoy data, particularly for remote species discrimination. This information may become useful to avoid FADs or areas with high abundance of bycatch species or undesirably small target tuna species, including bigeye tuna.

Silky sharks are the most commonly encountered oceanic shark in the purse seine FAD fishery. Understanding their behavior on FADs is an important part of trying to reduce fishery impacts on this species. ISSF has contributed to important findings on FAD associated silky shark behavior using a combination of electronic tagging technology (Filmalter et al. 2015). Silky shark movements when away from FADs are also being investigated with the use of PAT tags in the Atlantic Ocean (Itano et al. 2016 [a]).

3.2 ISSF/IATTC 2011 field study of behavior of SKJ, BET, and YFT associated with drifting fish-aggregating devices (FADs) in the equatorial eastern Pacific Ocean (EPO)

The objective of this study was to elucidate spatial and temporal differences in the behavior of skipjack, bigeye, and yellowfin tunas within aggregations associated with drifting FADs, in order to define opportunities for optimizing the capture of skipjack in purse-seine sets while reducing the capture of bigeye and other species of concern.

A research cruise was undertaken between 11 May to 23 July 2011 to the equatorial EPO aboard the Ecuadorian-flag purse-seine vessel Yolanda L., under a charter agreement between the vessel owner and the ISSF, and in collaboration with the IATTC. Ten separate experiments monitoring the simultaneous behaviors of skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), and yellowfin (*T. albacares*) tunas within large multi-species aggregations associated with FADs that were investigated using ultrasonic telemetry in the equatorial EPO. Purse-seine sets were made on the tuna aggregations associated with FADs at the termination of six of the ten of the experiments. Seventeen of the 44 tagged tunas were not recaptured indicating the transient nature of the associative behavior of tunas with FADs. Although there was considerable overlap in the depths of the three species, by day and night, there were some species-specific differences and diel differences within species. While we documented spatial and temporal differences in the schooling behavior of the three tuna species, the differences do not appear sufficient such that modifications in purse-seine fishing practices could effectively avoid the capture of small bigeye and yellowfin tunas, while optimizing the capture of skipjack tuna in purse-seine sets on FADs.

Relevant publication: Schaefer and Fuller 2013.

4 WCPFC Research Plan priority: **Acoustic FADs and discrimination of species on FADs**

4.1 Acoustic discrimination of tuna species at FADs

Modern purse seine fleets utilize sophisticated echo sounders, sonar and echo sounder equipped GPS buoys attached to drifting FADs to increase efficiency and CPUE. The acoustic identification of tuna size and species and the differentiation of tuna from non-target species is a high priority goal of ISSF bycatch mitigation efforts. Two ISSF research cruises on large purse seine vessels of the Spanish company Albacora concentrated on improving acoustic discrimination of tuna on dFADs (Sancristobal et al. 2014; 2016).

These cruises were able to define target strength (TS) measurements specific to skipjack and bigeye tuna which is a necessary step toward size and species-specific acoustic discrimination. Pre-set estimation of species and biomass from echo sounder data were compared with detailed onboard catch sampling that was used to refine future acoustic estimates, especially those from echo sounder GPS buoys. Target strength measurements for yellowfin tuna were not obtained as this requires a FAD aggregation of nearly 100% yellowfin tuna which is rarely encountered.

The ISSF Bycatch Steering Committee is fortunate in having an expert fisheries acoustician who leads the analysis and interpretation of ISSF acoustic data. Tuna species discrimination at dFADs was examined by using 3 echo-sounders operating simultaneously at 3 different frequencies (38 kHz, 120 kHz and 200 kHz) from the workboat of a tuna purse-seine vessel working on dFADs in Central Pacific and Atlantic Oceans. A similar protocol was followed to work with echo-sounder buoys by attaching the buoys to the DFAD before the catch. This work has confirmed the potential of using multiple frequencies to discriminate skipjack from yellowfin and bigeye tuna. Differentiating between yellowfin and bigeye tuna, i.e. being able to remotely identify the size and abundance of bigeye tuna with echo sounder is the next big goal. This work is described by Moreno et al. (2016 [a]). See Towards acoustic discrimination of tuna species at FADs. The definition of target strength and discrimination of yellowfin tuna will be conducted on captive yellowfin as described in section 4.3 below.

4.2 Tuna X-Ray Project

The relationships of target strength and tuna length were measured *in situ* where target strength of tunas from scientific echo sounder data was combined with estimated tuna lengths from intensive onboard length-frequency sampling of the catch (Sancristobal et al. 2014). In order to get a more complete understanding of how species-specific differences in anatomy and morphology influence acoustic discrimination, another approach is being taken.

In order to obtain accurate information on the morphology and internal anatomy of tunas, yellowfin tuna have been captured at an offshore anchored FAD and transported and held in the land-based tuna tank at the Hawaii Institute of Marine Biology on the island of Oahu. 18 YFT between 38 – 74 cm FL (a typical size range of FAD associated yellowfin), were X-rayed during two sessions and satisfactory dorsal and lateral images of the swim-bladder have been obtained. Bigeye tuna have not yet been captured for this experiment but efforts are ongoing. Additional yellowfin tuna are being held in captivity for further measurements.

4.3 Obtaining Target Strength Measurements of Yellowfin Tuna

Obtaining target strength of tunas in the wild requires acoustic tests on mono-specific schools, i.e. 100% skipjack or 100% bigeye tuna as was encountered during one ISSF research cruise (Sancristobal et al. 2014). This was an extremely fortunate situation but the same could not be repeated on the cruise for FAD associated yellowfin tuna. The ISSF is collaborating with the IATTC to conduct TS measurements on yellowfin tuna held in captivity in ocean net pens at the IATTC field station in Achotines, Panama. TS of captive yellowfin of 40 – 60 cm (typical FAD associated yellowfin size) will be measured in conjunction with the recording of tuna behavior with camera gear. The experiment will utilize four different GPS echo sounder buoy types with multi-frequency SIMRAD EK 60 echo sounders (38, 120, 200 kHz) and a wide-band SIMRAD EK80 scientific sounder operating from 85 – 170 kHz.

5 WCPFC Research Plan priority: ***Hotspot Analysis*** **- geographic hotspots or operational methods that result in high bigeye tuna catches**

The ISSF does not have any specific research projects pertaining to this Research Plan priority as it does not have access to the operational-level data that would be required. However, ISSF is highly supportive of this important work and research priority.

6 WCPFC Research Plan priority: ***Fleet Behavior***

6.1 The influence of FAD fishing technology on Fleet Behavior

The FAD IWG research priority regarding Fleet Behavior appears to have many aspects and possible areas of research relevant to FAD management, abundance estimates and stock assessment. Understanding how fishing technology and increases in FAD-related effort creep influence purse seine CPUE and fleet dynamics would seem to be a very important aspect of this research priority. ISSF scientists have devoted a great deal of research time on the influence of GPS echo sounder buoys on FAD CPUE, fleet behavior and their potential for pre-assessment of FAD aggregations for bycatch reduction and bigeye tuna avoidance. The rapid adoption of echo sounder equipped GPS buoys by advanced purse seine fleets with high catch rates offers strong empirical evidence of their value (Lopez, et al. 2014).

The adoption of echo sounder buoys has brought about dramatic changes in fishing strategy and planned or prospected fishing areas but most fishers were not able to effectively discriminate species using current buoy technology (Moreno et al. 2016[b]). See: The use of echo-sounder buoys in purse seine fleets fishing with DFADs in the eastern Pacific Ocean.

There is clearly a great deal of work and improvement needed in remote biomass and species estimation from acoustic devices.

7 Discussion

This paper provides examples of ISSF sponsored research that may be relevant and hopefully useful to the current FAD IWG research priorities. This is not meant to be an exhaustive or complete listing of all such research and it does not include a complete description of project materials, methods or results. References are provided to scientific papers and meeting reports that provide relevant details.

In addition to these areas of research, a great deal of the ISSF's bycatch reduction efforts have looked at options for the:

- Live release of non-target catch from the net; and
- Handling and release of non-target catch from the deck.

Examples of research on the live release of silky shark from purse seine nets: Itano et al. 2012; Itano et al. 2016b; Sancristobal 2016.

A critical aspect of developing best practices for the handling and live release of non-target species from the deck is to conduct scientific studies on post-release survival. The ISSF has been able to support these studies through strong industry collaboration. An important study on post release condition of silky sharks is documented in Hutchinson, et al. 2015.

8 Acknowledgments

ISSF research to reduce bycatch and improve the sustainability of tuna fisheries would not be possible without the cooperation, advice and assistance from the tuna industry. We would like to thank the many tuna fishing companies that have assisted in these efforts including ALBACORA S.A., CFTO, Saupiquet, Tri Marine, NIRSA, TTV Ltd. and others. Our gratitude is extended to the captains and crews of the many vessels we have worked with, recognizing that their advice and knowledge is key to developing practical solutions to reduce bycatch and improve the harvesting strategies of tuna fisheries. We are also indebted to the support of the major tuna RFMOs that have endorsed and in some cases collaborated with our work that include the IATTC and WCPFC and for additional collaboration and support of the Secretariat of the Pacific Community, the Forum Fisheries Agency and the many countries who have granted access to their EEZs for research purposes. Funding and support from the FAO-GEF ABNJ Tunas Project is kindly noted.

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