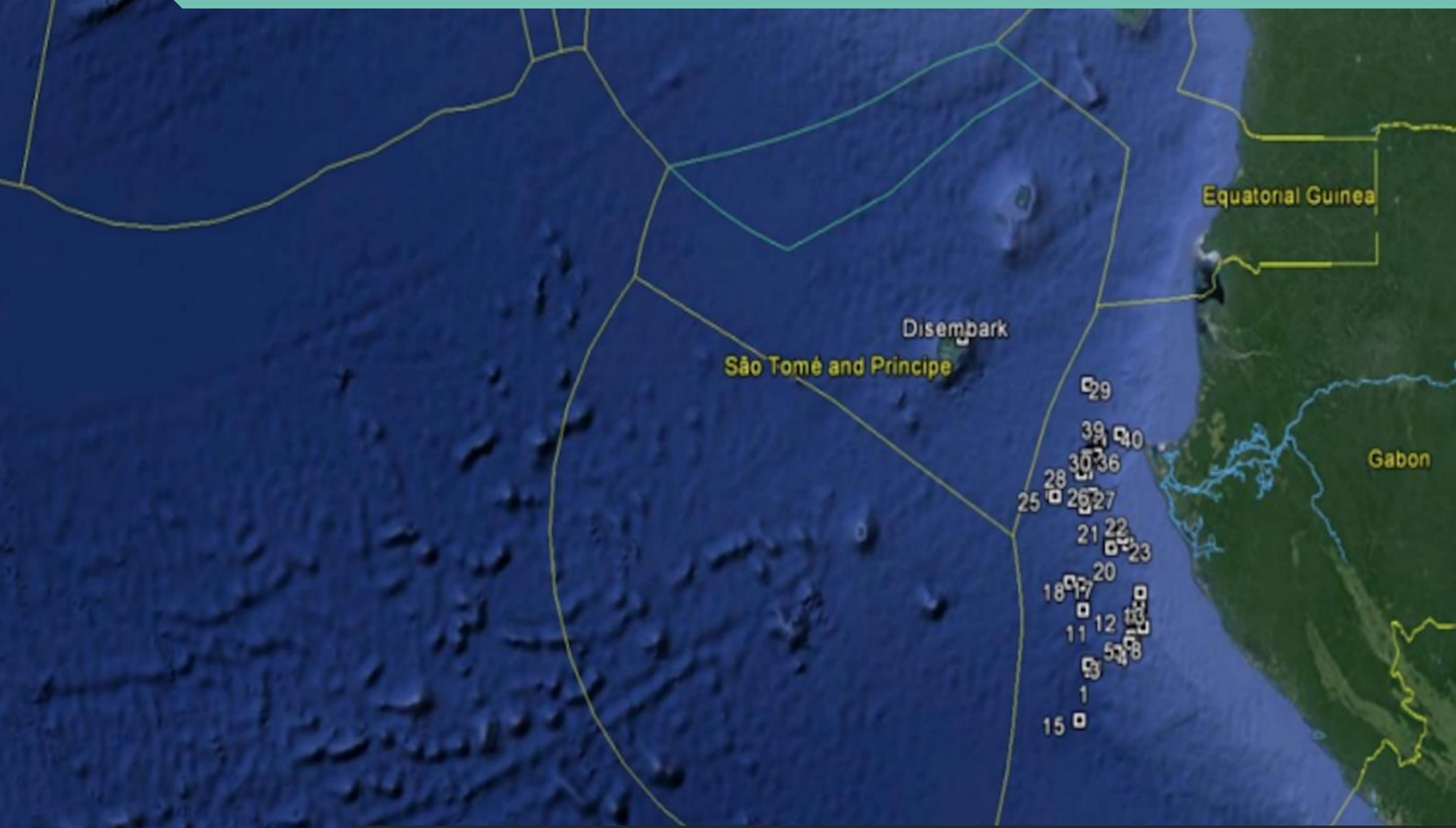
INTERNATIONAL SEAFOOD SUSTAINABILITY FOUNDATION

ISSF Technical Report 2018-20

COMPENDIUM OF ISSF AT-SEA BYCATCH MITIGATON RESEARCH ACTIVITIES as of September 2018



V. Restrepo, L. Dagorn, G. Moreno, F. Forget, K. Schaefer, I. Sancristobal, J. Muir, D. Itano, and M. Hutchinson / **October 2018**

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Topic Categories: Bycatch mitigation, purse seine, sharks, bigeye tuna, turtles

Abstract

ISSF conducts at-sea research to investigate potential mitigation measures for tropical tuna purse seiners, especially to reduce catches of bigeye tuna and sharks. Research activities can be classified in one of four hierarchical stages along a fishing trip: 1) Passive mitigation, 2) Avoid catching bycatch, 3) Release bycatch from the net, and 4) Release bycatch from the deck. This Technical Report summarizes all of the at-sea research that ISSF has conducted to date, in chronological order. Most of the research has been done onboard tuna purse-seine fishing vessels, but other vessel types have been used. For each research activity, a table that summarizes the objectives, methods, results and conclusions is presented. Following each research activity, there is a list of publications (peer reviewed as well as other literature) derived from that activity. The Conclusions section at the end of this report highlights some of the main findings of these research activities, with a focus on sharks, bigeye tuna, and turtles.

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October 2018

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Introduction

Each year, ISSF supports multiple initiatives to track, report on and minimize unwanted bycatch[1] among purse seine fishing vessels targeting tropical tunas. Since its inception in 2009, ISSF has dedicated considerable effort to better understand the issues of concern in global tuna fisheries (in particular linked to the use of fish aggregating devices – FADs; see Restrepo *et al.* 2014) by using scientific information – primarily from scientific observer programs – to quantify relative impacts. At the same time, ISSF conducts research to define and promote best practices that can positively impact this important issue. This research is mainly based on at-sea research to investigate potential mitigation measures, and is closely linked to two other key activities: 1) Leading workshops with tropical tuna purse seine vessel skippers to discuss mitigation techniques and seek skippers inputs about other potential mitigation measures (Murua *et al.* 2014), and 2) advocating to global tuna RFMOs for the adoption of essential bycatch data-collection and mitigation measures.

At-sea research, the focus of this report, is difficult and costly. At-sea conditions cannot be controlled easily, like in a laboratory setting. Working with wild fish often comes with surprises, especially when scientists are trying something out for the first time. Also, progress can sometimes be slow, especially when working opportunistically with commercial fishing vessels that have fishing efficiency as their main priority. Still, ISSF believes that this type of research offers opportunities that cannot be found in a lab or in a library. That is why ISSF has invested the past several years in these initiatives and will continue to do so.

For any given issue, such as avoiding catching small undesirable sizes of bigeye and/or yellowfin tunas, or sharks, ISSF's at-sea research follows a hierarchical logic, ordered by the time at which the measure takes place within the fishing operation:

1) Passive mitigation – before the vessels is at the FAD (e.g., non-entangling FADs)
2) Avoid catching bycatch– before setting when the vessel is at the FAD, (e.g., attraction of sharks away from FADs before setting, acoustic discrimination of species before setting)
3) Release bycatch from the net (e.g., release sharks and small bigeye and/or yellowfin tuna out of the net)
4) Release bycatch from the deck (e.g., release animals alive from the deck)

As for any research, it is key to prioritize activities to make the most of the available funds. Research priorities are guided by the ISSF Bycatch Mitigation Steering Committee, a group of world-renowned experts in relevant fields such as tuna fisheries, bycatch, gear technology, behavior, physiology, and ecology. Current and past members of the Committee are (* denotes past member):

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[1] Bycatch is any catch that is not the main objective of a fishing fleet. It is further defined as anything that is caught and discarded at sea, including targeted fish that are discarded due to undesired quality or size, or anything that is caught and taken back to port but that was not the target of the fishing trip, that is, "non target species."

Javier Ariz*, Diego Bernal, Richard Brill, Laurent Dagorn (Chair), Martin Hall, Kim Holland, David Itano, Bruno Leroy, Gala Moreno, Simon Nicol*, Miki Ogura*, Hiroaki Okamoto*, Tatsuki Oshima, Jacques Sacchi, Kurt Schaefer and Peter Sharples*.

This Steering Committee meets sporadically to review progress made and discuss what research activities should be modified or which new activities should be introduced. The Committee's deliberations also take into consideration suggestions from purse seine skippers, which are obtained through the ISSF Skippers' Workshops (Murua et al. 2014). Much of the emphasis of the research is focused on the two main issues of concern in tropical tuna purse seine fisheries: the bycatch of sharks (primarily silky sharks) and the catches of small undesirable sizes of bigeye and yellowfin tunas. While the latter is not, strictly speaking, a bycatch issue, potential mitigation techniques for small bigeye and yellowfin are addressed through similar lines of research as used for sharks.

Most of the efforts to develop any kind of measure to reduce bycatch have been mainly concentrated on fishing on drifting FADs. Critical items that are essential for the development of efficient mitigation measures for bycatch at FADs include:

- Knowledge on the behavior of the tunas and other fish at FADs, and within purse- seine nets
- Knowledge about the fishing practices used
- Improvement or development of technologies to better discriminate fish species and sizes (e.g., using acoustics and underwater video)
- Best practices for the release of animals in good condition from the net or from the deck
- Modifications in designs of FADs (e.g., non-entangling FADs, biodegradable FADs, shallow versus normal FADs) to lessen their impact on species of concern and the environment

The purpose of this Technical Report is to summarize all of the at-sea bycatch mitigation research that ISSF has conducted. Most of the research has been done onboard tuna purse seine fishing vessels but other vessel types have also been used. For each research activity, there is a table that summarizes the objectives, methods, results, and conclusions. At the end of each research activity, there is a list of publications (peer reviewed as well as gray literature) derived from that activity. Readers wishing to obtain more detailed information should consult those publications.

To date, ISSF has carried out 20 at-sea bycatch mitigation research activities, summarized below in chronological order, and explained in more detail in the following section of this report.

Research Activity	Passive Mitigation	Avoid before setting	Release from the net	Release from the deck
1. 2011 EPO Cruise on the F/V YOLANDA L	■			■
2. 2011 IO Cruise on the MV MAYA'S DUGONG	■	■		
3. 2012 EPO Cruise on the F/V VIA SIMOUN				■
4. 2012 IO Cruise on the F/V TORRE GIULIA	■	■	■	■
5. 2012 WCPO Cruise on the F/V CAPE FINISTERRE				
6. 2013 WCPO cruise on the F/V CAPE FINESTERRE		■	■	■
7. 2014 WCPO Cruise on the ALBATUN TRES	■	■	■	
8. 2014 CP-10 cruise (with SPC)		■		
9. 2015 AO cruise on the F/V CAP LOPEZ	■			
10. 2015 Biodegradable twine tests at U. Hawaii	■			
11. 2015-2017 tests of shallow versus normal depth FADs in the equatorial EPO	■			
12. 2015 CP-11 cruise (with SPC)		■		
13. 2015 AO Cruise on the SEA DRAGON	■	■		
14. 2016 AO Cruise on the F/V MAR DE SERGIO	■	■	■	
15. 2016 EPO Cruise on the F/V LJUBICA			■	
16. 2016 Acoustic research in Achotines, Panama (with IATTC)	■			
17. 2016 CP-12 cruise (with SPC)		■		
18. 2016 Biodegradable twine tests in the Maldives	■			
19. 2017 Test of biodegradable ropes in FADs in the western Indian Ocean	■			
20. 2018 AO Cruise on the F/V PACIFIC STAR			■	■

This Compendium will be updated periodically, as ISSF continues its at-sea research activities into bycatch mitigation.

1. 2011 EPO Cruise on the F/V YOLANDA L

Objectives:

(1) **Modifications in FAD designs to reduce impacts**: To test different designs of FADs that may not entangle turtles or sharks, including the potential for using biodegradable materials

(2) **Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs:** To evaluate the accuracy of the catch predictions by the fishing captain from the tuna aggregations associated with FADs, and the potential improvements in those estimates through the use of additional complimentary equipment and methods

(3) **Behavior of tunas and other fishes around FADs:** To elucidate spatial and temporal differences in the behavior of skipjack, bigeye, and yellowfin tunas within aggregations associated with drifting FADs, in order to reveal potential opportunities for avoiding the capture of undesirable sizes of bigeye, yellowfin, and other species of concern in purse-seine sets, while optimizing the capture of skipjack tunas

(4) **Behavior of tunas and other fishes within purse-seine nets:** To investigate the behavior of tunas and sharks captured within a purse-seine net, and determine if species-specific segregations occur, and the spatial and temporal characteristics of such segregations

(5) **Post-release survival of sharks:** To determine the at-vessel mortality, post-release survival, and the physiological, biochemical, and molecular responses of sharks incidentally captured by purse seiners

Scientists:

Kurt Schaefer (Chief Scientist) and Daniel Fuller of IATTC and Cory Eddy of the University of Massachusetts.

Vessel:

Chartered cruise of the YOLANDA L (Ecuadorian flag), a 66.5m tuna purse seiner built in San Diego, USA in 1974 with 1,375 GT and approximately 1,041 tons[2] of tuna carrying capacity.

Time and Area:

The cruise took place in the equatorial Eastern Pacific Ocean, starting and ending in Manta (Ecuador), from May 11th to July 23rd. A total of 9 fishing sets were made (Figure 1.1).

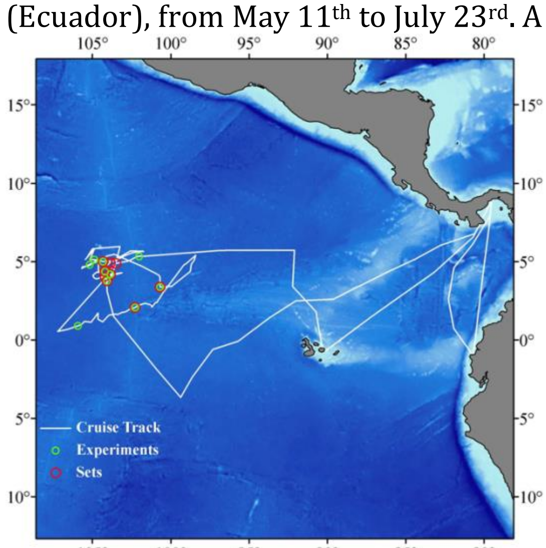


Figure 1.1. The cruise track and locations of where experiments and sets occurred during the cruise.

Progress made for each Objective

***(1) Modifications in FAD designs to reduce impacts**: To test different designs of FADs that may not entangle turtles*

[2] In this report, tons is used to denote metric tons (or tonnes).

or sharks, including the potential for using biodegradable materials

Methods

Ten "ecological" (non-entangling) FADs and 51 "standard" FADs were deployed during the routine fishing trip, preceding the research cruise. Two of the "ecological" FADs were constructed of all natural materials (palm fronds, bamboo). The other 8 "ecological" FADs had 2" stretch purse seine mesh net hung from the FADs, versus the common 4.5" or larger mesh net.

Results

All FADs checked during the cruise were evaluated as to their design, condition, presence of any entangled animals, and tuna biomass. There were no turtles or sharks observed entangled in the netting of any FADs during this cruise.

Conclusions

The objective was achieved, non-entangling, biodegradable FADs can be used in the fishery and still attract tunas.

(2) Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs: *To evaluate the accuracy of the catch predictions by the fishing captain from the tuna aggregations associated with FADs, and the potential improvements in those estimates through the use of additional complimentary equipment and methods*

Methods

Acoustic and optical surveys of the tuna aggregations were conducted utilizing a SIMRAD ES70 echo - sounder and SEABOTIX LBV 200 remotely operated vehicle (ROV) aboard a workboat. Pre-set estimates of the species composition, sizes, and quantities of tunas were provided by the Captain, based on acoustics from the purse seine vessel and light boat, and visual observations from mast men. Tunas loaded aboard the vessel from 9 sets were separated within wells, so as to obtain weights by species weight classes within sets, following unloading and sorting at the StarKist cannery in Manta, Ecuador.

Results

Catches from different sets were successfully separated in the wells and the separation was maintained during unloading and sorting at the cannery. Table 1.1 shows the differences in estimates from the skipper and the actual unloadings. The captain's predictions were significantly related to the actual total catch and catch by species, but not to size categories by species. His predictions of species composition were most accurate when estimates of bigeye and yellowfin tuna were combined.

Table 1.1. Estimates by the Captain of the tons of skipjack (SKJ), bigeye (BET), and yellowfin (YFT) tunas present at each of 8 FADs prior to setting, compared to the tons actually caught following the cannery classification.

		SKJ		BET		YFT		Total	
Set Number	Date	Pre-Set	Cannery	Pre-Set	Cannery	Pre-Set	Cannery	Pre-Set	Cannery
1	5/27/2011	35	90	18	11	22	25	75	126
2	5/31/2011	45	61	7	7	11	15	63	83
3	6/1/2011	13	18	5	1	2	5	20	24
4	6/4/2011	93	127	33	15	34	20	150	162
5	6/9/2011	8	21	30	17	12	18	58	56
7	6/23/2011	90	184	35	7	37	10	162	201
8	6/30/2011	65	122	35	2	30	33	130	157
9	7/10/2011	25	62	9	3	12	15	46	80

More detail on this research activity can be found in Fuller and Schaefer (2014).

Conclusions

The objective was successfully achieved, although the sample size is small. There is potential for a skipper to estimate amounts of (yellowfin+bigeye) from skipjack before a set, which could potentially be used for more selective targeting of skipjack.

(3) Behavior of tunas and other fishes around FADs: *To elucidate spatial and temporal differences in the behavior of skipjack, bigeye, and yellowfin tunas within aggregations associated with drifting FADs, in order to reveal potential opportunities for avoiding the capture of undesirable sizes of bigeye, yellowfin, and other species of concern in purse-seine sets, while optimizing the capture of skipjack tunas*

Methods

Ultrasonic telemetry experiments were to be undertaken at a minimum of ten drifting FADs, with a minimum of 30 tons of tunas present, including bigeye and skipjack. Proposed methods included the capture and tagging, with coded acoustic tags, 3 each of skipjack, bigeye, and yellowfin tunas, and continuous acoustic tags, in 3 additional skipjack. Each experiment was intended to be conducted for a minimum of 48 h. Should a monospecific skipjack school be observed, while active tracking to move a distance of 1 nm away from the FAD the purse seine vessel would target that school for capture. There were no such sets made during this cruise.

Results

Ten separate ultrasonic telemetry experiments were conducted with tagged skipjack, bigeye, and yellowfin tunas. A total of 28 skipjack, 26 bigeye and 33 yellowfin tunas were tagged with continuous or coded ultrasonic tags (Table 1.2)

Table 1.2. Numbers of skipjack (SKJ), bigeye (BET), and yellowfin (YDT) tunas tagged with coded or continuous ultrasonic transmitters for each experiment during the ISSF/IATTC purse seine research cruise. The "*" represents experiments where a skipjack received both a coded and continuous ultrasonic transmitter.

		SKJ			BET		YFT	
Experiment	Date	Coded	FL (cm)	Continuous	Coded	FL (cm)	Coded	FL (cm)
1	5/25- 27	0	50 - 58	2	3	53 - 59	3	60 - 66
2	5/28 – 31	2	51	0	3	53 - 57	3	52 – 57
3	6/1 – 4	4	47 - 53	2	3	64 - 67	3	57 - 65
4	6/7 – 9	1	47 - 49	2*	3	59 - 72	3	52 – 60
5	6/10 – 14	2	49 - 51	2*	3	53 - 56	3	55 – 59
6	6/16 – 20	3	41 - 57	2*	1	92	3	52 - 57
7	6/21 – 23	2	42 - 51	2	NA	NA	4	41 - 51
8	6/27 – 30	1	52 - 65	2*	3	57 - 63	3	55 – 62
9	7/5 – 8	2	50 - 54	0	6	47 - 62	6	45 – 62
10	7/11 – 12	1	44	0	1	55	2	39 - 42

Fine-scale spatial and temporal differences in the behavior of skipjack, bigeye, and yellowfin tunas were documented. Although there are significant differences in the day and night depth distributions, both within and between these species when associated with drifting FADs, the differences are small.

Percent time by day and night in which bigeye and yellowfin tunas, with acoustic tags, were within detection range of the VR2W receiver was similar. Skipjack, however, exhibited much lower detection rates at night, versus during the day, apparently due to much greater dispersion away from the FADs at night.

Based on the ultrasonic telemetry data coupled with visual and acoustic observations from the purse seine vessel, skipjack aggregations at drifting FADs are very dynamic and are not cohesive units.

More information can be found in Schaefer and Fuller (2013).

Conclusions

The main objective was successfully achieved, showing fine temporal and spatial differences between the three species around FADs.
Targeting skipjack schools when they move away from FADs does not appear to be a feasible solution to reduce fishing mortality on undesirable sizes of bigeye and yellowfin, nor sharks, and maintain any reasonable level of catch.

(4) Behavior of tunas and other fishes within purse-seine nets*: To investigate the behavior of tunas and sharks captured within a purse-seine net, and determine if species-specific segregations occur, and the spatial and temporal characteristics of such segregations*

Methods

The workboat was to remain adjacent to the FAD during a set at pre-dawn. Records from the echo-sounder were to be recorded during the set. Following dawn, the ROV was to be deployed with adequate light to observe and record the behavior of tunas and sharks within the net. Simultaneously, observations would be recorded by video from the mast of the purse - seine vessel of the behavior of the tunas and sharks within the net. Observations and recordings

	would be conducted for up to 6 h, after the rings are aboard and at 25% net in water.
Results	No experiments were undertaken for this activity, because the precautionary requirements stipulated by the Captain (such as sets on small tuna aggregations, and calm ocean conditions) were not available during the cruise.
Conclusions	The objective could not be achieved.
(5) Post-release survival of sharks*: To determine the at-vessel mortality, post-release survival, and the physiological, biochemical, and molecular responses of sharks incidentally captured by purse seiners*	
Methods	The numbers, species composition, at-vessel mortality, and physical condition of sharks loaded aboard the purse seine vessel were assessed during the cruise. The physical and physiological condition of sharks immediately after loading, and prior to release were determined, to characterize the overall impact of capture and handling. The post‐release mortality rates were to be determined by directly recording the sharks' vertical and horizontal movement patterns for 30-45 days, using Wildlife computers mini-PATs.
Results	There were 40 silky sharks loaded aboard, from 7 of the 9 sets during the cruise, and 8 sharks which appeared alive were tagged and released with mini-PATs. The post-release mortality rates were to be determined by directly recording the shark's vertical and horizontal movement patterns for 30-45 days with the mini-PATs. Two of the 8 sharks released survived, based on evaluations of the mini-PAT data sets. More results are presented in Eddy et al. (2016).
Conclusions	This objective was achieved successfully.

Derived publications:

Schaefer and Fuller (2011)
Schaefer and Fuller (2013)
Fuller and Schaefer (2014)
Eddy et al. (2016)

2. 2011 IO Cruise on the MV MAYA'S DUGONG

This cruise was organized by ISSF and partially funded through the EU MADE[3] project.

Objectives:

(1) **Behavior of tunas and other fishes around FADs:** Investigate the associative behavior of target and non-target species using acoustic telemetry

(2) **Avoiding the capture of sharks before setting:** Test if sharks can be attracted away from FADs using chum

Scientists:

Fabien Forget (IRD, SAIAB), John Filmalter (IRD, SAIAB) and Rhett Bennett (SAIAB).

Vessel:

A chartered cruise on the MV MAYA'S DUGONG (a non-fishing vessel, Seychelles flag) a 43m vessel built in Ontario, Canada in 1966.

Time and area:

The cruise took place in the Western Indian Ocean, departing from Mahe (Seychelles) on March 16th and ending on April 27th 2011. A total of 9 FADs were visited (8 different FADs, with one being visited twice, 10 days apart).

Progress made for each Objective

(1) Behavior of tunas and other fishes around FADs: *Investigate the associative behavior of target and non-target species using acoustic telemetry*	
Methods	Both target and non-target species were equipped with acoustic transmitters (Vemco) around drifting FADs to provide information on the residency of fish at FADs. The positions of drifting FADs were kindly provided by French and Spanish fleets. Vemco VR4-GLOBAL acoustic receivers were attached to the drifting FADs and recorded data from acoustic transmitters when present around the receiver. This data allows to characterize the behavior of the different species and is used to determine the species specific vulnerability to the purse seine gear during the day. Additionally, silky sharks were equipped with pop-up satellite tags and archival tags (Wildlife Computers) to provide information on the large-scale movements and detailed vertical behavior of fish.
Results	A total of 53 fish were equipped with acoustic transmitters at 3 different FADs: 14 silky sharks (3 were double tagged with pop-up satellite tags), 10 yellowfin tuna (4 were double tagged with archival tags), 5 skipjack tuna, 1 bigeye tuna, 13 oceanic triggerfish and 10 rainbow runners. The acoustic transmitters provided information on the residency of fish at FADs, as well as on the patterns of association and excursions away from FADs. These data, together with data from following cruises, were consolidated into a database. The following results originate from the completed database (i.e. IO 2011 Maya's Dugong, IO 2012 Torre Giulia and two other EU MADE cruises). The associative patterns and the vertical distribution of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*) (target species), as well as silky shark (*Carcharhinus falciformis*), oceanic triggerfish (*Canthidermis maculata*), and rainbow runner (*Elagatis bipinnulata*) (major non-target species) were determined. Distinct diel associative patterns were observed; the tunas and the silky sharks were more closely associated with FADs during daytime, while the rainbow runner and the oceanic triggerfish were more closely associated during the night.
Conclusions	This activity was conducted successfully. For the first time the associative behavior of target and non-target species could be monitored simultaneously. Minor changes in bycatch to catch ratio of rainbow runner and oceanic triggerfish could possibly be achieved by fishing at FADs after sunrise. However, as silky sharks display a similar associative pattern as tunas, no specific

[3] MADE: Mitigating adverse ecological impacts of open ocean fisheries

<table>
<tr><td></td><td>change in fishing time could mitigate the vulnerability of this more sensitive species. For the vertical distribution, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net. The pop-up satellite tags and archival tags (Wildlife Computers) provide information on the large-scale movements and detailed vertical behavior of silky sharks in the Indian ocean.</td></tr>
<tr><td colspan="2">(2) Avoiding the capture of sharks before setting: Attract sharks away from FADs using chum</td></tr>
<tr><td>Methods</td><td>The scientific protocol consisted of (i) assessing the numbers of sharks around the FAD at the start of the experiment (snorkeling), (ii) using a small tender to drift slowly away from the FAD with a bag full of fish chum (bait), (iii) assessing the number of sharks attracted and maximum distance of attraction using underwater GoPro cameras and a handheld GPS. Each experiment was terminated when either the tender reached a distance of 500 m from the FAD or when no more sharks were observed for several minutes</td></tr>
<tr><td>Results</td><td>Shark attraction experiments were conducted on 5 different FADs (Table 2.1). The results of the shark attraction experiment are summarized in the table below. Results indicate that sharks can be attracted away from the FAD up to 500 m using chum.

Table 2.1. Summary of the shark attraction experiment
<table>
<tr><td>FAD</td><td>Number of sharks at start</td><td>Number of sharks attracted</td><td>Maximum distance</td></tr>
<tr><td>1</td><td>9</td><td>3</td><td>500 m</td></tr>
<tr><td>2</td><td>2</td><td>1</td><td>120</td></tr>
<tr><td>3</td><td>3</td><td>2</td><td>80</td></tr>
<tr><td>4</td><td>2</td><td>1</td><td>80</td></tr>
<tr><td>5</td><td>2</td><td>2</td><td>250</td></tr>
</table></td></tr>
<tr><td>Conclusions</td><td>This activity was conducted successfully. Additional replicates are needed to fully investigate the potential of this mitigation technique.</td></tr>
</table>

Derived publications:

Dagorn et al. (2012)
Filmalter (2015)
Filmalter et al. (2015)
Forget et al. (2015)

3. 2012 EPO Cruise on the F/V VIA SIMOUN

Objective:

Post-release survival of sharks: Quantify rates of at-vessel and post-release mortality of silky and scalloped hammerhead sharks associated with drifting FADs in the equatorial EPO and incidentally captured by a tuna purse seiner

Scientists:

Corey Eddy (U. Massachusetts).

Vessel:

Opportunistic cruise on the VIA SIMOUN (Ecuador flag), a 68.9m purse seiner with 974 tons carrying capacity, built in 1980 in Dieppe, France.

Time and area:

The cruise took place in the Eastern Pacific Ocean, starting and ending in Posorja (Ecuador) between April 14th and April 26th, 2012.

Progress made for each Objective

(1) Post-release survival of sharks: *Quantify rates of at-vessel and post-release mortality of silky and scalloped hammerhead sharks captured by purse seiners.*	
Methods	The subjective physical condition of each shark was first assessed, the environmental conditions were recorded, and the sharks were tagged with Pop-up satellite archival tags (PATs) and plastic dart tags.
Results	For this cruise, the at-vessel mortality for all the sharks were ~ 15% and estimated total post-release mortality was ~ 80%. These results were combined with those of the EPO 2011 Yolanda L to quantify rates of at-vessel and post-release mortality of silky and scalloped hammerhead sharks associated with drifting FADs in the equatorial EPO and incidentally captured by a tuna purse seiner (Eddy et al. 2016). For both cruises conducted in 2011 and 2012, at-vessel mortality rate ranged from 15% to 70%, and total mortality rate (i.e. the combination of at-vessel and post-release mortalities) ranged from 80% to 95%.
Conclusions	This activity was conducted successfully. The findings of this study indicate that there is a high mortality rate of sharks incidentally captured in the tuna purse seine fishery. With best handling practices, some 15%-20% of the released sharks can survive.

Derived publications:

Eddy et. al. (2016)
Filmalter et al. (2015b)

4. 2012 IO Cruise on the F/V TORRE GIULIA

Objectives:

(1) **Modifications in FAD designs to reduce impacts**: Perform underwater visual census at FADs to quantify entangled fauna (mainly sharks and turtles) and relate it to the design of FADs.

(2) **Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs**: Determine the ability of the skipper to estimate the catch before the set using the vessel's various instruments.

(3) **Releasing by-catch species from the net**: Attract sharks and other non-target species out of the net by towing the FAD

(4) **Post-release survival of sharks:** Study the post-release survival of sharks

(5) **Post-release survival of vulnerable species:** Study the survival rate of whale sharks and other large animals caught in the seine (e.g., manta rays etc.)

(6) **Fundamental research:** Physiology of sharks

(7) **Fundamental research:** Biological sampling

(8) **Behavior of tunas and other fishes around FADs:** Natural behavior of target and non-target species associated with FADs using acoustic telemetry

(9) **Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics:** Validation of echosounder buoys

(10) **Releasing by-catch species from the net:** "Skimming scoop" activity to assess the feasibility of removing non-target species by "skimming" them out from the pre-sack using the brail.

(11) **Avoiding the capture of sharks before setting:** Double FADs activity to segregate species between 2 FADs and see if sharks choose only one of the 2 FADs so that catches are conducted on the other FAD.

(12) **Improving monitoring capabilities onboard purse seine vessels**: Test the automated observation of catch developed by Archipelago

Scientists:

Patrice Dewals (IRD, Chief Scientist), Fabien Forget (IRD, SAIAB) and John Filmalter (IRD, SAIAB)

Vessel:

Charted cruise on the F/V TORRE GIULIA (France), a 79m tuna purse seiner built in USA in 1997 with approximately 1,300 tons of carrying capacity.

Time and area:

The cruise took place in the Western Indian Ocean, starting in Mahe (Seychelles) on the 31st of March and ending in Mahe (Seychelles) on the 9th of May (figure 4.1).

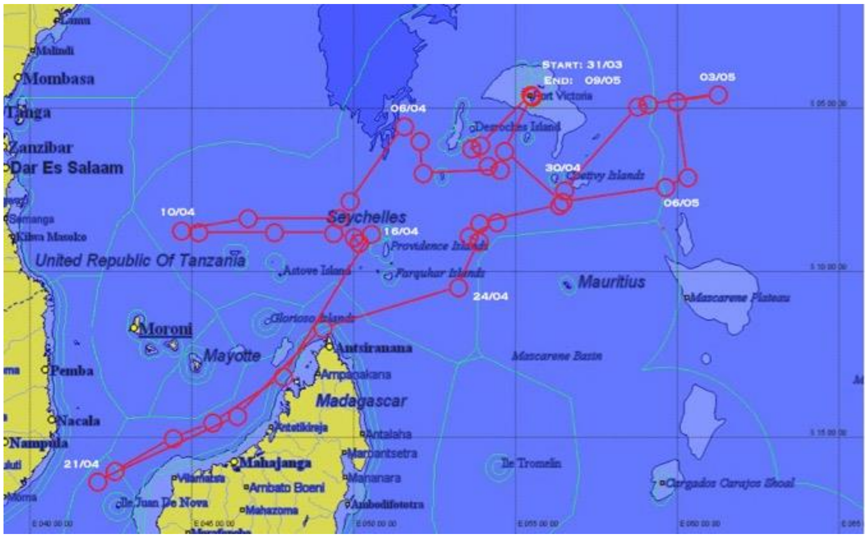


Figure 4.1. Trajectory map of the Torre Giulia cruise

Progress made for each Objective

<table>
<tr><td colspan="2">(1) Modifications in FAD designs to reduce impacts: Underwater visual census at FADs</td></tr>
<tr><td>Methods</td><td>Underwater Visual Census (UVC) were performed at FADs. The scientific divers approach the drifting FAD with the tender, performed safety checks at 5m below the FAD for 5 min. The divers then descended to 10 meters for 30 min where they (i) documented the species assemblages at drifting FADs, (ii) quantified any entangled fauna and documented the designs type of each FAD.</td></tr>
<tr><td>Results</td><td>A total of 44 UVC were carried during the 39-day cruise, 38 of them being on different FADs and 6 being replicates (4 of them done during the double-FAD experiments, and 2 FADs being revisited during the cruise). The 38 different floating objects visited were:

5 logs
1 artificial floating object that was not built by fishers (fiberglass box)
32 FADs (with rafts):

4 rafts attached to a log
2 "eco-FADs" (1 of them being attached to a log)
27 FADs (not ecological nor attached to a log)

The 2 "eco-FADs" are called "ecological" as they were built by some purse seiners to reduce entanglement of sharks and turtles. They are made of nets, rolled and tied, to avoid entanglement and these FADs are currently being tested in the Indian Ocean by some purse seiners.

<u>Shark entanglement</u>
A total of 11 FADs out of 32 (34%) were observed with sharks entangled (total 13 sharks). None of the 2 eco-FADs visited had a shark entangled, but one of them had a 1-m barracuda entangled (which demonstrates that it was able to entangle large fish) in the few open net meshes at the bottom of the bundle (Figure 4.2).</td></tr>
</table>

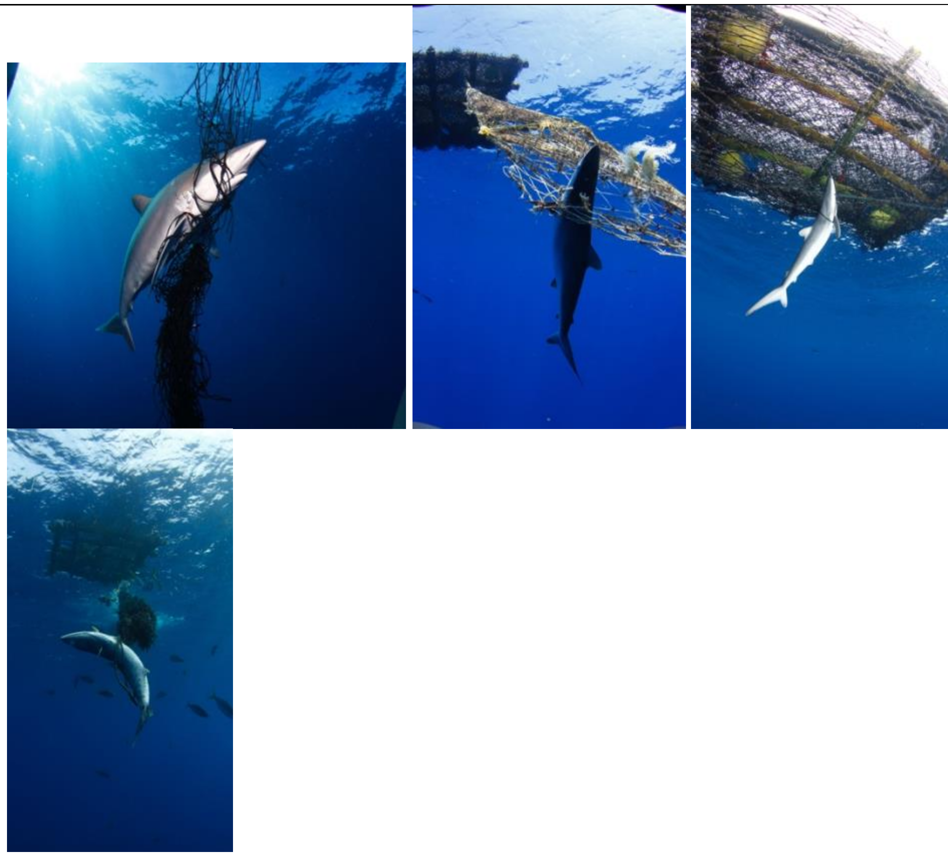


Figure 4.2. Sharks and a barracuda entangled in FAD nets. The photo above shows a barracuda entangled in an "eco-FAD"

These results were combined with those of other cruises (IO 2011 Maya's Dugong, 2 other EU MADE cruises) as well as with PATs data deployed during these cruises to assess the extent of the entanglement issue in the Western Indian Ocean (Filmalter et al. 2013). This study estimated that 480,000-960,000 silky sharks could be entangled every year in the Western Indian Ocean during 2010-2012.

<u>Turtles entangled</u>

Three FADs (8% of the 32 (UVC) +4 (no UVC) FADs visited) were observed with a turtle entangled on the top of the raft. All turtles were alive: one of them escaped by itself and the two others were released by the scientists and the crew. These two turtles could not escape by themselves as they were badly entangled. One of these FADs was one of the two previous "eco-FADs" (the same that also had a barracuda entangled). The turtle was entangled in a loose bit of net close to the surface of the FAD (Figure 4.3). Two more turtles were observed feeding or resting on the top of two other FADs, but they were not entangled.

Figure 4.3. The turtle entangled in the upper part of an "eco-FAD"

Conclusions	This activity was conducted successfully. The UVCs conducted during this cruise suggest that

entanglement events were more significant than what was previously thought. The use of netting for the construction of FADs represents an entanglement risk for sharks and turtles and, as such, should be avoided as building material to reduce entanglement risks. These results were key to demonstrate the need to change FAD designs to mitigate entanglement.

(2) Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs

Methods

The aim was to assess the ability of the skipper to estimate the species composition and overall biomass upon arrival at the FAD using on board equipment. The skipper was asked to estimate the species composition and overall biomass before setting.

Results

The skipper was not able to estimate the catch composition, but could only provide an estimation of the total catch. Table 4.1 provides estimates made by the skipper prior to setting and the corresponding estimates made by the crew when putting the fish onboard. All sets were made on floating objects, except two on free schools (#7 & 8) that were 'skunked' (school missed).

Table 4.1. Comparison of skipper's pre-set estimates and estimates of catch onboard during the brailing phase.

DATE	N° Set	Skipper's estimates (tons)	Catch estimates (tons)
02/04/12	1	5 - 10	5
03/04/12	2	<5	2
06/04/12	3	?	0.5
08/04/12	4	10	6
18/04/12	5	6 - 7	10
19/04/12	6	10	6
25/04/12	7*	50	0
27/04/12	8*	15	0
28/04/12	9	10	1
29/04/12	10	15	28
30/04/12	11	15 - 20	40
02/05/12	12	10	14
02/05/12	13	15	13
03/05/12	14	10	15
03/05/12	15	10 - 15	18
04/05/12	16	5 - 10	5
06/05/12	17	?	0.5
08/05/12	18	10 - 15	15

* Free swimming schools

Conclusions

This activity was conducted successfully. The vertical echosounder is almost never used for the estimates. The primary acoustic equipment used before setting are the long range sonar and the side scan echosounder. The absence of estimates of catch composition is mainly due to the fact that it does not affect the skippers' decision to set or not.

(3) Releasing by-catch species from the net: *Attraction of sharks and other bycatch out of the net*

Methods

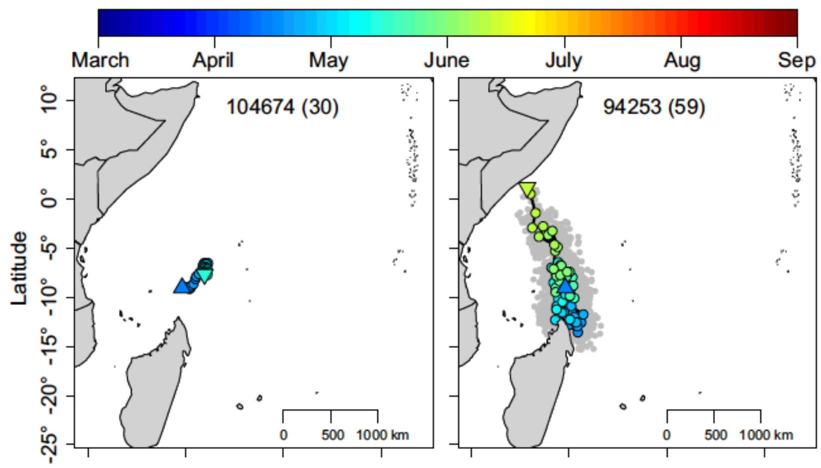
The objective was to attract and lure the sharks out of the net by towing the FAD out of the net through a gap between the net and the hull of the purse seiner. Scientists on board the tender used underwater cameras with live view (Seaviewer) and fish observed from the surface.

Results

Seven attraction experiments were conducted, with varying results. The sharks did not follow the FAD when it got towed by the tender out of the net. Only some triggerfish and rainbow runners were observed to escape during a few of the trials. It appears that the fish are scared by the noise of the vessel and the turbulence generated by the side thrusters. After discussing these results with the skipper of the vessel, it was suggested that an escape window placed at half net allowing the FAD to drift out of the net, with as little towing as possible from the tender, could maximize the chances of the sharks to escape. This escape window could be 15 meters deep and 15-50m wide.

Conclusions	This activity was conducted successfully. Passive drifts with the FAD (as opposed to actively towing the FADs with the tender) were more efficient to attract and move sharks inside the net.
(4) Post-release survival of shark: *post-release survival of sharks*	
Methods	The objectives of this study were to quantify rates of at-vessel and post-release mortality of silky sharks associated with drifting FADs in the Western Indian Ocean that are incidentally captured by a tuna purse seiner. The subjective physical condition of each shark was first assessed and recorded. The sharks were then tagged with Pop-up satellite archival tags (PATs) and plastic dart tags. The data from the PATs was then analyzed to determine the fate of each individual. Generally, a delayed shark mortality is diagnosed using the depth time series data when the shark sinks steadily up to 2000m, after which the PAT detaches itself from the presumably dead shark.
Results	A total of 18 sets were made, 16 on floating objects and 2 on free schools. • Numbers of sharks observed dead on the deck: 64 (56 kept onboard + 8 discarded). • Numbers of sharks released alive: 22 (12 tagged with a miniPAT + 10 tagged with a spaghetti tag) • Survival of the 12 sharks tagged with a miniPAT: 4 sharks died immediately or less than a week after release. • Survival of the 10 sharks tagged with a spaghetti tag: 3 were observed sinking immediately after release and were considered dead. The status of the 7 others is not known. As the status of 7 sharks released alive with spaghetti tags is uncertain, the final mortality rate is comprised between 82% (71 dead sharks) and 91% (78 dead sharks). These results were combined with those of two other EU MADE cruises to assess the mortality of silky sharks in the Western Indian Ocean: The overall mortality rate was 81%.
Conclusions	This activity was conducted successfully. The low survival rate suggests the need to develop methods to release sharks from the seine before the formation of the sack. In addition, use of best handling practices and rapid release from the deck may improve survival rates.
(5) Post-release survival of vulnerable species: *Study the survival rate of whale sharks and other large animals (e.g., manta rays).*	
Methods	MiniPATs were reserved in case such animals were encountered. During the cruise, the skipper was regularly in touch with other skippers to be informed of any encounter of a whale shark.
Results	No large animals, including manta rays, were caught during the 18 sets.
Conclusions	This objective could not be achieved as no whale sharks nor other megafauna were encircled during this cruise.
(6) Fundamental research: *Physiology of sharks*	
Methods	A large tank with oxygen probes was installed on the vessel to investigate the metabolic rate of silky sharks, which is needed as baseline information to develop mitigation techniques.
Results	Two trials were attempted. Unfortunately, the captured sharks were in poor condition despite coming directly from the deck where they were brailed. The experiment could not be successfully conducted.
Conclusions	This objective could not be achieved as the silky sharks did not survive.
(7) Fundamental research: *Biological samples*	
Methods	Biological material such as stomach samples, gonads, muscle and genetic samples were opportunistically collected from incidentally captured silky sharks, rainbow runners and oceanic triggerfish to improve the knowledge on the biology of non-target species.
Results	A total of 197 fish were sampled: 59 silky sharks, 108 rainbow runners, 30 oceanic triggerfish.
Conclusions	Sufficient samples were collected for laboratory analysis of the three species
(8) Behavior of tunas and other fishes around FADs*: Natural behavior of target and non-target species associated with FADs using acoustic telemetry*	
Methods	Both target and non-target species were equipped with acoustic transmitters (Vemco) around drifting FADs to provide information on the residency of fish at FADs. Vemco VR4-GLOBAL acoustic receivers were attached to the drifting FADs and recorded data from acoustic transmitters when present around the receiver. This data allows to characterize the behavior of the different species and was used to determine the species specific vulnerability to the purse

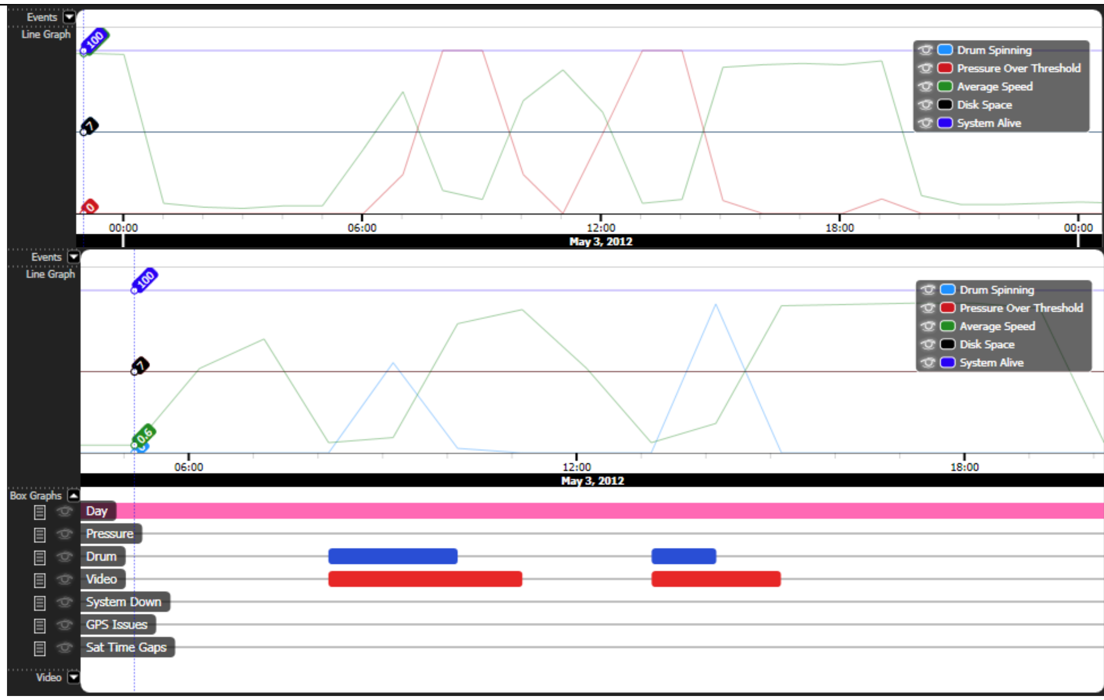
	seine gear during the day. Additionally, silky sharks were equipped with pop-up satellite tags and archival tags (Wildlife Computers) to provide information on the large-scale movements and detailed vertical behavior of fish. A silky shark was tracked actively with tender in order to obtain the fine scale movement behavior when associated to FADs.
Results	A total of 47 fish were equipped with acoustic transmitters at 3 different FADs: 15 silky sharks (5 were double tagged with pop-up satellite tags and 4 with archival tags), 10 yellowfin tuna, 2 skipjack tuna, 6 bigeye tuna, 7 oceanic triggerfish and 7 rainbow runners. The acoustic transmitters provided information on the residency of fish at FADs, as well as on the patterns of association and excursions away from FADs. These data, together with data from following cruises, were consolidated into a database. The following results originate from the completed database (i.e. IO 2011 Maya's Dugong, IO 2012 Torre Giulia and two other EU MADE cruises). The associative patterns and the vertical distribution of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*) (target species), as well as silky shark (*Carcharhinus falciformis*), oceanic triggerfish (*Canthidermis maculata*), and rainbow runner (*Elagatis bipinnulata*) (major non-target species) were determined. Distinct diel associative patterns were observed; the tunas and the silky sharks were more closely associated with FADs during daytime, while the rainbow runner and the oceanic triggerfish were more closely associated during the night. A silky shark was actively tracked during 2 h 46 min. During this time, the shark covered a total distance of 5,788 m, while the FAD drifted 2,395 m (Figure 4.4). The average speed of the shark was 0.79 m s^{-1}. The actively tracked individual made an excursion away from the FAD together with other tagged tunas and non-target species after which it returned to the FAD after being more than 1.2 km away.  **Figure 4.4**. Trajectories of the actively tracked silky shark and the drifting FAD Tracks and vertical data from the PATs (Figure 4.5) were consolidated into a database for a single analysis on the movements of silky sharks in the Indian Ocean, and in particular to investigate the possible role of drifting FAD in these movements.

	 **Figure 4.5**. Examples of trajectories of silky sharks equipped with PSAT tags in the Indian Ocean.
Conclusions	This activity was conducted successfully. The associative behavior of target and non-target species could be monitored simultaneously. Minor changes in bycatch to catch ratio of rainbow runner and oceanic triggerfish could possibly be achieved by fishing at FADs after sunrise. However, as silky sharks display a similar associative pattern as tunas, no specific change in fishing time could mitigate the vulnerability of this more sensitive species. For the vertical distribution, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net. The first active tracking of a silky shark at a drifting FAD in the world was conducted, showing that silky sharks can return to a FAD from a distance of at least 1.2 km. The pop-up satellite tags and archival tags (Wildlife Computers) provided information on the large-scale movements and detailed vertical behavior of silky sharks in the Indian ocean.
(9) Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics: *Validation of echosounder buoys*	
Methods	FADs were equipped with echosounder buoys (M3i). The biomass estimation from the buoy will then be compared with the actual catch to assess the performance of the buoy.
Results	The collected data has been gathered into a database for further analysis.
(10) Releasing by-catch species from the net: *Skimming scoop*	
Methods	This activity consisted in assessing the feasibility of removing non-target species by "skimming" them out from the pre-sack using the brail.
Results	This experiment was not tried because it was immediately clear that it would not be feasible and successful due to the high mixing of tuna and bycatch in the sack.
Conclusions	This method did not appear to be feasible to release the non-target species just before sack is "dried."
(11) Avoiding the capture of sharks before setting: *Double FADs*	
Methods	The objective is to investigate the potential for species (or, possibly, size classes) to naturally segregate when the various species (or sizes) are confronted by the choice of two closely adjacent aggregating devices: some species might choose only one of the two FADs (with not all species going to the same FAD), whereas some might split between the two FADs. Double FADs (two FADs attached together) were deployed before the cruise. The experiment consisted in separating the FADs, performing UVC and fishing on the two FADs the next morning to compare the species composition at each FAD.
Results	Five double FADs were deployed before the cruise. Three of them were visited during the cruise, but the protocol was conducted only on two of them. The first double FAD visited did not have any tuna around and it was decided to visit it towards the end of the cruise, but this was not possible. In the summary of results presented below, we consider that a species occupies both FADs when relatively similar numbers of individuals are observed on each FAD. A species is considered to select a FAD when the majority of individuals (> 60%) were observed on one FAD. Experiment 1: Only one species (*Aluterus monoceros*) occupied both FADs, while all other species selected the same FAD: *Elagatis bipinnulata, Kyphhosus vaigiensis, Decapterus*

<table>
<tr><td></td><td>macarellus, Abudefduf vaigiensis, Platax teira, Thunnus albacares, Acanthocybium solandri, Sphyraena barracuda, Coryphaena hippurus, Seriola riviolana, Canthidermis maculatus, Caranx sexfaciatus

<u>Experiment 2</u>:
4 species occupied both FADs in more or less equal numbers (Sphyraena barracuda, Acanthocybium solandri, Kyphosus vaigiensis, Lobotes surinamensis)
3 species selected FAD 'A': Decapterus macarellus, Aluterus monoceros, Thunnus albacares
8 species selected FAD 'B': Elagatis bipinnulata, Canthidermis maculatus, Seriola riviolana, Coryphaena hippurus, Carcharhinus falciformis, Abudefduf vaigiensis, Urapsis helvola, Aluterus scripta
As for all UVC, estimates of abundance of tuna (T. albacares) might not represent the real abundance.
A few species showed different behavior between the 2 experiments:
Aluterus monoceros split between the 2 FADs in the first experiment (total abundance 12) while they selected one FAD in the 2nd one (total abundance 3).
Sphyraena barracuda selected one FAD in the first experiment (total abundance 2) while they split between the 2 FADs in the second experiment (total abundance 10).
Acanthocybium solandri selected one FAD (total abundance 3) and split in the 2nd experiment (total abundance 3)
Kyphosus vaigiensis selected one FAD in the 1st experiment (total abundance 153) and split in the 2nd experiment (total abundance 80)</td></tr>
<tr><td>Conclusions</td><td>These preliminary experiments tend to show that most species seem to select one FAD, and that it is not always the same FAD that gathers all species. Further experiments are recommended.</td></tr>
<tr><td colspan="2">(12) Improving monitoring capabilities onboard purse seine vessels: Electronic monitoring</td></tr>
<tr><td>Methods</td><td>Two electronic monitoring systems made by Archipelago Marine Research Ltd. (Archipelago) were installed on the vessel. The primary objectives of the systems were to:
determine the feasibility of using EM to monitor tuna purse seine vessels
document fishing effort
document fishing event location
estimate total retained and catch (tons)
determine if set type (FAD, free-school, etc.) can be determined from the EM data.
The two systems that were installed included two GPS sensors, two satellite modem transceivers, a hydraulic pressure sensor, two rotational sensors, and eight video cameras. The sensors and cameras were installed so that fishing activity would be detected, and video recording would be limited to fishing events. One system was installed to monitor the stern deck area as fish were brought aboard, the second system was installed in the below deck area where fish are moved to the storage wells along conveyors.

Systems were equipped with satellite modem transceivers that transmitted a single line of data (location, hydraulic pressure, drum rotations, video on/off, system on/off), but did not transmit video or images. The data were monitored remotely by Archipelago staff in Victoria, Canada. Fishing events were indicated in the data by periods of high pressure, low speed, and conveyor belt rotation; there were 18 fishing events visible in the satellite data.</td></tr>
<tr><td>Results</td><td>The results suggested that EMS can be used to help determine if a set was on a free school or a FAD (Figure 4.6).</td></tr>
</table>

	 **Figure 4.6.** Two fishing events are shown on May 3, 2012, and indicated by drum spinning, low speed on the below deck system (bottom), and high pressure and low speed on the above-deck system (top).
Conclusions	This activity was conducted successfully. Generally, the system functioned as designed, activating when the hydraulic system was utilized. There were however some technical physical shortcomings with the systems' hardware components that were not adapted to the purse seine operation. A detailed report on the performance was generated (Ruiz et al. 2014)

Derived publications:

Chavance et al. (2013)
Dagorn et al. (2012)
Filmalter et al. (2012)
Filmalter et al. (2013)
Filmalter (2015)
Filmalter et al. (2015)
Filmalter et al. (2015b)
Forget et al. (2015)
Poisson et al. (2014)
Ruiz et al. (2014)

5. 2012 WCPO Cruise on the F/V CAPE FINISTERRE

Objectives:

(1) **Behavior of tunas and other fishes around FADs:** Underwater Visual census at FADs
(2) **Behavior of tunas and other fishes within purse-seine nets:** Behavior of target and non-target species in the net
(3) **Releasing by-catch species from the net:** Initial Release of fish from the net by towing the FAD
(4) **Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs**: Pre-Set estimation of catch and bycatch
(5) **Behavior of tunas and other fishes around FADs:** Vertical and horizontal behavior of target and non-target species at FADs
(6) **Avoiding the capture of undesirable sizes of bigeye and yellowfin tunas before setting:** Testing the efficacy of targeting skipjack after dawn while avoiding bigeye and non-target species
(7) **Post-release survival of sharks:** Condition and post-release survival of sharks
(8) **Post-release survival of vulnerable species:** Post release survival of the megafauna captured in the seine
(9) **Releasing sharks from the net:** Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets

Scientists:

David Itano (U. Hawaii, Chief Scientist), Jeff Muir (UH), Melanie Hutchinson (UH) and Bruno Leroy (SPC).

Vessel:

Chartered cruise on the F/V CAPE FINISTERRE (USA) a 72m tuna purse seine vessel built in Washington, USA in 1979 with 1,150 tons carrying capacity.

Time and Area:

The cruise originated from Pago Pago Harbor on 22 May 2012. The cruise (Figure 5.1) was divided into two segments, Cruise Leg 1 (May 22 – June 13, 2012) and Cruise Leg 2 (June 14 – July 1, 2012) separated by a brief port call to change out scientific staff. Thirteen sets were made during CL-1 for an estimated 225 mt. Eighteen sets were made during CL-2 for a total of 31 sets after which all 19 fish wells were loaded with target catch of skipjack, yellowfin and bigeye tuna from operations in the EEZs of Tuvalu, Kiribati (Phoenix Islands) and Tokelau. All but one of the 31 sets were made on drifting FADs or a floating object with one successful free school made.

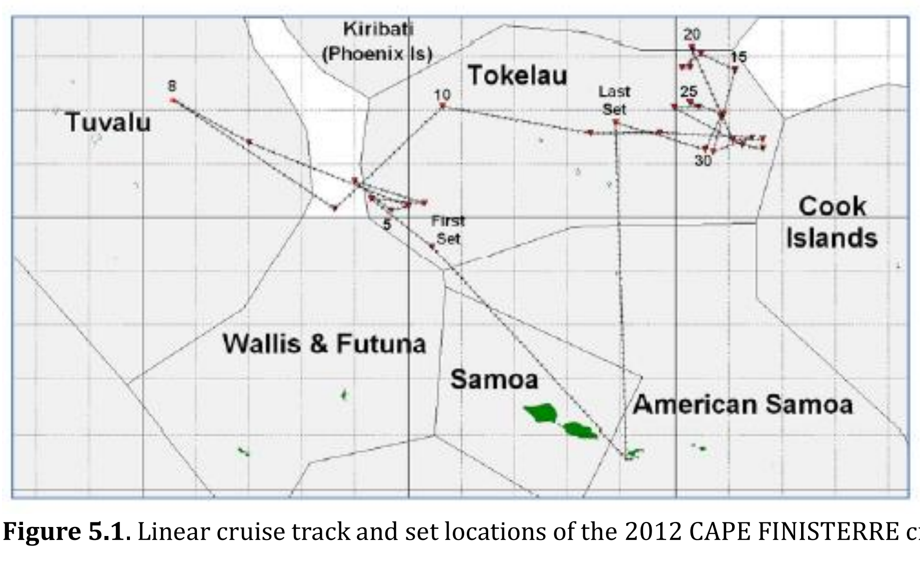


Figure 5.1. Linear cruise track and set locations of the 2012 CAPE FINISTERRE cruise.

Progress made for each Objective

(1) Behavior of tunas and other fishes around FADs: *Underwater Visual census at FADs.*	
Methods	Underwater Visual Census (UVC) were performed at FADs. The scientific divers approached the drifting FAD with the tender, performed safety checks at 5m below the FAD for 5 min. The divers then descended to 10 meters for 30 min where they documented the species assemblages at drifting FADs.
Results	Six FADs were surveyed with SCUBA gear during both legs of the cruise. Silky sharks, mahi mahi, wahoo, pelagic triggerfish, rainbow runner, bigeye jack, round scad, amberjack, rudderfish, filefish and yellowfin tuna were noted and their numbers recorded. Visibility was highly variable throughout the cruise and in some cases greatly limited the divers' ability to determine the species composition of FAD aggregations. The effective depth of the net aggregators observed often reached ~ 40 m in length.
Conclusions	This activity was conducted successfully.
(2) Behavior of tunas and other fishes within purse-seine nets	
Methods	Observations of fish behavior inside the net were performed by SCUBA divers and snorkelers. The divers documented the various behaviors of both target and non-target species inside when the net rings were up (i.e. the net was pursed closed).
Results	A total of fifteen SCUBA surveys were conducted in the purse seine net during fishing operations. Four additional sets were observed only by snorkelers. Clear separation of tuna by size class and of tuna from non-target species was apparent during the underwater observations. The degree of separation was surprising and encouraging as it suggested the possibility of selective release of undesirable species from the fishing operation. A striking feature of the separation of species in the net were repeated observations that silky sharks often grouped together and eventually ended up in a tight bend of the net that forms when about 3/4$^{\text{ths}}$ of the net has been retrieved. Later on during the set, silky sharks were seen to quickly become entangled in the middle or lower areas of the sack while small yellowfin tuna remained alive and in the upper areas of the sack. The majority of the skipjack often balled up at the very bottom of the sack and got rolled up in the first few pulls of the sacking up process. As sacking up continued, the silky sharks got rolled up in the outboard, bottom of the sack and were quickly covered with tuna. Small tuna tended to circle tightly, remaining in better condition while large tuna quickly became tangled and meshed in the webbing.
Conclusions	This activity was conducted successfully. Segregation of tuna by size and species and between tuna and non-target species was repeatedly observed supporting the potential for selective release of non-target species from the net. Observations made during the sacking process suggest that methods to avoid sharks completely or release sharks before brailing need to be developed.
(3) Releasing by-catch species from the net: *Initial Release of fish from the net by towing the FAD*	
Methods	The objective was to attract and lure the sharks and bycatch out of the net by towing the FAD out of the net through a gap between the net and the hull of the purse seiner. Scientists on board the tender used underwater cameras and also made observations from the surface.
Results	The FADs used during this cruise had long net panels beneath the FAD that hang down 30–65 m or more. A certain amount of speed was required to bring the netting to the surface so that it can clear the chain line when exiting the net. No non-target species were observed to remain with the raft or follow it out of the net.
Conclusions	FADs with long net panels cannot be easily removed out of the net through the gap between the net and the hull. Moving the FAD at high speed was inadequate to move the sharks and non-target species out of the net.
(4) Pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs	
Methods	The aim was to assess the ability of the skipper to estimate the species composition and overall biomass upon arrival at the FAD using on board equipment. The skipper was asked to estimate

the species composition and overall biomass before setting.

Results It was not possible to obtain the cannery receipts with which to compare the pre-set estimates.

Conclusions This objective was not achieved.

(5) Behavior of tunas and other fishes around FADs*: Vertical and horizontal behavior of target and non-target species at FADs*

Methods Both target and non-target species were equipped with acoustic transmitters (Vemco) around drifting FADs to provide information on the residency of fish at FADs. Vemco VR2W acoustic receivers were attached to drifting FADs and recorded data from acoustic transmitters when present around the receiver. The listening stations were recovered during the cruise. Additionally, silky sharks were equipped with pop-up satellite tags and archival tags (Wildlife Computers) to provide information on the large-scale movements and detailed vertical behavior of fish.

Results A total of 22 fish were equipped with acoustic transmitters at 2 different FADs: 1 silky shark (double tagged with a pop-up satellite tag), 10 yellowfin tuna, 5 skipjack tuna, 6 bigeye tuna. The acoustic transmitters provided information on the residency of fish at FADs, as well as on the patterns of association and excursions away from FADs. These data, together with data from following cruises, were consolidated into a database.

Conclusions This activity was conducted successfully.

(6) Avoiding the capture of undesirable sizes of bigeye and yellowfin tunas before setting: *Testing the efficacy of targeting skipjack after dawn while avoiding bigeye and bycatch*

Methods The aim was to actively track skipjack tuna using continuous acoustic tags to track the movements of the schools of skipjack tuna as they move away from the FAD after dawn. This information is useful to determine whether mono-specific sets away from FADs on skipjack tuna can be made during the course of the day while limiting the capture of non-target species that would remain more closely associated to the FADs.

Results Unfortunately the nature of the aggregations encountered during the cruise was not conducive to conduct this experiment.

Conclusions This activity could not be conducted successfully.

(7) Post-release survival of sharks: *Condition and post-release survival of sharks*

Methods During typical fishing operations we investigated the post-release survival and rates of interaction with fishing gear of incidentally captured silky sharks using a combination of satellite linked pop-up tags and blood chemistry analysis. To identify trends in survival probability and the point in the fishing interaction when sharks sustain the injuries that lead to mortality, sharks were sampled during every stage of the fishing procedure.

Results After 31 sets, a total of 295 juvenile (average total length, 113.5 cm) silky sharks and one oceanic whitetip shark were observed. Most of these animals were brought onboard during the brailing phase of the purse seining operations (n = 279, Table 5.1). Of these sharks, 200 were released in poor condition or already dead. Of the 37 sharks that were gilled in the net and landed early, 24 were released in excellent condition and 5, 2, 1 and 3 were released in good, fair, poor and dead condition respectively.

Table 5.1. Summary of the release condition of captured silky sharks during every stage of the fishing operation.

Release condition of sharks landed during each stage of fishing ops								
Release Condition	Pre-Assessment of FAD	Inside the Net	Gilled in the Net	First Brail	Later Brail	Spill	Wet Deck	Total
Excellent (4)	9	6	24	0	0	0	0	39
Good (3)	1	0	5	1	9	0	0	16
Fair (2)	0	1	3	5	12	0	0	21
Poor (1)	0	0	1	7	25	0	2	35
Dead (0)	0	0	3	14	142	4	2	165
Unkown	0	0	1	3	15	0	1	20
Total	10	7	37	30	203	4	5	296

Table 5.2. Satellite tagged shark morphometric, blood chemistry and tag deployment data for silky shark. TL: total length. NA: not available.

Tag type	ID	Sex	TL (cm)	Fishing stage	Lactate (mmol l^{-1})	Release condition	PAT fate	Deploy-ment (d)
miniPAT	54245	M	105	Pre-set	NA	4	Floater	26
miniPAT	54246	M	104	Encircled	NA	2	Floater	34
miniPAT	54247	M	104	Pre-set	NA	4	Floater	3
miniPAT	54305	M	127	Encircled	NA	4	Floater	6
miniPAT	54249	M	93	Pre-set	NA	4	Floater	15
miniPAT	54267	F	116	Entangled	1.19	4	Floater	5
miniPAT	54270	M	145	Entangled	2.37	4	Sinker	129
miniPAT	54274	M	144	Entangled	NA	4	Floater	32
miniPAT	62937	M	122.5	Entangled	5.3	4	Floater	10
miniPAT	62936	M	133	Entangled	2.19	4	Survivor	100
miniPAT	62941	F	136	Entangled	12.07	3	Sinker	0
sPAT	117916	M	123	Entangled	14.47	4	Sinker	25
sPAT	117917	F	128	1st brail	17.51	0	Sinker	0
sPAT	117918	M	107	Entangled	NA	1	Sinker	0
sPAT	117919	U	110	Entangled	2.13	4	Survivor	30
sPAT	117920	F	128	1st brail	NA	2	Sinker	0
sPAT	117921	M	116	Entangled	2.88	4	Survivor	30
sPAT	117922	M	137	Brail	13	2	Survivor	30
sPAT	117923	M	125	Entangled	1.99	3	Sinker	15
sPAT	117924	M	105	1st brail	NA	1	Sinker	0
sPAT	117925	F	104	Encircled	NA	4	Survivor	30
sPAT	117926	F	119	Pre-set	1.87	4	Sinker	30
sPAT	117927	M	111	Brail	14.91	0	Sinker	0
sPAT	117928	F	111	1st brail	15	0	Sinker	0
sPAT	117929	M	93	Entangled	NA	4	Floater	23
sPAT	117930	M	107	Brail	13.79	1	Sinker	0
X-Tag	19899	F	128	Entangled	14.61	4	NA	–
X-Tag	52210	M	128	Entangled	14.08	4	NA	–

The total mortality rates of silky sharks captured in purse seine gear was found to exceed 84%. It was found that survival precipitously declined once the silky sharks had been confined in the sack portion of the net just prior to loading.

Conclusions

This activity was conducted successfully. Future efforts to reduce the impact of purse seine fishing on silky shark populations should be focused on avoidance or releasing sharks while they are still free swimming.

(8) Post-release survival of vulnerable species: *Post release survival of the megafauna captured in the seine.*

Methods

MiniPATs were reserved in case such animals were encountered. During the cruise, the skipper was regularly in touch with other skippers to be informed of any encounter of a megafauna.

Results

No large animals, including manta rays, were caught during the cruise.

Conclusions

This objective could not be achieved as no megafauna was encircled during this cruise.

(9) Releasing sharks from the net: *Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets.*

Methods

While observing the *(2) Behavior of tuna and bycatch in the net*, scientists observed that silky sharks gathered in a pocket of net that often formed toward the latter stages of net retrieval. Before the second leg of the cruise (CL-2), an experimental release panel was installed at port measuring 5.5 m wide that extended down from the cork line for approximately 11 m in the area where the sharks were observed to accumulate.

Results

The panel (Figure 5.2) was opened during 7 sets, and closed during 5 of these events. The work boat operator quickly learned to open and close the panel with ease with the assistance of one other crewman. The panel was opened just before it reached the point at which it was situated directly opposite of the main vessel. Once the panel reached this point, the large net skiff attached to the starboard stern of the seiner and bow thruster were used to "pull" the boat/net and open escape panel for up to 9 minutes, in an effort to drift non-target species out of the net. After the net rolling resumed, the panel was closed to ease reassembly once the set was complete, as well as to avoid loss of target tuna species.

During the 7 sets that the panel was opened, sharks were present before opening the panel on every attempt. Only 2 silky sharks were observed to swim out of the panel during these 7 opening events, during two separate sets (i.e. one shark per set). During some sets, a group of

	sharks were observed directly in front of the open panel but they maintained their position inside the net relative to the seiner and net. Sharks and other non-target species (mahi mahi, rainbow runner, wahoo, triggerfish) seemed to not recognize the opening as an escape route out of the net, and perhaps still viewed the net with the opening in total as a visual barrier that they preferred to avoid. However, the two sharks that did exit the net did so without hesitation but under better conditions of current and water clarity (flowing strongly out of the open escape panel.  **Figure 5.2.** The closed release panel and the panel opening immediately after the zipper line has been pulled.
Conclusions	Observations and field testing suggest that the basic design of the release panel is functional and that it can be deployed in commercial fishing applications with minimal loss in time to the fishing operation and minimal risk of losing target species. There is no doubt that improvements to the placement, design and mechanics of this prototype panel can and should be made. In addition, ways to induce sharks and non-target species to pass through a release panel need to be developed and tested to medium sized loads.

Derived publications:

Filmalter et al. (2015b)
Hutchinson et al. (2012)
Hutchinson et al. (2015)
Itano et al. (2012)
Maksimovic (2015)
Muir et al. (2012)

6. 2013 WCPO cruise on the F/V CAPE FINESTERRE

Objectives:

(1) **Releasing sharks from the net:** Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets

(2) **Releasing undesirable sizes of bigeye and yellowfin tunas from the net:** Behavior of bigeye tuna before and during setting

(3) **Post-release survival of vulnerable species**: Post release survival of the megafauna captured in the seine

(4) **Fundamental research***:* Effects of FADs on the biology of tunas.

Scientists:

Jeff Muir (UH- Chief Scientist), Fabien Forget (SAIAB/IRD) and John Filmalter (SAIAB/IRD).

Vessel:

Opportunistic cruise on the F/V CAPE FINISTERRE (USA) a 72m tuna purse seine vessel built in Washington, USA in 1979 with 1,150 tons carrying capacity.

Time and Area:

This cruise originated from Pago Pago Harbor on 23 May 2013. This cruise lasted forty-five days, after which, on 4 July 2013, the scientific crew boarded the F/V CAPE ELIZABETH III, which was inbound for American Samoa. At the time of this vessel change, the CAPE FINISTERRE had made 46 sets for 788 metric tons of tuna. Fishing and sampling occurred in two distinct geographical areas (Figure 6.1) that of the US Line Islands, Eastern Kiribati group, and Cook Islands EEZs, and that of Tokelau, Phoenix Islands (Central Kiribati group), and Howland and Baker.

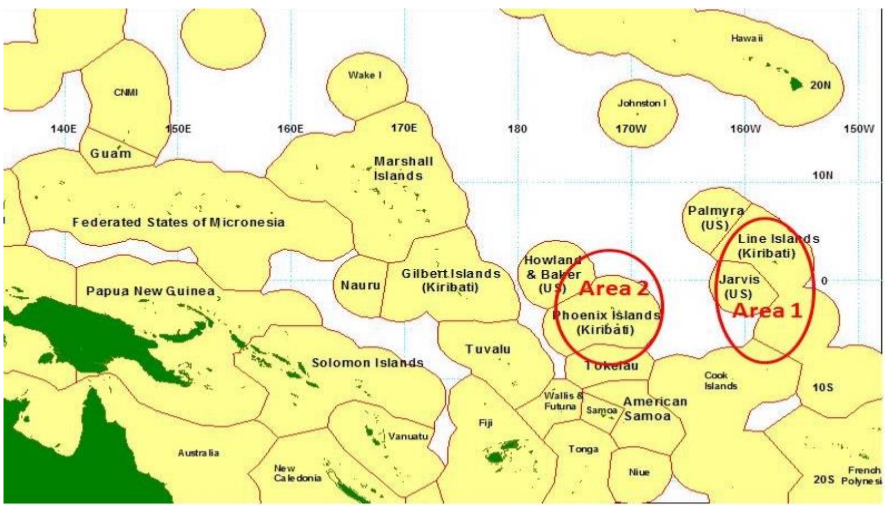


Figure 6.1. Research area of the 2013 CAPE FINISTERRE cruise, with sub-areas denoted by red ovals.

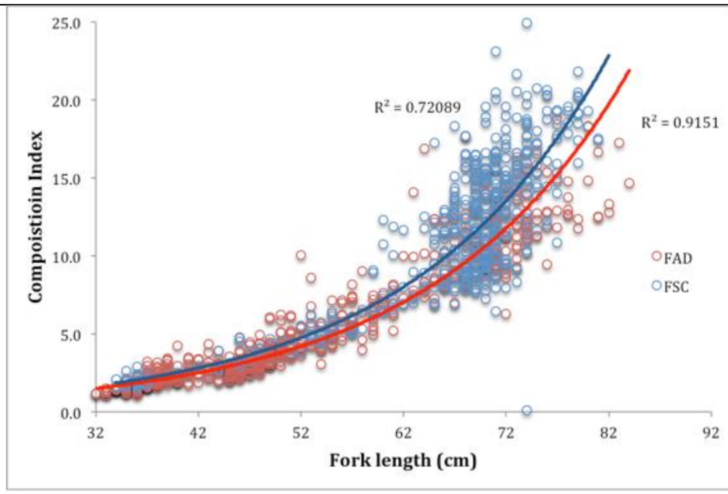
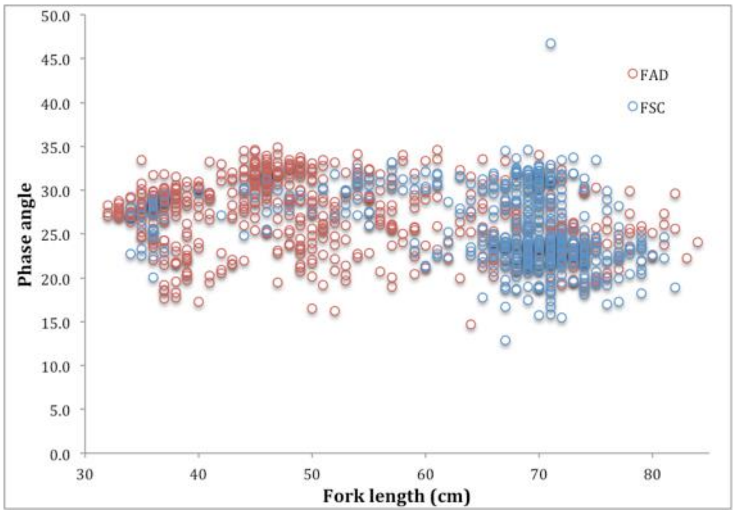
Progress made for each Objective

(1) Releasing sharks from the net: *Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets.*	
Methods	Two release panels were to be installed while in port in Pago Pago into the Cape Finisterre's net prior to commencing the cruise; one panel at half net, and one between ¼ net and the edge of the sack to test the efficacy of the two designs during normal fishing conditions.
Results	Unfortunately the panels could not be installed due to a mechanical failure in the net rolling crane at the net yard. At the point at which the breakdown occurred, the crew had half of the net off the boat in the yard. The installation of the release panels was aborted after it was determined that the crane could not be repaired in a timely fashion, and the net was hand stacked back onto the Cape Finisterre.
Conclusions	This activity could not be conducted successfully.

***(2) Releasing undesirable sizes of bigeye and yellowfin tunas from the net**: Behavior of bigeye tuna before and during setting.*	
Methods	This research activity aimed to investigate the behavior of bigeye tuna before and during setting of the purse seine net, mainly to investigate if there are changes in vertical behavior during setting (e.g., an 'escape response' in which the tuna dive deep).
Results	This objective was not completed. Fishing was slow during the 36 days of non FAD-closure fishing days, and there were not adequate opportunities to deploy acoustic tags in bigeye on a desirably sized aggregation of fish when it would not interfere with fishing operations
Conclusions	This activity could not be conducted successfully.
***(3) Post-release survival of vulnerable species**: Post release survival of the megafauna captured in the seine.*	
Methods	MiniPATs were reserved in case such animals were encountered. During the cruise, the skipper was regularly in touch with other skippers to be informed of any encounter of a megafauna.
Results	One whale shark was encountered during a set on free-swimming skipjack tuna. The whale shark was not visible before or during the set. The scientific team attempted to deploy a regular PAT tag into the dorsal musculature of the animal. Total length of the animal was 3m. There was no opportunity to create a pilot incision through the skin of the animal, and the tag was not successfully set into the dorsal musculature, due to the applicator bending from the force exerted on it. The animal was subsequently pulled over the corks by the tail and swam away in good condition.
Conclusions	This objective could not be achieved as the whale shark could not tagged successfully.
***(4) Fundamental research:** Effects of FADs on the biology of tunas. Condition factors of FAD associated and free school skipjack tuna*	
Methods	Bioelectric impedance analysis (BIA) is a predictor of body composition and condition of animals including fish. BIA was used to measure the relative condition of FAD associated and free schools of captured skipjack tuna. Phase angle and composition index were used as two complementary condition indices that reflect on the metabolic condition and the non-skeletal tissue condition respectively.
Results	A total number of 1057 measurements were made on skipjack tuna (Table 6.1). Generally, free swimming skipjack tuna had a higher composition index than FAD associated fish (Figure 6.2). This suggests that free swimming skipjack had a somatic lipid content than associated fish. Inversely, FAD associated tuna had a higher phase angle that free swimming tuna (Figure 6.3). Phase angle typically reflects in the metabolic condition. This results suggest that skipjack tuna in the western central Pacific have a higher metabolic condition that free swimming tuna.

Table 6.1. Metadata summary of BIA sampling

School type	**No. sets**	**Sampled Fish**
FAD	11	562
Free School	11	495

	 **Figure 6.2**. Composition index of FAD associated (FAD) and free swimming (FSC) skipjack.  **Figure 6.3**. Phase angle of FAD associated (FAD) and free swimming (FSC) skipjack.
Conclusions	FAD associated and free swimming skipjack tuna have marked relative differences in both their tissue composition and metabolic condition. At this stage the interpretation of these results is limited. Experimentation on captive fish is key to allow the interpretation of these observed differences between the two school types.

Derived Publications:

Filmalter et al. (2015b)
Maksimovic (2015)
Muir et al. (2013)

7. 2014 WCPO Cruise on the ALBATUN TRES

Objectives:

(1) **Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics:**

Attaching echo-sounder buoys from four different brands to the FADs to compare signals

(2) **Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics:** Use of a scientific acoustic echo-sounder (EK60) with frequencies of 38, 120 and 200 kHz onboard a work boat, followed by intensive spill sampling of the catch to compare acoustic data and species composition

(3) **Releasing sharks from the net**: Test escape panel for sharks

(4) **Releasing sharks from onboard the vessel**: Releasing sharks from the vessel

(5) **Improving monitoring capabilities onboard purse seine vessels**: Comparison of estimates of catch composition by scientists and by fishers

Scientists:

Igor Sancristobal (Chief Scientist, AZTI), Guillermo Boyra (AZTI), Fabien Forget (IRD) and John Filmalter (IRD) were onboard.

Vessel:

Opportunistic cruise on the ALBATUN TRES (Spain) a 115m tuna purse seiner built in 2004 in Spain with 4,406 GT (2,260 tons carrying capacity).

Time and Area:

The cruise took place in the Central Pacific Ocean, started in Christmas (Kiribati Is.) on May 3rd and ended in Tarawa (Kiribati Is.) on May 31st (Figure 7.1).

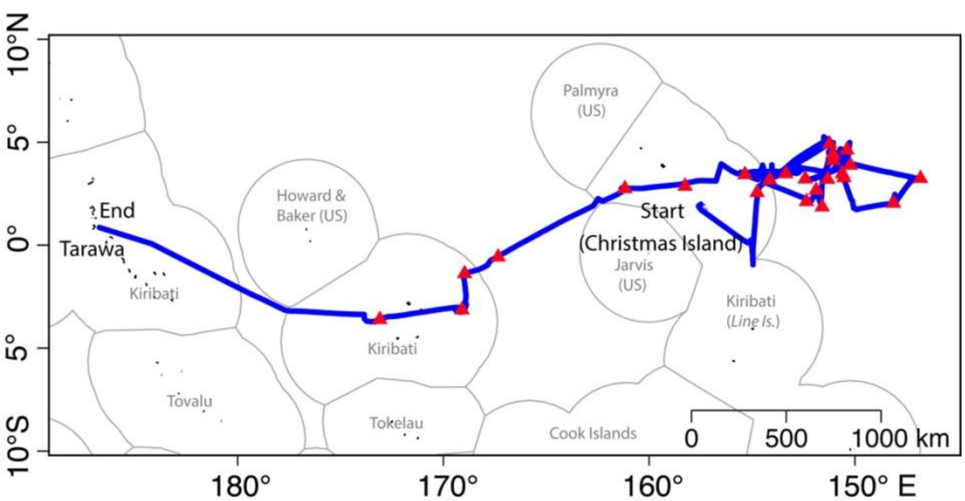


Figure 7.1. Map of cruise track (blue line) and set locations (red triangles) aboard the F/V ALBATUN TRES.

Progress made for each Objective

(1) Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics: *Attaching echo-sounder buoys from four different brands to the FADs to compare signals*	
Methods	The objective was to attach one buoy per type (M3i, M4i, Thalos and Zunibal) to the FAD which was already equipped with a Satlink buoy belonging to the vessel. This was to be done upon arrival, the evening before the set. This way, the buoys' echo-sounders would record data throughout the night until the set was made in the morning. The readings from the different buoys would then be compared against each other and to the actual catch in each set.

Results	**Table 7.1.** Number of replicates with each type of echo-sounder buoy.

	FAD	Free School
Satlink	18	1
Satlink + M4i	3	
Satlink + M4i. + Thalos	1	
Satlink + M4i. + Zunibal	1	
Satlink + M4i + Thalos + Zunibal	3	
nº Sets	26	1

Conclusions

The amount of replicates was not enough to compare the signals of the different buoys. However a database was built to analyze this information together with data gathered in other cruises. Data collection will continue during other cruises.

(2) Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics: *Use of a scientific acoustic echo-sounders with frequencies of 38, 120 and 200 kHz onboard a work boat, followed by intensive spill sampling to compare acoustic data and species composition*

Methods

A scientific acoustic echo-sounder Simrad EK60 of frequencies 38, 120 and 200 kHz were installed on board the "panguita" (i.e. work boat, Figure 7.2). The acoustic equipment was calibrated using a tungsten carbide sphere of 38.1 mm. During the cruise, the panguita was used in 20 of the 27 sets (Table 7.2). In each of these sets, the panguita was attached to the FAD starting about 10 minutes before the set and remained attached during the purse seiner's set. During the first part of the set, the panguita drifted with the FAD and, afterwards, it moved slowly to keep the FAD separated from both the net boundaries and the purse seiner. The transducers were focused vertically downwards, to acoustically sample the fish aggregation down to 200 m below the surface. In each set, around 60 to 70 minutes of acoustic data were recorded, with approximately 75% of the pings successfully detecting the tuna aggregation.

Figure 7.2. Acoustic equipment installed on board the panguita.

Spill sampling of the catch was conducted for 24 out of 27 sets, each time acoustic EK60 data was recorded. This was done in order to be able to compare the actual catch species composition with the signals recorded by the echo-sounders. Between 1 and 2 tons of fish were measured in each of these sets. Spill samples were selected randomly during each set to avoid bias. In general, samples were taken every 6th or 7th brail, which provided enough time for the entire sample to be processed before the next sample was chosen. Scientists identified species and measured each fish in the sample to the nearest centimeter on flat measuring boards. The weights of sampled individuals were estimated using length-weight relationships available for each species. These proportions by weight were then extrapolated to the total tonnage of each set, as estimated by the fishing master.

Results

Table 7.2. Purse seine sets and EK60, ES70 and FSV35 observation replicates.

Set	Latitude	Longitude	EK60	ES70	FSV35
1	2.53	-154.37	-	-	-
2	3.37	-151.28	-	-	-
3	3.36	-151.28	-	yes	-

4	4.34	-150.34	1	yes	-
5	3.1	-152.12	2	yes	-
6	3.44	-150.49	3	yes	-
7	2.01	-148.06	4	yes	-
8	3.13	-146.56	5	yes	-
9	4.03	-150.2	6	-	-
10	4.05	-150.17	-	-	-
11	3.54	-150.2	7	-	-
12	4.28	-151.01	8	yes	-
13	5.09	-151.19	9	yes	-
14	3.36	-153.33	10	yes	-
15	4.58	-151.03	11	yes	-
16	1.56	-151.37	12	yes	-
17	3.32	-155.33	13	yes	-
18	3.38	-152.38	14	yes	photo
19	-0.46	-152.41	-	-	-
20	3.05	-154.03	15	yes	photo
21	2.57	-158.26	-	-	-
22	2.36	-161.11	16	yes	photo
23	-0.53	-167.4	-	-	-
24	-1.25	-169.04	17	yes	photo
25	-3.03	-169.11	18	yes	photo
26	-3.02	-169.17	19	yes	photo
27	-3.4	-173.19	20	yes	photo
Total replicates			**20**	**19**	**7**

Preliminary analysis showed early patterns for different frequency response for the swimbladder (SB) and non-swimbladder (nSB) tuna species. The nSB tuna (i.e., skipjack) was more reflective on the high frequency echograms (120 and 200 kHz) (Figure 7.3), whereas the SB tuna (BET and YFT) were more intense on the low frequency echograms (Figure 7.4) which shows a great potential to discriminate these species using acoustic echo-sounders operating at different frequencies.

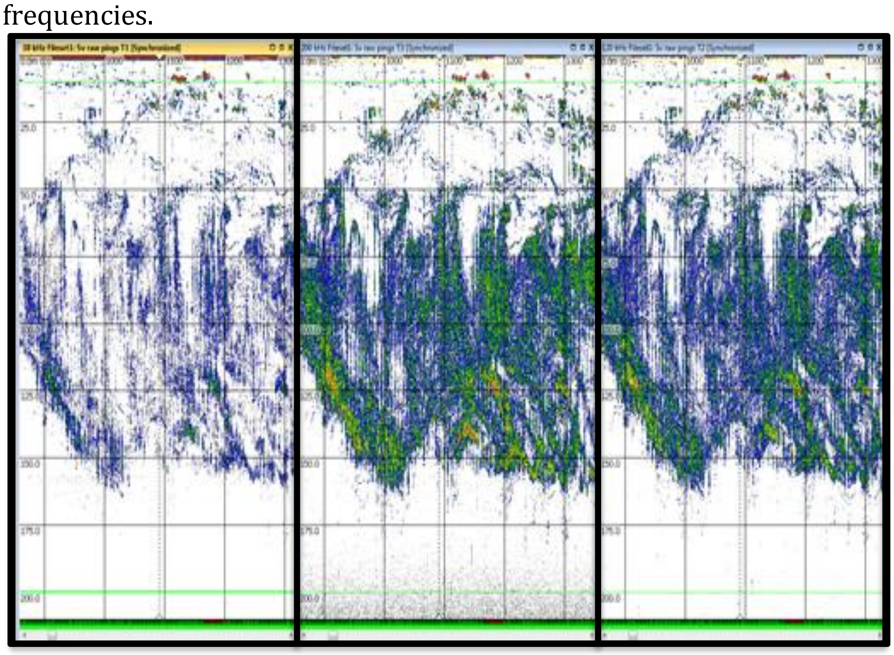
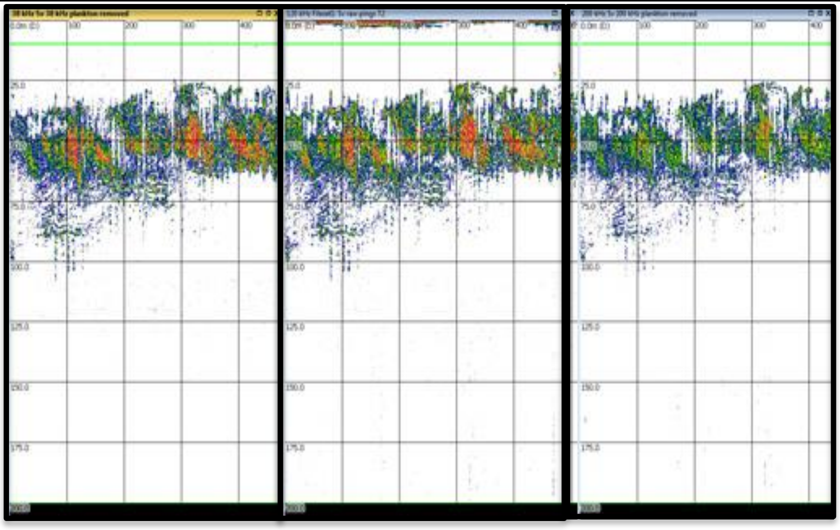


Figure 7.3. Skipjack tuna (non-swim-bladder fish) response to the different frequencies (38, 120 and 200 kHz from left to right respectively).

	 **Figure 7.4.** Bigeye tuna (swim-bladder fish) response to the different frequencies (38, 120 and 200 kHz from left to right respectively). A frequency response based mask was also developed to split the acoustic backscattering between tunas with and without swim-bladders (SBF and NSBF). The mask was adapted from Ballón et al (2011) and Korneliusen (2010), following two steps: A. Collective thresholding. A collective threshold was applied to the echograms. First, a virtual echogram was obtained by summing Sv echograms for the three frequencies (38, 120 and 200 kHz). Then the resulting samples of the echogram were 'thresholded' at a value of -180 dB. As a result, we obtained a bitmap with the same number of samples as the summed echogram, in which each pixel had a value of 1 if higher than the threshold and a 0 value if lower than the threshold. Each of the individual frequency Sv echograms were masked by this bitmap. Summarizing, Sv38 +Sv120 + Sv200 <> -180 dB fish vs. plankton B. Delta MVBS. For the second step, first the high frequency (HF) (120 and 200 kHz) Sv echograms were combined into one single virtual echogram in which each sample was the average of the samples of the individual frequencies. Then, this HF Sv echogram was subtracted from the low frequency one (38 kHz). And, similarly to the first step, a bitmap was built based on thresholding the resulting virtual echogram. The aim was to look for a threshold value that will distinguish fish with a swim-bladder (SB) and without swim-bladder (nSB). Ongoing analyses will comprise the following activities: - Obtaining TS-length relationships for the mono-specific (or almost so) tuna sets, i.e., skipjack sets 24, 26 and 27. - Obtaining TS-length relationships for the three main tuna species (SKJ, BET, YFT). - Adjusting and measuring the efficiency of the frequency response mask to discriminate between species. - Estimating the percentage of species and sizes of tuna present at FADs.
Conclusions	The objective was successfully achieved for SKJ and BET; insufficient data were collected for yellowfin. These data will be combined with data collected in other ISSF research cruises to discriminate these species using acoustic echo-sounders operating at different frequencies. The acoustic selectivity analyses will need to continue, with emphasis on yellowfin. Ultimately, the aim of this research would be transferring to fishers the knowledge acquired in order to help discriminate tuna species and sizes at FADs before setting.
***(3) Releasing sharks from the net**: Testing escape panel for sharks*	
Methods	The objective of this activity was to test if sharks can be effectively released alive from a set

through an escape panel, before being brought on board. This experiment had been carried out in a 2012 ISSF cruise on board the U.S. vessel CAPE FINISTERRE with promising results but a small number of observations.

In order to test the escape panel, it is essential to create a 'bend' in the net's shape, where sharks have been observed to accumulate while the net is being hauled. In observing the fishing process on board the ISSF research cruises to-date on board different vessels in the Indian and Pacific oceans, it became evident that the 'bend' is not always present.

Considering that this was not a chartered research cruise, the idea was to initially locate the ideal place in the net to situate the escape panel, according to the vessel's standard net setting and hauling procedure. Once this location was determined, the objective was to open the panel as many times as possible.

Results

The way the fishing master of the ALBATUN TRES hauled the net did not result in this 'bend' shape under normal conditions (Figure 7.5). The resulting shape was more similar to a mushroom, and such a round shape would not provide any particular area where sharks could concentrate for an extended period of time.

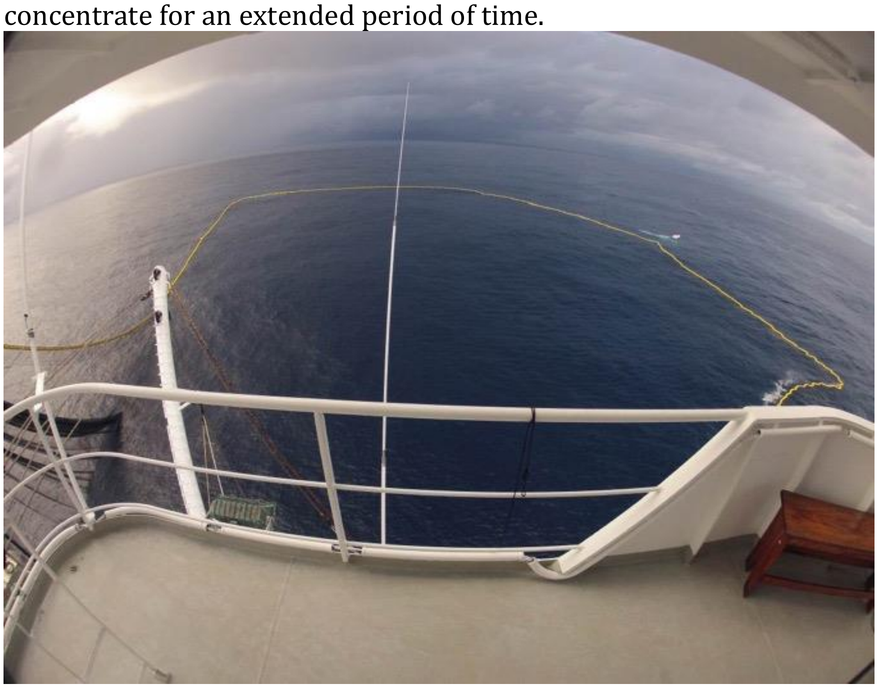


Figure 7.5. Vessel retrieving the net with the typical "mushroom" shape.

From a total of 27 sets during the trip, the creation of a bend occurred 9 times. However, in 6 of those 9 sets the bend was created only briefly and just before sacking-up, too late for testing an escape panel due to the high tension on the net at that stage of the net recovery (in addition to a high probability of tunas escaping). Therefore, only in 3 of the 27 sets (set #s 18, 21, 22, with 8, 8 and 30 sharks, respectively) was the bend created in time to theoretically be able to test an escape panel. However, all of these sets contained more than 50 tons of tuna so the pre-agreed conditions for the tests were never met.

During the majority of sets when sharks were seen while snorkelling, they were in close proximity to the tunas, and often mixed right in between them. They also moved around the net freely, and were seldom located at any one point for more than a few seconds. It is not known whether their behavior would change, and whether a greater spatial division would develop between sharks and tunas, if the maneuvers to create the net bend were carried out. It is possible that pulling persistently on the net towards the starboard side of the vessel, i.e. creating an outwards current towards the panel, might cause the sharks to separate more regularly from the tunas and accumulate in the bend area as observed during the 2012 CAPE FINISTERRE cruise. However, it

	would certainly require several replicates to ascertain this possibility. Early in the trip, it was thought that the bend was not being created due solely to the way of setting the net by the fishing master. Different procedures of setting the net might facilitate the creation of a bend. Setting with or towards the wind (more commonly used in vessels focusing on dolphin-tuna aggregations, or free school sets) might end up in a position where the wind is on the stern or port side of the vessel after the set. This would facilitate the use of thrusters sooner, without the risk of the net becoming entangled in them. On the contrary, the setting mode more commonly used among the vessels primarily fishing on FADs is to follow the current (parallel and in favor of the current). This setting mode prioritizes the direction of the current and therefore the wind is not always at the stern or from the port side after the set, causing the vessel to drift into the net itself and therefore creating a situation with high risk of net entanglement in thrusters if the fishing master uses them persistently. After a couple of weeks and several sets of observation and discussion with the fishing master and captain on board, the scientists concluded that the way of setting and the creation of a bend were not mutually exclusive. The bend creation is not subject to a particular way of setting, as the fishing master always holds the capacity and tools to create the bend if there are good oceanographic and meteorological conditions.
Conclusions	Main conclusions from this activity were that (i) the escape panel requires the skipper to actively create a bend in the net. This maneuver is already done in purse seiners fishing in the EPO in association with dolphins but it is believed to be risky and difficult for purse seiners using other net specifications and maneuvers more oriented to FAD fishing. (ii) There was no shark-tuna segregation within the net, and sharks were seldom located in a specific place, to facilitate an escape window in a given area.
(4) Releasing sharks from onboard the vessel	
Methods	After observing the way sharks (primarily silky sharks) were handled onboard during the sets, scientists tried to improve both the survival rate of sharks and the safety of the crew while handling sharks.
Results	A stretcher was constructed for carrying sharks from the lower deck to the upper deck, where they could be released (Figure 7.6). In this way, large sharks could be handled more safely when they were very lively, and thus have an improved chance of survival once released with lesser risk of injury to the crew. A total of 301 sharks were caught during the trip, 299 of which were silky sharks (*Carcharhinus falciformis*). The other two sharks were an oceanic whitetip (*C. longimanus*) and a hammerhead (*Sphyrnia sp*.). Measurements were only obtained for a few individuals, but estimates of total length of sharks from each set were made from a combination of underwater and on-deck observations. In this way the mean total length of silky sharks across all sets was estimated to be 1.4 m. An average of 11.1 sharks per set were caught during the trip.

	 **Figure 7.6**. Bycatch release stretcher .
Conclusions	Handling large sharks from the lower deck to the upper deck was difficult to put into practice due to the limited space in the vessel. Also this activity should be conducted as soon as the shark arrives to the lower deck. However, the availability of the crew to conduct this task depends on the fishing operation. Releasing sharks from the net or the upper deck is preferred.
***(5) Improving monitoring capabilities onboard purse seine vessels**: Comparison of estimates of catch composition by scientists and by fishers*	
Method	Spill sampling of the catch was conducted for 24 out of 27 sets, each time acoustic EK60 data was recorded (Table 2). This was done in order to be able to compare the actual catch species composition with the signals recorded by the echo-sounders (see Sections 1 and 2). Between 1 and 2 tons of fish were measured in each of these sets using a fiberglass box of dimensions 110cm x 70cm x 100cm (approximately 0.8 ton capacity, Figure 10). Spill samples were selected randomly during each set to avoid bias. In general, samples were taken every 6th or 7th brail, which provided enough time for the entire sample to be processed before the next sample was chosen. Scientists identified species and measured each fish in the sample to the nearest centimeter on flat measuring boards. The weights of sampled individuals were estimated using length-weight relationships available for each species. These proportions by weight were then extrapolated to the total tonnage of each set, as estimated by the fishing master. The vessel's fishing master also estimated catch composition for each set. This was achieved by spill sampling by the crew but on a smaller scale (only a few individual fish per brail were sampled).
Result	In all sets except for two, the scientist's estimation of bigeye was higher than that of the fishing master's. In most sets, the disparity was relatively large (Figure 7.7). Table 7.3 shows the difference in the percentage of bigeye estimated by scientists and the fishing master. **Table 7.3**. Species composition by weight as obtained from spill sampling by scientists and the fishing master onboard the Albatun Tres fishing in the central Pacific Ocean.

Date	Position Lat	Position Long	Set no.	Tonnage (m)	Shark caught	Scientists Spill Sampling % SKJ (weight)	Scientists Spill Sampling % BET (weight)	Scientists Spill Sampling % YFT (weight)	Fishing Master Estimation % SKJ (weight)	Fishing Master Estimation % BET (weight)	Fishing Master Estimation % YFT (weight)	% Difference BET
5/4/2014	2.53	-154.37	1	160	23	2.5	95.0	2.5	30.0	60.0	10.0	35.0
5/5/2014	3.37	-151.28	2	15	0	92.0	6.0	2.0	86.7	0.0	13.3	6.0
5/5/2014	3.36	-151.28	3	25	0	5.0	18.0	77.0	8.0	12.0	80.0	6.0
5/6/2014	4.34	-150.34	4	45	7	55.0	34.0	11.0	73.3	20.0	6.7	14.0
5/7/2014	3.1	-152.12	5	80	10	11.0	85.0	4.0	46.7	42.7	10.7	42.3
5/8/2014	3.44	-150.49	6	25	4	1.0	99.0	0.0	20.0	80.0	0.0	19.0
5/9/2014	2.01	-148.06	7	95	7	7.0	92.0	2.0	24.2	68.4	7.4	23.6
5/10/2014	3.13	-146.56	8	140	9	25.0	66.0	8.0	37.1	56.4	6.4	9.6
5/11/2014	4.03	-150.2	9	40	3	26.0	68.0	6.0	60.0	22.5	17.5	45.5
5/11/2014	4.05	-150.17	10	50	1	69.0	22.0	8.0	72.0	18.0	10.0	4.0
5/12/2014	3.54	-150.2	11	20	6	30.0	60.0	10.0	50.0	40.0	10.0	20.0
5/13/2014	4.28	-151.01	12	20	9	77.0	12.0	11.0	70.0	15.0	15.0	-3.0
5/14/2014	5.09	-151.19	13	55	14	66.0	27.0	8.0	85.5	9.1	5.5	17.9
5/15/2014	3.36	-153.33	14	80	9	28.0	68.0	5.0	49.3	44.0	6.7	24.0
5/16/2014	4.58	-151.03	15	55	19	49.0	46.0	4.0	76.4	20.0	3.6	26.0
5/17/2014	1.56	-151.37	16	60	2	21.0	73.0	6.0	35.0	48.3	16.7	24.7
5/18/2014	3.32	-155.33	17	180	1	38.0	56.0	6.0	59.4	35.0	5.6	21.0
5/19/2014	3.38	-152.38	18	65	12	25.1	70.7	4.2	35.4	60.0	4.6	10.7
5/19/2014	-0.46	-152.41	19	75	8	37.0	55.0	7.0	49.3	41.3	9.3	13.7
5/20/2014	3.05	-154.03	20	220	11	27.0	68.0	5.0	43.7	50.2	6.0	17.8
5/21/2014	2.57	-158.26	21	130	11	47.0	52.0	2.0	60.8	34.6	4.6	17.4
5/22/2014	2.36	-161.11	22	110	33	44.0	29.0	26.0	49.1	35.5	15.5	-6.5
5/23/2014	-0.53	-167.4	23	30	0	100.0	0.0	0.0	100.0	0.0	0.0	0.0
5/24/2014	-1.25	-169.04	24	170	24	100.0	0.0	0.0	99.4	0.0	0.6	0.0
5/25/2014	-3.03	-169.11	25	65	12	-	-	-	93.8	0.0	6.2	-
5/26/2014	-3.02	-169.17	26	125	8	94.0	4.0	2.0	95.2	1.6	3.2	2.4
5/27/2014	-3.4	-173.19	27	150	58	94.0	4.0	2.0	94.7	1.2	4.1	2.8
			Average	**84.6**	**11.1**	**45.0**	**46.5**	**8.4**				
			Total	**2285**	**301**							

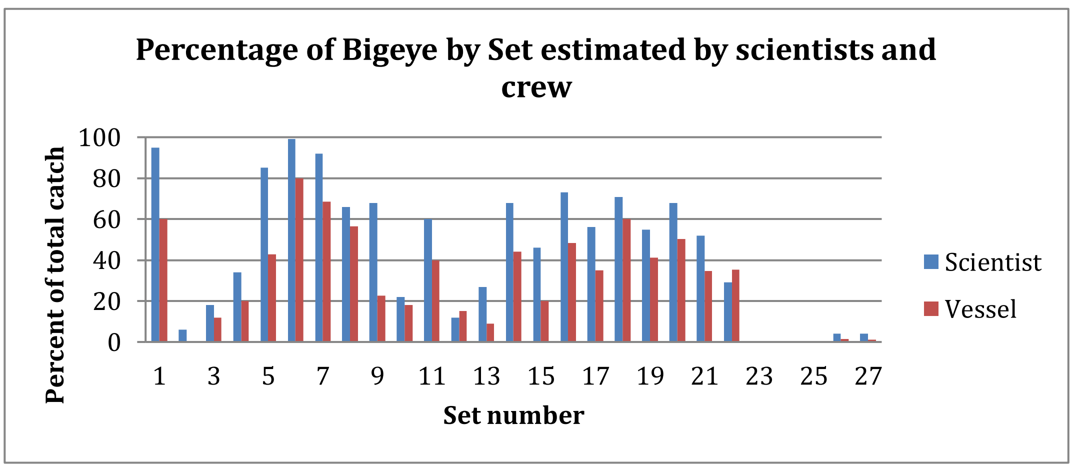


Figure 7.7. Comparison of scientist's (blue) and vessel's (red) estimation of bigeye catch in each set.

Conclusions

This objective was achieved successfully. Comparison of spill sampling estimates of catch composition by scientists against estimates from the vessel revealed important differences, especially for bigeye (suggesting an underestimation of bigeye composition by the crew). A likely cause is the difficulty of distinguishing small bigeye from small yellowfin, particularly in FAD sets, for crew who are not trained to do so.

Derived publications:

Boyra et al. (2018)
Lopez et al (2016)
Maksimovic (2015)
Moreno et al. (2016)
Orue et al. (2016)
Sancristobal et al. (2014)
Santiago et al. (2016)

8. 2014 CP-10 cruise (with SPC)

The "CP-n" cruises are conducted by the Secretariat of the Pacific Community (SPC) to conduct tagging that will help improve stock assessments conducted for WCFC. In this 10th cruise, ISSF participated for the first time. Previous CP cruises tagged tunas off oceanographic TAO buoys. In this cruise, Trimarine provided positions of FADs near the chartered vessel so as to increase fishing opportunities.

Objective:

Behavior of tunas and other fishes around FADs: To study the behavior of tuna and non-tuna species at FADs, including residency, vertical behavior, and daily presence/absence patterns. This information can be helpful for (i) discrimination of tuna species using acoustics, using as input fish vertical distributions and behavior, and (ii) assess the effects of FADs on associated species.

Scientists:

Bruno Leroy (Cruise Leader, SPC) and Jeff Muir (U. Hawaii) participated in this cruise.

Vessel:

SPC chartered the F/V PACIFIC SUNRISE (Tonga flag), a 22m fiberglass multi-purpose commercial fishing vessel built in 2003 by Westcoaster International, Australia. This vessel is equipped with longline gear used for fishing pelagic fishes (mainly tuna and swordfish).

Time and Area:

The cruise took place in the Western Pacific Ocean, from 1st to 25th August 2014 (Figure 8.1).

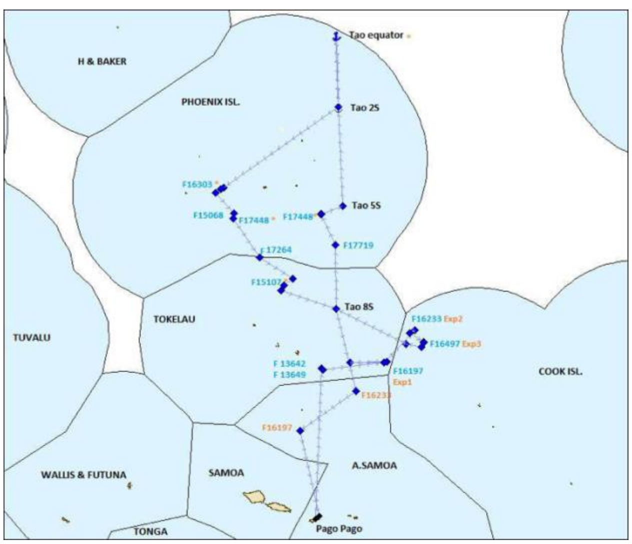


Figure 8.1. Cruise track during CP-10 showing position and name of each visited FAD. Fish have been tagged on the FADs identified by a * or with orange text.

Progress made for each Objective

(1) Behavior of tunas and other fishes around FADs: *Acoustic tagging*	
Methods	ISSF's component of the CP-10 cruise consisted of instrumenting 3 drifting fishing aggregating devices (FADs) with VR4 Global satellite communicating acoustic receivers manufactured by Vemco (VR4 Global unit allows the user to remotely monitor tagged fish, and eliminates the need to retrieve the receiver after the study has finished. The unit utilizes Iridium satellite communication to relay detection logs, status updates, and error messages to the user). Tagging was done on tunas (SKJ, YFT, BET) and non-tuna species (silky shark: FAL, rainbow runner: RRU, spotted oceanic trigger fish: CNT, oceanic white tip shark: OCS, wahoo: WAH) at these FADs with coded, pressure-sensitive acoustic tags (maximum 24 per FAD).

TriMarine provided positions of FADs linked to satellite IRIS buoys owned by them in the areas that the tagging vessel operated during the cruise.

Results

A total of 11 different FADs were visited and tagged fish were released in association with 6 of them, in three receiver stations (Table 8.1).

Table 8.1. Number of acoustic tags deployed by species and FAD.

Species	Exp.1	Exp.2	Exp.3	Total
YFT	6	7	7	**20**
SKJ	2	0	6	**8**
BET	3	3	0	**6**
FAL	5	5	3	**13**
RRU	2	0	2	**4**
TRI	5	5	5	**15**
WAH	0	1	0	**1**
OCS	0	1	0	**1**
Total	**23**	**22**	**23**	**68**

There were problems with the receiver not working properly on Experiment 1, so no data were collected.

For Experiment 2, the hydrophone on the VR4 failed and had to be replaced after 3 weeks. The auxillary VR2W receiver was downloaded, and the station was re-deployed and abandoned. Eleven of twenty-two tagged animals were detected at the station for 28,635 detections. It appeared that most of the aggregation had departed the FAD, and only a small school of YFT, BET, and CNT remained. Only one silky shark was spotted.

Experiment 3 functioned properly Twenty-three animals were implanted with V13 and V9 coded pressure sensing acoustic tags (table 2). During the time period of the cruise, this station appears to have been functioning properly and communicating via Iridium. The station was abandoned since there were implanted animals still transmitting at the tail end of the cruise.

Total detection days for each individual on each FAD are shown in Figure 8.2. Detection days for YFT in many cases reached 30d. Detection days for BET ranged from a few days to 12 days.

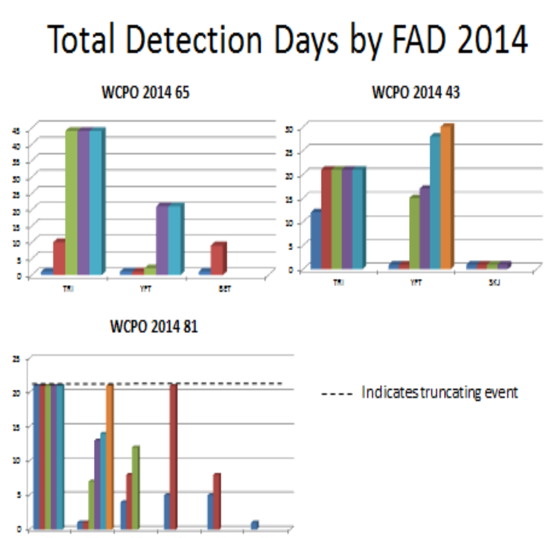


Figure 8.2. Total detection days by FAD CP-10 (left) and CP-11 (right).

Probability of presence by species for each FAD is shown in Figure 8.3. YFT and BET seemed to have less presence at FADs during daylight hours, indicating daytime departures from the FAD.

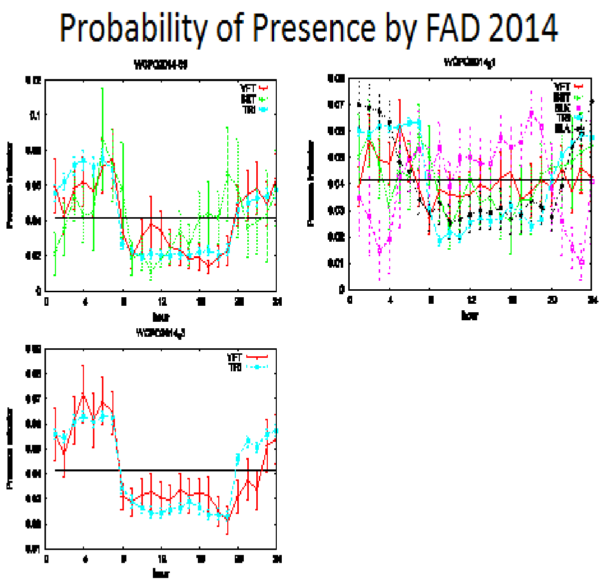
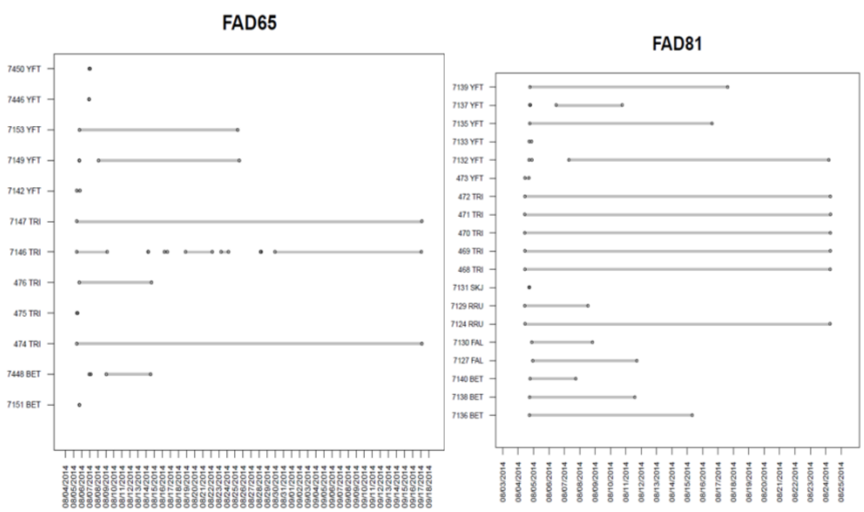
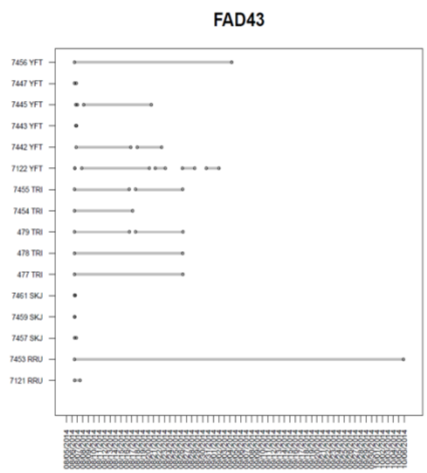


Figure 8.3. Probability of presence by hour at a FAD. The vertical axis represents the probability of presence, and the horizontal axis represents the hour of day in each plot Red lines indicate YFT, green = BET, light blue = TRI, black = RRU, dark blue = SKJ, and purple = FAL. Error bars represent standard deviation.

Figure 8.4 shows continuous residence time (CRT) for each individual on each FAD. With the exception of the ever-present triggerfish at many FADs, there are no repetitive patterns by other species by year or between years, although there are many interesting records of long absences by YFT and BET, and some simultaneous departures and arrivals indicative of schooling behavior.



	 **Figure 8.4**. CRT plots by FAD station for each species. Red line indicates truncating event such as a purse seine set.
Conclusions	Despite several equipment failures, the (ISSF) objectives were partially achieved. Future cruises to conduct acoustic tagging should utilize redundant equipment. The collaboration between SPC, Trimarine and ISSF proved very useful to find more fish than by just visiting TAO buoys.

Derived publications:

Leroy and Muir (2014)

9. 2015 AO cruise on the F/V CAP LOPEZ

Objectives:

(1) **Releasing sharks from the net:** Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets.

(2)**Post-release survival of vulnerable species**: Post release survival of the megafauna captured in the seine

(3) **Modifications in FAD designs to reduce impacts** Observation of shark and bycatch entanglement rates in drifting FADs with description of FAD types observed

Scientists:

David Itano (ISSF Consultant- Chief Scientist), Fabien Forget (ISSF/IRD) and John Filmalter (ISSF Consultant)

Vessel:

The Cap Lopez is a medium-sized tuna purse seine vessel of 53m built in France in 1982. The vessel is operated from Tema Fishing Port in Ghana by TTV Limited and has a fish holding capacity of 600 mt.

Time and Area:

The cruise originated from Tema, Ghana on the 20th of July and returned to port of Tema, Ghana on the 5th of August 2015. The vessel operated in the Ghana EEZ and the adjacent high seas.

Progress made for each Objective

<table>
<tr><td colspan="2">(1) Releasing sharks from the net: Test the efficacy and potential of a release panel that could be used to selectively release sharks from purse seine sets.</td></tr>
<tr><td>Methods</td><td>An experimental release panel was installed in the CAP LOPEZ net in Tema (Figure 9.1).


Figure 9.1. Construction of the top portion of the release panel (left) and detail of rings at the bottom corner (right).</td></tr>
</table>

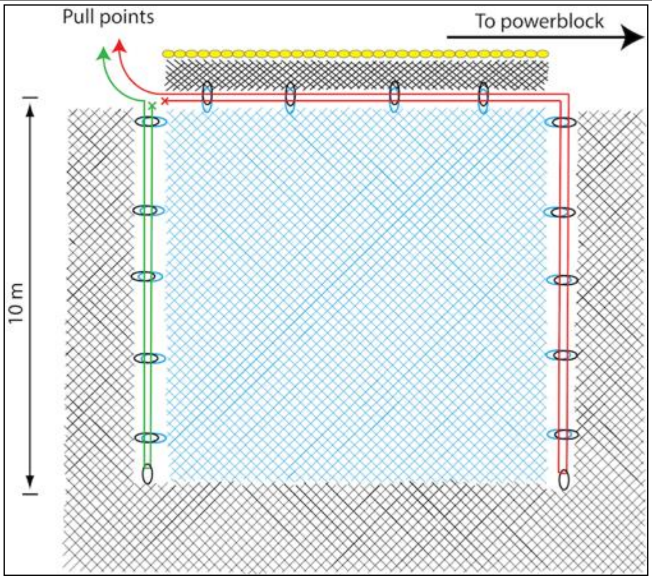
	 **Figure 9.2.** Design of the escape panel tested on Cap Lopez It was agreed to test the release panel if/when the Captain and Chief Scientist agree that the following five conditions exist at the time of the set: i) The fish aggregation is estimated to be no larger than 50 tons; ii) Meteorological conditions are sufficient to ensure the safe and proper operation of the release panel; iii) The currents affecting the net are not strong; iv) It is estimated that several sharks (>5) are present in the aggregation; and, v) The tuna school is not in the proximity of the release panel.
Results	Eleven sets were made during the time the ISSF scientists were onboard consisting of five free school sets on large yellowfin tuna and six sets on drifting FADs. All eleven sets resulted in target catch ranging from 5 – 55 tons with a wide range of associated bycatch species present. Only two sharks were observed in the net during the cruise. The scientists made direct in-water observations of one free school set and all six drifting FAD sets using snorkel gear and documented these underwater observations with digital photographs and video. The five conditions required before an attempt to open the release panel were never satisfied. The most common issue that prevented testing of the release panel was the lack of sharks observed during the cruise and the close proximity of tuna to the release panel. A significant issue with the operation of the release panel was related to the relatively small size of the vessel and shallower design of the net. The shorter boat length resulted in a narrow base between the stern area of the working deck to where the cork line was tied at the bow. The cork line was further shortened when the corks of the sack were bunched for brailing. These factors brought the release panel close to the vessel, which was already only 113 m from the end of the net. The proximity of the panel to the boat was further complicated when the large net skiff pulled the net and main vessel to starboard to form the bend or pocket in the net. The narrow net base at the vessel formed a tight bend in the net while the sack drifted out and upward, further shallowing the net. Tuna were observed to race from the vessel, through the narrow channel to the bend where the release panel was located. Opening the panel under these circumstances would have allowed them to escape (Figure 9.3).

	 **Figure 9.3.** Tuna in close proximity to the release panel during set #3. An attempt to open the release panel was made during set #6 when two silky sharks and 20 tons of tuna were observed inside the net. However, friction and bunching of the rings caused the rope to bind and prevented opening the panel.
Conclusions	This activity could not be conducted successfully. It was realized that the escape panel is highly dependent on the net design and vessel specifications and thus cannot be tested on board all types of vessels.
***(2) Post-release survival of vulnerable species**: Post release survival of the megafauna captured in the seine*	
Methods	MiniPATs were reserved in case megafauna were encircled. During the cruise, the skipper was regularly in touch with other skippers to be informed of any encounter of a whale sharks or other megafauna.
Results	No megafauna, including manta rays, were caught during this cruise.
Conclusions	This objective could not be achieved as no megafauna were encircled during this cruise.
***(3) Modifications in FAD designs to reduce impacts:** Observation of bycatch entanglement in FADs and description of drifting FAD types*	
Methods	Underwater visual census using snorkel gear by ISSF scientists prior to and during the set. Visual inspection of the FAD after the FAD was removed from the water and brought onboard.
Results	All FADs examined were lower entanglement risk type drifting FADs with 7cm netting tied tightly into a single "sausage" that hung 50 m below a raft type float. UVC was conducted on three TTV FADs but poor underwater visibility restricted observations to the upper 20 -30 m of the 50+m net sausage. Two additional drifting FADs were brought onboard allowing the inspection of all 50m of the underwater structure, including one FAD where four sharks were observed during UVC. No entanglements of sharks or other bycatch species were noted during the cruise.
Conclusions	No shark or bycatch entanglements were observed by UVC or from retrieved FADs on lower entanglement type FADs. However, very few sharks were observed during the entire cruise.

Derived publications:

Itano et al. (2016a)

10. 2015 Biodegradable twine tests at U. Hawaii

Objective:

Modifications in FAD designs to reduce impacts: Test a biodegradable material from natural origin, Coir (coconut husk fiber), to be used in drifting FAD structures.

Scientists:

Jeff Muir and Kim Holland (University of Hawaii).

Vessel:

None. This research was done in collaboration with ORTHONGEL, which supplied the materials.

Time and Area:

Plots were deployed at an anchored FAD offshore of Kaneohe, Oahu and in the lagoon at Hawaii's Institute of Marine Biology (Figure 10.1). The experiment was conducted during 2015.

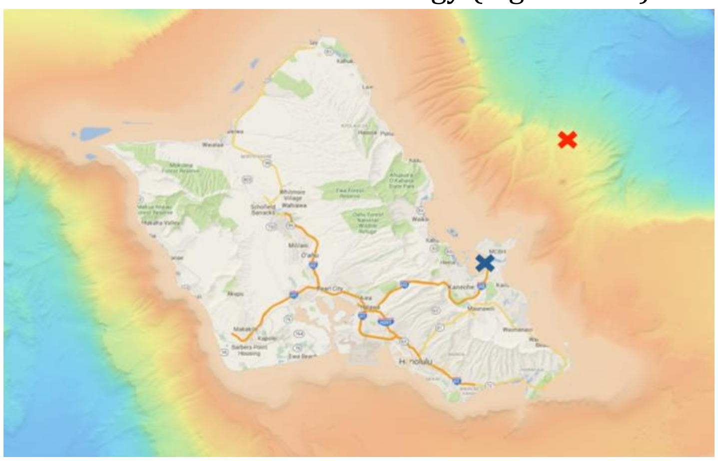
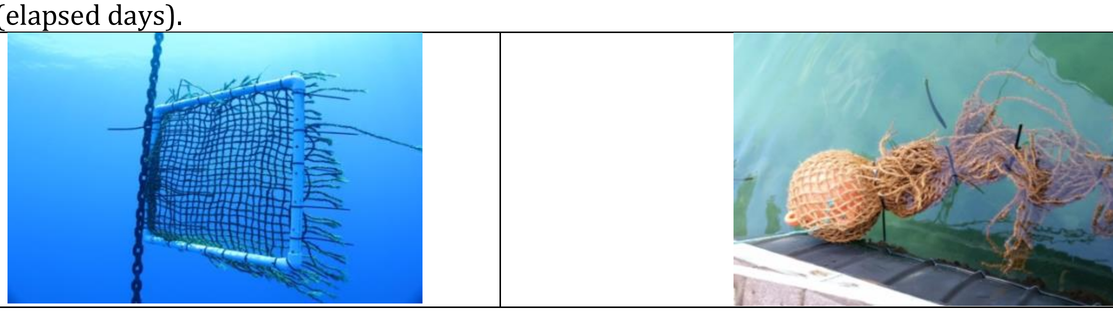
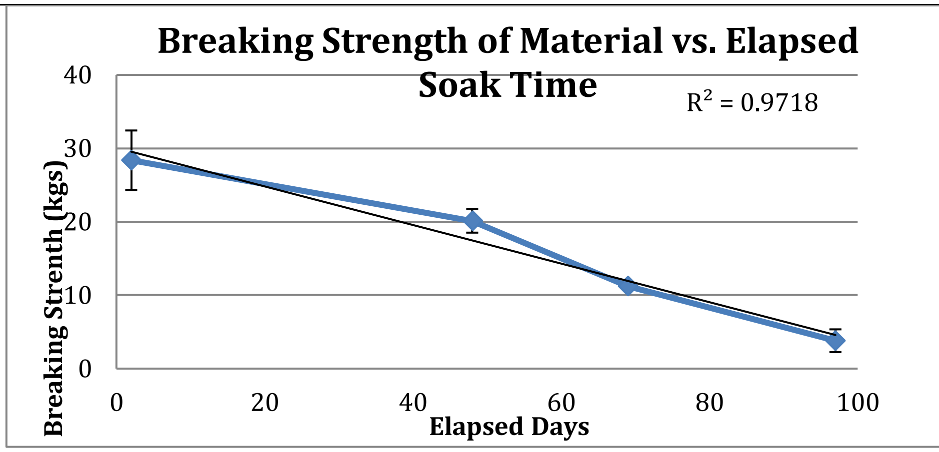


Figure 10.1. Map of study site, Oahu Hawaii. Red "X" denotes location of U FAD, blue "X" location of Coconut Island.

Progress made

(1) Modifications in FAD designs to reduce impacts: *Test of biodegradable twines*	
Methods	Coir (coconut husk fiber) material, manufactured in Sri Lanka, was delivered to HIMB in large diameter rope (approximately 80mm) and small mesh netting (approximately 10mm). Plots were deployed at U FAD, offshore of Kaneohe, Oahu (4 plots) and in the lagoon at HIMB (2 plots). In order to measure degradation, breaking strength was measured for different soaking time (elapsed days).  **Figure 10.2.** 1m x 1m plot of coir mesh deployed at U FAD, nearshore Kaneohe (left) and longline float with coir mesh wrap and tail deployed at Coconut Island, Kaneohe (right).
Results	Breaking strength sampling of material occurred at 2, 48, 69 and 97days. A regression line, pooling data from all plots showed a good fit (Figure 10.3, R^2 = .9718) of the relationship between breaking strength values and soak time (elapsed days). At 97 days, breaking strenth values were < 6 kg, and materials were easy to pull apart.

	 **Figure 10.3**. Breaking strength of coir material vs. elapsed soak time.
Conclusions	This objective was achieved. The material tested decomposes quite quickly and in such a way that its impact on beaches and reefs could be expected to be minimal and quite short-lived. Further, very low biofouling was observed on any of the samples. This would indicate that it is suitable material for sub-surface "tails" on FADs if appropriate strand dimensions could be formulated. However, the quite rapid decline in tensile strength suggests that this material would be-sub-optimal for binding FAD float components together. This weakness could possibly be overcome by increasing the size (diameter) of the strands used for this function. Further testing is required.

11. 2015-2017 tests of shallow versus normal depth FADs in the equatorial EPO

Objective:

Modifications in FAD designs to reduce impacts: To evaluate the performance of shallow versus normal depth drifting FADs in the EPO purse seine fishery, with an emphasis on the tuna species catch composition, seeking a practical solution to reduce purse-seine fishing mortality on bigeye tuna.

Scientists:

Kurt Schaefer (Senior Scientist) and Daniel Fuller (Associate Scientist) with IATTC.

Vessels:

This research is being undertaken in collaboration with NIRSA (Ecuador), including the full cooperation of their fleet of 11 tuna purse-seine vessels.

Time and Area:

Two experiments were conducted, the first from June 2015 through October 2016 (100 FADs planted), and the second from March 2017 through December 2017 (200 FADs planted). See Figure 11.1 for locations.

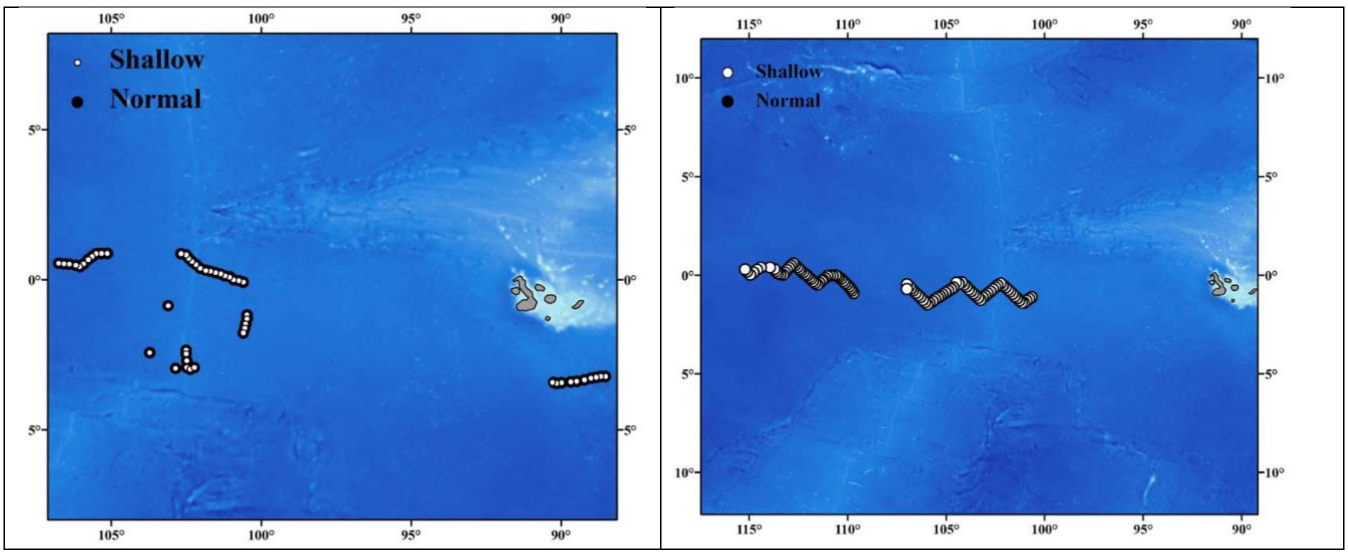


Figure 11.1. Locations where the shallow and normal depth FADs were deployed (experiment 1 on the left, experiment 2 on the right).

Progress made

(1) Modifications in FAD designs to reduce impacts: *Evaluating the performance of shallow versus normal depth FADs*	
Methods	The rafts for the 150 shallow and 150 normal depth FADs were all 1.2 x 2 m and1.5 x 2.3 m and construction materials, consisting of dried bamboo tied together with nylon twine, covered with Saran black shade cloth, and then wrapped tightly with 30mm sardine netting. Six net corks were tied beneath each raft under the shade cloth, and plastic bait containers with either fish or pig parts included were tied underneath all FADs at the time of deployments. The appendages hung beneath the normal depth FADs were approximately 37-46 m, and consisted of 2 coils of twisted and tied scrap tuna or sardine netting weighted with chain. The appendages hung beneath the shallow depth FADs were approximately 5 m, and consisted of 4 ropes (1-2" dia) with coconut palm fronds tightly laced, attached to a split bamboo frame weighted with chain (Figure 11.2).

Figure 11.2. Normal (left) and shallow (right) FADs.

Marine Instruments (MI) M3i echo-sounder buoys were attached to each of the 300 FADs. Arrangements were made with NIRSA and MI so as to receive the M3i buoy data for the FADs in real time, utilizing the MI software installed on an IATTC computer.

The normal and shallow depth FADs for experiment 1 were deployed from the NIRSA FV Milena A (62m length, 900 t capacity) simultaneously in pairs along 7 transects between 3°S -1°N and 89°-107°W during 25 June through 20 July, 2015. Each deployment was recorded by the navigator on a data form created specifically for this project which included data fields for FAD type, deployment position and date, M3i buoy number and the NIRSA ID numbers assigned and painted on each buoy. In addition, the IATTC observer monitored and recorded each of the deployments so as to independently verify the FAD types with the buoy ID numbers. The normal and shallow depth FADs for experiment 2 were deployed from the NIRSA FV Via Simoun(69m length, 975 t capacity) simultaneously in pairs along 2 transects between 2°S -2°N and 100°-116°W during 9 March through 13 March, 2017. Deployment metrics were recorded similarly to those in experiment 1.

A Bayesian inferential procedure was used to fit a range of different geo-additive generalized additive mixed regression models (GAMMs) to the set-specific tuna catch (tons/set) by species and for combined species. The response variable was catch (t) per set given 5 predictors: FAD type, species, month, set hour, and set location

Results

Eighty-four sets have been made on the FADs (45 on normal FADs and 35 on shallow FADs). The analyses show that:

- There was no significant difference in the average daily drift speeds between the normal depth (0.73 knots) and shallow depth FADs (0.72 knots), for the first 60 days following deployments;
- Model results indicate that proportion BET nor any of the other covariates, including FAD type, were significant predictors of set specific total tuna catch rates. There was no significant interaction between FAD type and proportion of BET captured.
- When modeling species-specific catch rates, there is a significant interaction between

FAD type and tuna species catch rate. However, as indicated by a higher standard error, the interaction between FAD type and species is both marginal and uncertain. See **Figure 11.3.**

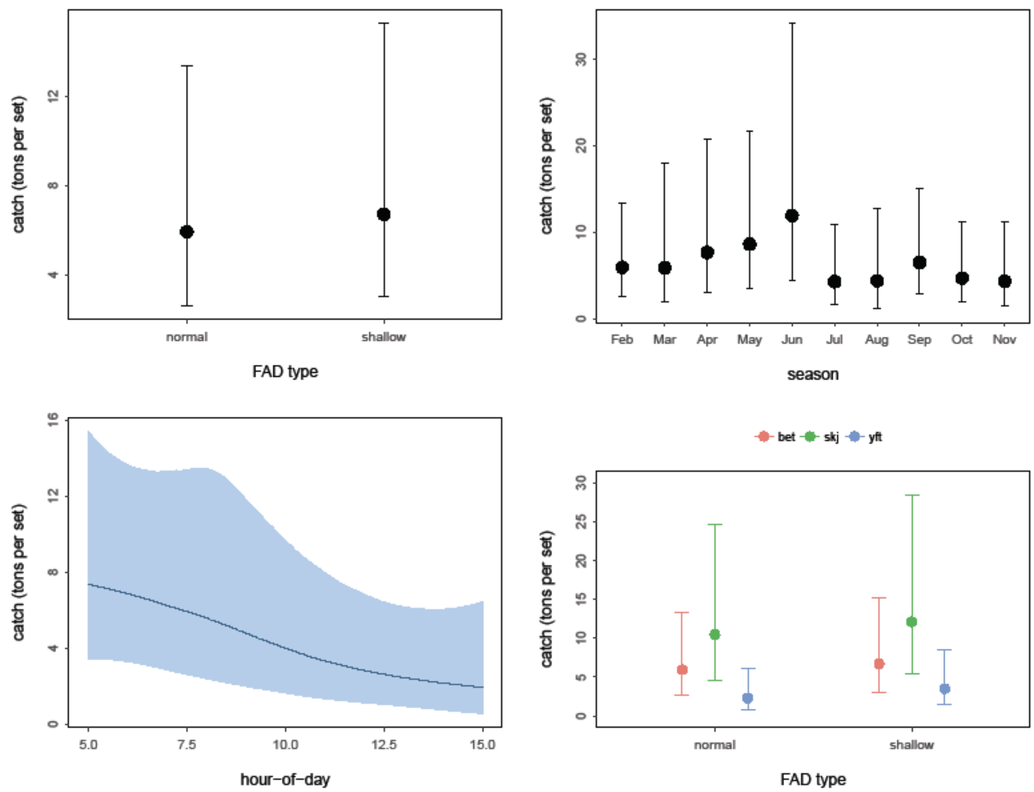


Figure 11.3. Results for the GAMM analyses of tuna-specific catch rates. Each plot shows the predicted catch rate for various covariates in the analyses.

Conclusions

The experiments showed that total tuna catch rates and tuna species catch rates were not significantly different by FAD depth. Thus, using shallow FADs in the EPO is not a useful mitigation technique to reduce the catch of bigeye tuna. It remains to be seen if the same conclusion would be made in other areas, e.g. where the thermocline is deeper.

On a positive side, it was shown that there was no significant difference in drift speeds between normal and shallow depth FADs, and both FAD types were equally successful in aggregating tunas. This is a useful conclusion because shallow FADs don't require as much materials in their construction, thus reducing environmental impacts (e.g. when the submerged FAD structure uses netting made out of synthetic materials). Also, the material beneath the shallow FADs consisted of 4 ropes which eliminate any potential entanglement of sharks and turtles beneath those FADs.

12. 2015 CP-11 cruise (with SPC)

The CP-11 cruise was the second collaboration with SPC in tagging in the Central Pacific. As in CP-10, Trimarine provided positions of FADs near the chartered vessel so as to increase fishing opportunities, and also provided a scientist to go onboard. CP-11 was divided into two legs. This report pertains only to Leg 1, when ISSF was involved.

Objective:

Behavior of tunas and other fishes around FADs: To study the behavior of tuna and non-tuna species at FADs, including residency, vertical behavior, and daily presence/absence patterns. These objectives help (i) discrimination of tuna species using acoustics, using as input fish vertical behavior (ii) assess the effects of FADs on associated species.

Scientists:

Bruno Leroy (Cruise Leader, SPC), Jeff Muir (U. of Hawaii) and Beth Vanden Heuvel (Trimarine)

Vessel:

SPC chartered the F/V GUTSY LADY 4 (USA flag), a 30m steel longline commercial fishing vessel. This vessel is equipped with longline gear used for fishing pelagic fishes (mainly bigeye tuna).

Time and Area:

Leg 1 of the cruise took place in the Central Pacific Ocean, from 9th September to 6th October 2015 (Figure 12.1).

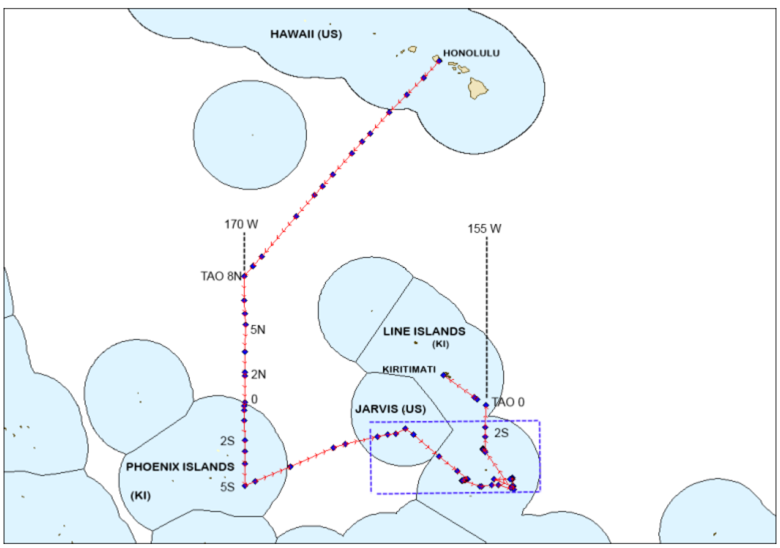


Figure 12.1. Cruise track during CP-11 Leg 1. Drifting Fads were fished inside the dashed blue line delimited area

Progress made for each objective

***(1) Behavior of tunas and other fishes around FADs**: Acoustic tagging*	
Methods	ISSF's component of the cruise consisted of instrumenting 3 drifting fishing aggregating devices (FADs) with VR4 Global satellite communicating acoustic receivers manufactured by Vemco. Coded, pressure sensitive acoustic tags were implanted in tuna (SKJ, YFT, BET) and non-tuna species (silky shark: FAL, spotted oceanic trigger fish: CNT). The VR4 Global unit allows the user to remotely monitor tagged fish, and eliminates the need to retrieve the receiver after the study has finished. The unit utilizes Iridium satellite communication to relay detection logs, status updates, and error messages to the user. TriMarine provided positions of FADs linked to satellite IRIS buoys owned by them in the

vicinity of the GUTSY LADY 4.

Results

A total of 9 different FADs were visited and fished; three of them were instrumented with VR4 acoustic receivers. A total of 59 fish were tagged (Table 12.1)

Table 12.1. Summary of animals implanted with acoustic tags.

Species	FAD1	FAD2	FAD3	Total
YFT	10	6	5	21
SKJ	0	3	7	10
BET	8	8	7	23
FAL	2	0	0	2
CNT	1	0	0	3
Total	21	17	21	59

Total detection days for each individual on each FAD are shown in Figure 12.2. These values ranged from a few days for individuals of all species, to 81d for a triggerfish. Of the tuna species, SKJ were not well represented in the detection data due to the difficulty of obtaining them in suitable condition for tagging, and this is reflected in the low amount of detection days for this species. Detection days for YFT in many cases reached 30d. Detection days for BET ranged from a few days to 51d at station 86, at which point there seemed to be a purse seine set which removed it and other tagged fish at the FAD. For the non-tuna species, RRU and TRI showed high fidelity to the FAD, in most cases remaining at the FAD until the receiver was collected or failed, indicating that these animals may have remained at the FAD for even longer.

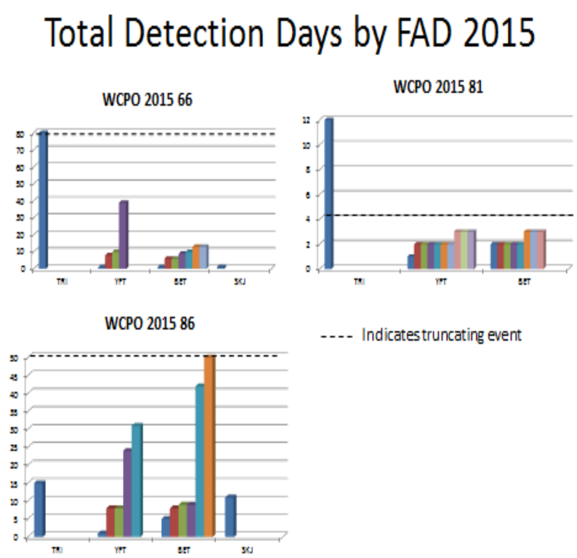


Figure 12.2. Total detection days by FAD CP-11.

Probability of presence by species for each FAD is shown in Figure 12.3. In the 2014 CP-10 cruise, YFT and BET seemed to have less presence at FADs during daylight hours, indicating daytime departures from the FAD. A converse pattern is present for YFT and BET on 2 stations during 2015, but then confounded again by the third station in 2015. Triggerfish showed less presence during daylight hours during 2014, which may be explained by the use of the smaller V9 acoustic tag, which has less transmitting power than the V13. This would decrease the range of detection of the receiver, and may provide a false pattern of absence during daylight hours. Triggerfish during 2015 were tagged only with V13 tags and showed almost no difference in detection for all 24 hours of day.

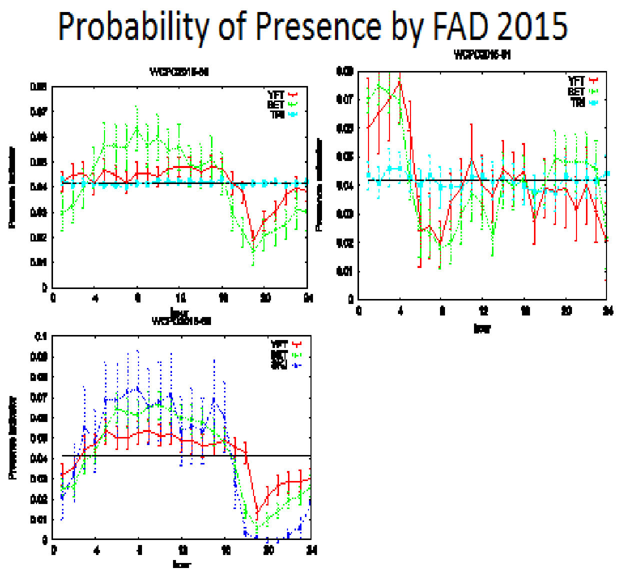
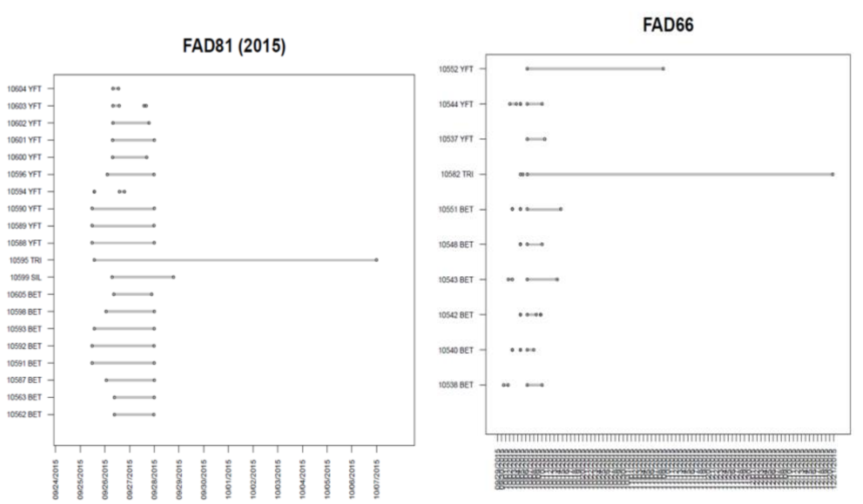
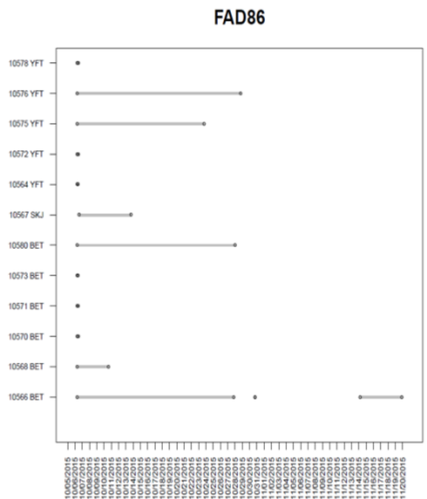


Figure 12.3. Probability of presence by hour at a FAD. The vertical axis represents the probability of presence, and the horizontal axis represents the hour of day in each plot Red lines indicate YFT, green = BET, light blue = TRI, black = RRU, dark blue = SKJ, and purple = FAL. Error bars represent standard deviation.

Figure 12.4 shows continuous residence time (CRT) for each individual on each FAD. Note the following:

- Station 86, BET 10566 displays 14.1d CAT.
- Station 86, 2 BET and 1 YFT depart simultaneously after 13d.
- Station 66, several BET and YFT remain on FAD for 15-20d, displaying simultaneous arrivals and departures ranging from 2-5d.
- Station 81, fishing event after 15d, after this event only 1 TRI and 1 FAL remain.



	 **Figure 12.4**. CRT plots by FAD station for each species. Red line indicates truncating event such as a purse seine set.
Conclusions	The release of tagged fish around drifting fads during Leg 1 was successful. The collaboration by Trimarine to provide FAD positions proved to be particularly crucial for the success of this CP11 cruise.

Derived publications:

Leroy et al. (2015)

13. 2015 AO Cruise on the SEA DRAGON

Objectives:

(1) **Behavior of tunas and other fishes around FADs**: Investigate the associative behavior of target and non-target species using acoustic telemetry and the horizontal movements of oceanic sharks using PAT tags.

(2) **Behavior of tunas and other fishes around FADs**: Active tracking of sharks, tuna and other non-target species at FADs

(3) **Modifications in FAD designs to reduce impacts:** Underwater visual census to assess entanglement and document diversity at FADs

Scientists:

David Itano (ISSF Consultant- Chief Scientist), John Filmalter (ISSF Consultant) and Melanie Hutchinson (ISSF/NOAA)

Vessel:

The Sea Dragon is a 72 ft. steel hulled sailing vessel operated by Pangaea Exploration. The vessel charters to private parties, often for scientific or survey cruises. ISSF elected to contract the Sea Dragon for this cruise to allow unrestricted access and time on drifting FADs such that tagging and FAD observations could be conducted at the discretion of the scientific party.

Time and Area:

The cruise departed from Dakar, Senegal on the 4th of October and returned to Dakar, Senegal, on the 22nd of October. The cruise location was located at 17°N latitude, well north of the core area of the Gulf of Guinea tropical tuna purse seine fishery. However, the vessel was able to access FADs that had drifted north and out of the main fishing areas.

Progress made for each Objective

(1) Behavior of tunas and other fishes around FADs*: Associative behavior of target and non-target species using acoustic telemetry*	
Methods	Target and non-target species were acoustically tagged at drifting FADs and were remotely monitored with VEMCO VR4G units that transmit data via satellites. The access codes of GPS buoys on drifting FADs were kindly provided by French and Spanish fleets allowing scientists to query and locate productive FADs. VEMCO V13P tags were deployed which provide presence/absence and time stamped depth data. This data collected will improve knowledge of the diurnal and vertical behavior of tuna and non-target species on drifting FADs as well as establish baseline information on the residency times of FAD associated fishes in the Atlantic Ocean. Additionally, information gained may be useful to improve the interpretation of echo-sounder and echo-sounder buoy data, particularly for species discrimination.
Results	A total of 107 fish were tagged and released on four FADs. 28 sharks were tagged with PATs. Table 13.1 describes each tag release category for the seven species in which tags were deployed. **Table 13.1.** Summary of electronic tag deployments by FAD. Non-shark species received an acoustic tag only

FAD #	SKJ	BET	YFT	RR	Trig	Silky Sonic	Silky sonic+ mini-PAT	Silky mini-Pat	C. long
FAD 1	3	7	5	4	4	0	2	1	0
FAD 2	3	7	5	5	5	0	3	3	1
FAD 3	1	5	5	5	5	1	4	1	0
FAD 4	0	4	5	5	5	2	0	0	0
	7	23	20	19	19	3	9	5	1
									107 Total

The acoustic transmitters provided information on the residency of fish at FADs, as well as on the patterns of association and excursions away from FADs. The associative patterns and the vertical distribution of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*) (target species), as well as silky shark (*Carcharhinus falciformis*), oceanic triggerfish (*Canthidermis maculata*), and rainbow runner (*Elagatis bipinnulata*) (major non-target species) were determined. Preliminary results indicate that there are diel associative patterns displayed by silky sharks and skipjack tuna, which were more closely associated with FADs during daytime, while a less distinct associative pattern was observed for bigeye, yellowfin, rainbow runner and the oceanic triggerfish (Figure 13.1).

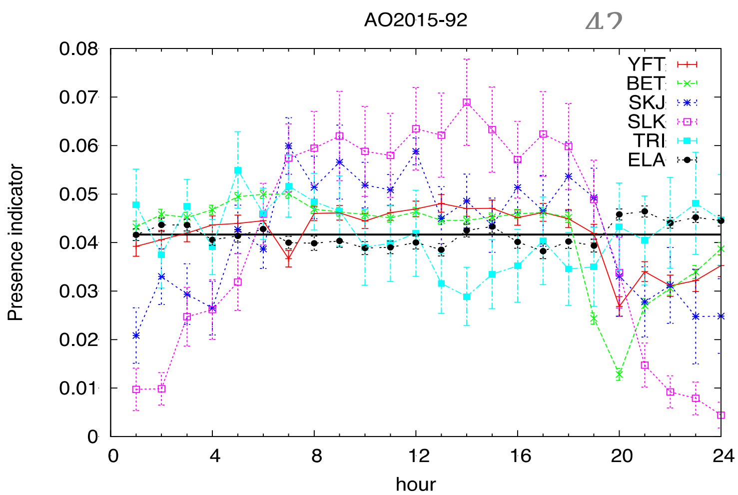


Figure 13.1: Example of presence rates of target and non-target species at a FAD during 24 hours.

Yellowfin and bigeye tuna appeared to have a deeper distribution than the other species (Figure 13.2).

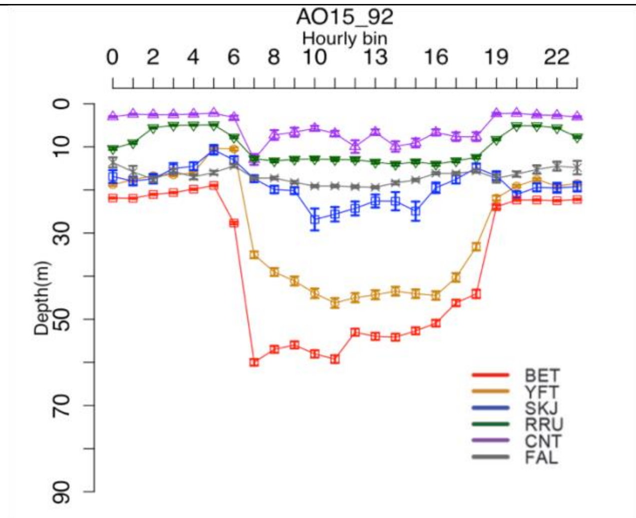
<table>
<tr><td></td><td>

Figure 13.2: Example of hourly mean depth distributions of target and non-target species at a FAD during 24 hours. Error bars indicate the standard error of the mean.</td></tr>
<tr><td>Conclusions</td><td>This activity was conducted successfully. For the first time the associative behavior of target and non-target species could be monitored simultaneously in the Atlantic Ocean. Preliminary analyses suggest that no specific change in fishing time could mitigate the vulnerability of silky sharks and other non-target species. For the vertical distribution, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net. It is interesting to note, however, that yellowfin and bigeye tuna occupy a deeper position in the water column during daytime. This vertical difference could potentially be amplified and used to enhance the vertical separation of these two species from skipjack tuna.</td></tr>
<tr><td colspan="2">(2) Behavior of tunas and other fishes around FADs: Active tracking of sharks, tuna and other non-target species at FADs</td></tr>
<tr><td>Methods</td><td>This activity consisted in actively tracking a silky shark (for 48 hours) and simultaneous tracking of a tuna and another FAD-associated predator (requiring 3 tracking vessels).</td></tr>
<tr><td>Results</td><td>Acoustic tracking was not conducted due to the unsuitability of the inflatable tender and main vessel to be fitted with the necessary tracking gear and the inability to track with the dingy during night time hours (during 24 hour cycles).</td></tr>
<tr><td>Conclusions</td><td>This activity could not be conducted due to logistical limitations.</td></tr>
<tr><td colspan="2">(3) Modifications in FAD designs to reduce impacts: Under water visual census to assess entanglement and document diversity at FADs</td></tr>
<tr><td>Methods</td><td>Underwater Visual Census (UVC) were performed by SCUBA gear and by snorkeling at FADs. The scientific divers approached the drifting FAD with the tender, performed safety checks at 5 m below the FAD for 5 min. The divers then descended to 10 m for 30 min where they i) documented the species assemblages at drifting FADs, ii) quantified any entangled fauna and documented the designs type of each FAD.</td></tr>
<tr><td>Results</td><td>No entangled sharks were observed during the inspections. The summary of the visual assessments are given in Table 13.2.

Table 13.2: Summary of FAD inspections and entanglement observations.</td></tr>
</table>

Date FAD # VR4G	Inspection type	Buoy #	Surface FAD type	FAD tail structure Entanglement (Ent) Risk Type	No. sharks seen	Sharks entangled	Depth inspected (m)
10/07/15 FAD #1 200096	Scuba	M4i 85769	Plastic rectangular raft, uncovered	Net sausage to 18 m, small mesh net hanging below, out of sight <Lower Ent Risk type>	4 silky	0	20m + 15 m visual
10/9/15 FAD #2 200092	Scuba	M4i 85767	Bamboo raft, tight mesh covered	Net sausage to 18 m, spread apart with bamboo , large mesh below this point , visible to 40 m but may have extended below. <Highest Ent Risk type>	4 silky, 1 hammer head	0	20m + 20 visual
10/11/15 NO VR4G	Snorkel	M3i 163977	NO FAD	Only sounder buoy In Sargassum field <NO FAD attached>	NA	NA	NA
10/11/15 FAD #3 200094	Scuba	M3i 168578	Bamboo raft, old	Single rope to 18 m, small mesh panel held apart by bamboo struts at least 50 m. <Lower Ent Risk type>	3 silky	0	20 m + 20m visual
10/14/15 NO VR4G	Scuba	M4i 83143	Bamboo raft, old	No appendage <non-entangling>	None	0	No appendage
10/15/15 FAD #4 200095	Scuba	DSL-70746	Plastic bottles in small mesh	Small mesh panel to 20 m. Rope with salt sacks descending much deeper. <Lower Ent Risk type>	3 silky	0	20m + 15m visual
10/18/15 FAD #3 200094	Scuba	M3i 168578	Bamboo raft, old	Single rope to 18 m, small mesh panel held apart by bamboo struts at least 50 m. Netting was cut free at 20 m on 10/12/15 <Lower Ent Risk type>	2 silky	0	20m + 15m visual
10/19/15 FAD #2 200092	Scuba	M4i 85767	Bamboo raft, old	Net sausage to 18 m, spread apart with bamboo, large mesh below this point, visible to 40 m but may have extended below. (Highest Ent Risk type)	6 silky	0	20m +20 visual
10/20/15 FAD #1 200096	Scuba	M4i 85769	Plastic rectangular raft, uncovered	Net sausage to 18 m, small mesh net hanging below, out of sight <Lower Risk Ent type>	7 silky	0	20m + 10m visual

Conclusions	This activity was conducted successfully. No sharks or turtles were found to be entangled in any of the FAD's components.

Derived publications:

Itano et al. (2016b)

14. 2016 AO Cruise on the F/V MAR DE SERGIO

Objectives:

(1) **Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics:** Attaching echo-sounder buoys from four different brands to the FADs to compare signals.

(2) **Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics:** Use of three scientific acoustic echo-sounders with frequencies of 38, 120 and 200 kHz and an EK80 wideband echo-sounder onboard a work boat, followed by intensive spill sampling to compare acoustic data and species composition

(3) **Behavior of tunas and other fishes within purse-seine nets**: Study of fish behavior inside the net

(4) **Releasing sharks from the net:** Fish and release sharks from inside the net

Scientists:

Igor Sancristobal (Chief Scientist, AZTI), Udane Martinez (AZTI) and Jeff Muir (University of Hawaii) were onboard.

Vessel:

Opportunistic cruise on the MAR DE SERGIO (Spain), an 83m tuna purse seiner built in Spain in 1984 with 2,767 GT and approximately 1,300 tons of tuna carrying capacity.

Time and Area:

The cruise took place in the Eastern Atlantic Ocean, starting in Abidjan (Côte d'Ivoire) on March 14th and ending in Dakar (Senegal) on April 11th. A total of 33 fishing sets were made (Figure 14.1).

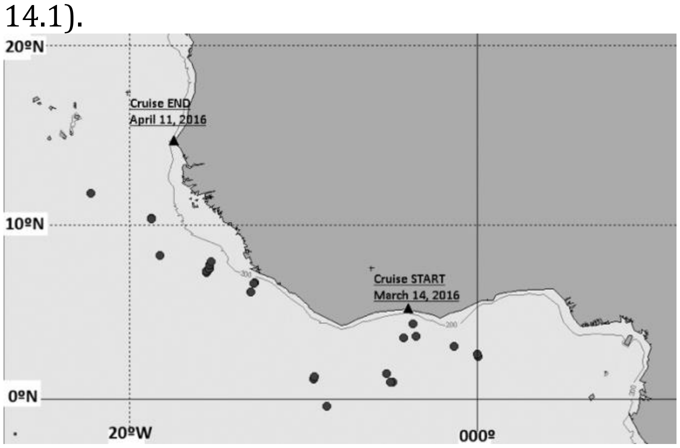
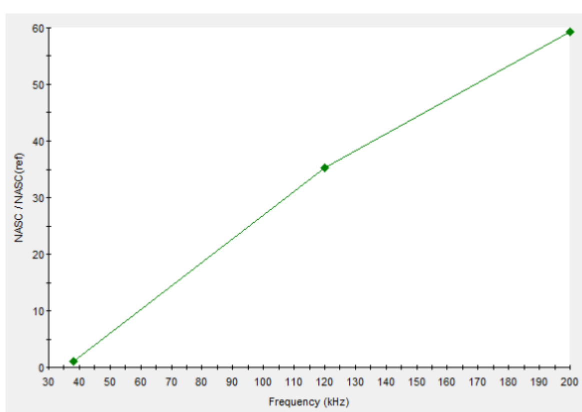


Figure 14.1. Map of cruise starting and ending ports (black triangles) and set locations (dots) aboard the F/V MAR DE SERGIO.

Progress made for each Objective

(1) Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics*: Attaching echo-sounder buoys from four different brands to the FADs to compare signals*	
Methods	The objective was to attach one buoy per type (M3i, M4i, Thalos MB and Zunibal) to the FAD which was already equipped with a Satlink buoy belonging to the vessel. This was to be done upon arrival, the evening before the set. This way, the buoys' echo-sounders would record data throughout the night until the set was made in the morning. The readings from the different buoys would then be compared against each other and to the actual catch in each set.
Results	Due to the fishing strategy during the trip, this activity was only carried out once. The four echo-sounder buoy brands were attached to a FAD but, afterwards, instead of setting on it, the vessel had to move towards the port.
Conclusions	The objective could not be achieved.
(2) Improving pre-set estimation of species, sizes, and quantities of tunas associated with FADs using acoustics: *Use of two scientific acoustic echo-sounders with frequencies of 38, 120 and 200 kHz onboard a work boat,*	

followed by intensive spill sampling to compare acoustic data and species composition	
Methods	A narrowband scientific acoustic echo-sounder Simrad EK60 of frequencies 38, 120 and 200 kHz was installed on board a work boat. In addition, a Simrad EK80 wideband system with a split-beam transceiver with operating software for the frequency band from 85 kHz to 170 kHz was also installed on board the work-boat. Both acoustic systems were calibrated. In each of the sets where the acoustic equipment was used, the work-boat was attached to the FAD starting about 10 minutes before the set and remained attached between 30-45min during the purse seiner's set. During the first 20-25 minutes, the work boat would drift together with the FAD. Then, it moved slowly to keep the FAD separated from both the net boundaries and the purse seiner. The transducers were focused vertically downwards, to acoustically sample the fish aggregation down to 200 m below the surface. In each set, around 20 to 30 minutes of acoustic data were recorded, with approximately 50% of the pings successfully detecting the tuna aggregation. Spill sampling of the catch was done each time acoustic EK60 data was recorded in order to help acoustic analysis to convert acoustic backscatter into skipjack, bigeye and yellowfin proportion at each set. In the case of FAD sets, approximately 1 ton of fish was measured in each of these sets using a plastic bin of dimensions 100cm x 70cm x 100cm (approximately 0.7 ton capacity). In general, samples were taken from the first or second brail and the last brail for sets less than 10-15 tons, for which normally there would be a maximum of 4 brails. For sets over 15t one additional mid-way sample would be taken as soon as first bin's sampling was completed. Scientists identified species and measured each fish in the sample to the nearest centimeter on flat measuring boards. The weights of sampled individuals were estimated using length-weight relationships available for each species (Cayré & Laloë 1986). These proportions by weight were then extrapolated to the total tonnage of each set.
Results	Due to a malfunction, no valid data was recorded for the wideband EK80 system. However, the EK60 system was used successfully in 15 of the 33 sets. From the 15 sets with acoustic data, two had over 80% of non-swim bladder tunas (Skipjack and *Auxis* Sp.), thus served to increase the database for the target strength (TS) and frequency response analysis of this species (TS and frequency response data were first obtained in the ALBATUN TRES cruise; this cruise served the purpose of augmenting that dataset). Unfortunately no valid acoustic data was recorded for sets that provided more than 80 % of YFT or BET. Preliminary analysis confirms the patterns of different frequency response for Skipjack tuna found in the 2014 Western Pacific Ocean ISSF survey data on-board the ALBATUN TRES. The non-swim bladder tuna (i.e., SKJ) was more reflective on the high frequency echograms (120 and 200 kHz, Figure 14.2), whereas the SB tuna (Bigeye and Yellowfin) were more intense on the low frequency echograms.  **Figure 14.2.** Preliminary frequency response for skipjack tuna (non-swim bladder fish) in the Atlantic Ocean

	Spill sampling of the catch was conducted 22 out of 33 sets. Each time acoustic EK60 data was recorded, spill sampling helped to adjust the species composition derived from the signals recorded by the echo-sounders. Additionally, spill sampling was also carried out in some free school sets in order to improve the catch composition calculated through the electronic monitoring system that the vessel had installed onboard. Ongoing analyses comprise the following activities: - Obtaining Target Strength (TS)-length relationships for the mono-specific (or almost so) tuna sets during this cruise. - Obtaining frequency response for the three main tuna species (SKJ, BET, YFT). - Adjusting a frequency response mask to discriminate between species; and validate the mask. One set had 80% of blue runner in number and another set had 56% blue runner. In both cases, echo sounder buoys estimated biomasses over 40t of tunas but the subsequent sets yielded 10t of tunas. Underwater visual observations confirmed that blue runners seemed to extend their habitat deeper than first 10-20 m layer, where some buoy manufacturers have established a threshold to classify the acoustic backscatter of fish as tunas versus non-tuna species. Blue runners' habitat extension, together with their relatively large swim bladder, could be one of the causes of incorrect tuna biomass estimations done by commercial echo-sounder buoys sometimes. Non-tuna species such as blue runners can be quite abundant in some sets. This should be taken into consideration in future acoustic discrimination studies.
Conclusions	The objective was successfully achieved for SKJ and BET; insufficient data were collected for yellowfin. These data will be combined with data collected in other ISSF research cruises to discriminate these species using acoustic echo-sounders operating at different frequencies. The acoustic selectivity analyses will need to continue, with emphasis on yellowfin.
***(3) Behavior of tunas and other fishes within purse-seine nets**: Study of fish behavior inside the net*	
Methods	Underwater visual surveys were to be conducted by snorkeling when feasible, considering sea conditions and other workload, with a focus on shark behavior. One of the main ideas was to see if a channel was formed in the net and if sharks congregated next to this bend, in order to see if an escape panel for sharks would work.
Results	Net hauling by the skipper of the MAR DE SERGIO was very consistent and the shape of the net was similar during every set. A bend between half and quarter net in a "shark fin" type shape was observed on almost all sets. Note that this shape differs from the "bend" observed in the WCPO aboard the CAPE FINISTERRE in 2012 and 2013 and quite similar to the shape on the net in ALBATUN TRES. This may be due to the skipper of the MAR DE SERGIO uses the skiff to pull the purse seine vessel in circles while hauling (facilitating faster hauling and consistent, safe net shape while hauling). Visual surveys were conducted 15 times (7 FAD sets and 8 Free School sets). There was a relatively low number of sharks present in the net in each set (range: 0 to 6 sharks per set). There was no consistent behavior or location of the sharks at any stage during the survey (which occurred between 1/2 net and the sack). Sharks were often seen swimming the perimeter of the net, both with and against the current, and in and outside the net, but not remaining in any location long enough for the use of a release panel as previously observed.
Conclusions	Due to the shape of the net during hauling, the use of an escape panel for sharks did not appear to be practical. The behavior of the sharks within the net suggested there is no specific point to install an escape panel.
***(4) Releasing sharks from the net:** Fish and release sharks from inside the net*	
Methods	Several skippers as well as the ISSF Bycatch Mitigation Steering Committee suggested the use of baited hooks to catch and release sharks after they are encircled by the purse seine net as a simple option to mitigate shark bycatch. To test the efficacy of the method, survival of the animals once fished and released out of the net was necessary. This was accomplished with the use of

survival and mini PAT (SPAT and miniPAT) electronic tags manufactured by Wildlife Computers.

Handlines and chunk fish bait (skipjack, yellowfin, bigeye, bullet tuna, rainbow runner and jacks) in the purse seine net were used during the early stages of net rolling. Handlines consisted of 10m of synthetic tuna cord, which was used as a mainline for a leader and hook. Various leader materials were used, including monofilament (1.6-2.2mm), Sevenstrand coated wire (1.2mm) and stainless steel cable (49 strand 1.6mm). Various circle and J-hook types (no. 26 BKN light and heavy wire, 28 BKN heavy wire, 12/0 VMC, 10/0 VMC) were also trialed during the experiment.

Fishing commenced shortly after rings up for each set during the experiment. A speed-boat containing all fishing equipment, tagging equipment, 2 scientists, and 1 volunteer fisherman was used to accomplish this.

Figure 14.3. Handline fishing for sharks within the purse-seine net, to be tagged and released.

Implantation of SPAT and miniPAT tags followed protocols used in previous ISSF experiments in the IO (Poisson et al. 2014) and the WCPO (Hutchinson et al. 2015), with the main difference in this experiment being that sharks were not supplied with a source of salt water to irrigate gills during tag implantation. The reason for this was to closely duplicate "real" fishing conditions, where fishermen would simply catch the shark, negotiate it over the corks, unhook or cut the line, and release the shark as quickly as possible. Upon release, the animal's condition was scored on a 0-4 scale, with 0 being dead, and 4 being excellent condition.

Results

Monofilament line was ruled out quickly, due to its susceptibility to being bitten through by sharks. Sevenstrand coated wire and stainless cable both worked well as leader material, with no distinguishable difference in fishing success when used solely and side by side. A notable difference, though, is the coated wire was easier and safer to work with, as it did not kink and bend and expose bare wire ends after use, which could pose a potential hazard to fishermen's hands when handling used leader portions.

It was found that heavier, larger hooks were preferable because they held up to larger animals both target and non-target (a 160cm YFT straightened a 26 BKN with virtually no effort), resulting in less fishing time lost re-tying and re-rigging handlines. This experiment, though, featured the availability of animals often less than 5m from the boat, feeding actively. This allowed scientists (and a volunteer fisherman from the vessel) to "sight fish", the practice of being able to see when an animal takes your bait, and then setting the hook before it swallows, making the use of "J" style hooks possible. It is preferable to use J hooks in some situations because they often hook animals more readily than circle hooks, and they are also easier to unhook in order to release an animal.

A total of 72 sharks where encircled in the 33 sets of the cruise. The shark catch and release activity was tried in 7 of these sets. A total of 11 silky sharks were fished and released out of the purse seine net among the 53 sharks caught on those 7 sets (i.e., 21%). All animals for this experiment were released in either good (3) or excellent (4) condition. According to the tagging

	data, 100% of the sharks survived past 21 days post-release, indicating that the animals suffered no insurmountable amount of stress or injury as a result of being fished and hooked, removed from the water, tagged, and released over the corks.
Conclusions	The objective was achieved successfully. Fishing sharks from the net was found to be a relatively simple and low-risk (to the catch and PS vessel's net) way of removing sharks from the net once they are encircled. Further testing and refinement of this method will continue on future ISSF research cruises.

Derived publications:

Boyra et al. (2018)

Sancristobal et al. (2016)

15. 2016 EPO Cruise on the F/V LJUBICA

Objective:

Releasing by-catch species from the net: To conduct back-down maneuvers on FADs

Scientists:

Kurt Schaefer (Chief Scientist), and Daniel Fuller of IATTC.

Vessel:

Opportunistic cruise on the LJUBICA (Panama), an 89.3m tuna purse seiner built in Spain in 2014 with 2,000 m^3 well volume and approximately 1,500 tons of tuna carrying capacity.

Time and Area:

The cruise took place in the Eastern Pacific, starting in Panama on April 2 and ending in Manta (Ecuador) on May 10th. A total of 9 back-down trials on FADs were made (Figure 15.1).

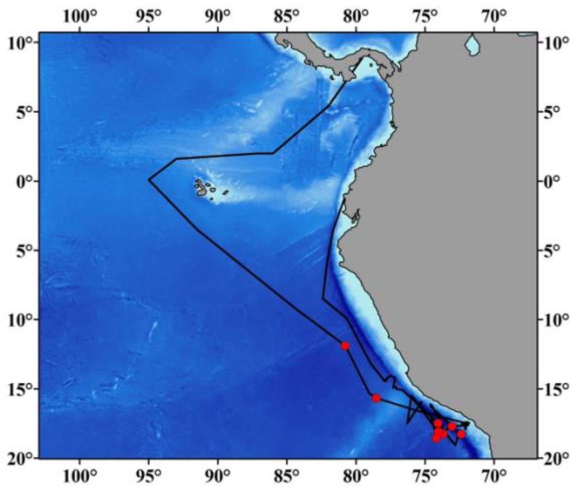
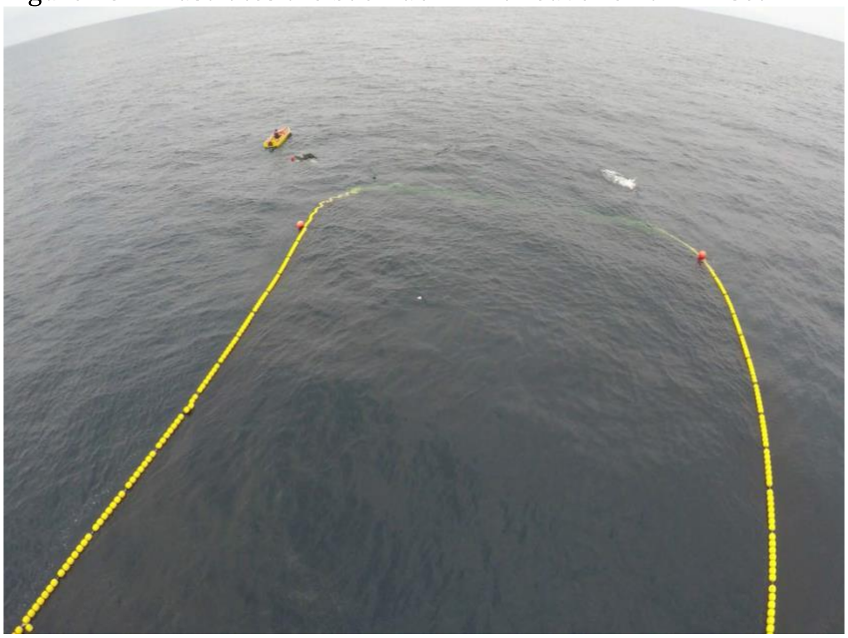


Figure 15.1. Cruise track and locations where 9 back-down trials were conducted (red dots) aboard the F/V LJUBICA during 2 April to 10 May, 2016 in the south-eastern Pacific Ocean.

Progress made for each Objective

(1) Releasing by-catch species from the net: *Conducting back-down maneuvers on FADs*	
Methods	The objective was to conduct back-down maneuvers with a tuna purse seine vessel, with a small mesh dolphin safety panel installed in the net, following sets on tuna aggregations associated with FADs, to evaluate whether it is a feasible method for the live release of non-tuna species, with an emphasis on shark bycatch mitigation efforts. The protocol followed was basically to apply the back-down maneuver used in the EPO on tuna-dolphin aggregations when setting on FADs. Scientists carry out visual inspections during the set to quantify the amount of sharks and other bycatch. After the rings are aboard a GoPro camera in a troll-pro housing will be suspended at 1m tethered to the FAD, and a second GoPro camera will be affixed to the opposite side. In an attempt to attract and retain non-tuna species more closely, a chum bucket containing chunks of fresh tuna will be tethered to the FAD, and chunks of also tossed loosely from another bucket aboard the work boat just before the back down maneuver commences. A mako magnet will also be hung from the speedboat just before the back-down procedure begins to attempt to attract sharks to within close proximity of the FAD. Utilizing an inflatable raft tied to the cork-line on one edge of the back-down channel apex, a scientist aboard with a pole-mounted GoPro camera would record the FAD and any fauna which exit over the submerged cork-line during the back-down maneuver.

	The species and quantities of all tunas and non-tunas which are brailed aboard the vessel following sets in which the back-down maneuver trials are conducted will be estimated by the observer aboard.
Results	Figure 15.2 illustrates the back-down maneuver on a FAD set.  **Figure 15.2**. The back-down channel is fully formed and the cork line is submerged. The speedboat and FAD can be seen outside the net while the back-down continues. During the cruise, there were 9 back down trials conducted following sets on tuna aggregations associated with FADs (Table 15.1), which proved to be of low risk for the tunas to escape. Also, there were no problems with small tunas becoming entangled in the net during those trials. The back down procedure, coupled with divers in the channel apex, proved to be ineffective for the release of dorado and wahoo, although neither of those species appear to be a conservation concern in the EPO. The fishing strategy during the trip was such that the vessel fished most of the time on free-swimming schools off Peru, far south from the equatorial zone where silky sharks would be more abundant. Thus, in order to evaluate whether the back down procedure is an effective method for the live release of silky sharks in the EPO following sets on FADs will require further trials undertaken in equatorial waters where silky sharks are commonly present, albeit in low numbers. **Table 15.1.** Preliminary results from back down trials conducted during 9 FAD sets aboard F/V LJUBICA in the south-eastern Pacific Ocean.

			Estimated Catch						Cork-line Submersion			
Trial	Date & Time	Position	SKJ (t)	YFT (t)	SKH	DOL	WAH	YTC	Duration (min)	Max (m)	Chum	Escaped
1	12-April 14:43	12°36 S 80°46 W	0	30	0	40	80	0	3.3	2.3	N	~50 Dorado ~30 Pilot fish
2	13-April 16:06	15°40 S 78°31 W	0	30	0	20	111	0	2.0	4.1	N	1 Pilot fish
3	19-April 13:27	17°42 S 73°02 W	25	0	0	324	7	0	4.2	2.5	N	0
4	23-April 05:45	18°15 S 73°40 W	155	15	SPZ SPK	254	0	6	2.1	10.8	N	~1-2t SKJ ~6 YTC
5	24-April 08:15	18°08 S 73°54 W	22	3	0	53	1	2	2.4	4.5	N	0
6	24-April 10:35	18°07 S 74°02 W	7	0	BSH	25	4	0	2.6	5.4	N	0
7	29-April 05:43	18°33 S 74°10 W	0	0	0	200	0	15	2.8	2.4	Y	0
8 (Floating Kelp)	30-April 13:02	18°10 S 72°22 W	2	2	0	62	0	73	3.0	3.0	Y	~5 YTC
9	02-May 15:29	17°29 S 74°02 W	2	2	0	11	90	0	2.8	5.3	Y	0

*SKJ = Skipjack tuna (*Katsuwonus pelamis*)
*YFT = Yellowfin Tuna (*Thunnus albacares*)
*SKH = Sharks
*DOL = Dorado (*Coryphaena hippurus*)
*WAH = Wahoo (*Acanthocybium solandri*)
*YTC = Yellowtail (*Seriola lalandi*)
*SPZ = Smooth Hammerhead shark (*Sphyrna zygaena*)
*SPK = Great Hammerhead shark (*Sphyrna mokarran*)
*BSH = Blue shark (*Prionace glauca*)

Conclusions	The objective was partially achieved. The back-down maneuver on FADs showed little risk of tuna escapement and mixed results in terms of release of bycatch species. Further tests for silky sharks will be required in the equatorial zone.

16. 2016 Acoustic research in Achotines, Panama (with IATTC)

Objectives:

(1) **Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics:** *ex-situ* target strength (TS) and frequency response measurements of isolated yellowfin tuna in an offshore cage in Achotines laboratory, Panama.
(2) **Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics:** to gather data using different brands of echo-sounder buoys (used by fishers to track FADs) to improve the remote estimates of abundance and size composition of the aggregation around FADs.

Scientists:

Gala Moreno (ISSF), Guillermo Boyra (AZTI)

Vessel:

None. This research was done in collaboration with IATTC in an offshore cage of 25 m of diameter and about 20 m depth deployed about 1 km offshore from Achotines Bay (Figure 16.1).

Time and Area:

The research took place in the IATTC Achotines Laboratory from 20th to 30th July 2016, located on the Pacific side of the Republic of Panama. The laboratory has ready access to a provision of yellowfin tuna along the year.

Figure 16.1. Location of the measurements outside the Achotines Bay.

Progress made for each Objective

(1) **Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics**	
Methods	A narrowband scientific acoustic echo-sounder Simrad EK60 of frequencies 38, 120 and 200 kHz was installed and routinely used on-board the Kihada Maru. The transducers were installed in a metallic plate deployed at around 0.25 m depth, attached to an arrangement of small buoys to achieve floatability (Figure 16.2). In addition, a Simrad EK80 wideband system with a 120 kHz frequency transducer was installed. Both acoustic systems were calibrated before and after the

measurements with the sphere method (Foote et al., 1987) using a tungsten carbide ball of 38.1 mm for the EK60 and a 38.1 plus a 12.1 mm sphere for different portions of the band of the EK80. Both acoustic systems were setup to work simultaneously, pinging alternately through the same 120 kHz transducer with the aid of a multiplexor.

Figure 16.2. The offshore cage that contained the tuna. Attached to the cage, the fishing boat "Kihada Maru", where the acoustic equipment was installed.

After the acoustic measurements, the surviving tunas were fished, and then sized and weighted.

The captured tunas were transported, conserved in ice, to a veterinary hospital to perform dorsal and ventral X-rays. The X-rays are expected to provide information about the internal anatomy of tunas, especially the size of the swimbladder, helping to interpret the results.

Results

Preliminary results are that the tunas were swimming in the cage at different places and depths (Figure 16.3). Given the low abundance of tuna in the cage, they showed clear single target detections, so that a priori we do not expect multiple echoes in the single target detection algorithm when determining TS-length relationship for yellowfin tunas.

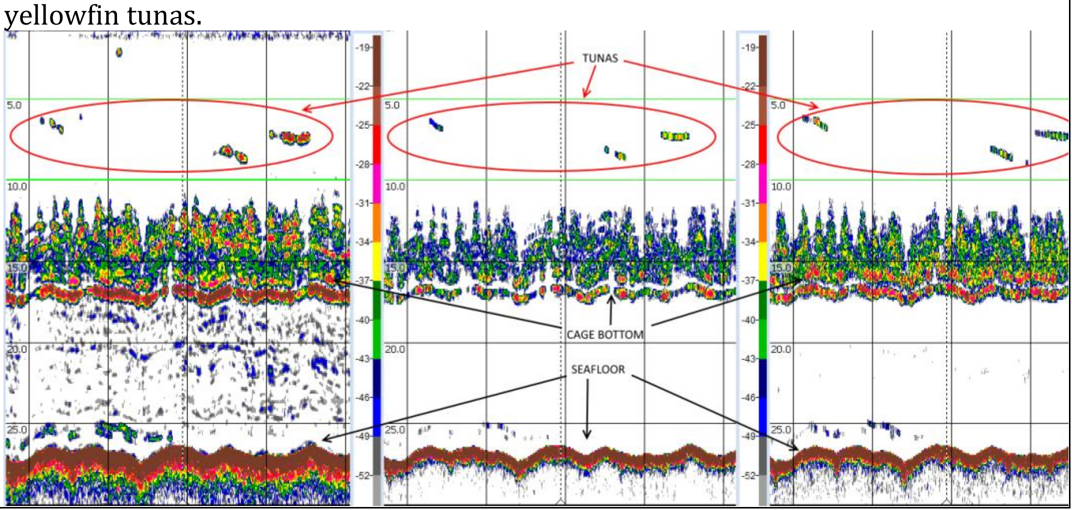


	Figure 16.3. Example of TS echogram showing tunas at the three frequencies 38 (left), 120 (middle) and 200 (right) kHz. The minimum threshold is set at -55 dB. The x-rays showed that tunas presented swimbladder length of about 11 cm, that is around 20 % of the tuna body length at dorsal view (Figure 16.4).  **Figure 16.4.** Dorsal and lateral x-rays of one of the studied tunas.
Conclusions	This research activity was successfully conducted. Yellowfin tuna *ex-situ* TS measurements were gathered together with X-ray images for the same individuals. Currently analyses are being conducted to: • Determine yellowfin tuna TS-length relationship. • Determine yellowfin tuna frequency response.
***(2)* Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics**	
Methods	Acoustic data was also recorded with echosounder buoys of four different brands: Marine Instruments, Satlink, Zunibal and Thalos. Raw acoustic data collected with the different buoys will be compared to the species composition and biomass obtained from spill sampling of the catch, to help understanding differences between different buoys' selectivity of by-catch and tuna. The results from these analyses will be presented at a later date.
Results	Not available yet, analyses are ongoing.
Conclusions	Data from the four different echo-sounder buoys was successfully collected in the cage with yellowfin tunas. Analyses will be conducted to understand different measurements of each echo-sounder buoy related to tuna and by-catch species.

17. 2016 CP-12 cruise (with SPC)

The CP-12 cruise was the third collaboration with SPC and Trimarine in tagging in the Central Pacific. As in CP-10 and CP-11, Trimarine provided positions of FADs near the chartered vessel so as to increase fishing opportunities, and also provided a scientist to go onboard. South Pacific Tuna Corporation also provided access to a number of their FADs, however due to logistical constraints none were visited. After three successful CP cruises where drifting FADs have proven to be vital for tagging success, it is quite apparent that future tagging cruises must have a diverse array of anchored and drifting FADs to ensure locating suitable aggregations of fish for tagging.

Objective:

Behavior of tunas and other fishes around FADs: To study the behavior of tuna and non-tuna species at FADs, including residency, vertical behavior, and daily presence/absence patterns. These objectives help (i) discrimination of tuna species using acoustics, using as input fish vertical behavior (ii) assess the effects of FADs on associated species.

Scientists:

Bruno Leroy (Cruise Leader, SPC), Jeff Muir (U. of Hawaii), Fabien Forget (IRD) and Beth Vanden Heuvel (Trimarine)

Vessel:

SPC chartered the F/V GUTSY LADY 4 (USA flag), a 30m steel longline commercial fishing vessel. This vessel is normally equipped with longline gear used for fishing pelagic fishes, however for this cruise and CP-11, it was retrofitted with dangler gear, a commercial handline style of fishing for tuna on the surface (mainly bigeye tuna).

Time and Area:

Leg 1 of the cruise took place in the Central Pacific Ocean, from 9th September to 13th October 2016 (Figure 17.1).

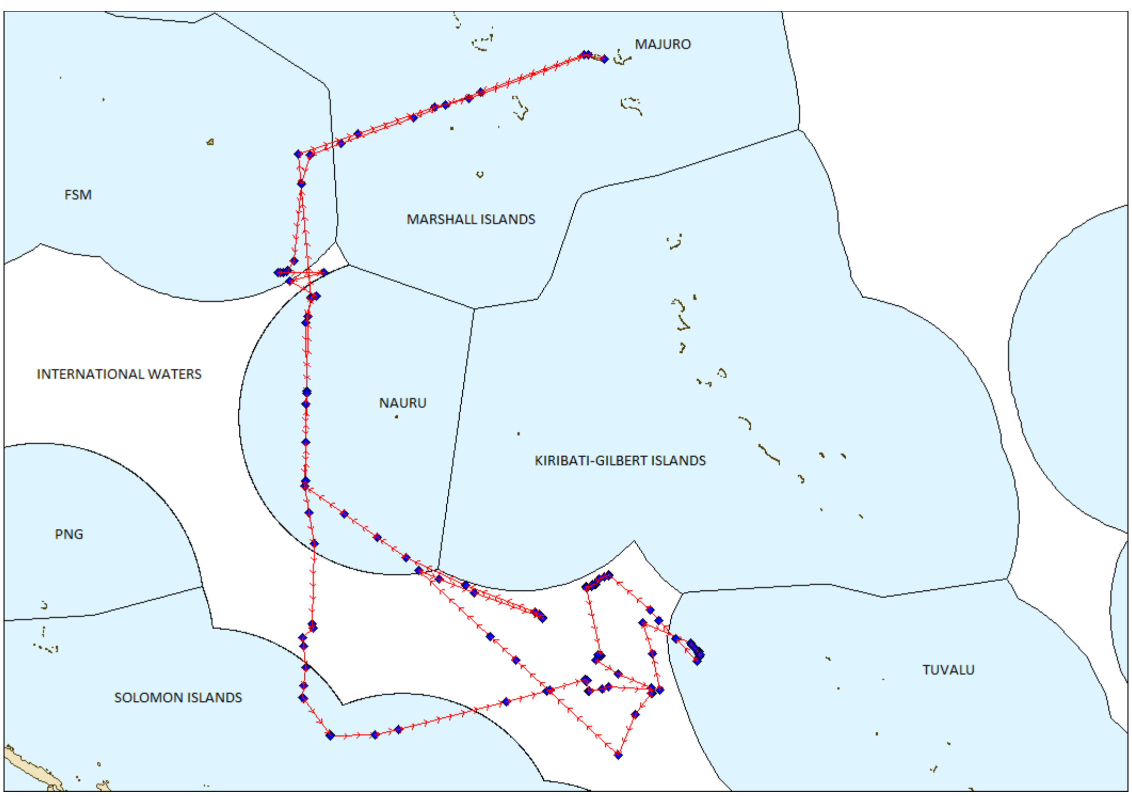


Figure 17.1. Cruise track during CP-12. Drifting FADs were fished inside the dashed blue line delimited area

Progress made for each objective

***(1) Behavior of tunas and other fishes around FADs**: Acoustic tagging*

Methods

ISSF's component of the cruise consisted of instrumenting 4 drifting fishing aggregating devices (FADs) with VR4 Global satellite communicating acoustic receivers manufactured by Vemco. Coded, pressure sensitive acoustic tags were implanted in tuna (SKJ, YFT, BET) and non-tuna species (silky shark: FAL, spotted oceanic trigger fish: CNT, and rainbow runner: RRU). The VR4 Global unit allows the user to remotely monitor tagged fish, and eliminates the need to retrieve the receiver after the study has finished. The unit utilizes Iridium satellite communication to relay detection logs, status updates, and error messages to the user.

TriMarine provided positions of FADs linked to satellite Satlink and IRIS buoys owned by them in the vicinity of the GUTSY LADY 4.

Results

A total of 15 different FADs were visited and fished; four of them were instrumented with VR4 acoustic receivers. A total of 128 fish were tagged (Table 17.1)

Table 17.1. Summary of animals implanted with acoustic tags. (#) indicate the animal was double tagged with an archival tag.

Species	Exp.1	Exp.2	Exp.3	Exp.4	Total
YFT	4	5 (3)	3(1)	3(1)	**15**
SKJ	7		6	16	**29**
BET	5(3)	10 (2)	7 (4)	7 (3)	**29**
FAL	3	6	10	7	**26**
RRU	3	8	2		**13**
CNT	3	5	5	3	**16**
Total	**25**	**34**	**33**	**36**	**128**

Analyses of the data collected are ongoing.

Conclusions

The release of tagged fish around drifting fads during this cruise was successful. Promising datasets are ready for analysis. The collaboration by Trimarine to provide FAD positions proved to be particularly crucial for the success of this CP12 cruise.

Derived publications:

Leroy et al. (2016)

18. 2016 Biodegradable twine tests in the Maldives

Objective:

(1) **Modifications in FAD designs to reduce impacts:** Due to the lack of data on the behavior of biodegradable materials while testing experimental FADs in real fishing conditions, this project aimed at evaluating the time evolution of three different biodegradable ropes, under controlled conditions. Specific objectives were (i) to select the most appropriate biodegradable materials and ropes among those with potential to be used at FADs and (ii) to test them in controlled conditions.

Scientists:

Gala Moreno (ISSF), Riyaz Jauhary (Marine Research Centre, Maldives) and Shiham M. Adam (Marine Research Centre, Maldives, and International Pole and Line Foundation, IPNLF).

Vessel:

None. This research was done in collaboration with International Pole and Line Foundation (IPNLF) and the Maldivian Marine Research Institute. Ropes where anchored in Maldivian waters.

Time and Area:

Samples were deployed in June 2016 in 2 different sites simultaneously (Figure 18.1), in offshore waters attached to a mooring rope, simulating a FAD in oceanic waters and in a shallow lagoon close to the reef in Maniyafushi island, simulating the arrival of a FAD to the coast. These 2 different environments allowed monitoring the behavior of the ropes simulating a FAD while in oceanic waters as well as when a beaching event occurs, monitoring the time needed for a FAD to degrade in a reef.

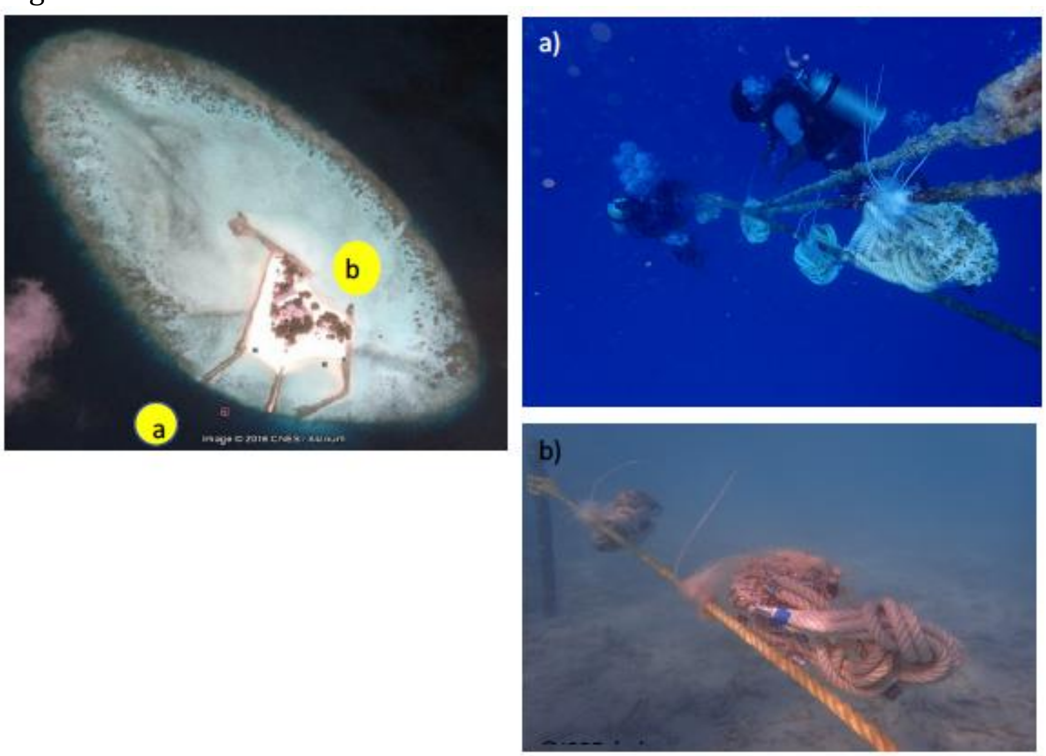


Figure 18.1. Study site, Maniyafushi island. Biodegradable ropes deployed a) anchored in offshore waters and b) within the lagoon.

Progress made

(1) **Modifications in FAD designs to reduce impacts:** *Test of biodegradable twines*	
Methods	Three types of ropes were selected from the diverse possibilities to be tested at sea, taking into account cost, availability, rope diameter easy to handle onboard, being from natural origin

(Figure 18):

1.Twisted 100 % cotton rope: 20 mm diameter
2.Twisted 50% cotton and 50% sisal rope: 20 mm diameter
3.Cotton, Sisal and linen rope with loops 16 mm diameter core with loops

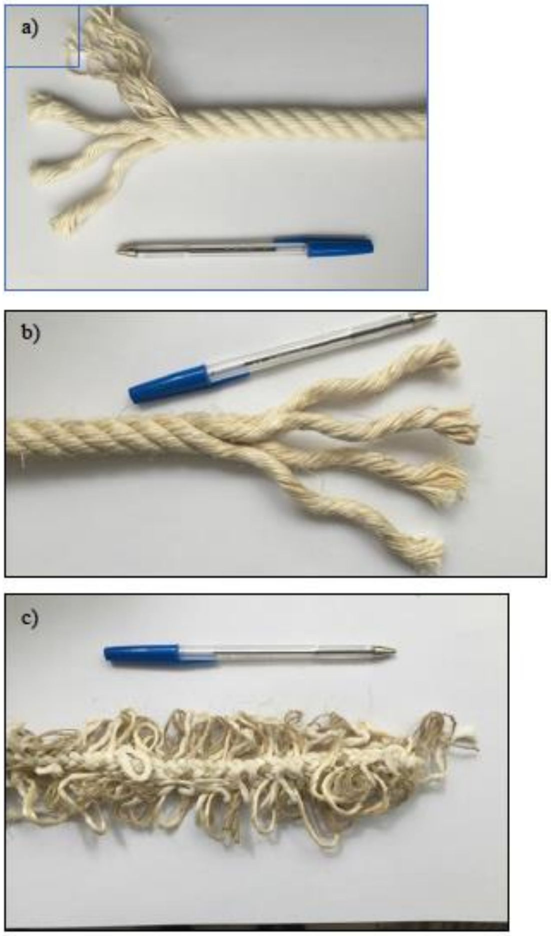


Figure 18.2. Selected ropes for the experiment: a) cotton rope; b) sisal and cotton rope; c) cotton, sisal and linen rope with loops.

Samples of the three twines were deployed at sea in two different sites simultaneously (Figure 18.1). Evolution of the samples was followed during one year to measure degradation with time. Once every 2 months, samples were retrieved from the 2 sites and the breaking strength of the yarns in kg (defined as the weight at which the strings break) for the 3 different ropes was measured using a dynamometer. Breaking strength (Kg) of the strands was measured from month 6 to month 12. The amount of biofouling adhered was also assessed and the weight of the ropes with time at sea measured.

Results

Results on the breaking strength of the strings clearly showed that the most resistant rope in terms of breaking strength was the cotton and sisal twisted rope, followed by the 100% cotton rope that had similar performance with time at sea (Figure 18.3). The weaker rope appeared to be the looped rope, as it suffered a step drop with time, presenting after 6 months at sea a poor performance.

Once the strings were too weak to test the breaking strength, measurements were conducted using strands (months 6 to 12, Figure 18.4). Measurements with the strands for cotton rope and mixed, cotton and sisal ropes, showed clearly the robustness of the sisal and cotton rope compared to the one made of 100% cotton. Type 3 rope was too weak after 6 moths to test its breaking strength.

The breaking strength measurements for both samples in the lagoon as well as for samples anchored offshore, showed similar results (Figure 18.3 and 18.4).

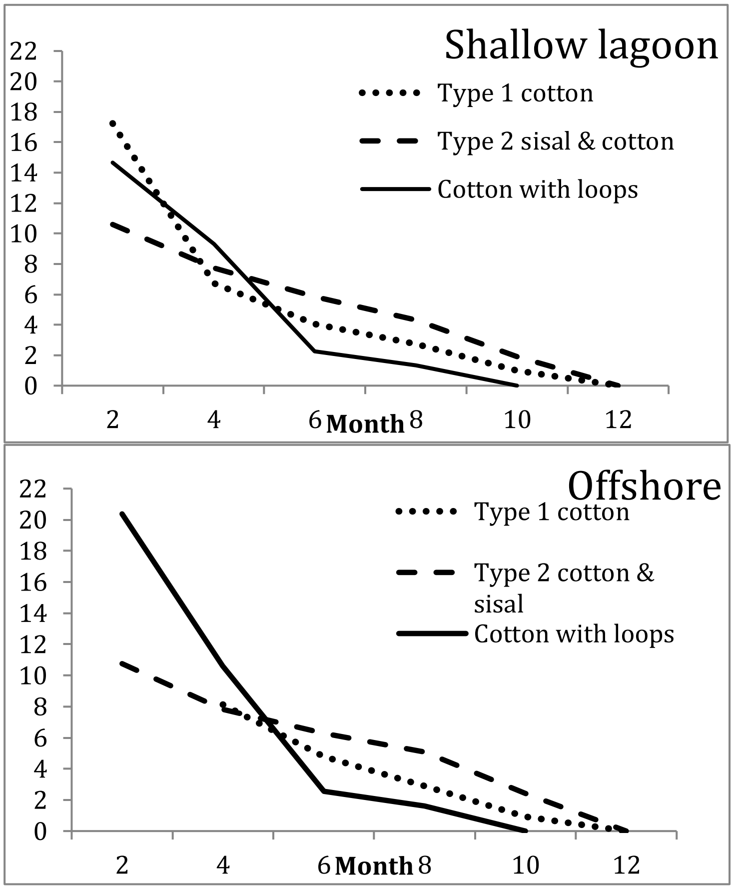
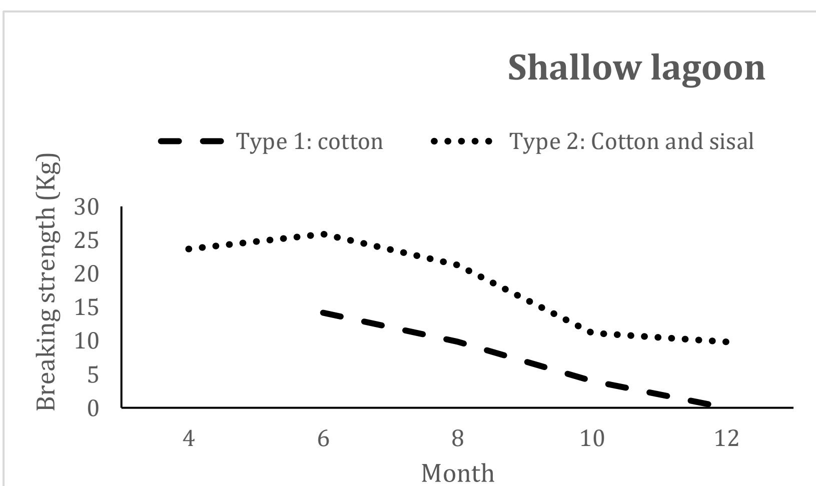
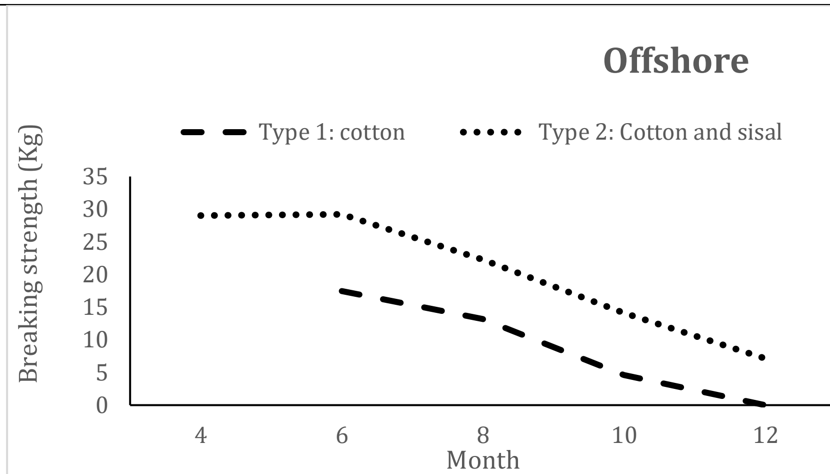


Figure 18.3. Biodegradable ropes' strings degradation with time. For those anchored in the lagoon (top) and anchored in offshore waters (bottom)



	 **Figure 18.4**. Biodegradable ropes' strands degradation with time. For those anchored in the lagoon (top) and anchored in offshore waters (bottom)
Conclusions	The objective was achieved. Taking into account the results of this project on breaking strength, the 100% cotton rope seems to better fulfil needed characteristics to be used at FADs. Its breaking strength is not as strong as the mixed sisal and cotton rope. However, it is ductile and its useful lifetime matches that suggested by fishers as necessary for FADs, *i.e.* around one year. While it appears from our results that the mixed, sisal and cotton rope would remain strong after 1 year. The rope with the loops would allow bio-fouling (as used in mussel farming); however, it seems that it will not be strong enough to last a year. A good compromise could be using the 100% cotton rope to support the main structure of the FAD, so that bio-fouling would not affect the weight and the FAD would last longer (as shown by the breaking strength results) and using the rope with the loops just to provide more volume to the FAD close to the surface.

Derived publications:

Moreno et al. 2017a

19. 2017 Test of biodegradable ropes in FADs in the western Indian Ocean

Objective:

(1) **Modifications in FAD designs to reduce impacts:** The main objective of the pilot was testing at sea a limited number of biodegradable FADs to identify the potential difficulties that could be found in an ulterior large-scale experiment to test biodegradable FADs. Other specific objectives were comparing biodegradable and non-biodegradable FADs on their ability to aggregate fish.

Scientists:

Gala Moreno (ISSF), Blanca Orue (AZTI), Victor Restrepo (ISSF)

Vessel:

Six large purse seiners from the INPESCA fleet, fishing in the western Indian Ocean.

Time and Area:

The study area was the western Indian Ocean (Figure 19.3). Biodegradable FAD deployment started in February 2017.

Progress made

(1) **Modifications in FAD designs to reduce impacts:** *Test of biodegradable FADs at sea*	
Methods	From the results on the test of biodegradable materials under controlled conditions (see Sections 10 and 18, above), two different biodegradable ropes were used to replace the submerged structure of experimental FADs: One cotton rope with loops (similar to the ropes used in mussel farming) and a cotton rope twisted without loops. These ropes were used in 2 different FAD designs working at different depths: The first working shallower at 10 m and 30 m depth (design type 1, Figure 19.1), and the other working deeper at depths of 30 m, 50 m and 70 m (design type 2, Figure 19.2). In order to compare the ability to aggregate tunas of biodegradable and non-biodegradable FADs, as well as their longevity, together with the biodegradable designs, identical designs but with traditional ropes or net tied in sausages were deployed (Table 19.1).  **Figure 19.1.** FAD design type 1: used at 10m and 30m depth

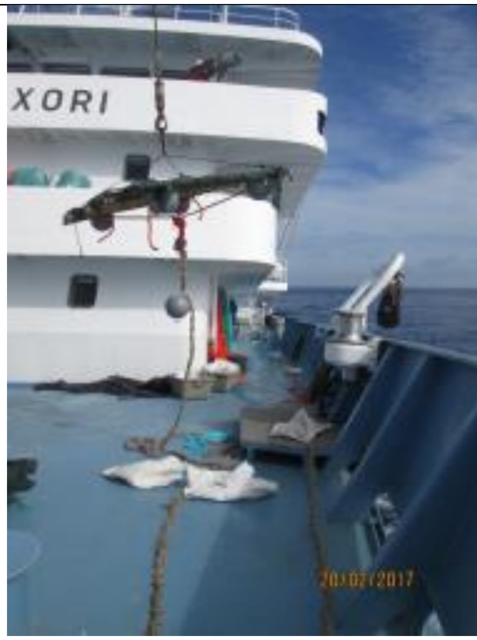


Figure 19.2. FAD design type 2: A single rope hanging from the center of the raft. This design was used at 30 m 50 m and 70m depth.

Table 19.1. Biodegradable FADs (BIO FADs) and Non-biodegradable FADs (Non-Bio FADs) deployments in 2017.

Deployments	BIO FADs	NON-BIO FADs	Total
February	13	6	19
March	22	22	44
April	32	22	54
May	18	39	57
Total	85	89	174

Fishers shared their echo-sounder buoy data, including biomass estimates, for the 174 FADs with 2 months delay. Analyses to study the aggregative pattern of fish for biodegradable and non-biodegradable FADs were conducted using Generalized Additive Mixed Models (GAMM) (Wood, 2006) with a Gaussian error distribution and identity link function. The mathematical notation for the fitted GAMM was:

Biomass ~ s (Day, k=4) + random= ~ (1 | ID_DFad)

Results

The 174 FADs deployed in this project covered the main fishing grounds in western Indian Ocean (Figure 19.3). The results presented here represent 3 months of FAD monitoring, from February to May 2017.

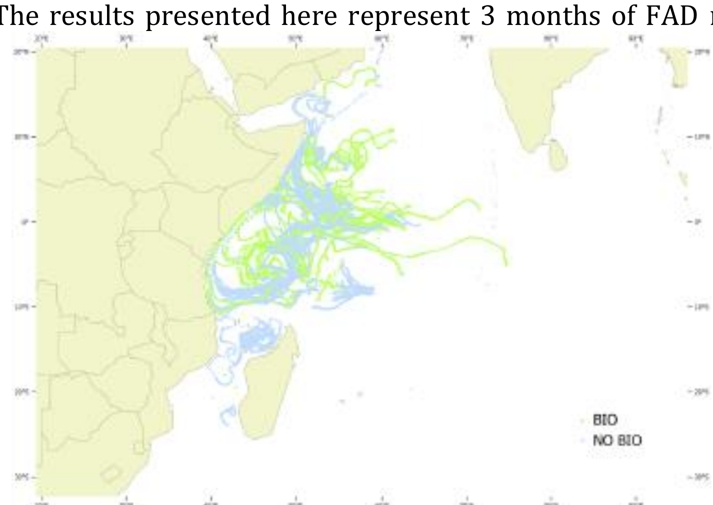


Figure 19.3. Spatial coverage of FADs deployed in the present project from February to May 2017, both biodegradable FADs (in green) and non-biodegradable FADs (in blue).

For the period of observation, there were 5 fishing activities on non-biodegradable FADs, the catches ranging from 5 to 80 tons. There were no fishing activities on non-biodegradable FADs deployed by this project. Maximum time at sea observed for a biodegradable FAD up to the end of August 2017 was 6 months. However, during our 3-month observation period, an average of 46,5 % of biodegradable FADs and 82% of non-biodegradable FADs became unavailable to the vessel that deployed them. These FAD loss events were mostly due to FADs being appropriated by other vessels, but also due to sinking and beaching.

Analyses conducted to compare aggregation patterns of tuna and non-tuna species related to days at sea showed no significant differences between the 2 types of FADs tested, biodegradable and non-biodegradable ones (Figure 19.4). For FADs studied in this experiment, the time at sea at which maximum biomasses are reached appears to be shorter for biodegradable FADs compared to non-biodegradable FADs.

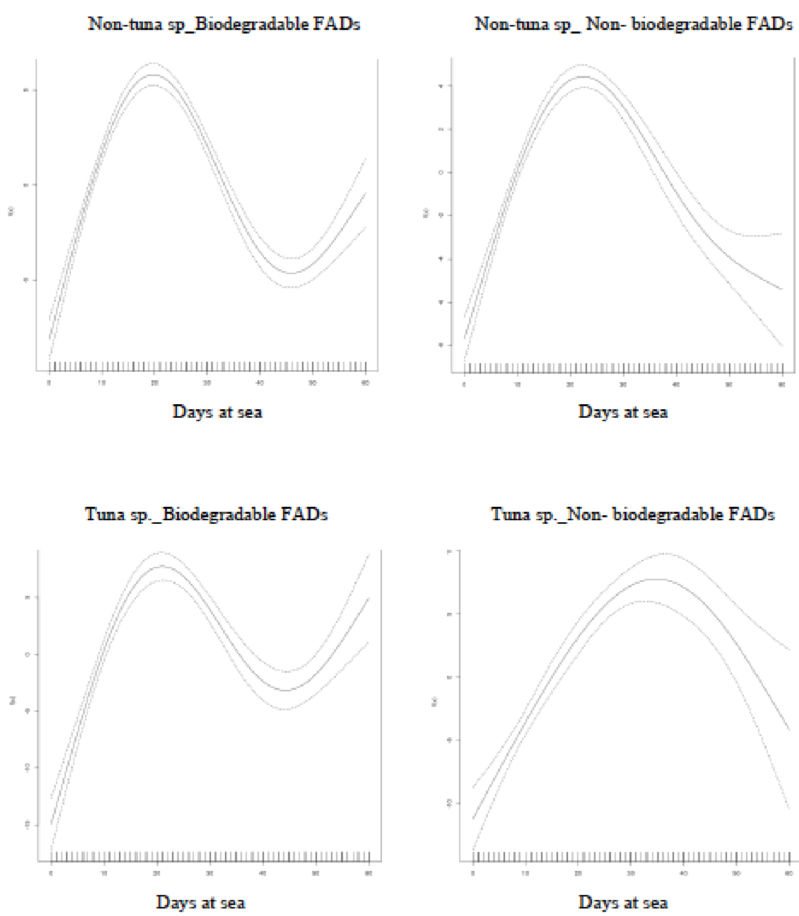


Figure 19.4. Results of GAMM analyses showing the non-parametric relationship between non-tuna species biomass (top) and tuna species biomass (bottom) and days spent at sea by the FAD. The dashed lines depict 95% confidence intervals.

Conclusions

The results were partially achieved.

From the analyses of biomass aggregation over time at sea, there is no doubt that FADs made with biodegradable components in the submerged structure are as effective as non-biodegradable FADs, for both tuna and non-tuna species. Similar aggregative patterns were

	observed for the non-biodegradable and biodegradable FADs; biodegradable FADs reachead maximum aggregated biomasses even earlier than non-biodegradable FADs. However, it was not possible to compare catches from sets made on both types of FADs. The western Indian Ocean is a small fishing ground where FADs change hands very often, as observed in this experiment. Most of the FADs were appropriated and probably re-utilized by other vessels but scientists did not have access to these data. Thus, in order to follow the performance of experimental bodegradable FADs in terms of actual fishing, it is very important to deploy a significant number of FADs at sea and that the different fleets operating in the area collaborate in the tests. By the end of August 2017, the maximum time for a biodegradable FAD at sea monitored by this project was 6 months. Taking into account the fact that FADs are appropriated and re-used, it could be expected that some biodegradable FADs remained at sea but were being monitored by other vessels that did not participate in this project. Thus, the study confirmed that designs chosen are adequate in terms of durability of a time scale desirable for fishers.

Derived publications:

Moreno et al. 2017b

20. 2018 AO Cruise on the F/V PACIFIC STAR

Objectives:

(1) **Estimate post-release survival of sharks (from the net)**: To estimate the survival rate of juvenile silky sharks caught inside the net (with handlines) then released outside the net using satellite tags.

(2) **Test the feasibility of crew members releasing sharks from the net:** To test the feasibility of the above method being utilized by the crew to remove sharks from the net.

(3) **Estimate post-release survival of whale sharks (from the net):** Assess survival of whale sharks released from the net.

(4) **Estimate post-release survival of rays (from deck):** Assess survival of mobulid rays released from the deck.

Scientists:

Melanie Hutchinson (Chief Scientist, JIMAR - University of Hawaii), Alfredo Borie (Federal University of Rondônia, Brazil) and Alexander Salgado (AZTI-Tecnalia, Spain. Note: Mr. Salgado also served as observer onboard).

Vessel:

Opportunistic cruise on the PACIFIC STAR (Curaçao flag), a 107m tuna purse seiner built in Spain in 1990 with 3,500m^3 of fish hold volume.

Time and Area:

The cruise took place in the Eastern Atlantic Ocean, departing from Abidjan, Cote d'Ivoire on 25 June 2018, and ending in July 21, 2018 in Sao Tome for a crew swap. A total of 40 sets were made in the EEZ of Gabon where the vessel was licensed to fish (Figure 20.1).

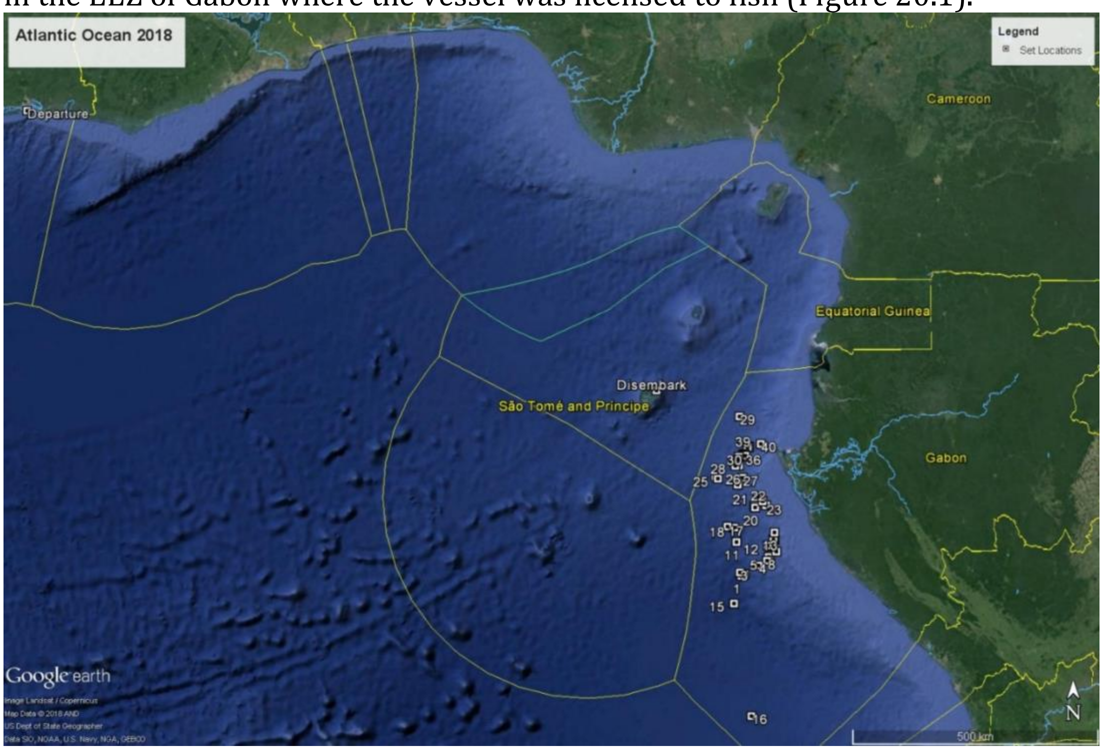


Figure 20.1. Cruise set locations.

Progress made for each Objective

(1) ***Estimate post-release survival of sharks (from the net)****: To estimate the survival rate of juvenile silky sharks caught inside the net (with handlines) then released outside the net using satellite tags.*	
Methods	Scientists and crew worked to build a stretcher that could be attached to the side of a small work boat, so that when a shark was captured it could be leadered into the stretcher, where the

animal could be safely restrained to facilitate tagging and release without having to bring the shark onboard a small boat. The stretcher (Figure 20.2) was made out of two PVC pipes forming a V, heavy metal chain to sink the opening and two layers of small mesh FAD netting. The apex of the V was attached to the rail of the small boat and the other two ends formed handles that could be opened to bring the animal in and closed to restrain the animal against the vessel. The stretcher was light and maneuverable, kept the animal in the water, thus facilitating safe handling on a small boat where maneuverability is limited while allowing the animal to ventilate.

Figure 20.2. Stretcher configuration prior to adding the netting (left) and use at sea (right).

During the cruise, the scientists had access to the vessel's 5m 'panguita' that was normally used to assess species composition and density under FADs. During FAD sets, the FAD was typically pulled out of the water as soon as the net had been pursed. The scientists were then able to board the panguita shortly thereafter to begin fishing for sharks. During free school sets, the scientists were able to board the vessel as soon as the net was closed and the jet boats had been recovered. This maximized the amount of time for fishing inside the net until it was too small to maneuver the panguita in it (35-50 minutes).

Sharks were captured using handlines composed of small 11/0 and 14/0 galvanized circle hooks with depressed barbs, 0.5 meters of braided wire leader to 20 m of nylon line. Hooks were baited with skipjack or small scombrids. Hooked animals were leadered into the stretcher and restrained in the water while they were measured and tagged. Captured sharks were tagged with satellite linked pop-off archival tags (miniPAT; Wildlife Computers Inc.) programmed for 180-day deployment periods. Sharks were released with the hook to simulate the condition of release by commercial fishers.

Results

This method was tested on nine occasions, during all FAD sets (n=3) and during six free-school sets. Sharks were only captured on FAD sets and it was only juvenile silky sharks (*Carcharhinus falciformis*) that bit the hooks (bait was taken by a hammerhead on one occasion, but it was not hooked).

The first FAD set was set number 11, where three sharks were removed from the net in 48 minutes of fishing (two entangled hammerheads and one juvenile silky shark -FAL-). The FAL was hooked, tagged and released outside the net in excellent condition (see Table 20.1 for tagging details). The next FAD was set number 15. During 35 minutes fishing, scientists captured two juvenile FAL, one was a neonate and had swallowed the hook so it was not tagged, but it was released outside the net in fair condition. The other FAL was tagged and released outside the net in excellent condition. Set number 16 was the third and final FAD set during this cruise. In 36 minutes fishing in the net, scientists captured four juvenile FAL. One was a neonate and too small for a PAT so it was tagged with an identification tag and released outside the net in excellent condition. The other three were all measured, tagged with PATs, leaders were cut at the hook eye and then released outside the net in excellent condition.

Table 20.1. Tag deployment data

Date	Set	Species	Sex	TL/DW	Released from	Release Condition	Fate
3-Jul-18	11	*Carcharhinus falciformis*	F	105 cm	Fished from net	Excellent	*in situ*
6-Jul-18	15	*Carcharhinus falciformis*	F	120 cm	Fished from net	Excellent	*in situ*
7-Jul-18	16	*Carcharhinus falciformis*	F	110 cm	Fished from net	Excellent	*in situ*
7-Jul-18	16	*Carcharhinus falciformis*	M	159 cm	Fished from net	Excellent	*in situ*
7-Jul-18	16	*Carcharhinus falciformis*	M	106 cm	Fished from net	Excellent	*in situ*
15-Jul-18	32	*Mobula tarapacana*	F	275 cm	Entangled	Fair	Too deep
15-Jul-18	32	*Mobula tarapacana*	F	299 cm	Brail	Good	Too deep
15-Jul-18	32	*Mobula tarapacana*	M	265 cm	Brail	Fair	Too deep
15-Jul-18	33	*Rhincodon typus*	U	> 10 m	Sack	Good	*in situ*
16-Jul-18	34	*Mobula tarapacana*	F	269 cm	Brail	Good	Too deep
16-Jul-18	34	*Mobula tarapacana*	M	290 cm	Brail	Good	Too deep
16-Jul-18	34	*Mobula tarapacana*	M	300 cm	Brail	Fair	*in situ*
17-Jul-18	38	*Rhincodon typus*	U	> 10 m	Sack	Good	*in situ*

Sets 2, 12, 18-21, and 27 were all free-school sets where scientists also fished for sharks. There were sharks encircled in all of these sets except 12 and 18. During each of these sets, scientists fished from the earliest possible opportunity to enter the net until it was closed. Fresh bait was used, alternating bait types and chumming the water heavily throughout the entire operation but never had a bite from any of the larger sharks. During several of these sets the larger sharks were landed with whole skipjack in their mouths. Many of the larger sharks expelled their gut contents on deck and they were full of small engraulid baitfish.

None of the five tags deployed on silky sharks in this study have reported as of early September, 2018. Most studies that have assessed post release fate of silky sharks captured in purse seine fisheries have shown that mortalities due to the fishing interaction will occur immediately or within a 10-day window of release (Poisson et al. 2014; Hutchinson et al. 2015; Eddy et al. 2016). Therefore, it is assumed that all of the animals captured with handlines, while the net was still open and the sharks were free swimming, tagged and then released outside the net, have survived.

Conclusions
The objective was achieved. The five sharks tagged in this study survived, adding to the evidence that sharks survive if they are removed from the net while it is still open enough for them to swim. The challenge of finding an effective means of removing them from the net remains. On the other hand, catching sharks in the net during free-school sets proved impossible during this cruise and a different solution may be necessary.

(2) Test the feasibility of crew members releasing sharks from the net: *To test the feasibility of the above method being utilized by the crew to remove sharks from the net.*

Methods
The scientific protocol for this test was to have only one scientist onboard the speedboat, with 2 crew members. The scientist would count the number of sharks caught and released outside the net, and document any difficulties encountered by crew during the operation, but also measure the time needed to catch and release a shark. Once a shark was caught, it would not be tagged.

Results
There was no opportunity to conduct this activity. There were several complicating factors. The primary issue was that the vessel set on FADs in only 3 of 40 sets. The 37 free-school sets almost always contained large adult sharks which were not biting as they were very successfully foraging within the tuna schools. Additionally, handling these sharks would have been very dangerous for crew members without considerable experience hooking and handling large, very active sharks.

Conclusions
The objective not achieved.

(3) Estimate post-release survival of whale sharks (from the net): *Assess survival of whale sharks released from the net.*

Methods
Survival PAT tags were to be used opportunistically if any whale sharks were encircled during a set, in order to estimate their survival after the release maneuver used by the vessel. The freeboard on this vessel was too high to tag anything from the deck of the purse seiner so tagging was done from the panguita. As soon as the whale sharks were observed, the panguita was deployed and tags were attached from the small boat with a tagging pole fabricated from a

	¾” diameter pipe found onboard the purse seiner.
Results	Three whale sharks were captured during two different sets (33 and 38), both of which were on free-swimming schools. On both sets the animals were not seen until the end of the net haul back when the crew was sacking up. The first whale shark, in 33, was over 10 m in total length, and its sex was not determined. It was tagged with a PAT and then immediately released from the sack by dropping the corks and rolling the net out from under the shark (see Table 20.1, above). Most of the target tuna catch was retained during this operation with minimal losses as the whale shark was being released. Brailing commenced after the shark was released. On set 38, two female whale sharks, both over 10 meters total length, were encircled. Only one of these sharks was tagged with a PAT. The second shark was not tagged because the anchor configuration of the two remaining tags (Domeier anchors) could not be adapted to fit onto the tagging pole at that moment. Both animals were released in good condition immediately after tagging, from the sack via the same method described above. This set was a null set but it is unclear if it was because the school was missed or if it was because the net had to be pulled all the way up and out from under the sharks, to roll them both out of the net. It was noted by the observer and the crew that on both sets where whale sharks were captured, conditions had been ideal for the safe release of all of these animals because they were all facing towards the bow. On occasions where the animal is facing the stern, it is much more difficult to get them out of the net because the stern portion of the sack cannot be dropped as easily. Neither of the tags that were deployed on whale sharks during this cruise have reported as of September 2018. The tags are not scheduled to pop-off until January of 2019, thus it can be assumed that they have survived to date.
Conclusions	The main objective was successfully achieved, indicating that the two whale sharks tagged survived.
(4) Estimate post-release survival of rays (from deck): *Assess survival of mobulid rays released from the deck.*	
Methods	Survival PAT tags were to be used opportunistically if any manta rays were incidentally, in order to estimate their survival after the release by the crew using best practices (Poisson et al., 2012; ISSF 2016).
Results	Chilean devil rays, *Mobula tarapacana* (RMT) were captured in sets 30, 32 and 34, all of which were on free swimming schools. On set 30, the target school was missed so the sack, containing eight to ten RMT, was opened to release the rays. All appeared to be in good condition and swam out of the net. On set 32, three RMT were captured. One female ray came up entangled in the net while the other two were landed in the later brails (12 and 15 of 15 brails). The animal landed in brail 12 was a mature male and the other landed in brail 15 was a female. All three were tagged with miniPAT satellite tags and released by the crew. This method requires the crew to maneuver the animal from the brail onto a large piece of net that can be picked up with a crane and lifted over the deck to release the animal back into the water (Figure 20.3).  **Figure 20.3**. Safe release of two *Mobula tarapacana* from the deck. On the left the line that was used to

<table>
<tr><td></td><td>maneuver the animals is shown. At right the animal is shown on the netting used to lift it and return it to the sea.

Eight RMT were captured in set number 34. All of these animals were landed via brailing and released using the aforementioned best practices. The first animal that was tagged was an adult male, landed in the first brail and released in good condition. Two RMT were landed in the second brail, one of these was a female and was tagged. The other was an adult male and was not tagged, they were released together and in good condition. The third brail contained another mature male that was also tagged and released in fair condition. Brails 4, 5 and 6 contained four additional adult RMT that were released alive using the recommended practices but were not tagged.

As of September 2018, five of the six tags have popped off. All of the tags initiated release because the animals had exceeded the tag's critical depth threshold of 1,400 meters. Typically, this would be indicative of mortality, or an animal sinking through the water column. All of the apparent mortalities occurred between two and 10 days post-release with one tag that is not scheduled to initiate release until January 12, 2019 (180 day deployment period).

Interestingly, this species was captured during three sets in groups of three to about nine, indicating there was some evidence of schooling. Yet, post-release, each of the tags that have reported show unique movement trajectories (Figure 20.4). Each of the tagged mobulids left the aggregation site and location of tagging immediately and headed in different directions. Figure 8 shows the most likely locations for each day of the deployments for all five rays. It appears as if they all headed offshore (West and Northwest) towards the islands of Sao Tome and Principe via unique paths, until the tags sank with the animal and came off.

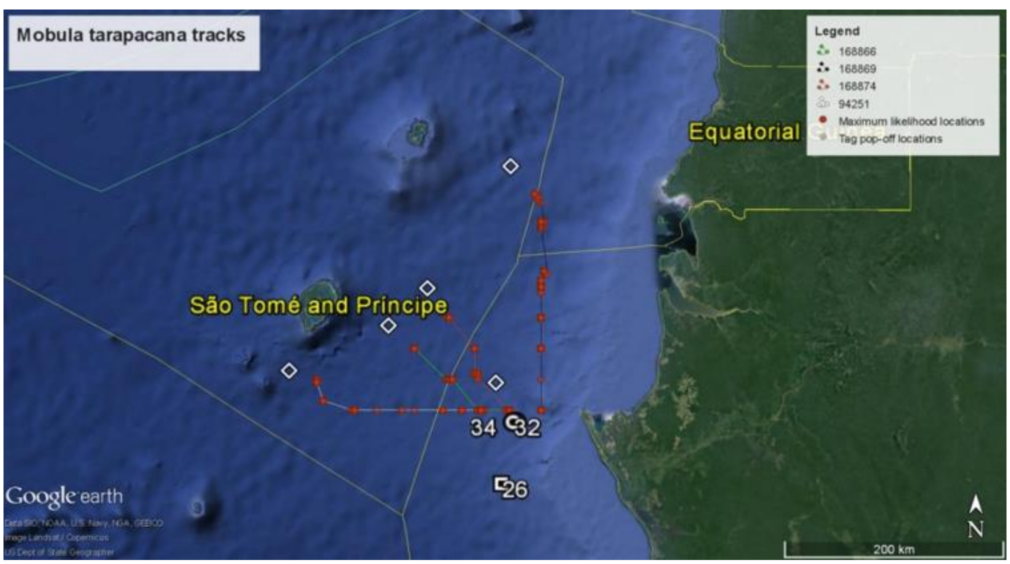


Figure 20.4. Mobula tarapacana tracks for five of the six tagged. Diamonds indicate locations where the tags initiated release from the animal after it had died and sank.</td></tr>
<tr><td>Conclusions</td><td>The objective was achieved. Unfortunately, 5 of 6 tagged devil rays died within 10 days after release. It appears as if releasing animals using best practices may reduce mortality to a small percentage of mobulids that are brought on board the vessel, but the physiological impacts of the interaction cause delayed mortality in a larger proportion (see also Francis and Jones, 2016, who found similar results tagging M. japanica). These data suggest that alternative mitigation actions, such as avoiding hot spots or releasing them from the sack or while the net is still open, may be more effective for reducing mortality of mobulid rays.</td></tr>
<tr><td colspan="2">Other notes</td></tr>
<tr><td>Best practice</td><td>It was observed that crew members that were releasing sharks were not always following safe practices. The scientists recommend that best handling practice guidelines produced by ISSF</td></tr>
</table>

	(2016) be updated to include the use of a stretcher with details on materials and instructions for fabrication.
Sharks and rays in FS sets	Sharks tend to be a more common type of bycatch in FAD sets than in free-school sets. However, during the cruise, sharks were caught in 31 of 37 free school sets. The ratio of number of sharks per ton of tuna in these 31 sets ranged from 0.01 to 9.0; median=0.1. The observer on the vessel noted that this is not uncommon for this area and time of the year. It would be useful to analyze observer records in order to identify shark "hot spots" in the eastern Atlantic Ocean. All whale sharks and mobulid rays caught during the cruise were caught on free-swimming schools.
Incorporating oceanography into bycatch mitigation	Gabon in July appears to be an important area for feeding and may support several breeding populations of coastal and pelagic teleosts, sharks, rays, turtles and marine mammals. A recent analysis of the diversity patterns and environmental characteristics of the bycatch assemblages in the tropical tuna purse seine fishery in the eastern Atlantic Ocean found that the bycatch assemblages showed preferences for specific oceanographic characteristics such as the equatorial and seasonal coastal upwelling systems, the Cape Lopez front system and the Guinea dome (Lezama-Ochoa et al. 2018). Thus, integration of temporal oceanographic parameters into future bycatch mitigation techniques is the next step in improving the sustainability of this fishery. Avoidance of elasmobranch interactions and additional controls (e.g., avoiding hot spots, setting catch or effort limits) may be the best conservation strategies for this region, particularly during upwelling seasons. A better understanding of habitat requirements for biological imperatives and times and areas of aggregations of bycatch species is required.

Conclusions

ISSF's at-sea research is a valuable means for evaluating methods that could potentially mitigate bycatch. The research cruises also serve as a platform for collecting data to address other key issues related to the sustainability of tuna fisheries, such as the effects of FADs on the behavior and biology of tunas and other FAD-associated species. These are some of the main findings so far:

Sharks

Passive mitigation

Traditional FADs that use open netting with large mesh size for the hanging structure can result in very large amounts of ghost fishing through entanglement. ISSF collaborating scientists have created guidelines for the design of non-entangling FADs (ISSF 2015). Three tuna RFMOs now require that fleets deploy non-entangling FADs. Objectives were achieved and research on this topic is finished.

Avoid catching sharks before the set

Analyses of the daily associative behavior of sharks with FADs in contrast to target tunas show that it is not possible to significantly reduce the catch of sharks by manipulating the time of the day when a set is made. This is because the peak times of shark presence coincide with the peak times of tuna presence. Objectives were achieved and research on this topic is finished in relation to FADs. However, in some areas and seasons, sharks can be caught in large quantities on free-swimming schools (e.g. off Gabon in July). It may be useful to develop methods to quantify the ratio of sharks to tunas acoustically before a set.

Release sharks from the net

Although observations and field testing in one of the cruises suggested that the basic design of a release panel was functional and that it could be deployed in commercial fishing applications, other cruises have shown that many factors come into play. The success of such a measure appears to depend on the size of the vessel, the characteristics of the net, the depth of the thermocline, the skippers' skills and the behavior of the sharks which appears to be (at least) area-dependent. Investigations of other solutions or further experiments (still considering the above limitations) are needed.

Results to-date suggest that sharks can be effectively released from the net by simply fishing for them with handlines, with 100% survival. It represents a promising technique, but it seems to work only on FAD sets; sharks on free-swimming school sets seem interested in foraging and it appears difficult to attract them with a few baited hooks. More tests are required to increase the dataset, to better assess how many sharks per set could be released through this technique, in parallel with the investigation of the survival of released individuals. Ongoing research.

Release sharks from the deck
Tagging has shown that 50% of the live sharks released from the deck can survive if they are released promptly and following best practices (Poisson et al. 2014). Combined with the percentage of sharks arriving live or dead on the deck, this leads to an overall estimate of 15-20% survival for all sharks that are encircled and brought onboard, if good practices are put in place. Study completed.

Bigeye tuna

Passive mitigation
Tests were conducted in the EPO to determine if FAD design (e.g., depth of hanging structure) can alter the amount of bigeye caught. Results showed no difference in bigeye or total tuna catch rates between shallow and deep FADs in this region. However, it is not known if the results could be different in other regions with different features such as a deeper thermocline.

Avoid catching bigeye
The investigation of scientific echo-sounders with different frequencies has quantified the differences in acoustic response of skipjack (which have no swim bladder) and bigeye (which do). This knowledge has the potential to be used by both the manufacturers of echo-sounders onboard purse seiners and manufacturers of echo-sounder buoys used to track FADs, to discriminate tuna species, thus allowing skippers to remotely identify which FADs have a lot of bigeye tuna. Research is ongoing to obtain yellowfin tuna frequency responses from captive yellowfin and the collection of *in situ* target strength for the 3 tropical tuna species in different oceans. Research on the Target Strength of skipjack has been completed.

Analyses of the daily associative behavior of bigeye with FADs in contrast to other target tunas show that it is not possible to significantly reduce the catch of bigeye by manipulating the time of the day when a set is made. This is because the peak times of presence of the three tuna species coincide. However, more tests are needed in different ocean regions, and research is ongoing.

Release bigeye from the net
Underwater surveys have demonstrated that bigeye do separate at times from other species inside the net, and tend to be deeper. However, this separation is in the order of tens of meters, so it is necessary to manipulate the behavior in order to enhance this segregation. Research on sensory physiology of three tuna species is necessary, before further investigation on tunas in a net.

Turtles

Passive mitigation
Traditional FADs that use open netting with large mesh size for the hanging structure can result in ghost fishing of turtles through entanglement. ISSF collaborating scientists have created guidelines for the design of non-entangling FADs (ISSF 2015). Three tuna RFMOs now require that fleets deploy non-entangling FADs. Objectives were achieved and research on this topic is finished.

Release turtles from the deck
Research has shown that turtles survive if they are released promptly and following best practices (Poisson et al. 2014). Objectives were achieved and research on this topic is finished.

Other finfish species

Analyses of the daily FAD-associative behavior of oceanic triggerfish and rainbow runner in contrast to target tuna species, show that it could be possible to reduce the catch of these species by adapting the time of day when sets are made. This is because the peak times of presence at FADs of these species and those for tunas appear, at least in some oceanic regions, to differ. However, more tests are needed in different ocean regions and research is ongoing.

Impacts of FADs on the ecosystem

Lost FADs are a form of marine debris, and they can end up in reefs and other sensitive areas. Tests of FADs made with biodegradable materials show that they can also perform as well as traditional FADs in terms of attracting tunas. However, more tests are needed in different ocean regions, using different designs, and research is ongoing.

Data collected on the behavior and biology (e.g., condition factors) of tunas and other FAD-associated species contribute to the investigation of the effects of the presence and densities of FADs in the oceans on the behavior and biology of tunas and other associated species (the so-called ecological trap hypothesis).

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