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Acronyms

AMAFRAD	Agency for Marine and Fisheries Research and Development (Indonesia)
AMAFRHR	Agency for Marine and Fisheries Research and Human Resources
BET	Bigeye Tuna
CFR	Centre for Fisheries Research
CODES	Centre for Ore Deposit and Earth Sciences (University of Tasmania)
CSL	Central Science Laboratory (University of Tasmania)
DGCF	Directorate General of Capture Fisheries (Indonesia)
FAD	Fish Aggregating Device
FMA	Fisheries Management Area
HS	Harvest Strategy
IBIS	Institute for Integrative Biology and Systems, Laval University, Canada
IOTC	Indian Ocean Tuna Commission
MSE	Management Strategy Evaluation
NGO	Non Government Organisation
RFMO	Regional Fisheries Management Organisation
RIMF	Research Institute for Marine Fisheries (Indonesia)
RITF	Research Institute for Tuna Fisheries (Indonesia)
RIFEC	Research Institute for Fisheries Enhancement and Conservation (Indonesia)
RCFMC	Research Centre for Fisheries Management and Conservation (Indonesia)
RCCF	Research Centre for Capture Fisheries (Indonesia)
SPC	Secretariat of the Pacific Community
WCPFC	Western and Central Pacific Fisheries Commission
YFT	Yellowfin Tuna

2 Executive summary

The Project:

Developing research capacity for management of Indonesia’s pelagic fisheries resources. ACIAR Project FIS/2009/059.

Key issues:

Indonesia’s pelagic fisheries resources are of considerable importance to the nation’s economy and as an important source of protein for Indonesia’s large population of 261 million people. Two species of critical importance to Indonesia and to neighbouring countries in the Indian and Western Pacific Ocean regions are yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*), and together accounted for around 6.3% of total value of Indonesia’s capture fisheries commodities in 2015 (MMAF 2016). Current assessments and management strategies are based on assumptions of single, separate Indian Ocean and Western Pacific Ocean stocks of both species. Understanding of connectivity of these species across the Indonesian archipelago and adjoining oceans was considered a high priority for improved management.

During the project development phase there was considerable concern about the rapidly increasing number of fish aggregating devices (FADs) in Indonesian waters, the associated impacts of increased fishing pressure on stocks of juvenile tunas, and likelihood of unsustainable fishing practices.

Primary objectives:

To improve Indonesia’s capacity to assess and manage its tuna fisheries by addressing key information gaps, particularly for yellowfin tuna (YFT) and bigeye tuna (BET), and to improve Indonesia’s pelagic fisheries research capacity. The immediate objectives of the project fell within three primary components: 1. defining the population structures of YFT and BET in Indonesia’s archipelagic waters and connectivity with adjoining regions; 2. assessing and characterising Indonesia’s FADs associated tuna fisheries, and 3. the communication of the project’s findings and recommendations to the Indonesian and international science and policy communities.

Population structure study methodologies:

Using three independent, complementary techniques – genetics (next generation sequencing and Single Nucleotide Polymorphism markers), otolith chemistry[1] (analyses of stable isotopes and elements) and occurrence of parasites - to determine the degree of population structure and connectivity of YFT and BET between the central Indian Ocean, IAW and Western Pacific Ocean.

FAD fisheries study methodologies:

1. A review (as a bibliography compilation) of earlier FAD related studies in Indonesian waters; 2. An enumeration program at 4 key tuna landing locations (Padang, Palabuhanratu, Kendari and Sorong) to gather information on a wide range of aspects of the FADs and the FAD-based fisheries; 3. A preliminary survey of socio-/bio-economic aspects of FAD-based fisheries at Kendari and at Palabuhanratu; and 4. Trials of acoustic and visual census of assessing fish aggregations on and around FADs.

[1] *Otoliths are structures in the inner ear that can be ‘read’, similar to the growth rings of trees, to determine factors such as the fish’s age. The chemical composition of specific sections can be compared with geographic variation in ocean chemistry to indicate location at known ages and thus movement through time.*

Population structure study outcomes:

The three techniques provided outcomes that were consistent with the inference of multiple populations for YFT and BET across the geographic range of the project. The outcomes of the genetics analyses suggested at least 2 or 3 genetic groupings for both species, with clines of genetic variation across the geographic range. The patterns of distribution of parasites suggested limited to no movement of fish (both species) westwards from the Indonesian archipelagic waters (IAW) into the eastern and central Indian Ocean, and also little movement from the Western Pacific Ocean westwards into the Indonesian archipelago. The overall outcome from the otolith chemistry analyses was that the YFT and BET had not moved large distances in their first 4 - 6 months of life. These results suggest that the current national and regional governance arrangements are likely to be consistent with the structure and connectivity of YFT and BET populations. The study achieved capacity development for Indonesian scientists in the analytical fields of three techniques, in addition to skills associated with the large-scale sampling program.

FAD fisheries study outcomes:

1. The literature review produced a bibliography of 116 FAD related research studies from Indonesian waters; 2. The enumeration program achieved 2,564 fishing trips surveyed for 3 vessel types (hand-line/troll-line, pole & line, and purse-seine) across the 4 focus locations and a total of 48,368 fish measured in the biological sampling program, and was sustained at two of the locations for 39 months; 3. The socio-/bio-economic study provided useful insights into the cost ‘dynamics’ of the FAD fishery operations, and capacity development in assessing the socio-economic aspects of the fisheries; and 4. The acoustic and visual census trials on FADs provided a foundation for further research on the behaviour of fish species following fishing events i.e. ‘recovery’ times around the Indonesian anchored FADs.

Impacts anticipated:

The population structure study, albeit a ‘first-look’ investigation involving only the juvenile life-history stages of the two species, has outcomes that will be a valuable contribution to current considerations by Indonesia and Regional Fisheries Management Organisations (including as inputs into the structure of regional stock assessments) on appropriate management for these globally significant resources. The study’s results will play a key role in defining future research activities to further investigate the degree of connectivity of the tuna populations in IAW and adjoining oceans, in particular the level of exchange with the WCPO. The capacity developments achieved in the project will ensure Indonesia’s fisheries scientists play key, prominent roles in the future research.

Impacts achieved:

The FAD study was initiated in response to the need for targeted information on the deepwater tuna FADs and associated fishing operations, and, overall, its outcomes have met that need. The catch characterisations results have already assisted in gear selectivity analyses as part of Indonesia’s current Harvest Strategy (HS) development and confirmed that juveniles of both species comprise significant proportions of the catch of the gears (hand-line/troll-line in particular) fishing on Indonesian deepwater anchored FADs. This information has informed the HS process and will assist the technical development of management measures for improved sustainability of the fisheries. The capacity development achieved in the preliminary study assessing the socio-/bio-economic aspects of the fisheries will be directly relevant to minimising the impact of new management measures on the most vulnerable components of the fishery (i.e. the small-scale subsistence fishers).

Recommendations:

This project demonstrated that the question of connectivity between IAW and adjacent oceans can be addressed through a combination of populations structure methods. Refining and extending these result through multi-year sampling of spawning adults and or larvae and use of methods that provide more direct estimates of annual exchange between areas, such as close-kin Mark Recapture, should be a high priority for future work.

With increasing recognition of the importance of including socio-economic impacts on fishing communities (in particular impacts to small-scale fishers) in development of new management measures, the capacity development of Indonesian scientists in socio-/bio-economic assessment skills should continue and, if possible, be expanded.

Similarly, there is need for an ongoing capacity development[2] for Indonesia's fisheries scientists and relevant staff within the Directorates of MMAF in all aspects of developing and implementing harvest strategies, including operating models, Management Strategy Evaluation, and identifying realistic and practical management measures for the complex Indonesian fisheries.

[2] *Currently being addressed by the follow-on ACIAR Project FIS/2016/116.*

3 Background

Indonesia's tuna fisheries resources are of high importance to the nation's economy and as a domestic food resource, and includes production from several gear types in both commercial and small scale/artisanal sectors. The Indonesian tuna fisheries span a broad geographical range including the eastern and north eastern Indian Ocean, the Indonesian archipelago, and into the Western Pacific Ocean. Combined overall catch of the four most important tuna species - skipjack (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*T. obesus*) and albacore tuna (*T. alalunga*) - in 2016 was 657,582 tonnes[3], based on combined figures of Indonesia's reports to the Scientific Committees of Indian Ocean Tuna Commission (IOTC) and Western and Central Pacific Fisheries Commission (WCPFC) in 2017 (Ruchimat et al. 2017, MMAF-RI 2017). Both in terms of catch volume of these *large pelagic fish* (as they are referred to Indonesian fisheries statistics) and fleet size (all gears combined), Indonesia is one of the largest tuna fishing nations in the world.

In 2015, the combined value of Indonesian production of yellowfin tuna (YFT) and bigeye tuna (BET), to both export and domestic markets, amounted to IDR 6,897 billion (~AU$690 mill.), around 6.3% of total value of Indonesia's capture fisheries commodities (MMAF 2016). These two species are also important to fisheries of country neighbours in the Indian Ocean (IO) and Western and Central Pacific Ocean (WCPO) regions. Stock assessments in these regions at time of development of this project (2010 – 2012) were that both YFT and BET, although overall were not overfished, may have been overfished in some areas (Langley et al. 2009, IOTC 2010, WCPFC 2010, Davies et al. 2011). IOTC and WCPFC had recommended there needed to be appropriate control of fishing pressures, and that accurate assessments of the stocks were difficult to make because of a serious lack of high-quality, validated information on the true scale of the catches of these tunas (juveniles in particular) by the Indonesian and Philippine fishing fleets. In keeping with Indonesia's increased participation in both RFMOs at that time, the (Indonesian) Agency for Marine and Fisheries Research and Development[4] (AMAFRAD) identified that filling information gaps surrounding these two important species in Indonesian waters, and the fisheries based on them, as high priority for the next phase of Indonesia–Australia collaboration on pelagic fisheries research. This was vital for developing Indonesia's internal fisheries management plans of action as well as making major contributions to the regional strategies developed through the RFMOs.

Population Structure Study

In considering the high priorities for achieving improved management of Indonesia's tuna fisheries, Indonesia's Ministry of Marine Affairs and Fisheries (MMAF), through the Directorate General of Capture Fisheries (DGCF) and AMAFRAD, identified the need for a better understanding of the amount of mixing between tuna stocks/populations across Indonesia's eleven Fisheries Management Areas (FMAs), and the degree of connectivity to stocks/populations in the IO and WCPO. YFT and BET were identified as the two highest priority species; research with high national importance for domestic fisheries management but also of international importance, for assisting improved assessments by the RFMOs.

Stock assessments for YFT and BET at time of development of this project were based on assumptions of separate, biologically distinct stocks of both species in the Indian Ocean

[3] *This combined catch figure excludes albacore caught by Indonesian vessels in the WCPFC statistical area, as the albacore catch is currently under review (MMAF 2017a).*

[4] *AMAFRAD is now AMAFRHR (Agency for Marine and Fisheries Research and Human Resources) is the research arm of Indonesia's Ministry of Marine Affairs and Fisheries.*

and WCPO (Chiang et al. 2008, Davies et al. 2011, IOTC 2011, Langley et al. 2011) and those assumptions currently remain unchanged (Grewe et al 2016, McKechnie et al 2017, Tremblay-Boyer et al 2017). The YFT and BET caught in Indonesian waters were treated as IO fish if landed at ports and landing places within the IOTC Statistical Area (principally western Indonesia) and as WCPO fish is landed at ports within the WCPFC Statistical Area (principally eastern Indonesia). However, the results of some genetic (Grewe et al. 2000, Appleyard et al. 2002, Dammannagoda et al. 2008) and otolith chemistry (Wells et al. 2012) investigations began to question the validity of these assumptions, suggesting meta-population structure across relatively small spatial scales. Tagging studies in Hawaiian Islands region had demonstrated retentive behaviours of YFT and suggested that long-distance (>1000 km) movements by this species were rare (Itano and Holland 2000).Tagging of both YFT and BET in the WPO, including in eastern Indonesian archipelagic waters (SPC 2012) in 2009 - 2010, also suggested the extent of spatial movements and regional mixing by these tuna species may not be as extensive as earlier thought.

With advances in genetic analytical techniques and emergence of next generation sequencing (Allendorf et al. 2010; Davey et al. 2011, Nielsen et al. 2012, Peterson et al. 2012), there was strong agreement on both Indonesian and Australian sides that this next phase project should examine the level of heterogeneity across the region. However, in recognition of the strengths in using a multi-technique approach to elucidating stock/population structures for fish species, we decided on using not only the new genetic technologies but also otolith chemistry analyses and parasites characterisation. These two latter techniques had proven their worth in investigations of stock structures of other species (Lester et al 2001, Rooker et al. 2003, Rooker et al. 2008, Lester and MacKenzie 2009, Schloesser et al. 2010, Zeigler and Whitledge 2011, Moore et al. 2012) and, in some earlier studies of pelagic species, the three techniques had been used together, drawing on the strengths of each but also recognising their respective limitations (Gunn et al. 2002, Buckworth et al. 2007, Welsh et al. 2009). The key advantage of using a multi-technique approach is that each method is informative about the fish's life history at different spatial and temporal scales. Genetics has the potential to inform about the evolutionary patterns as well as rates of mixing of fish from different regions, whereas parasites and otolith microchemistry are directly influenced by the environment and so have potential to inform about the patterns of movement during the fishes lifetime. Growth patterns are influenced by both genetic and environmental factors. Due to these differences, the use of these techniques in a holistic approach increases the chance of detecting different stocks where they exist (Buckworth et al. 2007, Welsh et al. 2009).

FAD Fisheries Study

As already mentioned, in the international arenas of the RFMOs concern had been expressed about the importance of addressing information gaps for the YFT and BET fisheries in the IO and WCPO, including determining the true scale of catches of juveniles of these species by the Indonesian and Philippine fisheries. It was known that for Indonesia several different gear types were used in catching tuna, both in commercial and small scale/artisanal sectors (Proctor et al. 2003, WWF 2008), and that fish aggregating devices (FADs) had become a common tuna fishing tool. Deepwater anchored FADs first appeared in Indonesian waters in the 1940s, used by the *mandar* fishers of West Sulawesi (Subani and Barus 1988). However, it was not until the early 1980s that their use became more prevalent, and deepwater FADs have since become an integral component of Indonesia's tuna fisheries, for purse-seine, pole and line, and hand-line/troll-line vessels. At time of development of this project (2010 – 2011), the need for stricter management of the FAD-based fisheries by RFMO member countries had been voiced as a high priority issue (IOTC 2011, WCPFC 2011). The number of anchored FADs in Indonesian waters was known to be increasing at a fast rate, already reaching hundreds if not thousands in number, and the lack of even basic information about FAD numbers, FAD locations, FAD construction, and FAD utilisation was voiced by DGCF (Budhiman[5], pers. comm., 2011) as their "biggest management challenge". At that stage there was no effective FAD registration system or effective FAD related regulations of any type, and DGCF specifically asked for a FAD fisheries study to be included in the next phase of Indonesia – Australia collaboration in tuna fisheries research. AMAFRAD supported DGCF in their request, as there was recognition that a better understanding of all aspects of the FAD-based fisheries was required as foundation to establishing management measures and for Indonesia to be in an improved position to meet its RFMO obligations[6]. These obligations extended beyond the reporting of the basic statistics of FAD numbers and types. Indonesia was also under pressure to achieve improved capability to meet its annual reporting obligations to the RFMOs, particularly with respect to catch by gear and by species for artisanal/small-scale fisheries (WCPFC 2011 and 2012). Conflicts between fishing gears using the Indonesian tuna FADs had also become a significant issue for DGCF, and information on the 'dynamics' of FAD ownership and FAD use in Indonesian waters was needed to address the issue.

AMAFRAD, CSIRO, and ACIAR recognised that inclusion of a FAD fisheries study in the project and its associated enumeration program would enable capacity development in methods of data and information collection for the FAD-based fisheries, and development of an enumeration protocol that would meet Indonesia's domestic and international reporting needs. A large component of these fisheries was known to be small scale/artisanal, and addressing the information gaps around this sector of the Indonesian fisheries had already been identified as high priority.

There was also recognition that the new phase of collaboration afforded opportunity to further develop Indonesia's capacity in the area of socio-/bio-economic assessment of fisheries. This capacity had taken a significant step forward in 2010 with a bio-economic, socio-economic and fishing capacity training workshop in Jakarta, as part of ACIAR Project FIS/2006/142 (*Developing new assessment and policy frameworks for Indonesia's marine fisheries, including the control and management of Illegal, Unregulated and Unreported (IUU) Fishing*). The knowledge gathering to occur on the operations of the FAD-based fisheries was extended to include a preliminary assessment of bio- and socio-economic aspects of the fisheries in two regions (West Java and SE Sulawesi). This was to increase the utility of the FAD Study findings, but also to provide capacity development for Indonesian partner scientists in this increasingly important area of fisheries research.

A key recommendation that emerged from the International Conference on "Tuna Fisheries and Fish Aggregating Devices" in Tahiti , French Polynesia, in 2011 was that the outcomes of studies of fish aggregations on FADs in one region may not be directly applicable to other oceanic regions, as variability in environmental factors (both physical and biological) are likely to result in different fish schooling behaviours. The recommendation extended to suggesting that countries 'grappling' with the challenges of FADs management should conduct appropriate research to better understand fish behaviours on and around FADs in their waters, such as 'recovery times' of aggregations on FADs after purse-seine fishing events. It was for this reason that the project included in its planning, the idea of doing trials of scientific fish aggregation assessment, using both acoustics and visual assessment methods, but also as a means of delivering capacity building in new skills in spatial dynamics research.

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[5] Mr Agus Apun Budhiman, Director of Fisheries Resources, Directorate General of Capture Fisheries, Indonesia[6] Indonesia has been a Full Member of IOTC and WCPFC since 2007 and 2013 respectively. Prior to 2013 Indonesia was a Cooperating Non-Member of WCPFC.

[6] Indonesia has been a Full Member of IOTC and WCPFC since 2007 and 2013 respectively. Prior to 2013 Indonesia was a Cooperating Non-Member of WCPFC.

At time of this project's initiation, three key developments had yet to emerge; developments that would greatly increase the potential for transition of project's outputs to more highly significant impacts:

1. The "*Strategic plan for ACIAR engagement in capture fisheries research and capacity development in Indonesia, 2015–25*", developed by ACIAR and AMAFRAD in collaboration with ABARES and CSIRO (ACIAR Project FIS/2011/030). The plan was developed during 2012- 2014 and released in 2015;
2. Harvest Strategy development for Indonesia's tuna fisheries. The development process commenced in late 2014;
3. FADs management plan. The formal process for developing improved management for Indonesia's tuna FADs began in early 2017.

The ways this project has been delivering and will continue to deliver impacts in these three areas are covered in Section 8 –Impacts.

4 Objectives

Research questions

There were several key research questions that needed to be answered for the project's objectives (see below) to be met. They can be generically summarised as follows:

- Is there evidence of population structure in yellowfin tuna (YFT) and bigeye tuna (BET) across the Indonesian archipelago to the extent of justifying regional assessment and regional management?;
- What is the level of connectivity between the tunas in eastern Indonesia waters and those in western Indonesia waters, and between those in Indonesian waters and those in adjacent oceanic regions—Western Pacific Ocean and Indian Ocean?;
- What is the true scale of catch of YFT and BET in Indonesian waters, with particular reference to juvenile tunas caught by multiple gears as FAD-based fisheries?;
- How do the different gear types operate and interact around FADs and what are the primary factors determining fishing success?;
- How important are the YFT and BET components in the overall tuna catch by Indonesian artisanal/small-scale fisheries and what are the likely socioeconomic ramifications if catches undergo dramatic decline through unsustainable fishing pressures and/or the introduction of new management measures?
- What are the interplays between artisanal/small-scale fishing operations and commercial/industrial domestic and international markets?

Aim and objectives

The overall aim of the project was to improve Indonesia's pelagic fisheries research capacity, especially that related to management of its important tuna fisheries resources, and in particular in relation to YFT and BET. The immediate objectives of the project fell within three primary components: 1. defining the population structures of YFT and BET in Indonesia's archipelagic waters and connectivity to populations in adjoining regions; 2. assessing and characterising Indonesia's tuna fisheries that are based around FADs, and 3. the communication of the project's findings and recommendations.

Specific objectives for each component were:

1. <u>Population structure study</u>
   (i) Using three independent, complementary techniques (genetics, otolith chemistry and parasite loads), determine the degree of population structure and connectivity of YFT and BET over a wide geographical range;
   (ii) Advise, in consultation with the relevant RFMOs, on the implications of the results of the above investigation for approaches to assessment and management of fisheries harvesting these stocks;
   (iii) Provide capacity development for Indonesian scientists in the aforementioned analytical techniques.

2. <u>FAD fisheries study</u>
   (i) Assess the number, type and distribution of tuna fishery FADs across the Indonesian archipelago;
   (ii) Characterise the catch on FADs by gear, species and size of fish, for target tunas and bycatch species;
   (iii) Establish, through trial programs at four ports, improved port-based monitoring procedures for obtaining high-quality, long-term catch and effort data for the FAD fishery operations;

(iv) Draw on information obtained through the above, to scope/complete preliminary assessments of bioeconomic, socioeconomic, fishing capacity and risk aspects of the FAD-based tuna fisheries for each major gear type;
(v) Provide capacity development for Indonesian scientists in areas of tropho-dynamics, reproductive biology, fish ageing and spatial dynamics.

3. <u>Communication of project’s objectives, findings and recommendations</u>

An outcome of ACIAR’s Research Review Committee appraisal of this project’s Preliminary Proposal was the suggestion of including Communications as an additional, stand-alone objective. This highlighted the high importance assigned to the dissemination of information to all key stakeholders. The primary methods were to include face-to-face meetings with fisheries agencies and port authorities, those involved in policy development, local stakeholder meetings, media and networks, and using extension materials (brochures, posters, newsletters, dvds). The primary objective was to disseminate to Government agencies, to all sectors of fishing industry, to local fishing communities and associations, and to broader community groups, the objectives of the project, its findings and recommendations, and the benefits that will flow from achieving sustainable fisheries. A high priority was to be placed on reaching the higher levels of policy making and policy adoption.

The project’s progress and, in particular, the results from the various research activities, was be disseminated to the RFMOs and to the broader scientific community through papers and presentations presented to annual Scientific Committee meetings of the RFMOs (IOTC, WCPFC), and at relevant conferences (e.g. International FADs Conference, International Tuna Conference) and workshops.

5 Methodology

The methodologies detailed in this Section are presented as non-technical summaries to keep within the space limits defined in the Final Report guidelines. The more detailed methodologies are presented the stand alone final reports for the population structure study and the FAD fisheries study (in prep at time of submission of this report).

5.1 Population Structure Study

5.1.1 Fish sampling

Sampling strategy

The YFT and BET upon which the genetics, otolith chemistry and parasites analyses were based, were sampled in two periods: late April – mid June 2013, and early June – late July 2014; periods that were sufficiently similar in season to enable an inter-annual comparison of 'signals' from the three techniques, without the impacts from temporal differences. The samples were obtained from 11 fishing ports: 9 locations across the Indonesian archipelago and 2 'outlier' locations for comparison – the Maldives and the Solomon Islands. The Indonesian sampling ports (Figure 5.1) were Padang (West Sumatera), Palabuhanratu (West Java), Prigi (southern East Java), Kendari (SE Sulawesi), Gorontalo (North Sulawesi), Bitung (North Sulawesi), Ambon (Maluku), Sorong (West Papua), and Jayapura (Papua). Malé and Noro were the sampling ports for the Maldives and Solomon Islands respectively. The choice of ports for Indonesia was largely based on what would provide good representation across the nation's Fisheries Management Areas (FMAs) in which tuna fishing activity was known to occur. There were other areas that could have been included if budget and sufficient time had been available, including ports in provinces of Bali, West Nusa Tenggara, East Nusa Tenggara, and other locations in the provinces of Maluku and North Maluku.

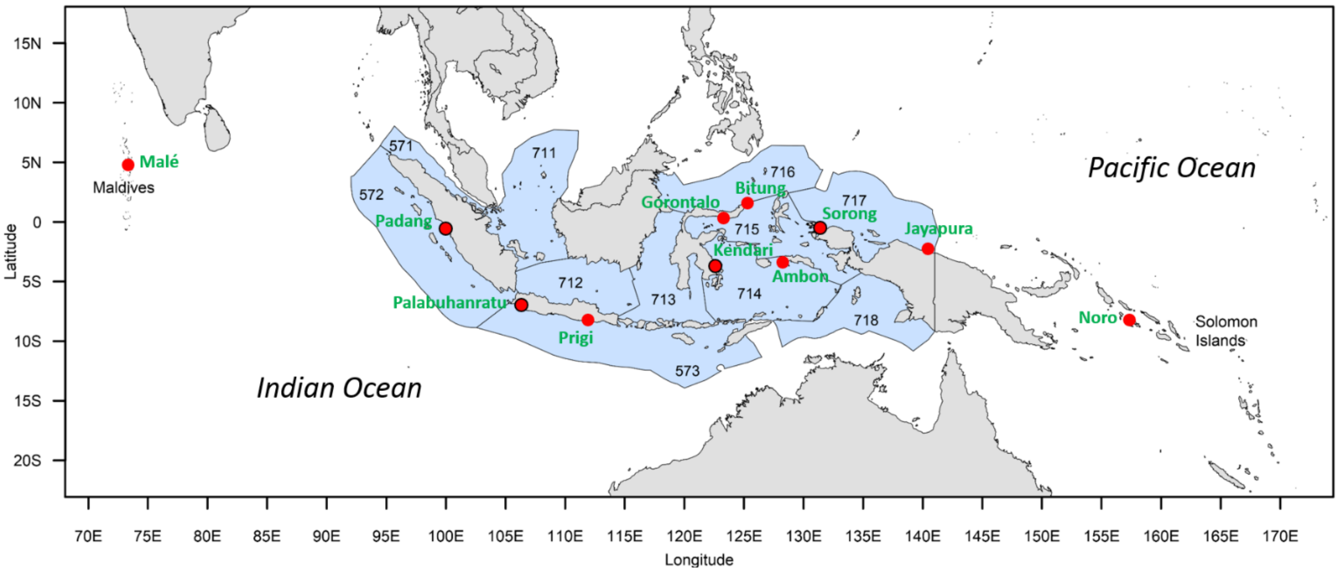

Figure 5.1. Map showing the location of fishing ports (red circles) where sampling was done for juvenile YFT and BET in 2013 and 2014. The four ports which were also location of enumeration for the FAD fisheries study are shown by red circles with black outline. The blue shaded areas with three digit numbers represent the eleven Indonesian Fisheries Management Areas (FMAs).

A protocol was drafted for the sampling and used as the guideline for training for the sampling teams. The target size range of fish sampled, for both YFT and BET, was 25 –

50cm FL; fish of age 4 to 6 months (see reference to ageing below). This was considered appropriate for this first look at population structure, as it was unlikely the fish would have moved large distances from their spawning locations. It is also a size of fish that is commonly landed by Indonesian purse-seine, pole and line, handline/troll-line and gill-net vessels, and so we had confidence that we could achieve the required samples at all sampling locations. This size of fish was also chosen because the juvenile YFT and BET were an important component of the Indonesian fisheries and achieving more clarity around the true scale of catch of the juveniles had been voiced as a high priority by both IOTC and WCPFC.

Three sampling teams, each comprised of 3 scientists from Indonesia’s fisheries research institutes[7] and/or CSIRO, left Jakarta simultaneously to sample at 3 Indonesian locations each, with 3 – 4 days required in each location. The sampling teams were instructed, to as best as possible, spread the sampling across catches from multiple vessels during the 3 – 5 days of sampling at each location. This was aimed at achieving a representative sample for the landings of juvenile YFT and juvenile BET for each region. In general this was achieved, and the total sampled fish from each location were comprised of multiple “batches”, with a “batch” being a sample from one vessel, or, in some cases, a sample from a fish distributor (‘middle-man’). Effort was made to obtain as best information as possible on the actual catch location of the fish sampled. This ranged from the most precise – latitude and longitude positions as provided by the GPS waypoints of skippers, to the least precise – approximate catch areas provided by skippers, vessel owners, fish distributors or agents.

The original target for the sampling of this study was 100 YFT and 100 BET from each of the 11 sampling locations in the size range 25 – 50 cm FL. The size ranges and numbers of fish sampled in both rounds of sampling (2013 and 2014) are presented in Table 7.1. The dissection procedure for sampling the tissues for genetics, otolith chemistry and parasites analyses is described in detail in the sampling protocol (copy submitted with this report).

Direct age estimates

To determine the age of the fish collected for the study, and their approximate spawning dates, a subset of otoliths were selected for daily ageing. This is a direct method for determining age. Indirect methods, such as converting length to age using length-at-age keys, are subject to more uncertainties. Nineteen of the fish selected were between 39 and 42 cm FL, around the mean of the fish sampled and indicative of the length range of fish analysed for otolith microchemistry. Four larger fish were selected for daily ageing, representing the largest fish among those sampled. The otoliths sections were prepared and read by Fish Ageing Services Pty Ltd. The age determination results are presented in Section 7.1.1.

5.1.2 Methodologies: Parasites

For those samples collected for parasite analysis, gills and viscera were removed, placed into individual plastic bags with a label giving location, date and time of capture and FL, and then frozen. In 2013 the gill and viscera samples became separated and only one of the pair was examined in some cases. In 2014 gills and viscera from the same fish were kept together and both were dissected. Approximately 10 fresh fish of each species were examined at the start of the project to detect and identify parasites that would be useful in the project.

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[7] Research Centre for Fisheries Management and Conservation (Jakarta) (now Centre for Fisheries Research), Research Institute for Marine Fisheries (Jakarta), Research Institute for Tuna Fisheries (Bali), and Research Institute for Fisheries Enhancement and Conservation (Jatiluhur).

For parasitological examination frozen tissues were thawed, the gill arches opened and external and internal gill surfaces examined under a dissecting microscope. The viscera were separated into stomach, pyloric caeca, intestine and liver, and scanned individually under a dissecting microscope. Parasites found were removed, identified, counted, and preserved in 70% alcohol. All counts were performed by the Ms Pratiwi Lestari (RIMF), and samples were not dissected in any particular order. The identification of a subset of each parasite species was confirmed using molecular techniques, the detail of which is highly technical and is presented in the stand-alone population structure study final report.

Statistical analyses - parasites

The data were analysed with reference to FMAs, initially using results from all parasitological examinations. Subsequent more detailed analyses excluded fish which lacked data from either gill or viscera. Summary statistics were compiled for each tuna species by source FMA, and included mean abundance (total number of individuals of a particular parasite per sample divided by the total number of hosts examined, including uninfected hosts) and prevalence (number of hosts infected with a particular parasite divided by number of hosts examined, expressed as a percentage) for each parasite species deemed suitable for use as a biological tag, following the terminology of Bush et al. (1997). Summary statistics were compiled for each collection year and for both years combined. Maps of individual parasite species' abundance and prevalence were generated to visually inspect spatial and temporal patterns in these parameters across the sampling locations.

Natural log-transformed (i.e. $\ln(x+1)$) abundance data for those species with a prevalence of > 10% in at least one of the samples (component species; Bush et al. 1997) were compared among FMAs using a series of one-way permutational univariate analysis of variance, using the *vegan* package (Oksanen et al. 2017) in R version 3.3.10 (R Core Team 2016). Each permutational analysis of variance was based on a Euclidean distance similarity matrix and 999 permutations of the data. A p-value of < 0.01 was considered significant for all tests. Samples of BET from FMA716 in 2013 and the Maldives in 2014 were excluded from these analyses due to small sample sizes (n=2 and 5, respectively).

Linear discriminant analysis (LDA) was performed to provide a visual indication of the similarities in parasite community assemblages among FMAs for each tuna species in each collection year, using the *MASS* package (Ripley et al. 2016) in R version 3.3.10 (R Core Team 2016). Results of the LDA were plotted as graphs of the first and second discriminant axes, with 95% confidence interval ellipses established for each sample group.

Data from groups of fish caught in the same month from different locations within individual Indonesian FMAs allowed an examination of the potential degree of mixing within FMAs. Differences in parasite community assemblages among groups were examined using permutational multivariate analyses of variance using the *vegan* package (Oksanen et al. 2017) in R version 3.3.10 (R Core Team 2016), following the permutational analysis of variance approach described above.

5.1.3 Methodologies: Otolith chemistry

Sagittal otoliths were sampled from bigeye and yellowfin tuna that were landed at 11 port locations in a narrow sampling period in both 2013 and 2014 (see Table 7.1). This generated 44 groups of samples: from 2 species, 11 locations, in 2 years. The otoliths were received and archived at the CSIRO laboratories in Hobart.

From each of the 44 groups, 25 samples for analysis were chosen by size, around the mean of fish length, with the aim to analyse fish that had been spawned at the same time. Analyses were conducted at two facilities: carbonate $\delta^{13}C$ and $\delta^{18}O$ values, i.e. stable isotope ratios of carbon (C13:C12) and oxygen (O18:O16), were analysed at the Central

Science Laboratory, University of Tasmania (CSL); and elemental concentrations of the isotopes ^{7}Li, ^{23}Na, ^{24}Mg, ^{31}P, ^{39}K, ^{43}Ca, ^{55}Mn, ^{56}Fe, ^{57}Fe, ^{63}Cu, ^{65}Cu, ^{85}Rb, ^{88}Sr, ^{137}Ba, ^{208}Pb were analysed at the Centre for Ore Deposits and Earth Sciences at the University of Tasmania (CODES).

Where possible, we chose samples that had two intact otoliths so that one from each pair could be analysed at CSL and the other at CODES, i.e. sister otoliths (from the same fish) were analysed at the two facilities. For stable isotope ratio analysis, the whole otolith was dissolved to determine an isotopic signal from the entire life of the fish whereas, for elemental concentrations, otoliths were prepared as thin sections along which material was ablated by laser at 4 positions (Figure 5.2), providing a chemical signal at particular stages in the fish's life, as follows:

Position 1) 10-20 days from the primordium (beginning of life);

Position 2) at the first inflection, when the fish was 30-40 days old,

Position 3) inside the margin, covering material deposited within 3 weeks of capture when, at around 40 cm FL, the fish were 3-4 months old;

Position 4) a replicate of point 1 but on the other side of the primordium.

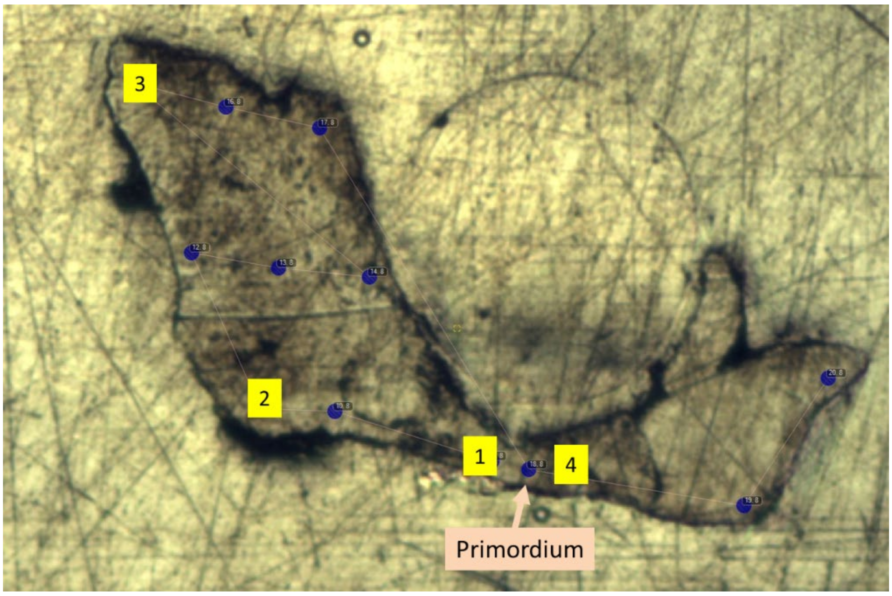

Figure 5.2. Positions of laser points 1-4, along otolith sections for measuring elemental concentrations.

Statistical analyses – otolith chemistry

Data from the stable isotope analysis and elemental composition analysis were investigated separately to determine whether differences existed between samples collected from different Fishery Management Areas (FMAs; see Figure 5.1), as well as those collected from the two outlier sites, Maldives and Solomon Islands. Note that for convenience, we refer to the Maldives and Solomon Islands as FMA 111 and FMA 999 respectively, even though they are not true FMAs. Initially, simple summary statistics and plots were used to look for broad patterns in the data and do a preliminary comparison amongst FMAs. Subsequently, univariate and multivariate statistical models were used to more formally compare data amongst FMAs.

For the elemental composition data, the distribution of values for most elements are right-skewed, so we log-transformed the data so they more closely follow a normal distribution (an assumption of the statistical analyses performed). Prior to looking for differences among FMAs, we first investigated how the data for each element compared between the four different otolith positions (using paired t-tests of equivalence, as well as calculating correlations), as this would guide how we proceeded with further analyses. The results showed significant differences in the data for almost all elements and positions, so in subsequent analyses, the element data were analysed for each otolith position separately.

Univariate analysis of variance (ANOVA) models were fit to the data from each stable isotope and element separately with FMA, season and their interaction as covariates. For the element data, the models were also fitted to the data from each otolith position separately. We ran the ANOVAs using (i) all FMAs, and (ii) leaving out the Maldives (FMA 111) and Solomon Islands (FMA 999) to see if differences existed within just the Indonesian archipelago.

Quadratic discriminant analyses (QDA) were also carried out on both the stable isotope and element data with FMA as the grouping variable. QDA is a type of classification analysis that is useful in determining whether a set of variables (in our case, either the stable isotope variables or the element variables) is effective in predicting group membership (i.e. which FMA a sample belongs to). QDAs were run for each species and season separately since the ANOVA results showed a significant season effect for both the stable isotope data and most elements in the elemental composition data, and for the elemental composition data, separate QDAs were also run for each otolith position. For the element data, we also ran QDAs using different subsets of elements to try and determine a set of elements that was most useful for distinguishing between FMAs; we used results from the ANOVAs, as well as correlations between elements, to help guide our choice of subsets to try. Thus, for the stable isotope data, 4 models were run (2 species x 2 seasons); whereas for the element data, 16 models were run (2 species x 2 seasons x 4 otolith positions) for each subset of elements tried. We used leave-one-out cross-validation to determine classification success rates. In order to determine how much better the classification success rate is than random (e.g., with only two areas, you would expect to classify 50% of the samples to the correct area simply by chance, even if the explanatory variables were not at all informative about area), we also randomized the FMAs and re-ran the QDAs, and we repeated this 1000 times.

We chose to use QDA rather than linear discriminant analyses (LDA) because LDA makes the assumption that the covariance matrices between groups (FMAs in our case) are equivalent, and in most cases this assumption was not met for our data based on Box's M-tests for homogeneity of covariance matrices (performed in R using the function *boxM* in package *biotools*).

For QDA, we needed to specify prior probabilities of a sample belonging to each FMA. Most commonly, either equal or proportional (i.e., proportional to the number of samples in each FMA) prior probabilities are assumed (noting that these would be the same if sample sizes were the same among all FMAs). Equal priors assume that a sample has an equal prior probability of belonging to any FMA, whereas proportional priors assume that a sample has a greater probability of belonging to an FMA with a larger sample size (which would be true if sampling was proportional to the population). Since sampling was not done in proportion to population size in our study, we used equal prior probabilities.

5.1.4 Methodologies: Genetics

Biopsies of white muscle were obtained from the YFT and BET, sampled close to the main dorsal fin and preserved in RNAlater® (Life Technologies) for shipment to laboratory for DNA extraction. Representative individuals from each of the sampling location and species were chosen from the total sample pool collected for the project (Table 5.1). Approximately 15mg of tissue was subsampled from these biopsies and used for DNA extractions. Total genomic DNA was isolated using one of two protocols; either a Machery Nagel Nucleo-Mag bead based DNA isolation kit or a CTAB protocol, a Phenol-

Chloroform based method described by Grewe *et al*. (1993). The bead based extractions were performed on an Eppendorf EP-Motion-5075 robotic liquid handling station. DNA aliquots were shipped to Diversity Array Technologies in Canberra where DNA complexity reduction and library construction was performed prior to sequencing that was used to generate genotype data for each individual.

Table 5.1. Locations and numbers of individual bigeye (BET) and yellowfin (YFT) chosen for the genetic analysis.

Sampling location	BET		YFT	
	2013	2014	2013	2014
Maldives	44	48	50	46
Padang	48	48	46	46
Palabuhanratu	48	48	46	46
Prigi	36	43	58	51
Ambon	48	48	46	46
Kendari	48	48	46	46
Gorontalo	48	1	46	88
Bitung	4	23	90	71
Sorong	31	48	63	46
Jayapura	16	34	78	60
Solomon Islands	48	48	46	46

For the genetic DNA profiling of each individual, we used the ddRAD approach protocols described in a report by Grewe et al. (2015) that successfully resolved population structure for yellowfin tuna among three sites sampled in the Pacific Ocean. The choice of this approach was based on recent analysis of yellowfin tuna populations that demonstrated the potential of new SNP (Single Nucleotide Polymorphisms) analysis techniques to reveal genetic differentiation over previously used techniques that lacked sufficient resolution (e.g. protein electrophoresis, mitochondrial DNA, and DNA microsatellites). While these latter techniques have merit for certain applications (e.g. species identification and examining individuals for close kin and gene tagging), they cannot match the resolution offered DNA profiling for population genetic analysis using SNP markers. The SNP genotype data was quality checked using the program RADIATOR (available on gitHUB) to eliminate poor quality loci and individuals. Two types of statistical analysis approaches were then used to examine the SNP genotype data including genetic distance from F_{ST}, and a newly published approach called stockR (Foster et al. 2018).

More detailed methodologies for the genetics analyses, including the DArTseq genotyping and genotype data analysis, will be provided in the stand-alone Population Structure Study Final Report (in prep).

5.2 FAD Fisheries Study

5.2.1 Review of earlier FAD studies in Indonesian waters

An original objective of the FAD Fisheries Study was to do an initial review of the current 'FAD situation' in Indonesian waters, as a first phase activity. However, early in the project it became clear that little information was readily available and that the planned enumeration program and field surveys would hopefully provide the necessary information. Also, there was recognition that there had been many earlier research studies linked to FADs in Indonesian waters, but that the outcomes of the majority of these earlier studies were only available in Bahasa Indonesia and were unpublished. The review part of the study subsequently morphed into creating a bibliographic compilation of abstracts (in both Bahasa

Indonesia and English versions for each study) of all known FAD studies that had been done in Indonesian waters. The identification of the earlier studies and sourcing of associated abstracts was done primarily by on-line literature searches (including library databases held by the research institutes within MMAF and those of Indonesian universities), and by direct enquiries (in person for some and via a letter of enquiry for many others) to the research institutes and universities.

5.2.2 Enumeration program at focus ports

Early discussions in the planning for the FAD Fisheries Study identified that establishing a daily enumeration program at multiple tuna landing ports, combined with port visits by the project's scientists, would be the best way of obtaining information on all aspects of the FAD-based fishery operations. Four ports were chosen for enumeration: Padang (West Sumatra), Palabuhanratu (West Java), Kendari (SE Sulawesi), and Sorong (West Papua) – see Figure 5.1. Their selection was based on geographical coverage (two ports in western Indonesia and two ports in eastern Indonesia) and on gear types. These 4 ports were considered appropriate for information gathering on all the key gears/vessel types that fish for tuna on FADs in Indonesian waters; purse-seine, pole and line, troll-line, and hand-line. Earlier visits to the ports for the sampling of the Population Structure Study afforded the opportunity to confirm their suitability for the enumeration.

Two enumerators were recruited at each port. Some of the recruits had prior experience as enumerators in other programs e.g. the Western Pacific and East Asia (WPEA) program of RCFMC/WCPFC, whereas others were new to fisheries monitoring. At one port, Palabuhanratu, the enumerators were existing staff of the port authority (*Pelabuhan Perikanan Nusantara Palabuhanratu*). In Padang, one of the recruits was staff of the local fisheries office (*Dinas Kelautan dan Perikanan Kota Padang*).

A sampling protocol (Proctor *et al.* 2018) and data collection sheets were developed, both as Bahasa Indonesia and English versions, in the months prior to the commencement of enumeration in October 2013. The sampling protocol was largely based on that developed for the WPEA program (Widodo et al. 2013), but with additions tailored to the FAD-based operations. As example, the enumerators were tasked with obtaining information from skippers at time of a vessel's return to port, on FAD types used, FAD locations, and numbers of FADs visited in the fishing trip. In-field training was provided by the project's scientists to the enumerators at each port. For the first year of the enumeration program, the enumerators submitted their completed data collection sheets (landings forms and biological sampling forms) to Jakarta via mail, for data entry by RCFMC staff.

An Oracle-Apex database, named the *FAD Fisheries Database* (*Database Perikanan Rumpon*), with internet-interface, was developed and established by project member Scott Cooper (CSIRO), with inputs from Indonesian counterpart, Bayu Sedana (RCFMC), and from Craig Proctor. The database provided both Bahasa Indonesia and English options and was designed to capture and validate all the information collected by the enumerators on the landings and biological sampling forms. A *Data Entry User Manual* was prepared and used as the basis for training delivered to the enumerators at the Enumerators Training Workshop in Bali in October 2014.

5.2.3 Preliminary bioeconomic/socio economic assessment

Data and information for the preliminary socio-economic survey were obtained in a total of 78 interviews with vessel owners and vessel captains; 60 in Kendari (SE Sulawesi) and 18 in Palabuhanratu (Sukabumi, West Java). The Kendari interviews were across 3 fleets: purse-seine (PS) - 31 respondents, pole and line (PL) - 17 respondents and hand-line/troll-line (HL/TL) - 12 respondents. All the Palabuhanratu interviews were for the HL/TL fleet.

The survey collected information on fishing costs, the characteristics of the vessel (size, engine type), fishing gear, crew size, catches, social aspects (age, education level, formal training, perception of ideal distance of FADs, other information), various aspects of FADs, fish prices, average revenue and the share-systems in operation.

Bio-economic modelling analysis was based on a simplified aggregated model for multispecies and multi-fleets fishery (Zulbainarni 2012). Biological analysis was done using a surplus production model developed by Schaefer (1957).

Cost, revenue and profit functions were estimated from the primary data and bio-economic models then compiled to yield estimates of static reference points (open access equilibrium, MSY, MEY). A comparison was then made between the existing level of fishing and associated profits and the level of fishing corresponding to maximum sustainable yield (MSY) and maximum economic yield (MEY). Economic analysis was based on fisheries economics and modelling by Arnason (2015). Stochastic frontier analysis followed a model developed by Batesse and Coelli (1995).

5.2.4 Trial acoustic and visual census of fish aggregations on FADs

The trials were conducted in areas located in the Eastern Indian Ocean (FAO area 57), south of the island of Java, approximately 50 – 300 nmi from the coastline. Depth range was 1,500 – 2,500 m. Three surveys were done during period August 2016 – December 2017, utilising 5 FADs in two different areas. First survey coincided with the southeast monsoon, while the second and third surveys coincided with the northwest monsoon.

The investigations were done on a small scale fishing vessel (HL/TL) of 14 m length, equipped with Multifrequency SIMRAD EY 60 and EK 80 scientific echosounder 38 (200 kHz), a conductivity, temperature, and depth mini logger, a M4i buoy trifrequency echosounder (Marine Instruments), and a 360° GoPro and Nikon Key Mission 360°.

Acoustic data were collected along a star survey pattern with eight branches, according to method of Josse *et al.* (1999) (Figure 5.3). Each branch was 1.2 nmi in length, without duplicate tracks and with nominal survey vessel speed of approximately 3 knots. The Elementary sampling units were defined by partitioning of the survey area into 45 degree angular sectors. Therefore, the survey areas were divided into eight horizontal strata with one branch per stratum. Depth categories included one 40 m layer for depths between 10 and 50 m, and nine 50 m layers from depths between 50 and 500 m.

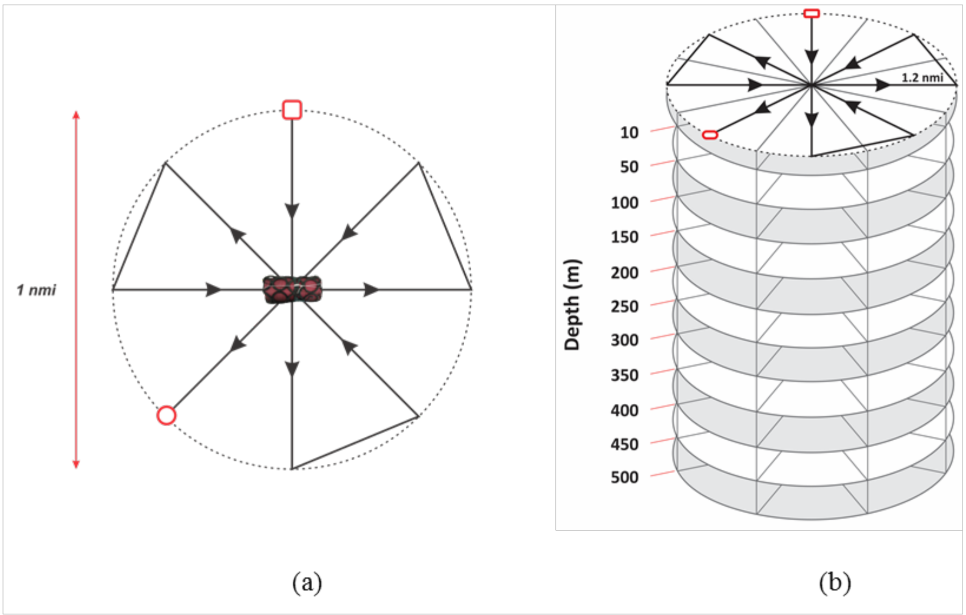

Figure 5.3. (a) Diagram illustrating the survey patterns used during acoustic surveys around FADs; (b) Stratification of survey area. (Modified from Josse et al. 1999).

S_A values corresponding to fish density around FADs were observed based on vertical (depth) and horizontal (distance from FAD) strata. Fish aggregations were not characterized by shape and assemblages criteria. Ground truth validation was only possible down to 30 m depth using GoPro 360° or Nikon Key Mission 360°. Where fish aggregations were detected the GoPro 360° or Nikon Key Mission 360° were set with consideration of the current direction and practical condition of wire. Environment data were collected using CTD (*mini logger*).

6 Achievements against activities and outputs/milestones

Objective 1: To define the population structures of yellowfin tuna (YFT) and bigeye tuna (BET) in Indonesia's archipelagic waters and connectivity to populations in adjoining regions

No.	Activity	Outputs/ milestones	Completion date	Outputs realised
1.1	Sampling of YFT and BET at locations across Indonesian archipelago and at locations outside of Indonesian waters	Two rounds of sampling. Samples collected and transferred to either RIMF or to CSIRO (Hobart)	July 2014	Overall, the two rounds of sampling at the 11 sampling locations were achieved successfully, providing sufficient samples for the 3 techniques: • Round 1 sampling in April – June 2013; • Round 2 sampling in May – July 2014; • 11 Indonesian scientists from 4 research institutes, and 3 CSIRO scientists participated in the two rounds of sampling; • A total of 3536 fish were sampled (2,229 YFT, 1,307 BET) for muscle tissue, otoliths, and viscera for parasites; • Target of 100 fish per species was difficult to achieve for BET at some of the eastern Indonesia locations and in the Maldives.
1.2	Parasite investigations on YFT and BET	Initial parasite characterisation complete. Training delivered to RIMF scientist(s).	Nov 2014	Initial training delivered by Prof. Robert Lester (University of Queensland) to Ms Pratiwi Lestari (scientist of RIMF) and 3 other scientists (1 RIMF, 2 RIFEC) on dissection methodologies and identification of parasites of gills, viscera and liver in juvenile YFT and BET: • Training at RIMF 25 – 28 Nov 2012; • Training at RIMF 26 Feb – 1 Mar 2013. Ms Lestari received 3 weeks of training at University of Queensland in Nov 2014, in morphological (through staining) and molecular (through DNA sequencing) validation of parasite species identification. Training was delivered by Prof. Lester, Dr Tom Cribb, Dr Scott Cutmore., and Mr Russell Yong.
		Investigations completed for parasites on all samples or representative subsets of samples (dependent on number of types and infestation levels of parasites encountered. (A & *PC)*	April 2016	Dissections were successfully completed on a subset of Round 1 (2013) and Round 2 (2014) samples for both species. Gills and viscera from a total of 1,203 YFT and 768 BET were examined and parasites identified and counted by Ms Lestari. She had occasional dissection assistance from other RIMF scientists, Ms Pustika Ratnawati, Ms Wahyuni Nasution, Ms. Arlini Batubara and Ms. Atiah. The dissections were on hold for a period of about 4 months in 2015 when Ms Lestari was on maternity leave. Also, dissections on Round 2 samples from Solomon Islands were delayed by the samples requiring to be transferred from CSIRO Brisbane to RIMF in Jakarta.

		Report on outcomes of parasite investigations completed. (A & *PC)*.	June 2017	• The Parasites team produced their draft final report in June 2017. This was preceded by progress reporting at the Project Coordination Meetings in April 2014, March 2015, Feb 2016, and the Data Assessment Workshop in Nov 2016. Draft final report was revised and finalised in Jan 2018; • During 2015, Ms Lestari and scientists at UQld produced a Didymozoid identification guide, based on the parasites isolated from YFT and BET; • Ms Lestari also led production of the first paper: Lestari, P., Lester, R., and Proctor, C. (2016) ***Symbionts of bigeye and yellowfin tuna as potential stock markers for tuna in Indonesian archipelagic waters***, which was submitted to the WCPFC SC Meeting in Aug'16: WCPFC-SC12-2016-ST-IP-05; • A second paper was published in 2017: Lestari, P., Lester, R., and Proctor, C. (2017). *Parasites as potential stock markers for tuna in Indonesian waters.* Ind. Fish. Res. J. 23 (1): 23 – 28.
1.3	Otolith chemistry investigations on YFT and BET	Training delivered and preparations completed on a subset of the location samples. *(A and PC)*	April 2015	Two rounds of training were provided for otolith chemistry trainee, Mr Arief Wujdi (RITF) at CSIRO Hobart; 6 weeks in Feb – March 2014, and 8 weeks in Feb – April 2015. Training was done at CSIRO and at Central Science Laboratory (CSL) and Centre of Excellence in Ore Deposits (CODES), Uni. Tasmania. Training included otolith cleaning and archiving for solution-based stable isotope analyses, trace element analyses, otolith imaging analysis and digital labelling, otolith measurement and weighing, database entry, otolith embedding in resin, sectioning, grinding and polishing, mapping sampling points in LA-ICP-MS.
		Pilot analyses completed and results assessed. *(A and PC)*	Feb 2014	Pilot analyses successfully completed. Eight 'batches' of samples (total 280 otoliths) were analysed for stable isotopes and trial analyses on Round 1 samples for trace elements, with laser ablation ICP-MS, were done.
		Preparations complete on second year otolith samples and remaining first year samples, for both tuna species. Otolith chemistry analyses completed.*(A and PC)*	June 2017	• Analyses for ^{18}O and ^{13}C isotopes at CSL, UTas, completed. Target of analyses on a minimum of 25 otoliths per sampling location (for both YFT and BET) achieved; • Analyses of element characterisations using laser ablation ICP-MS at CODES, UTas, were completed. Target of analyses on a minimum of 20 otoliths per sampling location (for both YFT and BET) achieved, except for a few sites where 20 BET were unavailable. • Mr Wujdi participated in the specimen preparations and analyses during his two training visits to Hobart. He also took on and completed the task of producing an *Otolith Proportion Index* for all otoliths analysed for stable isotopes; • The period of analyses ended up longer than expected due to the time consuming and complicated preparation time required for laser ablation analyses. A contributing factor was also Mr Wujdi's unavailability to assist in preparations, outside of the periods of his training visits.
		Report on outcomes of otolith chemistry completed. (A & *PC)*.	Jan 2018	Final draft of final reporting for the otolith chemistry was completed in Jan 2018. This was preceded by progress reporting at the Project Coordination Meetings in April 2014, March 2015, Feb 2016, and the Data Assessment Workshop in Nov 2016.

1.4	Genetics investigations on YFT and BET	Training delivered and preparations and analyses completed on a subset of the location samples. *(A and PC)*	April 2015	• Two rounds of training were provided for genetics trainee, Mr Muhammad Taufik (RIMF) at CSIRO Hobart; 6 weeks in Feb – March 2014, and 8 weeks in Feb – April 2015; • Training included manual DNA extraction techniques including CTAB, Qiagen DNAeasy, robotic DNA extraction using Machery Nagel mag bead system on Eppendorf EPmotion, targeted DNA amplification using PCR, DNA sequencing using ABI BigDye terminators and ABI-3730 capillary electrophoresis, analysis of DNA by Agarose Gel electrophoresis, DNA sequence Data Analysis using DNAstar software, and database management of sample meta-data.
		Pilot genetics analyses completed and results assessed. *(A and PC)*	July 2014	DNA extractions were done on the muscle tissue samples from 1056 fish. Subsequent good progress on developing quality DNA markers for mtDNA and PCR primers for DNA microsatellites. The preliminary results obtained were assessed for Restriction-site Associated DNA (RAD tags) and single nucleotide polymorphisms – SNPs for a subset of the sampling locations.
		Genetics analyses on second year samples and remaining first year samples completed. *(A and PC)*	May 2016	• DNA extractions DArT analyses completed on Round 1 and Round 2 samples (a total of 1305 YFT and 1306 BET); • Focus devoted to mtDNA SNPs for species ID confirmations (i.e. YFT v BET); • Developed quality controls of the SNP-DArT data, to identify samples with poor genotype quality and also possible mislabelled/misidentified fish.
		Report on outcomes of genetics investigations completed. (A & *PC)*.	Jan 2018	Analyses, once completed, formed a very large data set. This required drawing on expertise outside of the project to identify the appropriate software package and statistical methodologies for the SNP-DArT data. Inputs were provided by statistician Dr Scott Foster (CSIRO Hobart) and Dr Thierry Gosselin (Institute for Integrative Biology and Systems, Laval University, Quebec, Canada). Preliminary reporting: • Paper submitted to Scientific Committee Meeting of WCPFC, Bali, Aug'16: *Population structure and provenance of tropical tunas: recent results from high throughput genotyping and potential implications for monitoring and assessment.* Authors: P. M. Grewe*, Taufik, M.*, Wujdi, A.*, Lestari, P.*, H. E. Irianto*, C. H. Proctor*, K. Schafer, D. Itano, A. Killian, C. R. Davies*, WCPFC-SC12-2016-SA WP-01. **Members of this project.* • Oral presentation given by Ms Pratiwi Lestari at the Australian Marine Sciences Association Conference, Darwin, 3 – 6 July'17: Lestari et al. (2017) *A multi-technique investigation of population structure of tunas in Indonesian archipelagic waters.*
1.5	Overall assessment of population structures - comparison of outcomes from each technique. *(A and PC)*	Final Report completed. *(A and PC)*	Feb 2019	

		Completion of a scientific paper comparing the outcomes of the three techniques *(A & PC)*	E: May 2019	
1.6	Extension materials. *(A and PC)*	Completion of extension materials e.g. manuals, for each technique. *(A and PC)*	Dec 2017	• The sampling protocol for this study, prepared in 2013 – 2014, has been used as 'model' for sampling protocol for the IOTC/FAO funded multi-agency, multi-national Indian Ocean stock structure project (*Population Structure of IOTC species and sharks of interest in the Indian Ocean: Estimation with Next Generation Sequencing Technologies and Otolith Micro-chemistry*); • A training video on the sampling protocol for the population structure study is complete. • Appendix 12 for this population structure study includes detailed descriptions of the methods used in specimen preparation, analyses, and data processing for the three techniques.
1.7	Capacity development (other)		Nov 2017	In Sept 2015, the project was fortunate in engaging RITF scientist Ms Ririk Sulistyaningsih as a John Allwright Fellowship recipient, for her Masters of Applied Sciences at Uni.Tasmania (Jan 2016 – Nov 2017). Ms Sulistyaningsih did her 2nd year i.e. research project year, of her Masters at CSIRO Hobart, on a project with direct application to this project's population structure study Her project centred around otolith shape analysis and used the otoliths of YFT and BET collected by this ACIAR project.

PC = partner country, A = Australia; E = Estimated

Objective 2: To assess and characterise Indonesia's tuna fisheries that are based around Fish Aggregating Devices (FADs)

No.	Activity	Outputs/ milestones	Completion date	Outputs realised
2.1	Review of existing information on FADs and FAD-based fisheries in Indonesian waters. *(A and PC)*	Country Report (status report) on Indonesian FAD pelagic fisheries. *(A and PC)*	Jan 2018	Early in the project, the proposed Country Report changed to a bilingual bibliography of earlier FAD-related research done in Indonesian waters. Approximately 116 abstracts of earlier studies were collected through literature searches, visits and letter requests to universities and fisheries colleges, and requests to research institutions. The process of collation was time consuming and the majority of abstracts required translation from Bahasa Indonesia to English. *Natsir, M., Proctor, C., Wudianto, Nurdin, E., Sadiyah, L., Taufik, M. and Hargiyatno, I.T. (2017). A collection of abstracts of FAD fisheries research in Indonesia. A publication of Australian Centre for International Agricultural Research Project FIS/2009/059. Center for Fisheries Research. Agency for Marine and Fisheries Research and Human Resources. Jakarta. 308pp.*

2.2	Trial monitoring program for the FAD-based fisheries at 4 select ports. *(A and PC)*	Training provided, protocols developed, and monitoring program trials commenced at the select ports.	Oct 2014	• Enumeration was established at the 4 focus ports – Sorong (West Papua), Kendari (SE Sulawesi), Padang (West Sumatra) and Palabuhanratu (West Java); • 2 enumerators were recruited for each port and training delivered by RCFMC/RIMF and CSIRO scientists, on location in Oct – Nov 2013; • Further training delivered in an Enumerators Training Workshop at Research Institute for Tuna Fisheries, 21 – 23 Oct 2014; • A *Port Sampling Protocol for FAD Fisheries Study* was prepared during Aug – Sep 2013 and used as the primary resource for the training (and as ongoing extension material).
		Database created and functioning as central repository for the data collected by the program. *(A and PC)*	Sep 2014	• An Oracle-Apex database, named the *FAD Fisheries Database* (*Database Perikanan Rumpon*), with internet-interface, was developed and established by project member Mr Scott Cooper (CSIRO), with inputs from Indonesian counterpart, Mr Bayu Sedana (RCFMC), and from Mr Craig Proctor. The database provided both Bahasa Indonesia and English options; • The database was designed to capture all the information collected by the enumerators on the Landings and Biological Sampling forms; • A *Data Entry User Manual* was prepared and used as the basis for the training at the Enumerators Training Workshop in Oct 2014.
		Monitoring program fully operational and data collected over 12 – 24 month period. *(A and PC)*	Dec 2016	• The enumeration program ran for more than a year longer than originally planned, at 2 of the 4 ports, Palabuhanratu and Kendari, achieving 39 months of continuous daily enumeration; • The project's program ceased in May 2017, only because of the Indonesian Government's introduction of a "One Data" program with standardisation of fisheries enumeration across the nation; • Enumeration at Padang and Sorong experienced several issues around personnel and accessibility to landings, but did achieve useful landings records over the first 15 - 16 months; • During the first 12 months of the program, data entry was done at RCFMC by data entry by two staff, Ms Okta and Dr Puji Rahmadi, from the hard-copy Landings Forms submitted from the 4 ports; • Following provision of laptops and training at the Enumerators Training Workshop in Oct'17, the enumerators commenced self-data entry, direct into the database; • 2,564 vessel trips surveyed (all 4 ports), over the enumeration period, to end of 2016; • 48,368 fish (tunas and bycatch species) measured.

2.3	Preliminary bioeconomic, fishing capacity, and risk assessments. *(A and PC)*	Preliminary assessments of bioeconomic, fishing capacity, and risk completed for the FAD fisheries (for each gear type). *(A and PC)*	Jan 2018	• 60 skipper/vessel owner interviews completed at Kendari (SE Sulawesi), across 3 gear types: purse-seine, hand-line/troll-line, and pole and line; • 18 skipper/vessel owner interviews completed at Palabuhanratu, for hand-line/troll-line; • Planned papers and conference presentation.
2.4	Training workshop for bioeconomic, fishing capacity, and risk assessments. *(A and PC)*	Training workshop conducted for a target group larger than project members, including both RCFMC/RIMF and DGCF participants *(A and PC)*		A decision was made at the Project Coordination Meeting in Feb'16 not to proceed with this proposed training workshop. The capacity development in the bio-/socio-economic area was considered still important but a higher priority had arisen. There was consensus that the project should concentrate on the Harvest Strategy development for the tuna fisheries and the associated training. The training in the area of bio-/ socio-economic assessment of fisheries was subsequently ear-marked as an appropriate capacity development activity of follow on project FIS/2016/116.
2.5	Extension materials. *(A and PC)*	Extension materials, including manuals on sampling strategies, database construction, course notes. *(A and PC)*	Dec 2017	• The *Port Sampling Protocol for FAD Fisheries Study* and *Data Entry User Manual* are the two primary extension materials from the FAD fisheries study; • A video (length 7.5 mins) was produced, in Bahasa Indonesia, to illustrate the sampling procedures for genetics, otoliths, and parasites; • Fish ID website (www.fishIDER.org), under development within an ACIAR Small Research Activity Projects (SRA/2016/048, SRA/2018/116) is aimed at improving fish identification skills of enumerators and observers, and is a direct outcome of this tuna project. As such we view it as extension material.
2.6	Capacity development in fisheries research.	Opportunities provided by FAD-fisheries study utilised for capacity development for Indonesian scientists in areas of tropho-dynamics, reproductive biology, fish ageing and spatial dynamics.	Dec 2017	• The project continued to assist in the establishment of an otolith prep./fish ageing lab at Research Institute for Tuna Fisheries (Bali); • Trials of acoustics research on FADs on fish aggregations were completed, using the m4i acoustic buoy and SIMRAD EK sounder purchased by the project during 2015. Mr Andria Utama, who led the team for these trials, presented the preliminary results to the Project Coordination Meeting in Bali in Nov'16. The trials were to lay foundation for more targeted research to address key questions about fish behaviours around the FADs, including 'recovery' time of aggregations following purse-seine sets; a key question to be answered for improved management; • The project supported participation by three RCFMC/RIMF scientists in training provided by SIMRAD Fish Research (Kongsberg Maritime, Norway) for use of the Simrad acoustic equipment, 8 – 10 April 2015, in Jakarta.

PC = partner country, A = Australia

Objective 3: To communicate the project's objectives, findings and recommendations to stakeholders

No.	Activity	Outputs/ milestones	Completion date	Outputs realised
3.1	Extension materials	Brochures, posters, newsletters, dvds produced to disseminate project's activities and sustainability goals to local fisher communities.	Dec 2017	• This is one area of project activity in which our outputs did not match the level of our original plans; • At the various project coordination meetings through the course of the project there was 'brainstorming' about what we could produce in the way of short videos, with minimal text and perhaps in cartoon format, and/or infographics to deliver the messages of sustainable fisheries to fishers, fishing companies, and other fisheries stakeholders; • .There was regular discussion about holding a sustainable fisheries 'expo' at one or more key fishing ports, perhaps in association with Indonesia's *National Fisherman's Day* (early April), or *World Tuna Day* (2 May). However, this did not eventuate. It is still considered an idea worth pursuing.
3.2	Meetings with local fishing communities. *(A and PC)*	Delivery of information on project details and sustainability goals to fisher communities in 1. the nine Indonesian ports sampled for population study, and 2. the four ports used as base for trial FAD-fisheries monitoring program.	Dec 2017	• Several formal stakeholder meetings were held during the course of the project. These meetings are included in the list of oral presentations in Section 7.3. By "formal" we mean meetings arranged before the meeting itself and with formal invitation process and meeting agenda (including Powerpoint presentations); • In addition to the abovementioned formal meetings, we had many informal, opportunistic meetings with local fishers, fishing companies, local fisheries authorities, and port authorities. Many of these discussions occurred during the period of the two rounds of sampling for the population structure study, and also during the establishment phase of the enumeration program for the FAD fisheries study; • The formal and informal meetings were opportunities for delivering information about the project's objectives and progress, but also for obtaining information about the fishing activities, fishing 'behaviours', and factors impacting on the fisheries.

3.3	Engagement with the RFMOs.	Active participation in the RFMO forums (e.g. annual Scientific Committee meetings)	Nov 2017	• Engagement with WCPFC through the Harvest Strategy (HS) development workshops for Indonesia's tuna fisheries, with particular focus on FMAs 713- 717. This included 4 Technical HS Workshops and 7 Stakeholder HS Workshops between Oct 2014 and Nov 2017 (all workshops were 2 – 3 days). The project made key contributions at all these workshops, including the data from the FAD Fisheries Study being considered one of the important datasets for assessment of the fisheries. Project member Campbell Davies also played a key role in leading the HS process; • Engagement with the RFMOs indirectly through FADs management discussion workshops in Feb 2017 (Bali) and Oct 2017 (Bogor); • Paper submitted to the WCPFC Scientific Committee Meeting in Bali, Aug'16: Widodo, A.A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I.T., and Cooper, S. (2016) *Characteristics of tuna fisheries associated with Indonesian anchored FADs in waters of the West Pacific and the Indonesian archipelago.* Submitted to the 12th Scientific Committee Meeting of Western and Central Pacific Fisheries Commission, Bali, 3 – 11 August 2016. WCPFC-SC12-ST-IP-06. 19pp. • Also, paper presented to the IOTC Working Party on Tropical Tunas in Nov'16: Widodo, A.A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I.T., and Cooper, S. (2016) *Characteristics of tuna fisheries associated with anchored FADs in the Indonesian Fisheries Management Areas 572 and 573 in the Indian Ocean.* Submitted to the Indian Ocean Tuna Commission 18th Working Party on Tropical Tunas, Seychelles, 5 – 10 November 2016. IOTC-2016-WPTT18-29. 15pp.

PC = partner country, A = Australia

7 Key results and discussion

The results and discussion in this Section are presented as summaries to keep within the space limits defined in the Final Report guidelines. Additional information for some of the subsections is provided in the Appendices 1 - 4 The full results for the *Population Structure Study* and the *FAD Fisheries Study* are available as stand-alone final reports (Proctor et al. 2019a, 2019b).

7.1 Population Structure Study

7.1.1 Fish sampling

The original target for the sampling of this study was 100 YFT and 100 BET from each of the 11 sampling locations in the size range 25 – 50 cm FL. The size frequencies for the fish sampled and the numbers of fish sampled in both rounds of sampling (2013 and 2014) are provided in Table 7.1. For YFT this target was achieved, and in many cases surpassed (> 100 fish), at almost all locations in both rounds of sampling. Among the few cases where less than 100 YFT were sampled, the minimum was 73 (in Maldives in 2013). Achieving the target of 100 fish sampled for BET proved far more difficult than for YFT, at many of the 11 locations. Only on 4 of the 22 sampling visits to ports, across the two rounds of sampling, was the target fully achieved, with several of the locations in eastern Indonesia proving particularly difficult (e.g. Bitung in 2013 and Gorontalo in 2014, with less than 5 BET able to be sampled).

Table 7.1. Numbers (n) of fish sampled for this study, by species and by year, for each sampling location.

BET		**2013**	**2013**	**2014**	**2014**
Location	**Place**	**Length**	**n**	**Length**	**n**
1	Padang	32.5 - 40.0	124	30.0 - 50.0	97
2	Palabuhanratu	30.0 - 41.0	102	29.0 - 43.5	103
3	Prigi	28.0 - 42.0	36	30.5 - 45.0	43
4	Kendari	30.0 - 54.5	52	38.5 - 49.0	93
5	Gorontalo	34.5 - 58.5	68	46.0	1
6	Bitung	33.5 - 46.5	4	39.5 - 49.0	23
7	Ambon	32.0 - 48.5	57	39.0 - 47.0	60
8	Sorong	39.0 - 48.0	100	37.0 - 51.0	71
9	Jayapura	33.0 - 49.0	17	38.0 - 50.0	35
12	Maldives	34.0 - 43.5	44	26.0 - 62.0	49
13	Solomon Is.	35.0 - 48.5	75	38.0 - 54.0	52
YFT		**2013**	**2013**	**2014**	**2014**
Location	**Place**	**Length**	**n**	**Length**	**n**
1	Padang	30.0 - 40.0	102	30.5 - 47.0	102
2	Palabuhanratu	29.5 - 43.0	102	30.0 - 46.5	100

3	Prigi	29.0 - 42.0	97	27.0 - 46.5	106
4	Kendari	30.5 - 50.0	100	34.5 - 47.5	105
5	Gorontalo	30.5 - 44.5	100	29.0 - 49.5	88
6	Bitung	29.0 - 56.0	100	29.5 - 48.0	104
7	Ambon	31.5 - 44.5	100	38.0 - 47.0	104
8	Sorong	36.5 - 44.0	100	39.0 - 50.0	106
9	Jayapura	31.0 - 42.5	100	34.0 - 47.0	108
12	Maldives	30.0 - 45.0	73	20.5 - 49.0	112
13	Solomon Is.	31.0 - 45.5	99	32.5 - 50.5	122

Eleven Indonesian scientists, from 4 research institutes (CFR, RIMF, RITF, RIFEC) within AMAFRHR participated in the sampling for this project and for many it was their first experience with collecting samples for genetics and with extraction of otoliths.

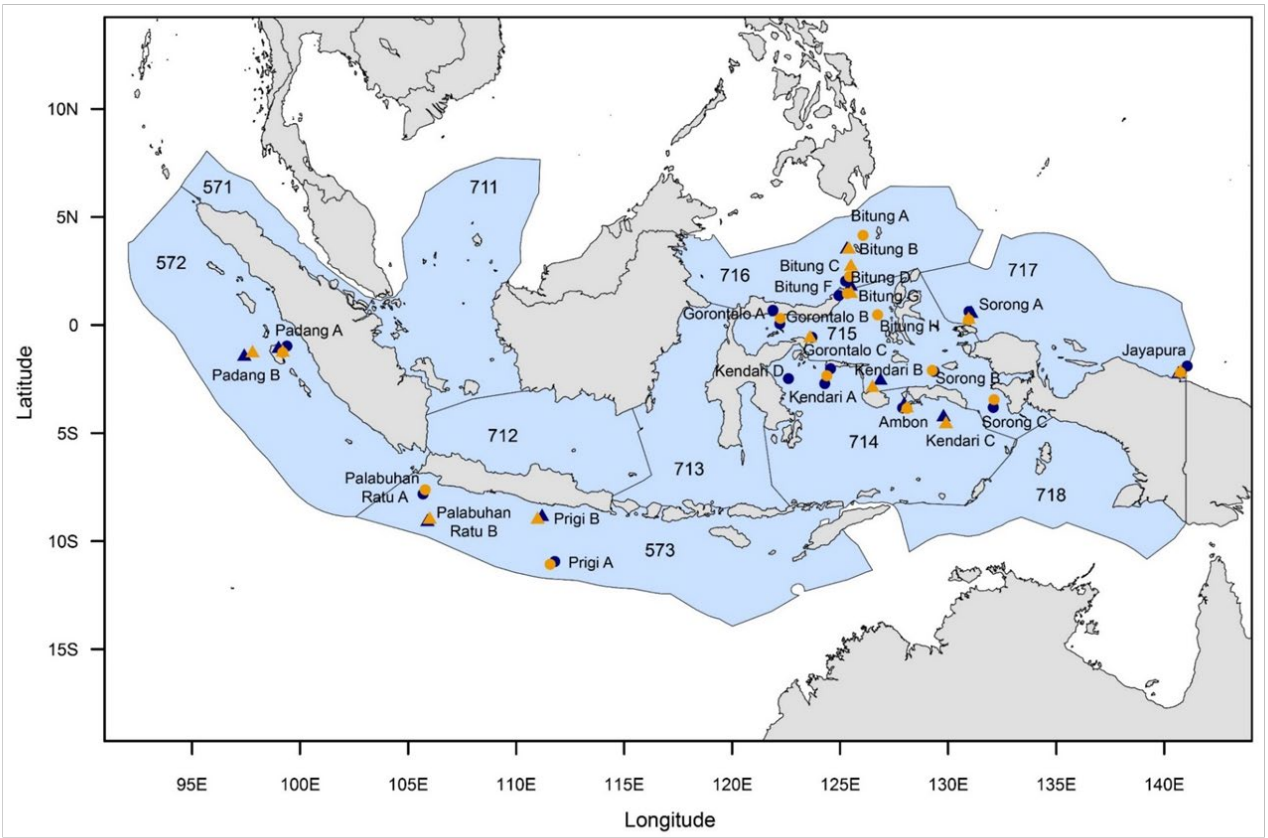

Figure 7.1. Map of Indonesia showing the 'as best known' locations of the catch locations of fish sampled from Indonesian waters. Blue = BET, orange = YFT. Circles = 2013, triangles = 2014. Numbered blue shaded zones are the eleven Fisheries Management Areas.

The approximate catch locations (based on best available information from persons from whom the fish were sourced) of the fish sampled in this project are shown in Figure 7.1.

Direct age estimates

Direct age estimates were made by counting daily increments on otolith sections. For the 9 BET that were chosen for daily ageing, fish lengths were 40-42 cm (approximating the length range chosen for elemental chemistry and stable isotope analysis) and the mean age was 135 days, or 4.5 months (see Table 7.2). For the 10 YFT, fish lengths were 39-41 cm and the mean age was 118 days, or 3.9 months. The larger BET were 56.5 and 58.5 cm and aged at 234 days and 159 days respectively. The larger YFT were 53 cm and 56 cm and were aged at 205 days and 233 days.

Table 7.2. Samples from which daily age counts were made, daily age estimates and back-calculated spawning dates.

	Species	LCF (cm)	Sampling date	Sampling location	Increment count (days)	Age (months)	Back-calculated spawning date
1	YFT	39	30/04/2013	Padang	107	**3.6**	13/01/2013
2	YFT	40	29/04/2013	Padang	108	**3.6**	11/01/2013
3	YFT	40	30/04/2013	Sorong	137	**4.6**	14/12/2012
4	YFT	40	30/04/2013	Sorong	113	**3.8**	7/01/2013
5	YFT	40	30/04/2013	Sorong	111	**3.7**	9/01/2013
6	YFT	53	30/04/2013	Bitung	205	**6.8**	7/10/2012
7	YFT	56	30/04/2013	Bitung	233	**7.8**	9/09/2012
8	YFT	40	24/06/2014	Padang	116	**3.9**	28/02/2014
9	YFT	40	25/06/2014	Padang	115	**3.8**	2/03/2014
10	YFT	40	25/06/2014	Padang	122	**4.1**	23/02/2014
11	YFT	40	17/06/2014	Sorong	117	**3.9**	20/02/2014
12	YFT	40	12/06/2014	Jayapura	130	**4.3**	2/02/2014
13	BET	41	3/05/2013	Sorong	132	**4.4**	22/12/2012
14	BET	41	4/05/2013	Palabuhanratu	124	**4.1**	31/12/2012
15	BET	41	30/04/2013	Sorong	146	**4.9**	5/12/2012
16	BET	42	25/04/2013	Prigi	143	**4.8**	3/12/2012
17	BET	57	25/04/2013	Gorontalo	159	**5.3**	17/11/2012
18	BET	59	25/04/2013	Gorontalo	234	**7.8**	3/09/2012
19	BET	40	23/06/2014	Padang	137	**4.6**	6/02/2014
20	BET	40	23/06/2014	Padang	136	**4.5**	7/02/2014
21	BET	40	25/06/2014	Padang	130	**4.3**	15/02/2014
22	BET	41	24/06/2014	Ambon	147	**4.9**	28/01/2014
23	BET	41	17/06/2014	Sorong	129	**4.3**	8/02/2014

7.1.2 Technique 1: Parasites

Team personnel: Ms Pratiwi Lestari (RITF), Dr Brad Moore (SPC/UTas), Dr Scott Cutmore (UQ), Prof Robert (Bob) Lester (UQ).

A total of 767 BET and 1,197 YFT were dissected for parasites over the duration of the project. Eleven parasite species or species complexes were identified (Table 7.3) based on morphology in the two tuna species, of which nine (seven didymozoids and two acanthocephalans) were considered suitable for use as long-term biological tags. The two omitted were the copepod *Hatschekia* sp. and the digenean *Hirudinella* sp. They were considered to have possibly short residence times in the fish and therefore might be lost as fish moved from one area to another. Didymozoids were considered to be permanent parasites. They were observed within the tissues of the fish and hence were not easily dislodged. Though some didymozoids are known to be lost annually or at spawning, the tuna sampled were generally no more than 6 months old and immature so it was assumed no didymozoids had been lost.

Table 7.3. Parasites encountered in juvenile bigeye tuna (BET; *Thunnus obesus*) and yellowfin tuna (YFT; *Thunnus albacares*).

Host	Code for analysis	Component	Tentative identification	Site of infection
BET	*Didymocystis bifurcata*	Y	*Didymocystis bifurcata*	Gill filament
	Didymozoon longicolle	Y	*Didymozoon longicolle*	Gill filament
	Didymosulcus type 3	N	*Didymocystis* sp. 1	Gill arch
	Koellikeria type 1	Y	*Wedlia globosa*	Stomach wall
			Wedlia sp. 1	Stomach wall
	Koellikeria type 2	N	*Wedlia* sp. 2	Liver
	Koellikeria type 3	Y	*Coeliotrema thynni*	Pyloric caeca
	Koellikeria type 4	Y	*Koellikeria* sp. 1	Intestinal wall
	Hatschekia sp.	N	*Hatschekia* sp.	Gill
	Hirudinella sp.	N	*Hirudinella ventricosa*	Stomach
	Bolbosoma sp.	Y	*Bolbosoma* sp.	Gut wall
	Rhadinorhynchus sp.	Y	*Rhadinorhynchus* sp.	Gut wall & intestine
YFT	*Didymocystis bifurcata*	Y	*Didymocystis bifurcata*	Gill filament
	Didymozoon longicolle	Y	*Didymozoon longicolle*	Gill filament
	Didymosulcus type 3	N	*Didymocystis* sp. 1	Gill arch
	Koellikeria type 1	Y	*Wedlia bipartita*	Stomach wall
			Wedlia bipartita	Stomach wall
			Wedlia orientalis	Stomach wall (small)
			Wedlia globosa	Stomach wall (large)
	Koellikeria type 2	N	*Wedlia* sp. 2	Liver
	Koellikeria type 3	Y	*Wedlia pylorica*	Pyloric caeca
			Wedlia pylorica	Pyloric caeca
			Wedlia pylorica	Pyloric caeca
			Wedlia pylorica	Pyloric caeca
	Koellikeria type 4	Y	*Koellikerioides*	Intestinal wall
			Koellikerioides	Intestinal wall
			Koellikeria sp. 1	Intestinal wall
	Hatschekia sp.	N	*Hatschekia* sp.	Gill
	Hirudinella sp.	N	*Hirudinella ventricosa*	Stomach
	Bolbosoma sp.	Y	*Bolbosoma* sp.	Gut wall
	Rhadinorhynchus sp.	Y	*Rhadinorhynchus* sp.	Gut wall & intestine

The results of the univariate analysis of individual parasite species/species type and multivariate analysis of parasite community assemblages are summarised below. Select figures and tables for more detail of these results are provided in Appendix 1. The complete description of the results will be presented in the population structure study's stand-alone final report (in prep)[8]:

- BET and YFT from the Maldives appeared different to those from the eastern Indian Ocean FMAs (FMAs 572 and 573), owing to significantly higher abundances and a higher prevalence of *Didymozoon longicolle* in Maldives fish (Figure 7.2);

[8] The results of the parasites component of the population structure study are also close to publication in a paper submitted to and accepted by ICES Journal of Marine Science: Moore, B.R., Lestari, P., Cutmore, S.C., Proctor, C., and Lester, R.J.G. (2019) Movement of juvenile tuna deduced from parasite data.

- BET and YFT from the Solomon Islands appeared different to those from neighbouring Indonesian FMAs (FMAs 714, 715, 716 and 717). This was evidenced by significantly lower abundances of *D. longicolle* in 2013 samples of both tuna species compared to most Indonesian FMAs, significantly higher numbers of this parasite in 2014 samples of both tuna species relative to the Indonesian FMAs (Figure 7.2), significantly higher abundances and greater prevalence of *Bolbosoma* sp. in Solomon Is. samples of both tuna species in 2014, and significantly higher abundances of *Didymocystis bifurcata* in BET samples from 2014;
- Within Indonesian waters, both BET and YFT from the eastern Indian Ocean FMAs (FMAs 572 and 573) had significantly lower numbers (both abundance and prevalence) of *D. longicolle* compared to those from within the archipelago, suggesting little movement of both tuna species from the archipelago to the Indian Ocean (Figure 7.2);
- Both BET and YFT from FMA 717, and particularly those sampled near Jayapura near the eastern-most boundary of this FMA, had consistently higher numbers (both abundance and prevalence) of *D. longicolle* compared to fish sampled within the Indonesia archipelago. In addition, both BET and YT had sampled from FMA 717 in 2013 had greater numbers of *Koellikeria* type 4 than those from within the archipelago. Combined, these results suggest both BET and YFT from FMA 717 had experienced a different history to those from within the archipelago;
- A greater number of differences in parasite fauna between FMAs were observed for YFT than for BET, suggesting YFT may be more site attached than BET;
- Differences within FMAs were observed. The most striking differences occurred in YFT from FMA717 between Sorong 'A' at the western limit and Jayapura in the east. Samples collected near Jayapura had very high numbers of *D. bifurcata*, *D. longicolle*, *Koellikeria* types 1, 3 and 4 and *Bolbosoma* sp. compared to Sorong 'A', with these latter samples appearing more analogous to those from within the archipelago. Differences were evident in BET but were less marked. This result suggests that even within this FMA considerable group fidelity had occurred in both species.

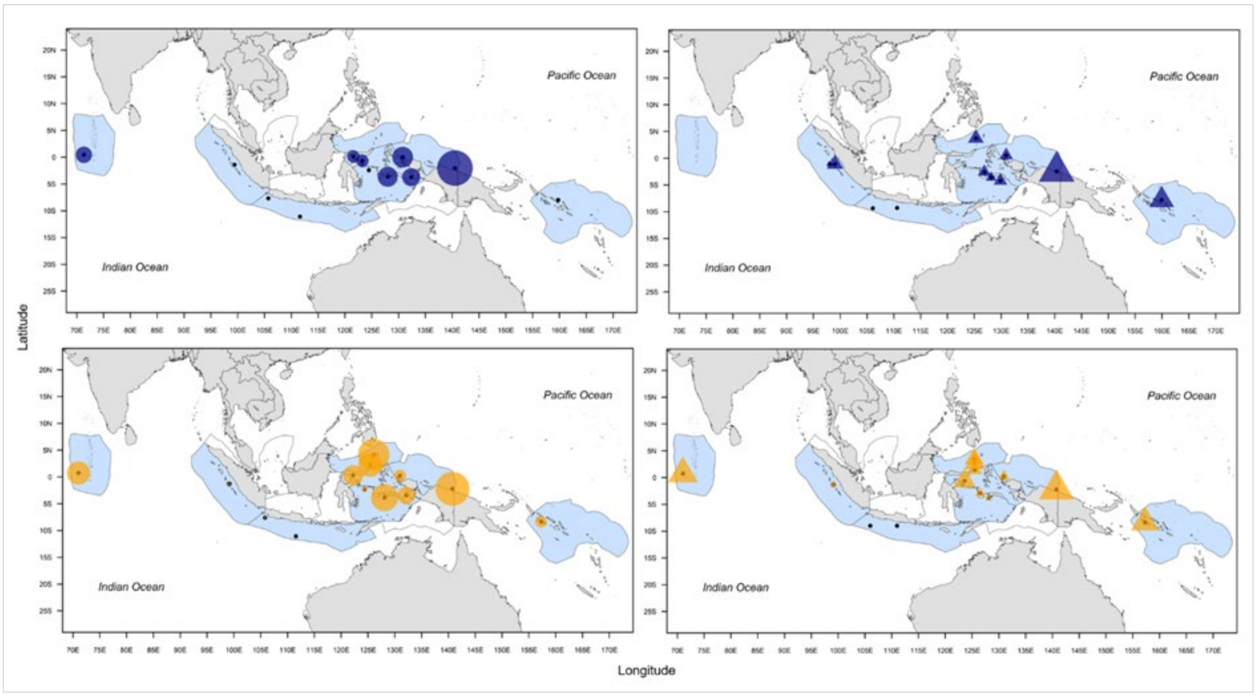

Figure 7.2. Relative prevalence of *Didymozoon longicolle* from samples of BET (top row) and YFT (bottom row) in 2013 (circles; left column) and 2014 (triangles; right column). Only

those locations where > 8 fish were dissected are shown. Zero prevalence is indicated by a solid black dot.

Discussion

The technique of using parasites to discriminate between stocks ideally requires abundant parasites. Many fish examined in the present study had zero or very few parasites so that on the LDA graphs these fish tended to be grouped together regardless of which area they had come from (see Appendix 1: Figure A1-2). An effective analytical technique employed in other studies is to assign individual fish to area according to their parasites and compare the results with actual collection site. This was not feasible here because the absence of a key parasite such as *D. longicolle* in an individual fish automatically assigned the fish to the Indonesian Indian Ocean FMAs where this parasite appeared largely absent even though the fish had been caught in a school with a rich parasite fauna.

A key assumption in using didymozoids as biological tags was that they had been in the fish for several months. While most adult didymozoids have life spans of about a year, and/or are lost during spawning, they were considered as permanent parasites in the current study as the fish sampled were less than 6 months old and immature. While the lifecycles of didymozoids are largely undefined, it is believed that the tuna acquire them by feeding on a small forage fish. While the feeding ecology of larval bigeye and yellowfin tuna is not known, skipjack tuna are piscivorous from a very early age. If BET and YFT are similar, the parasite signal represents several months of the fishes' lives.

Overall, the parasite data suggest the histories of both BET and YFT from the Maldives and Solomon Islands differ from neighbouring Indonesian waters. Within the Indonesian EEZ, three trends were evident. BET sampled from areas within the Indonesian archipelago had similar parasite faunas, suggesting they shared a common history or had grown in a similar environment. They harboured a different parasite fauna to those from outside the archipelago in the eastern Indian Ocean. This difference was largely driven by high numbers in abundance and prevalence of *D. longicolle.* The parasite was abundant in fish sampled within the archipelago, and generally absent in eastern Indian Ocean fish. A similar result was found with YFT. While the data does not rule out movement of both tuna species eastwards from the eastern Indian Ocean into the archipelago, the data suggests few fish had moved from within the archipelago westwards to the eastern Indian Ocean.

On the Pacific side, differences were observed between the parasite fauna of fish within the Indonesian archipelago and those outside in the western Pacific Ocean near Jayapura, largely driven by higher numbers of *D. longicolle* in the western Pacific Ocean samples. Again, while fish from within the archipelago may have moved eastwards, accumulated the parasite fauna characteristic of the western Pacific Ocean samples, and thus become indistinguishable from these fish, the parasite data suggests limited movement from the western Pacific Ocean into the Indonesian archipelago.

Despite displaying overall similar patterns, a greater number of significant differences in parasite abundance among FMAs were evident for juvenile YFT compared to BET. It may be that juvenile YFT are more site-attached than BET. However, many more YFT were dissected than BET, and parasites were slightly less common in BET compared to YFT, so the larger data set from YFT may be reason for the apparently greater differences between areas in YFT compared with BET rather than differences in the ranges of individual fish.

7.1.3 Technique 2: Otolith chemistry

Team personnel: Ms Naomi Clear (CSIRO), Ms Paige Eveson (CSIRO), Mr Craig Proctor (CSIRO), Mr Arief Wujdi (RITF), Mr Matt Lansdell (CSIRO), Dr Chris Dietz (CSL/UTas), Dr Jay Thompson (CODES/UTas).

Stable isotope ratios

BET had higher [9]values for both stable isotopes than YFT, and for a given species, $\delta^{18}O$ is on average higher in 2014 than 2013 (Figures 7.3 and 7.4). The difference in $\delta^{18}O$ values between seasons is largely driven by the western-most FMAs, particularly FMA 111 (Maldives) and FMA 572. Although both isotopes vary quite a lot within each FMA (this is particularly true for $\delta^{13}C$ for YFT), there are still noticeable differences between some areas. In general, the $\delta^{18}O$ values are highest in the easternmost FMAs, whereas the $\delta^{13}C$ values are highest in the western most areas.

The amount of variability within FMAs is large, however differences amongst FMAs are still apparent in the raw data (Figures 7.3 and 7.4), and more so when the data are plotted as means and standard errors. In particular, for YFT and BET, FMA 111 (Maldives) tends to have the largest $\delta^{18}O$ values, whereas FMA 999 (Solomon Islands) tends to have the highest $\delta^{13}C$ values. Within the Indonesian archipelago, the patterns are more species and season specific. Patterns in the data are quite consistent between seasons for BET, but less so for YFT.

The ANOVAs run using data from all FMAs confirm that, for YFT and BET, both stable isotopes differ significantly among FMAs. $\delta^{18}O$ differs significantly between seasons for both species, whereas $\delta^{13}C$ does not differ significantly between seasons for BET and only marginally for YFT ($p=0.013$). The results for the ANOVAs leaving out the two outlier sites (FMAs 111 and 999) are very similar, which suggests some significant differences exist within the Indonesian archipelago (noting that the data only needs to differ between two or more areas in order for FMA to be a significant factor).

Overall classification success rates from running leave-one-out cross-validation QDA models with FMA as the group variable and $\delta^{18}O$ and $\delta^{13}C$ as the explanatory variables, were ~30% for YFT and closer to 40% for BET in both seasons (Table 7.4). These rates are much better than with randomized FMAs (Table 7.4). The classification results broken down by FMA show that samples were most often correctly classified to the FMA where they were captured, and when this was not the case, they tended to be classified to adjacent or nearby FMAs (see Appendix 2 Table A2-1).

Table 7.4 Overall classification success rates (% correct over all FMAs) from the leave-one-out cross-validation QDAs run on the isotope data for each species and season separately. For comparison, the mean, minimum and maximum classification success rates from 1000 bootstraps with randomized FMAs are also given.

			% Correct from randomized FMAs		
Species	Season	% Correct	Min	Mean	Max
YFT	2013	32.4	1.4	11.6	27.9
	2014	29.4	1.4	11.0	25.1
BET	2013	36.3	2.3	13.4	29.3
	2014	40.3	0.8	11.4	33.9

[9] Technically, amounts of isotopes are normally reported as "heavier/lighter" rather than "higher/lower", but for the purposes of this report we have used the latter.

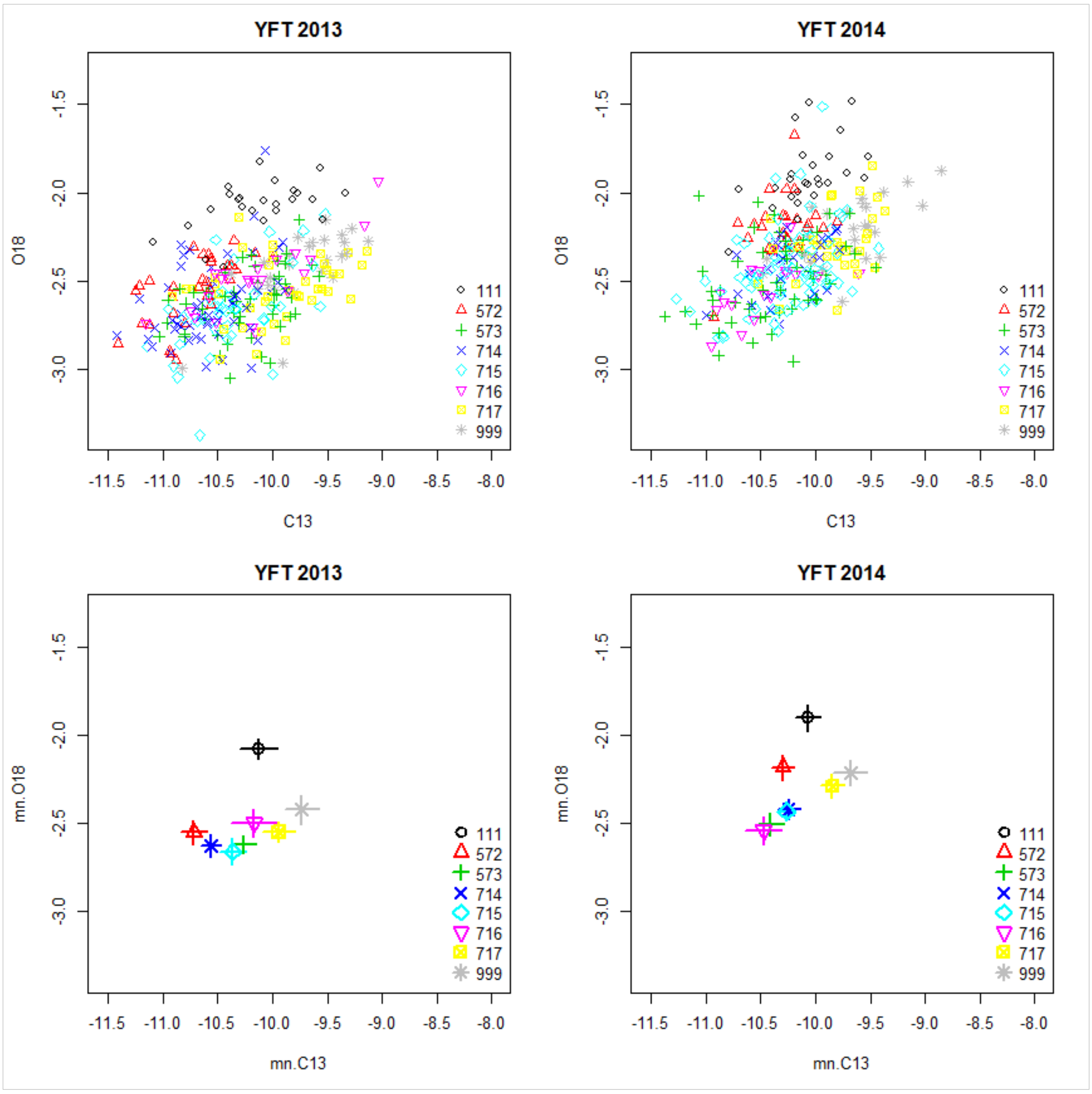

Figure 7.3. Scatterplots of δ^{13}C (labelled as C13) vs δ^{18}O (labelled as O18) for YFT by season, colour-coded by FMA. The top plots show the raw data so that the variability within and overlap between FMAs can be seen. The bottom plots show the mean values +/- 2 standard errors.

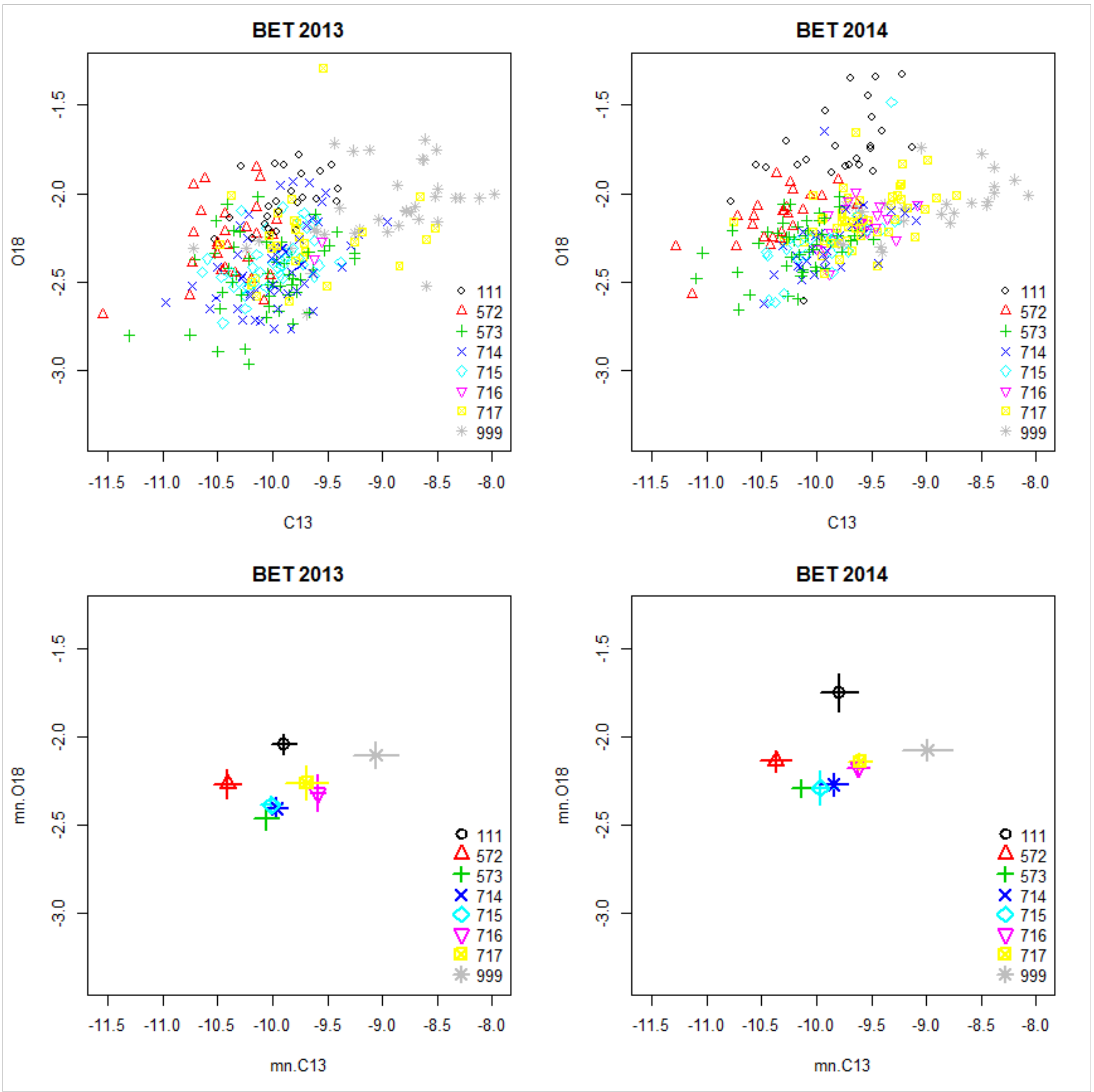

Figure 7.4. Scatterplots of $\delta^{13}C$ (labelled as C13) vs $\delta^{18}O$ (labelled as O18) for BET by season, colour-coded by FMA. The top plots show the raw data so that the variability within and overlap between FMAs can be seen. The bottom plots show the mean values +/- 2 standard errors.

Elemental concentrations

The elements that varied the most amongst FMAs and also between seasons depended on the species and the otolith position. For example: ^{39}K and ^{85}Rb appear highly variable between seasons and also FMAs; whereas ^{31}P and ^{137}Ba are quite variable between FMAs but similar between season (see Appendix 2: Figures A2-1 to A2-4).

Results from ANOVAs run using data from all FMAs show that most elements differ significantly among FMAs for both species and all otolith positions, with the most common exceptions being: (i) ^{65}Cu, which does not differ significantly between FMAs in any case except YFT position 1, and (ii) ^{7}Li, which does not differ for YFT position 3 or BET position 1, and only marginally for BET position 3. Most elements also differ significantly between seasons and have a significant FMA:season interaction, but there are more exceptions and less consistencies across species and otolith positions. Results from ANOVAs leaving out the two outlier sites (FMA 111 and 999) are very similar, which suggests there are significant differences in the data between at least two FMAs within the Indonesian archipelago.

We initially ran QDAs using all elements. Then, based on the ANOVA results, we sequentially left out ^{65}Cu and ^{7}Li. Omitting these two elements gave consistently good results for both species and all otolith positions. We tried further reductions in elements, but the results varied a lot depending on the species and the otolith position. Thus we only present results from the QDAs using all elements except ^{65}Cu and ^{7}Li. The leave-one-out cross-validation success rates over all FMAs ranged from 28.4% to 50.8% for all species, season and otolith positions, which are much better than with randomized FMAs (Table 7.5). Across the board, the classification success rates were higher in 2013 than 2014. Within a season, they were lowest for otolith position 2 and highest for position 3, with the exception of BET in 2014.

As for the stable isotope QDA results, samples were most often correctly classified to the FMA where they were captured, and when this was not the case, they tended to be classified to adjacent or nearby FMAs (Appendix 2: Table A2-2). This general pattern was true for both otolith positions 1 and 3, even though the overall classification success rate was lower for position 1 (with the exception of BET 2014). We might have expected the classification success rates to be highest for the outlier sites, FMA 111 (Maldives) and FMA 999 (Solomon Islands), and while this was often true, there were many exceptions. For the same species and otolith position, the results could vary quite a lot between the two seasons, particularly for the Solomon Islands where the classification success rate was much lower in 2014 than 2013 for both species and otolith positions.

Table 7.5. Overall classification success rates (% correct over all FMAs) from the leave-one-out cross-validation QDAs run on the element data for each species, otolith position and season separately.[1] For comparison, the mean, minimum and maximum classification success rates from 1000 bootstraps with randomized FMAs are also given.

				% Correct from randomized FMAs		
Species	**Position**	**Season**	**% Correct**	**Min**	**Mean**	**Max**
YFT	1	2013	35.2	3.8	12.3	21.2
		2014	31.9	5.2	12.4	22.5
	2	2013	34.6	5.6	12.2	22.6
		2014	28.8	5.4	12.6	21.5
	3	2013	50.4	3.0	12.2	23.1
		2014	46.7	4.6	12.9	24.4
	4	2013	47.4	3.9	12.2	22.4
		2014	30.8	6.2	13.0	21.3
BET	1	2013	43.5	6.2	14.5	26.4
		2014	39.2	5.0	12.7	23.1
	2	2013	36.1	5.7	13.8	23.2
		2014	31.3	4.5	12.6	23.2
	3	2013	50.8	5.8	14.4	24.9
		2014	36.6	5.2	12.2	21.5
	4	2013	36.8	4.7	14.1	25.9
		2014	28.4	3.1	12.5	23.2

Discussion

In this study, otolith chemistry has identified structure among the YFT and BET populations in the Indonesian archipelago. Applying discriminant function analysis to both the stable isotopes and elemental chemistry data sets, fish were often correctly classified to the FMA where they were captured, and when this was not the case, they tended to be classified to adjacent or nearby FMAs. This may indicate that fish generally did not move large distances between birth and capture (estimated to be at 3-4 months of age). However, this could also simply be due to the ocean environments being more similar amongst FMAs that are closer in proximity, in which case, even if fish remained in the same FMA between birth and capture, their otolith chemistry would still be more similar to nearby FMAs than to distant ones. While these two scenarios are not distinguishable with the data we have available (to do so would require data on the ocean chemistry of these regions in the two seasons for which we have otolith samples), in either case they suggest that these fish did not moved large distances in their first few months of life.

This could be further explored using the elemental composition data, for which data are measured at multiple otolith positions. If fish have remained within the same FMA between birth and capture, then the classification of samples to the FMAs where they were captured should be equally good using data from all otolith positions. However, if fish have moved substantially, such that they have spent time in multiple FMAs, then we would expect classification success rates to be best using data from the otolith position near the margin, since this position represents roughly two weeks in the last month of a fish's life (during which time the fish was likely to be in the FMA of capture). In comparison, we would expect classification results for the otolith position near the primordium to be worse than for the margin position, since this position represents several days in the first two weeks of a fish's life, at which time the element composition would not be expected to match the location of capture. Classification rates to the capture FMA were in fact higher at the margin than at the primordium for YFT in 2013 and 2014 and for BET in 2013. In 2014, the BET classification rate at the margin was 36.6% and slightly higher, 39.2%, at the primordium. A complication is that the data at the primordium may be influenced by maternal effects (e.g. Ruttenberg et al. 2005), in which case the lower classification rate at the primordium may not actually reflect fish movement, but instead reflect differences in maternal effects between fish.

Following on from the above discussion, if we assume that fish were in the FMA where they were caught during the few weeks prior to capture, then the elemental composition data at the margin should provide a "signature" for each FMA; i.e., the level of variability observed amongst fish captured in the same FMA should reflect the amount of variability that can be expected even for fish that have not moved. Thus the success rate for classifying fish to the FMA where they were captured that was obtained using the margin data should be the highest that can be achieved for fish that have not moved. The fact that the classification rate can be quite low at the margin for some seasons and regions presumably reflects that the chemistry of the ocean is more difficult to distinguish amongst regions in some seasons (e.g., due to the ocean chemistry at different regions being more similar to each other, or having greater variability such that differences are harder to detect). For example, consider BET in 2014: using element data from the margin, the classification success rate for fish caught around the Solomon Islands (FMA 999) was only 30.0% (6 out of 20), compared to 63.6% in 2013, and 2 fish were classified to the Maldives (FMA 111), from which we know they could not have travelled within such a short timeframe. This indicates that the otolith chemistry for BET around the Solomon Islands in 2014 overlapped significantly with the otolith chemistry for BET from other regions, presumably due to the ocean chemistry at the Solomons being less distinguishable from other FMAs in this year. This hypothesis is supported by the fact that the classification success rate for YFT caught at the Solomon Islands (FMA 999) using margin data was also lower in 2014 than 2013.

Overall, the otolith chemistry results for both tuna species provide evidence that, in their first 3-4 months of life, fish are unlikely to have moved great distances, and many fish are likely to have remained within the same FMA. We cannot say for certain whether some fish could have moved between the outlier sites (Maldives and Solomon Islands) and the Indonesian archipelago; a reasonable number of fish from the outlier sites were classified to the nearest FMAs within the archipelago (using both the stable isotope data and elemental composition data), but as noted above, this could just indicate the ocean chemistry being similar at these sites and not fish movement.

We observed significant differences in the otolith chemistry data ($\delta^{18}O$ and many elements) between 2013 and 2014 for both species and most locations. As discussed in the Introduction, ambient temperature can affect stable isotope levels in seawater, and thus their levels in fish otoliths. If the water temperature at a given location changed between seasons, then this could explain at least some of the observed differences in $\delta^{18}O$. To investigate, we extracted sea surface temperature (SST) within a +/-1.5 degree square of each sample location over the 6 months prior to the sampling date, and compared the average with the average $\delta^{18}O$ and $\delta^{13}C$ values at those locations. We found that SST was lower in 2014, and correspondingly, the $\delta^{18}O$ values were higher (heavier) at almost all locations. We did not find a consistent relationship between SST and $\delta^{13}C$.

The otolith chemistry data collected during this study could be a valuable resource to investigate the relationship between the otolith chemical fingerprint of groups of tuna and oceanographic parameters. In addition examining the elemental chemistry and stable isotopes in the otoliths of older BET and YFT could be an important next step for understanding how otolith chemistry is affected by ontogeny, and for identifying movements of fish beyond the first few months of life.

7.1.4 Technique 3: Genetics

Team personnel: Dr Peter Grewe (CSIRO), Mr Matt Lansdell (CSIRO), Mr Muhammad Taufik (RIMF), Ms Peta Hill (formerly CSIRO, now UTas), Dr Scott Foster (CSIRO), Dr Thierry Gosselin (IBIS, Canada).

Sampling effort for both species permitted a reasonably robust testing of connectivity for both BET and YFT. Target sample sizes ($n \geq 46$) analysed for YFT were achieved for all 11 sites in both years (with the exception of Sorong in 2014, n = 36). Achieving target samples sizes for the BET analysis, proved to be more difficult due to rare occurrence of this species in the overall catches at each site. Despite this, overall sampling effort was considered sufficient for both species with at least 9 of 11 sites yielding $\geq$ 30 individuals per site in each year. Interestingly, the filtering of genotype data revealed only a small number (< 4) individuals where tissues from an individual had been sampled multiple times but labelled as a different fish. This duplication may either have happened during sampling on-site or during sub-sampling at the lab. The low frequency of occurrence did not affect sampling strategy robustness for the overall analysis and one individual from each of the duplicate pairs was eliminated from final population analysis. Duplicate DNA was also intentionally run from some individuals as an internal quality control check. These were also eliminated from the final population analysis. During the quality control filtering of the data, a few individuals (< 12 total from 3 sites) were discovered that had been mislabelled the wrong species. Species identification of individuals, which were tested using mitochondrial DNA markers, were confirmed to have been mislabelled as the incorrect species and were subsequently eliminated from consideration in the population analysis. Again, removal of these individuals had no impact on the overall statistical precision of the analysis as they were present at such a very low frequency of the overall sampling effort.

Genetic analysis of single nucleotide polymorphisms (SNPs) for both bigeye (BET) and yellowfin (YFT) tuna samples revealed interesting patterns of connectivity among the 11 sampling locations examined. Most importantly, for both species the pattern of connectivity appeared to be temporally stable for each of the sampling years. For each species, two types of analysis were applied to examine patterns of connectivity and stock. The first method compared genetic relatedness among all individuals grouping them into "K" different levels of genetic clusters. This analysis was done without giving information about prior groupings or sampling location and gave an assignment of each individual to one of "K" genetically related groups. A total of seven different levels (K = 2 to 8) of clustering or groupings were examined and the proportion of individuals in each genetic group was then plotted for each sampling site (Figures 7.5 and 7.6). Cross-validation at various groups of K were analysed to determine the percentage of repeatable assignment at a given number of K groupings. This cross-validation analysis revealed a substantial drop from 85% at K=3 to 70% at K=4 for BET and for YFT from 86% (K=2) to 74% (K=3) (Figure 7.7). Thus, for the purposes of this summary report we have only presented the K = 3 for BET and K=2 for YFT cluster analyses (Figures 7.5 and 7.6).

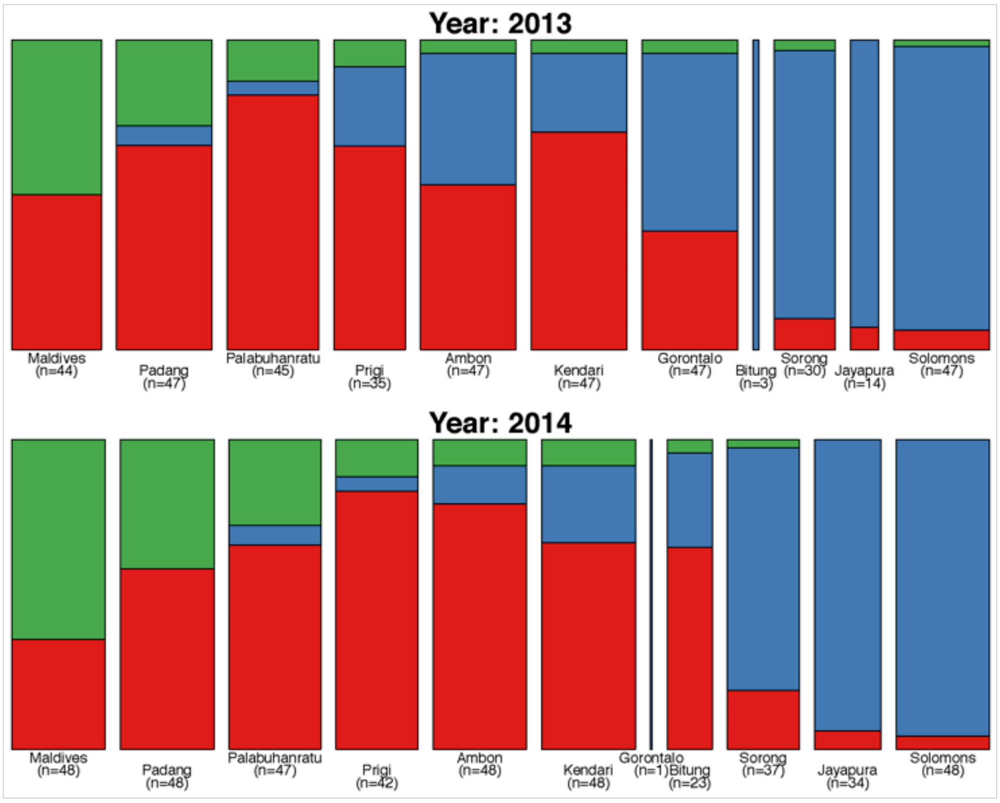

Figure 7.5. Proportion at each sampling site of BET clustered into three genetically partitioned groups (K = 3). Sample sizes for each location and time point are indicated in parentheses.

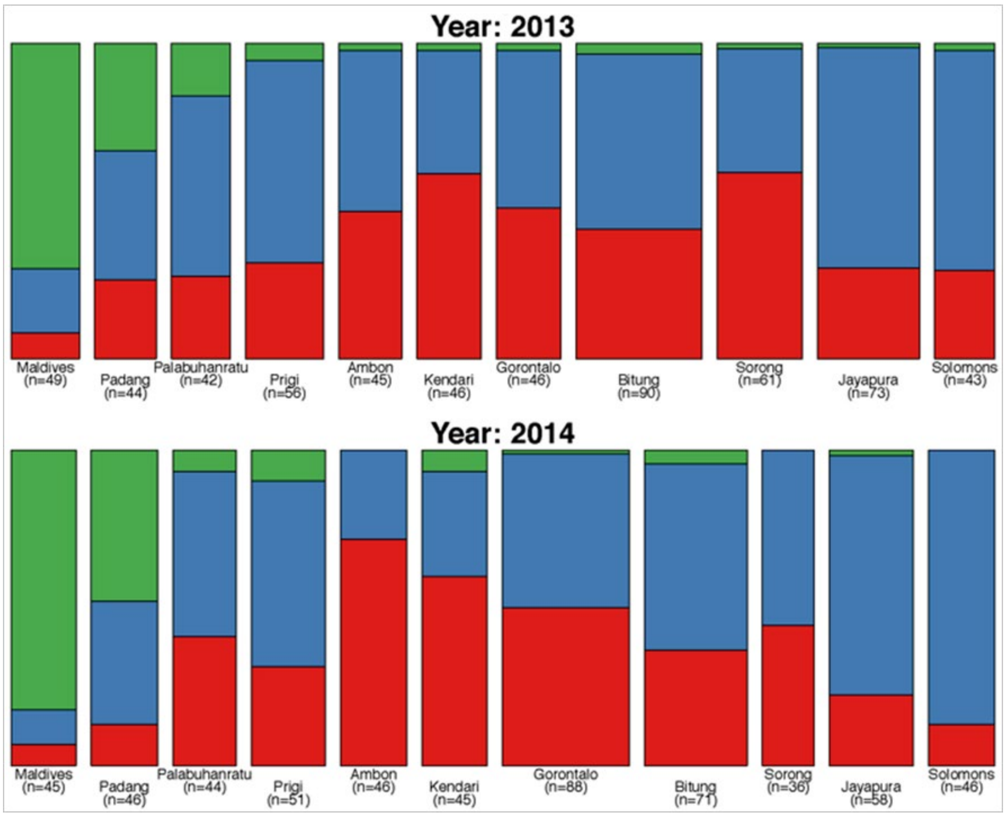

Figure 7.6. Proportion at each sampling site of YFT clustered into two genetically partitioned groups (K = 2). Sample sizes for each location and time point are indicated in parentheses.

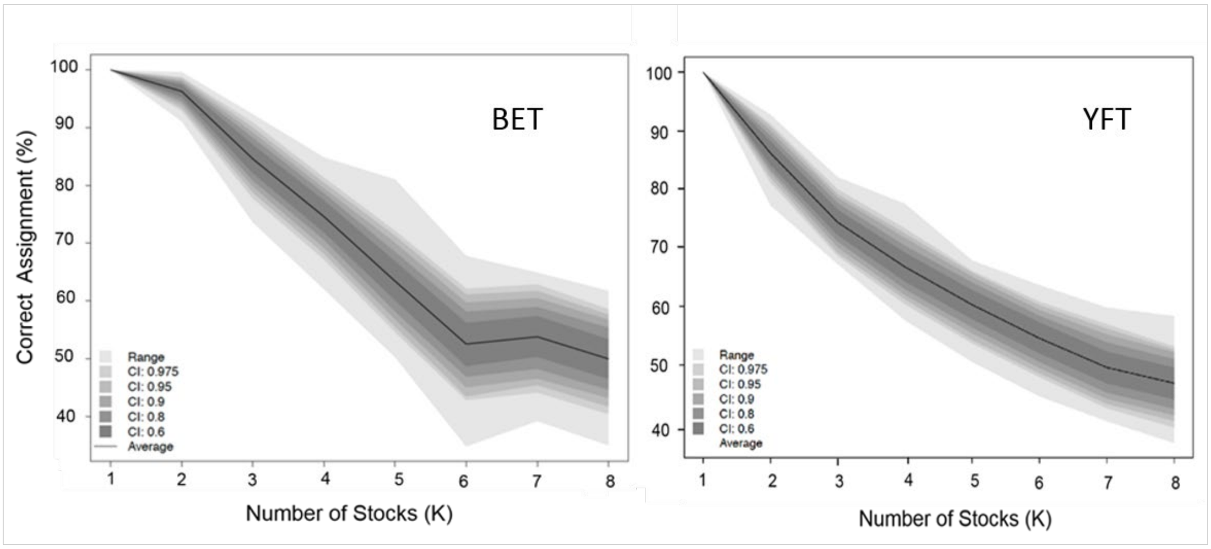

Figure 7.7. Cross-validation percent correct assignment (y-axis) of an individual to its original K-group given the number of K genetic groups under consideration (x-axis), for BET (left) and YFT (right). Shaded regions indicate confidence intervals surrounding assignment estimates.

The analysis of BET appears to demonstrate restricted connectivity between Indian Ocean (Maldives, Padang, Palabuhanratu, Prigi) and Pacific Ocean (Sorong, Jayapura, Solomons). Samples from the central Indonesian sites (Kendari, Ambon, Gorontalo, Bitung) appear to have limited connectivity to both areas with geographically adjacent sites showing greatest similarity to each other. The second analysis produced a tree dendrogram (Figure 7.8) that used F_{ST} genetic relatedness estimates to define a level of differentiation between pairs of sites. Interestingly, the tree analysis also supported results from stockR, in that sites geographically close to each other also appeared to be more similar genetically.

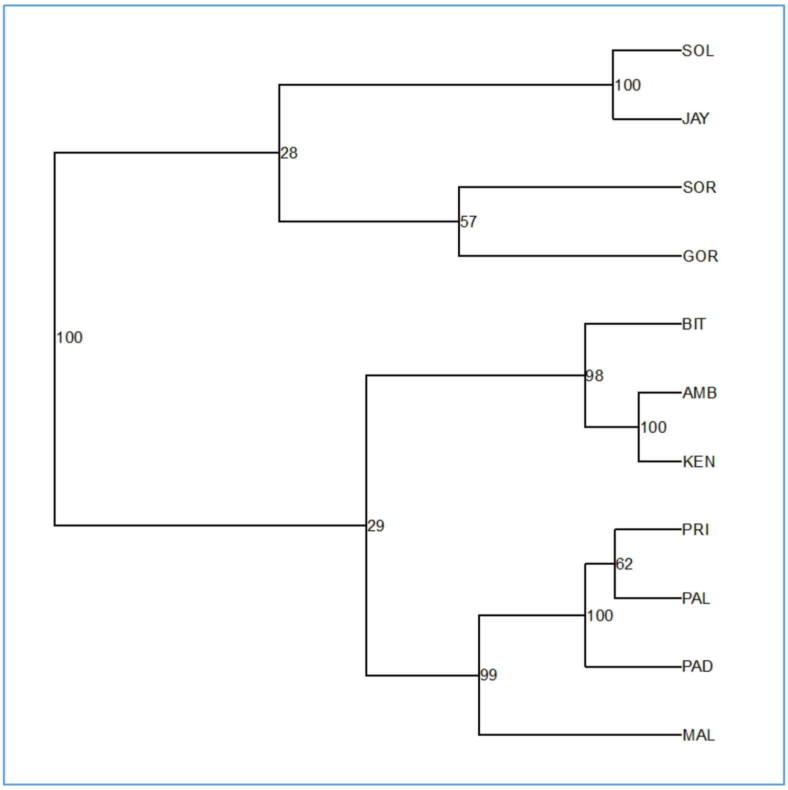

Figure 7.8. BET: Tree of genetic relatedness of each sample location, based on similarity as calculated using F_{ST} measure of genetic differentiation between pairs of sample locations.

Bootstrap values of reproducibility percentage are indicated for each node of the dendogram.

In general, F_{ST} values were greater among BET than those observed among YFT sites. However, while YFT appears to be less differentiated than BET, there is still a marked difference observed between samples from the central Indian Ocean (MAL) and those of Western Pacific origin (SOL, JAY, SOL). Interestingly, internal Indonesian sites (AMB, KEN, GOR, BIT) show very limited if any differentiation from the western Pacific sites (SOL, JAY, SOL) which may be an indication of higher genetic connectivity for YFT than BET in this region (Figure 7.9). This pattern of differentiation among the sampling location regions may be an indication of limited gene flow between central and eastern Indian Ocean sampling regions with more pronounced gene flow among central Indonesian and Western Pacific sampling regions. Additional sampling among these areas will certainly help to further resolve this hypothesis.

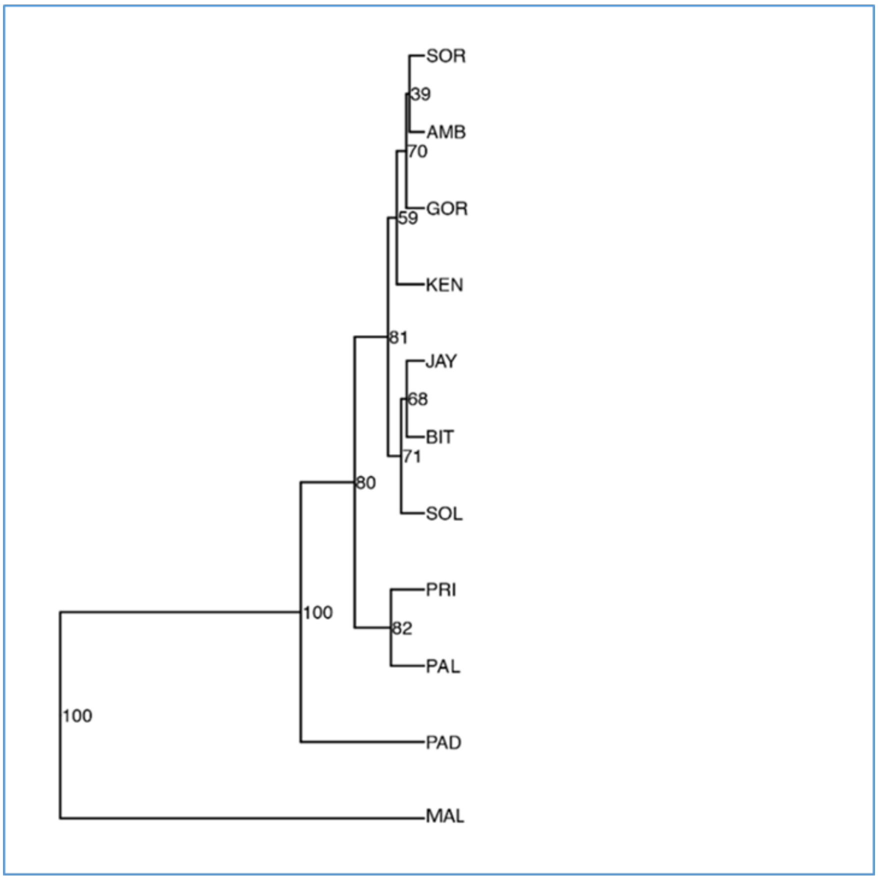

Figure 7.9. YFT: Tree of genetic relatedness of each sample location, based on similarity as calculated using F_{ST} measure of genetic differentiation between pairs of sample locations. Bootstrap values of reproducibility percentage are indicated for each node of the dendrogram.

The genetic subdivision observed by this study has revealed more structure than previously described for YFT in the Indo-Pacific region by some studies (Ward et al. 1997, Appleyard et al. 2001, Grewe and Hampton 1998, Davies et al. 2014). In retrospect, these previous studies, which used mtDNA and DNA microsatellite markers, were incapable of the genetic resolution offered by DArT-Seq analysis as demonstrated by Grewe et al. (2015). While the genetic resolution was able to reveal the presence of structure among the sampling sites, the putative stock structure appears to be more complex and not as differentiated as other studies have purported on smaller geographic scales than examined by our study (Diaz-Jaimes and Uribe-Alcocer 2006, Dammannagoda et al. 2008). Our data appears to demonstrate presence of multiple (at least 2 - 3) genetically distinct groups within each sampling location. A variety of hypotheses could explain this observation, with perhaps the simplest explanation being that the fish sampled in this study were 4 - 5 months of age and therefore already at a point where mixing of genetically differentiated spawning locations could have occurred. Further examination of genetic data obtained from a sample of larvae or ripe and running adults would be required to further address this hypothesis.

In summary, the connectivity for BET and YFT in the Indo-Pacific region of Indonesia was assessed through analysis using a genetic clustering approach to group individuals, as well as examination of F_{ST} measure genetic relatedness among sampling locations. Analysis of the distribution of genetic cluster groups for both BET and YFT among the sampling sites appears to demonstrate presence of subtle genetic structure of at least 2 or 3 genetic groupings. There is a geographic partitioning of the groups among the sampling locations that appears to be positively correlated with proximity of sampling locations and could indicate clinal genetic variation consistent with an isolation by distance model. The most differentiated populations are on the extreme ends of our sampling distribution and represent central Indian Ocean versus Western Pacific Ocean regions. Support for this outcome was observed in the tree-based examination of genetic relatedness F_{ST}) among sampling locations. The geographic partitioning of the sampling locations appears to have a strong genetic basis that was temporally stable over the two years of the project. Further sampling of additional sites and additional year classes will help to provide further support for both temporal stability and geographic connectivity with respect to regions and may lead to additional clues as to the origin of major spawning locations. The data generated by this project is consistent with the presence of multiple genetic groups. This information can now be used to guide future sampling strategies to further elucidate the genetic patterning and examine population structure in these two important tuna species.

7.1.5 General Discussion

This study's primary goal was to investigate presence or absence of structure in YFT and BET populations across Indonesia's oceanic waters (both archipelagic and non-archipelagic) and the degree of connectivity of those populations to adjacent regions in the Indian and Western Pacific Oceans. The outcomes were to assist Indonesia and international partners (primarily through the RFMOs) in developing management measures on appropriate geographic scales for these two important tuna species. The study was intended as a first exploration of the population structure and not entered into with expectation of a comprehensive, fully definitive outcome, especially given that the resources of the project limited the study to one life-history stage; juvenile tunas of average 4 – 5 months of age.

The investigation employed the three techniques – genetics (using next generation sequencing), otolith chemistry (analyses of stable isotopes and elemental chemistry), and parasites (characterisations of parasite species and abundances). This multi-technique approach was considered the best way of having 'a strong first look' at the degree of population structure, recognising that each of these techniques have strengths and limitations for providing definitive answers. We thought that by employing the three techniques together, as had been done earlier by others (Buckworth et al. 2007, Welsh et al. 2009), the likelihood of achieving an informative and useful 'picture' of the degrees of movement and connectivity of the tunas across a broad geographic range was high.

The three techniques have provided outcomes that overall are in agreement. The outcomes of the genetics analyses suggest at least 2 or 3 genetic groupings ("a subtle genetic structure") for both species of tuna and with clines of genetic variation across the geographic range, consistent with an isolation by distance model. Within the BET samples there were three reliably identifiable genetic groups and two such groupings among the YFT samples, and the groupings for both species appeared temporally stable, with similar patterns evident for the 2013 and 2014 samples. The most significant differentiation, based on the DNA profiles, was between the fish from the two outlier locations, Maldives (central Indian Ocean) and the Solomon Islands (western Pacific Ocean).

The outcomes from the parasites characterisations and otolith chemistry analyses concur with the genetics outcomes in suggesting multiple populations for both species across the geographic range of the study. The patterns of prevalence and abundance of didymozoid parasites suggested limited to no movement of fish westwards from the Indonesian archipelago into the eastern and central Indian Ocean, and also very restricted movement from the Western Pacific Ocean westwards into the Indonesian archipelago. Therefore, the outcomes from the parasites indicated at least three groups (populations) based on the YFT and BET dissected in the study, and overall the patterns were similar from both the 2013 and 2014 samples. A higher number of significant differences in parasite abundances across the range was observed for YFT compared to BET, a result possibly influenced by more YFT having been sampled and by parasites being more abundant in YFT in general. However, it could also indicate that juvenile YFT show more regional fidelity than BET.

The overall outcome from the otolith chemistry analyses, using both stable isotopes and elemental chemistry, was that YFT and BET had not moved large distances in their first 4 - 6 months of life. Based on discriminant function analyses of both otolith chemistry data sets, the majority of fish were classified to the FMAs where they had been captured or to nearby FMAs. The differentiation of fish sampled at the outlier sites (Maldives and Solomon Islands) from those sampled within the Indonesian FMAs was not as strong for either species compared to that for the genetics and parasites (e.g. a small percentage of fish sampled at these outlier regions were classified to Indonesian FMAs based on their otolith chemistry). This is due in part to the nature of otoliths, with each of the measured stable and elemental isotopes occurring in all otoliths, and the nature of otolith chemistry data, which are continuous rather than being a discrete measure of presence or absence (such as the parasite data). In addition, there are many factors that can influence the otolith data, such as ontogenetic effects, maternal effects and water chemistry. For example, widely separated sampling regions with similar ocean environments could result in similar otolith chemistry, without any mixing of fish between the regions. More information about oceanography and these other factors would be required to draw stronger conclusions.

Examination of the spatial dynamics of these two tuna species, which were based on mark-recapture tagging studies of juveniles similar to the size and age to those in the current study, have shown mixed results with respect to regional fidelity. Tagging studies carried out in the Western and Central Pacific Oceans, and including fish tagged in Indonesian archipelagic waters (Schaefer et al. 2015, SPC 2012), showed low levels of long-distance movements (> 500 nmi) from points of release. Similarly, movements of YFT and BET, tagged in Western Pacific regions (including Solomon Islands) to east of Indonesia, into Indonesian EEZ waters were also observed to be at low level (SPC 2012). In contrast, large scale tagging of YFT and BET in the western Indian Ocean showed a higher proportion of long distance movements (average distances travelled of 710 nmi and 657 nmi for YFT and BET respectively) and lower levels of regional fidelity (Hallier and Million 2009).

The outcomes of this study are a useful contribution to the discussions and planning around current development of harvest strategies and regional management for Indonesia’s tuna fisheries. They further confirm that there is no or low level of mixing of stocks of both species between the Indian and Western Pacific Oceans. The results also suggest meta-populations with some degree of regional fidelity may well exist within the Indonesian archipelago, and therefore should be considered in scenarios of regional management, at level of FMA or other scales. Further research, especially on older fish, appears to be highly desirable.

7.2 FAD Fisheries Study

The information provided for the following sections, relevant to the project's FAD fisheries study, are presented as summaries to keep within the page limit guidelines. Additional information, including supplementary tables and figures are provided in Appendices (referenced in each section). The full details of the FAD Fisheries Study are available in a stand-alone final report (Proctor et al. 2019b).

7.2.1 Review of earlier FAD studies in Indonesian waters

The investigations into earlier studies with links to FADs in Indonesian waters yielded a total of 116 abstracts. These were compiled (alphabetically as the first level of order) into a bibliography, and published in May 2018:

Natsir, M., Proctor, C., Wudianto, Nurdin, E., Sadiyah, L., Taufik, M. and Hargiyatno, I.T. (2017). *A collection of abstracts of FAD fisheries research in Indonesia.* A publication of Australian Centre for International Agricultural Research Project FIS/2009/059. Center for Fisheries Research. Agency for Marine and Fisheries Research and Human Resources. Jakarta. 308pp.

The long period (more than 4 years), from commencement of compilation of the abstracts to publication of the bibliography, was the combination of time required to source and collate the abstracts, and the time consuming process of translation of the majority of the abstracts to English. Due to budget constraints, the latter task could not be done with a professional translation service, and relied on the joint efforts of the abovementioned authors. It is intended that the bibliography of abstracts will be a living document and will be updated as more FAD related studies, done in Indonesian waters, come to light. The authors are currently exploring ways of having the bibliography readily accessible via on-line portal, in addition to having it downloadable from the project's page on the ACIAR website.

7.2.2 Enumeration program at focus ports

Key components of the results from the project's enumeration program are provided in Appendix 4. This includes information under the following sub-headings:

A4-1. General information on tuna FADs in Indonesian waters;
A4-2. Vessel trips enumerated and data entry;
A4-3. Catch characteristics - by location and gear type;
A4-4. Biological sampling - length frequencies of tuna species;
A4-5. FAD 'dynamics' – numbers, locations, ownership and usage.

The full results are covered in the project's stand-alone FAD Study final report (in prep).

The following is a summary as key points:

- A total of 2564 fishing trips were enumerated across the four focus ports (Padang – West Sumatera, Palabuhanratu – West Java, Kendari – SE Sulawesi and Sorong – West Papua) by the project's enumeration program, during period October 2013 – December 2016;
- Focus was on fishing trips involving use of FADs by the gear types hand-line/troll-line (HL/TL), pole and line (PL), and purse-seine (PS), and carrier vessels (CV) that collect catch from PL and PS vessels;
- The original plan was for the program of data and information collection to run for a minimum of 15 months. At Padang and Sorong the program ran for 18 months, and at Palabuhanratu and Kendari for 39 months, thereby exceeding expectations;
- The program's initial implementation phase, with identification and recruitment of suitable enumerator personnel (2 per port) and provision of on-site training was successful. Less successful was maintaining the quality of enumeration at Padang and Sorong beyond 12 months – the result of personnel and company access issues;

- The combination of direct observations by the enumerators of catch unloadings from vessels, data they collected from fish auction places (*Tempat Pelelangan Ikan*) and processing companies, and information collected via interviews with vessel skippers enabled adequate completion of the data collection sheets in most cases;
- In general, the program experienced an excellent level of cooperation from vessel skippers and crew, vessel owners, fishing companies, port authorities and other persons and offices linked to fishing activity;
- As expected, some areas of the enumeration proved challenging, including obtaining accurate data on catch locations (and associated FAD locations), numbers of FAD events[10] in a fishing trip, and measures of success of those events;
- The individual FAD location information that was obtained, and that provided by other sources, confirmed that in some areas with high numbers of FADs, the inter-FAD distances are significantly less than the minimum of 10 nmi stipulated by Indonesia’s current FAD regulations (see section below);
- Anchored FAD types vary by region (most notably the absence of bamboo raft type from western Indonesia), but the ‘*gabus’* styrofoam type has become more common through cost considerations;
- Types of FAD ownership and operational management also vary by region; in some cases provided by to fishers by local government (by Provincial or by Regency), but the majority are privately owned by fishing companies, vessel owners or fishers groups;
- The use of FADs varies from access being restricted to vessels of the FAD owner (company, individual or fishers group) through to sharing arrangements that provide access and use by ‘outside’ vessels. The sharing will in some cases involve payment of a fee in money or proportion of catch, or by payment with a service (e.g. acting as ‘watch-dog’ and reporting to FAD owner of unapproved use);
- Conflicts between vessels of different gear types on FADs have been a significant issue, and cutting of FAD mainline ropes as a result of such conflicts/competition is a common occurrence;
- Turnover in the FADs is high. The average ‘life-span’ of an Indonesia anchored tuna FAD is generally given as 2 years – losses due to degrading of FAD construction materials, severe weather events, strong currents, and from the abovementioned conflict incidents;
- The biological sampling program as a key component of the enumeration program achieved length measurements on a total of 48,368 fish (tunas and bycatch species) from the four ports;
- Results of particular importance to the current Harvest Strategy development and sustainability goals for Indonesia’s tuna fisheries include: - juveniles of YFT and BET together comprise large proportions (as high as 60% of catches), in catches of HL/TL vessels operating from Padang, Palabuhanratu and Kendari. The proportion of those juveniles in the catches of PL and PS vessels operating from Kendari and Sorong was much less than for HL/TL but still significant (as high as 32%);
- For reason(s) that are unclear, YFT and BET in size range 80 – 110 cm FL are largely absent from the catches of gear types examined in this study but also from catches of other non-FAD associated gears (notably longline and gill-net).

The following are two sections that we feel are worthy of inclusion in the main body of this report rather than included in the Appendix 4, as they are integral to the Conclusions and Recommendations (Section 9).

[10] *Here “event” refers to conducting fishing activity on or around a FAD.*

Past and Current FAD regulations and initiatives for improved management

The foundations of Indonesia's fisheries regulations relevant to FADs date back to 1997, with the **Minister of Agriculture Decree Number 51/Kpts/IK.250/1/97** "about the installation and utilization of FADs". According to the wording in the Decree, this followed recognition that the use of FADs was increasing rapidly, was unregulated, with potential for threatening fish habitat patterns and the sustainability of fish resources, and potential for causing social tension among fishermen. The Decree defined FADs into 3 types: 1. *Rumpon perairan dasar* (bottom water FAD), 2. *Rumpon perairan dangkal* (shallow water FAD), and 3. *Rumpon perairan dalam* (deepwater FAD) were defined as those installed in marine waters of > 200 m depth. The bottom and shallow water FADs were further defined as those under regulation of Regional governments; Level 2 Regional Government for waters from shore to 3 nmi, and Level 1 Regional Government for waters > 3 – 12 nmi from shore. The Decree stipulated that deepwater FADs could only be installed by fishing companies, government agencies, and research institutes and universities (the latter in a framework for developing science and technology). Fishing companies wanting to install deepwater FAD(s) were required to a obtain a Deepwater FAD Installation Permit from the Director General of Fisheries, and provide the planned timing and coordinates (Lat/Long) of installation and a copy of the proposed FAD design. The FAD installation permits were to be valid for 3 years with option of extension upon expiry.

Under the abovementioned 1997 Decree, in addition to requiring a FAD installation permit, fishing companies were required to:

- not install FADs in shipping lanes;
- have a minimum inter-FAD distance of 10 nmi;
- not disrupt the movement of fish in marine waters, and specifically not install FADs in a "zig-zag" effect that threatens the sustainability of pelagic fish species;
- not install FADs in waters < 200 m deep;
- not install FADs in waters < 12 nmi from shore;
- have the FAD marked for identification and maintain the FAD in the one location (i.e. nominated place of installation).

Use of installed deepwater FADs by other parties was permitted under the Decree, but only with the FAD owner's permission. And furthermore, fishing companies with deepwater FADs "shall be obliged to provide opportunities for small-scale fishermen to catch fish in the vicinity of FADs installed inside the Indonesian EEZ". Article 10 in the Decree refers to the allowed gear types for deepwater FADs as pole and line, hand-line, or troll-line. Purse-seine was also permitted but with the specific requirement of only to be used within the Indonesian EEZ and at least 20 nmi from the outer boundary of the Regional Seas (*Laut Wilayah*). Holders of FAD installation permits were also required to provide 6 monthly reports to the Director General of Fisheries and to the Head of Local Level 1 Fisheries Office (*Kepala Dinas Perikanan Daerah tingkat I setempat*).

The 1997 Decree did not include any limitation on the number of FADs that could be installed by any one fishing company, but did include the clause "To foster the preservation of fish resources, control and prevent social tensions, the Director General of Fisheries can restrict the number of Deep Water FAD Installation Permits".

The next significant development in Indonesia's FAD regulations came in 2004 with a review of the 1997 Decree under the Decree of the **Minister of Marine and Fisheries number KEP.30/MEN/2004**. Significant changes included:

- those able to apply for a FAD Installation Permit included "individuals" (Chapter III/Article 10) and not only fishing companies. However, confusingly, in Chapter

5/Article 12 of the Decree it is stated that "the utilisation of FADs may only be done by fishing companies";

- the changes to the jurisdictional zoning, with installation permits granted by the relevant governing body: Regency Government for FADs in zone 2 – 4 nmi from shore, Provincial Government for those in zone > 4 – 12 nmi from shore, and National Government for those installed in the > 12 – 200 nmi (i.e. boundary of the EEZ);
- the permit period of 2 years, with option of extension upon expiry;
- the granting of permission to install FADs must consider the carrying capacity of fish resources and their environment and the socio-cultural aspects of the local community;
- each FAD installed must be given an ID by the relevant governing body, and the form and format of that identification will be stipulated by the Director General of Fisheries.

During the following decade there were other developments in Indonesia's FAD regulations, including Regulations of the **Minister of Marine Affairs and Fisheries Number PER.02/MEN/2011** which include regulations on FAD and light (wattage) combinations for use by purse-seine vessels, determined by size of vessel, zone of operation and Fisheries Management Area.

Further significant amendments were made to the FAD regulations in concert with the drafting of Indonesia's National Tuna Management Plan. In June 2014 came the **Minister of Marine Affairs and Fisheries Regulations Number 26/PERMEN-KP/2014** "about FADs". Many of the earlier regulations, referred to above, remained unchanged or were upgraded. The most significant revisions/additions were as follows:

- the definition of FADs as either a drifting or an anchored FAD;
- the first mention in the regulations of sub-surface attractors as a key component of FADs;
- the inclusion of bottom FADs (*rumpon dasar*) as a type for attracting demersal fish;
- the stipulation that the anchored FADs must have a surface floating buoy (i.e. anchored FADs with sub-surface 'floats' not allowed);
- the FAD attractors must be composed of non-entangling, biodegradable, natural materials;
- the FADs must be made of materials strong enough to withstand heavy seas and strong currents;
- the FAD anchors must be of sufficient weight to maintain the FAD in position;
- the use of "*Surat Izin Pemasangan Rumpon*" (SIPR) as the permit to install a FAD, and the stipulation that every person who installs a FAD and every vessel which operates on a FAD must have a SIPR;
- the application for a SIPR to the Director General of Fisheries must include detail of the number of proposed FADs, the coordinates (Lat/Long)of proposed installation, an estimate of the proposed frequency of use, an estimate of the type and number of fish to be caught in each fishing operation, and drawings of the proposed FAD design and construction materials;
- inclusion in the requirements for installation that FADs should "avoid the capture of unwanted species (unwanted bycatch)" and, as such, no netting materials are to be used in FAD construction;

- that FADs and their installation are to monitored by officers and observers designated the Director General and to include regular written reporting to the Director General;
- that each vessel is only permitted to install a maximum of 3 FADs;
- that the use of FADs can be banned, based on time of fishing and/or fishing area, to protect the sustainability of fish resources and the environment, and to meet international requirements/standards;
- that every FAD must be equipped with an identification plate (including details of FAD owner, fishing license number, coordinates of installation, names of vessels using the FAD;
- that every FAD must be equipped with a radar reflector;
- that all holders of a SIPR must submit a report with details of the FAD(s) installation, within 14 days of installation, either direct to the Director General or via the reporting of officers monitoring the FAD installations.

In addition to Minister of Marine Affairs and Fisheries Regulations Number 26/PERMEN-KP/2014, this same year saw the release of the "Indonesia Fish Aggregating Devices Management Plan in Western Central Pacific Ocean (FADs Management Plan for 2015 – 2017)" (DGCF 2014).

In principle, these current regulations, if executed to their full intention, would have provided the foundation for effective management of the FAD situation in Indonesia, or at least, the basis for a greatly improved assessment of the FAD situation. Unfortunately, until now, there has been little evidence[11] that the implementation and enforcement of the regulations has occurred to any significant degree for all the regions of Indonesia where deepwater tuna FADs are in use.

Indonesia's Directorate General of Capture Fisheries is fully aware of the challenges to implement the FAD regulations and the shortcomings to date and has been proactive in participating in stakeholder discussion workshops to determine appropriate options for improved FADs management. The discussion fora[12] have included participation by the relevant research institutes within AMAFRHR, University of Wageningen, CSIRO, several NGOs, including Masyarakat Dan Perikanan Indonesia (MDPI), PT Hatfield, The Nature Conservancy (TNC), International Seafood Sustainability Foundation (ISSF), Sustainable Fisheries Partnership (SFP), World Wildlife Fund (WWF), and representatives from tuna fishing associations, including Asosiasi Pole & Line and Hand-line Indonesia (AP2HI) and Himpunan Nelayan Purse-seine Nusantara, fishing companies, and port authorities and provincial fisheries offices.

Key issues that have been voiced in these workshop discussions and in other reports (e.g. PT Hatfield Indonesia 2016) include:

[11] *On a recent survey trip to Ambon in November 2018, participating scientists for ACIAR Project FIS/2016/116 saw evidence of the FAD regulations being effectively enacted, with an up-to-date register of FADs held by the Office of Control and Surveillance of Fishing Vessels, and several FADs in the port that had been removed (i.e. mainlines cut) by patrol vessel for not being marked with the required identification markers and without evidence of current SIPR (pers. comm. Mahiswara, Widodo, and Proctor).*

[12] *Including FAD Fisheries Management Workshop, Bali, 21 February 2017 (a collaboration between DGCF, AMAFRHR, TNC, MDPI, University of Wageningen, CSIRO/ACIAR); National Forum on the Management of FADs, Bogor, 25 – 26 October 2017 (a collaboration between DGCF, MDPI and TNC).*

- The *sosialisasi*[13] of the FAD regulations to the persons who are required to comply with the has not yet been adequately achieved. An insufficient understanding of the 'finer points' of the regulations and how they are to be followed has been widely reported and was certainly evident from all interviews conducted in this project's activities with persons involved in the tuna fishing activities across Indonesia. This includes staff of some of the offices who have responsibility for implementing and enforcing the regulations in their respective regions;
- The *sosialisasi* has also failed to deliver sufficient information for adequate understanding by participants in the fisheries of the benefits that will come from their complying to the regulations and from improved FADs management. As example, this includes the benefits that accrue from having FADs at least 10 nmi apart, and not having too many FADs in the one region. This lack of understanding has contributed to a low level of 'engagement' with the regulations;
- There are no current guidelines to assist the offices charged with responsibility of implementing and enforcing the regulations;
- There are no maps readily available to fishing companies, vessel captains, and others wanting to install anchored FADs to show them the shipping lanes they are required by law to avoid;
- The wording and level of detail in some of the regulations is inadequate and makes them difficult to enforce and proceed through to successful prosecutions in courts of law. As one example, the regulation that FADs are limited to installation of 3 units per vessel (Chapter V/Article 14) requires revision if the intention of the regulation is to be an effective control of fishing effort. During the course of this project's FAD study, some individual vessel owners interviewed possessed up to 20 vessels or more in their fleet, and in theory, could potentially have their vessels operating on more than 60 shared FADs under the regulations;

The current regulations for FADs do little to mitigate the catch of juvenile YFT and juvenile BET, which, as detailed in Appendix 4 (sections A4-3 and A4-4), make up significant proportions of FAD-based catches of Indonesian hand-line, pole and line, and purse-seine vessels and occupy the issue of greatest concern for the sustainability of the fisheries regionally.

The FADs situation is universally accepted by all participants (MMAF, provincial and regency fisheries offices, industry associations, NGOs, RFMOs, contributing international experts) as one of the highest priority issues for addressing in the moves to improved management for Indonesia's tuna fisheries. And as such, the momentum for achieving effective fisheries regulations pertaining to FADs continues to strengthen.

Lessons learnt through the enumeration program

The following is a point summary of 'lessons learnt' through the course of our project's trial enumeration program at the four focus ports. The majority of these points are not new and have been voiced by earlier enumeration programs or reviews of fisheries data collection programs (ANOVA 2011, Brogan 2002, Itano and Coan 2003, Moreno 2014 & 2015, Stobberup and Geehan 2015). Although most of these points are obvious, we consider them to worthy of restating here and hopefully of relevance for persons involved in developing new or upgrading existing data collection programs in Indonesia or elsewhere. We have added sub-comments in italics, specific to our experiences with this project's program.

[13] "sosialisasi" in Bahasa Indonesia differs in meaning of "socialisation" in English, and essentially means the provision of information to individuals, groups, or communities to enable their understanding of something that is being introduced/implemented.

Planning, recruitment, training and inception

- Consultation with all stakeholders groups during the planning and development phase to identify what sources and methods of information gathering are realistic. This ideally would include the relevant fisheries scientists within MMAF, fisheries offices (at national, provincial, regency, and district levels), port authority offices, fishing industry associations/groups, fishing company and processing company representatives, select vessel owners and captains, and members of other organisations/initiatives (e.g. universities, NGOs) linked to the fishery(s) in focus;

  Although no large, formal stakeholder meetings or workshops were held prior to the commencement of the enumeration program, we did discuss the planned program with the most relevant parties at the 4 focus ports during the Round 1 of the sampling of the population structure study.

- Engaging the abovementioned stakeholders at earliest opportunity and ensuring, as best as possible, their understanding of the objectives of the enumeration and the benefits that will be received from their respective cooperation/collaboration in the program;

  As above. And in hindsight, it would have worthwhile to strengthen the information delivery about the program with use of brochure, flyer, poster, or dvd or all of those media (in Bahasa Indonesia).

- Development of the sampling/data collection protocol should be flexible and readily adaptable to the dynamic (ever changing) conditions of the fishery(s). This is particularly relevant to Indonesia's marine fisheries where changes in government policy and regulations, and/or changes in fishing operations from factors such as fuel price and market accessibility are commonplace. This requires regular review of status of the fishery(s) and in particular, keeping track of changes in fleet, fishing operations and catch unloading 'behaviours'. Incorporating a system of regular reporting (providing updates from the field) by the enumerators of any such changes is highly recommended;

  The primary review of the enumeration program's progress, and associated 'issues' at the 4 ports, occurred at the Enumerators Workshop, held one year into the program. This was supplemented by one-to-one communications between the enumerators and Mr Bayu Sedana, the program's data coordinator at CFR, on an 'as needs' basis. There were also opportunities for review when scientists of the project were visiting those 4 ports for other project activity, including the Round 1 and Round 2 sampling visits. However, in hindsight, a more regular, more formal system of review would have been beneficial.

- Delivery of training and facilities – ensuring the enumerators are fully knowledgeable of the sampling protocol, fully capable with respect to the methods of data collection, including completion of landings forms, cross checking of data, subsampling and measurement of catch, techniques for skipper interviews, and the all-important skills for fish identification (see also below), and fully equipped to complete their tasks, efficiently and safely.

  Overall, we feel our program performed adequately in delivery of training and facilities. Of course, this is one area where more is always better. The one-on-one training delivered at time of recruitment of the enumerators, in situ at each port, was supplemented by training delivered at the Enumerators Workshop, and by opportunistic training during port visits for other project activity. In hindsight, a more formal, more regular program of training for the enumerators, both in the field and in 'classroom' as a group, would have been beneficial for their development but also for the quality and breadth of data collected. However, the costs associated with such extensive training was the key limiting factor.

- Training for fish identifications. It can be said that enumerators who, for whatever reason(s), are insufficiently skilled to make confident, accurate identifications of the species in their respective fishery, are the ‘achilles heel’ of data collection programs. This applies to both key/target species but also non-target/bycatch species within the fishery. If enumerators are recording erroneous data through incorrect identifications, that can have more negative ramifications for fisheries assessments than having no data at all.

  Overall, we feel our program performed well in the delivery of training for fish identifications, both through the initial training at time of enumerator recruitment, at the Enumerators Workshop, and through provision of fish ID resources[14]. However, in hindsight, we should have incorporated more follow-up assessments of the enumerators’ abilities in fish IDs, ideally through direct in-field observations and/or via testing of their skills at enumerator workshops. Their ability to confidently identify between YFT and BET at small size (e.g. < 60cm FL) was the skill of highest priority, given the prevalence of these fish in the catch landings being enumerated and the need for quality data on these species for regional stock assessments.

- Recruiting suitable personnel as enumerators. Obtaining persons who have sufficient availability (i.e. time available for the required duties), are of suitable character/personality, and with sufficient commitment to the demanding role of an enumerator can be difficult. Given the repetitive nature of the tasks, day after day, it can be a challenge for enumerators to maintain their enthusiasm and dedication to the work. This is understandable, particularly if their duties as enumerators are impacted, time-wise, by the duties of other work, or if they view their job as enumerators as short-term while waiting for other career/job prospects to appear. Often, if recruiting locally, there may be a limited pool of available, suitable persons to recruit from. The challenge of keeping enumerators engaged for the longer term can be made less onerous if those managing the program are providing regular feedback to the enumerator teams and by incentivising through ongoing capability development, through provision of additional skills.

  The recruitment experience in our enumerator program was, overall, positive. There were personnel issues that led to a cessation of the enumeration at Padang and Sorong after around 15 months (compared to Palabuhanratu and Kendari where the program continued for 39 months under the project’s management). In Padang the enumerators had difficulty in maintaining the necessary commitment to daily data collection because of imposts of other duties, even though at time of recruitment the agreement was full time commitment to the project. In Sorong the situation was exacerbated by restricted access by the primary fishing company to the catch landings of focus. That understandably led to a reduced level of enthusiasm of the enumerators to the tasks. The overall performance of the enumerators in Palabuhanratu and Kendari through the longer term period was exemplary.

Sustaining the program

- Maintaining a good working relationship with fishing companies, vessel owners, vessel captains, and crew is obviously extremely important for the success of an enumeration program. The personality of the enumerator and the ways in which he/she performs his/her duties can play a large role in how accepting and cooperative the fishing industry is to the program’s information requests and sampling activities. Where a team of enumerators is operating at a location, having

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[14] The development of the fish identification skills website, www.fishIDER.org, in ACIAR Projects SRA/2016/048 and SRA/2018/116, is actively addressing the need for improved fish identification skills for enumerators and other data collection staff in fisheries.

an effective team coordinator/'front person', who has the good working relationship with the industry players, can have a large influence on the success of the program;

Our project's enumerators were provided with guidance on 'best practice' for doing their enumerator duties via the sampling protocol, the initial training, and at the Enumerators Workshop. However, it is one area where more 'on-the ground' guidance and review is likely to have been beneficial.

- Data entry into a database by the enumerators themselves is viewed as preferable to enumerators sending their hard-copy data sheets to another place for 'remote' data entry. Doing so gives the enumerators more ownership of the data, but equally important, it significantly reduces the level of transcription errors from misinterpretations of what has been recorded (most often through poor legibility of handwritten information). Progression to methods of direct electronic recording/reporting by enumerators, through smart phones, tablets and alike, is occurring (as trialled and/or in current use by other organisations e.g. the "I-Fish App" used by MDPI's enumerators for direct uploading of collected data to their I-Fish database) and will obviously make this less of an issue.

This project decided not to trial methods of e-recording/reporting, partly because of budget reasons but also through concern that using such new technology might 'spook' some vessel captains and result in less information provided in interviews. Also, one advantage of using hard-copy data sheets is the ability for enumerators to quickly capture descriptions provided by interviewees on fishing gears, fishing methods, and other in annotated sketches more easily than in 'e-form'. However, as technologies progress such advantage is likely to lessen.

- The importance of review workshops, and other forms of regular review of an enumeration program cannot be over-stated. Ideally such reviews should include participation by the enumerators themselves, providing opportunity for joint discussion on issues impacting on their data collection duties. Such forums also enable direct checks with enumerators on any 'questionable'/unusual data and opportunity to review how well the data collection is meeting data needs and for addressing data gaps. They also provide opportunity for feedback to the enumerators on results of data analyses.

Only one review workshop (the Enumerators Workshop, Bali, October 2014, after 1 year of operations), was held during the course of this project's enumeration program, with participation of all the enumerators. Ideally we would also have had a get-together early in the program and one at its completion. However, review discussions were had with the enumerators during visits by the project's scientists to the respective port locations, both before and after the Enumerators Workshop.

7.2.3 Preliminary socio- and bio-economics surveys of FAD-based tuna fisheries at two key ports

The following is a much summarised version of the outcomes of the socio-/bio-economic surveys at the two ports, Kendari and Palabuhanratu. The outcomes of the bio-economic modelling for both ports are not included here as they are highly technical in nature and occupy several pages. That reporting is done in our project's stand-alone final report for the FAD fisheries study (Proctor et al. 2019b).

Kendari (SE Sulawesi)

The interviews with 60 vessel owners and vessel captains in Kendari were distributed across 3 fleets: purse-seine (PS) - 31 respondents, pole and line (PL) - 17 respondents and hand-line/troll-line (HL/TL) - 12 respondents. The information collected provided insights into the costs of construction and installation of FADs, the ownership and operational arrangements for FADs, and socio-economic aspects of the FAD-based fisheries (including profit sharing arrangements).

The average total cost of construction and installation of FADs was USD1,880, with a large component (typically > 70%) of the costs being for the mainline rope. The average depth of the ocean where the FADs of the Kendari fleets are located is 3,500 metres. The costs of FAD components are provided in Table 7.6

Table 7.6. FAD components and cost.

FAD Component	Quantity	Price (USD)	Total Cost (USD)	Average Cost (USD)
Attractor (coconut leaf)	5 – 45 leaf	0.15 – 0.37	0.8 – 16.8	2.8
Rope	500 – 7500 m	0.16 – 0.49	82 – 2,393	1,382
Ponton/Raft (Float)	1 – 5 Rafts	7.9 – 15.0	37 – 636	98
Sinker	7 – 35	7.5 – 25.6	52 – 224	267
Labour	3 – 7 days	15.0 – 37.4	45 – 262	131
Total FAD Cost			218 – 3,532	1,880

FAD ownership in Kendari has many variations. Most FADs were built and owned by vessel owners. This is especially true for PL and PS vessels. Some FADs are owned by individuals who do not operate fishing vessels, but they invest in FADs in order to collect shares from vessels that utilise their FADs. There are also several governments owned FADs which were usually provided as part of government (both provincial and district government) assistance to small boat owners who mainly use HL/TL to increase their catch.

As detailed in Table 7.7, similar arrangements are used by the PS and PL fishing fleets, whereas the HL/TL vessels employ different arrangements. HL/TL vessels are generally able to utilise the FADs as a place to ‘anchor to’, but in return they usually perform a role as a ‘watcher’ for the owner of the FAD in question and report to the FAD owner if another vessel is seen fishing on the FAD. This enables the FAD owner to seek a ‘utilisation’ payment.

Table 7.7. Operational arrangements for the use FADs, by vessel gear type.

	Purse Seine	Pole and Line	Hand line/Troll line
FAD sharing arrangement with other companies /vessels	Yes, with acknowledgment to the other companies /vessel	Yes, with acknowledgment to the other companies /vessel	No, free to use the FAD but if the owner want to use it they should leave
Arrangement of the operation	After the revenues are subtracted from the logistic cost then profit is divided by 3 (2 for the vessel, 1 for the FAD owner)	After the revenues are subtracted from the logistic cost then profit is divided by 3 (2 for the vessel, 1 for the FAD owner)	No
‘Rolling system’ for the FADs to make sure they are guarded from use/abuse by other vessels?	No, just watch each other FADs	No, just watch each other FADs, fishing and guarding the FADs at the same time	Help the FADs owner to watch their FADs

No formal education is needed for the young men to become good fishers or captains, as their knowledge is developed through the 'autodidact' educational system. Young boys become fishermen at very young age, normally when they have finished elementary school at the age of 12 and became trained fishermen after the age of 20, although that does depend on the learning skills of each individual. Formal education is only required when fishermen want to undertake the training necessary to apply for the captain or engineer certificate. Such training is available through fisheries training institutes, including those in the cities of Bitung, Tegal, Banyuwangi and Ambon. Fishermen generally have no clear path to follow. Some of them become successful captains and vessel owners, while others remain as crew members for the rest of their lives until they become old and cannot continue fishing anymore.

The ways in which revenue from the fisheries is split between crew and FAD owners, according to fixed rules and arrangements, is summarised by vessel gear type in Appendix 5.

Table 7.8 provides catch and CPUE for the three vessel types, based on landings data provided by Kendari Port Authority.

Table 7.8. Catch, effort and CPUE for Kendari FAD associated tuna fisheries.

Year	Purse seine			Pole and line			Hand line & troll line		
	ffort (trip)	Catch (ton)	CPUE (ton/trip)	Effort (trip)	Catch (ton)	CPUE (ton/trip)	Effort (trip)	Catch (ton)	CPUE (ton/trip)
2010	,075	15,544.95	5.06	940	5,032.41	5.35	387	826.85	2.14
2011	2,538	13,856.39	5.46	673	3,805.29	5.65	293	861.26	2.94
2012	2,606	14,450.96	5.55	485	3,419.24	7.05	290	856.42	2.95
2013	2,465	14,904.77	6.05	522	3,561.86	6.82	380	961.60	2.53
2014	2,178	14,589.88	6.70	683	4,083.78	5.98	267	847.25	3.17
Average	**2,572**	**14,669.39**	**5.76**	**661**	**3,980.52**	**6.17**	**323**	**870.68**	**2.75**

Table 7.9 provides a breakdown of the cost variables for the three vessel gear types (based on information sourced in the interviews).

Table 7.9 Cost variables of the tuna fishing fleets in Kendari. All figures in USD.

Cost variables	Purse seine	Pole and line	Hand and troll line
Total Cost (Capital+Fixed+Variables)	**86,846.1**	**97,284.8**	**15,250.7**
Capital investment	**79,856.1**	**88,242.6**	**12,509.3**
Boat	48,881.5	74,794.3	8,601.3
Engine	9,844.8	10,512.0	2,842.2
Auxiliary 1	792.5	804.0	828.1
Auxiliary 2	544.0	-	-
Fishing gear	17,763.6	102.4	88.1
Permit	149.6	149.6	149.6
FAD	1,880.2	1,880.2	-
Fix cost	**5,357.7**	**7,127.3**	**1,904.2**
Maintenances			
Boat	2,508.7	4,038.9	448.8
Main Engines	1,656.8	2,772.4	568.4

Auxiliary	586.4	284.2	56.1
Fishing gear	605.8	31.8	224.4
Variable cost	**1,632.3**	**1,914.9**	**837.1**
Fuel	642.9	472.7	349.2
Lubricant	40.6	88.3	33.1
Bait	-	56.1	22.7
Ice	203.5	113.7	95.2
Logistic	696.7	558.7	278.8
Wages	-	-	15.0
Spare part	48.6	74.8	43.2

Source: Interviews with vessel owners and captains in 2014 and 2015.

In pursuing a preliminary socio-economic and bio-economic analysis of the FAD associated tuna fisheries in Kendari (SE Sulawesi) and estimating the technical efficiency[15] of the tuna fishing fleets, the main constraints were the lack of long-term time series for catch and effort data and insufficient biological data to build a robust biological analysis for the bio-economic model. There was also need for more detailed information about the fishing operations around the FADs to improve the outputs from the technical efficiency analyses. Better data would allow other possibilities in the analyses, such as deriving the long run dynamic equilibrium for the bio-economic model, and also a more detailed stochastic production function frontier analysis. However, the results from this project proved useful for exploring the FAD associated tuna fisheries in Kendari and showed the potential for data analyses that could be done to support the policy planning and implementation.

Palabuhanratu (West Java)

The 18 interviews conducted with vessel owners and vessel captains in Palabuhanratu were restricted to the HL/TL fleet. No PL vessels operate in the West Java region and although tuna PS vessels do operate in waters to the south of Palabuhanratu, these vessels are not based in West Java and do not land their catches at PPN Palabuhanratu.

The overall design of FADs used by HL/TL fishers in Palabuhanratu is similar to that of FADs used by fishermen in PPS Kendari and in other regions, apart from their being no 'live-on' FADs i.e. the type of FADs that occur in some parts of eastern Indonesia that include a bamboo raft (*rakit*) and bungalow as part of the surface structure. For details of design of Indonesian anchored tuna FADs, see Appendix 4 (Section A4-1).

The costs of making FADs include: purchasing 100 pieces (i.e. branches) of coconut or nipa palm, with an average price of USD 0.19 – 0.31 per piece and an average total cost of USD 26; the mainline rope with average cost of USD 3615; an average cost for USD 498 for the floats; and an average cost of USD 196 for the anchor weights. The average total cost of making a FAD was USD 4,413, much higher than the average cost of FADs in Kendari. This is because the deeper waters in the fishing grounds of the Palabuhanratu region require a longer and stronger mainline rope, and the rope cost is by far the largest component of the overall costs. The details of the costs for FAD construction are given in Table 7.10.

Table 7.10. Costs associated with FAD construction in PPN Palabuhanratu.

FAD Component	Quantity	Price (USD)	Cost Range (USD)	Average Cost (USD)

[15] *For the results of the technical efficiency analysis refer to the project's stand alone final report for the FAD Fisheries study (in prep).*

Attractor	100 leaf	0.2 - 0.3	19.2 - 30.8	26.2
Rope	7,000 – 10,000 m	0.3 – 0.6	3231 - 3877	3615
Styrofoam (Float)	1 – 3 Rafts	154 - 385	308 - 769	498
Sinker	30 - 37	4.2 - 7.7	131 - 269	196
Labour	1 package	38 - 115	38 - 115	77
Total FAD Cost			**3,726.92 – 5,061.54**	**4,413.15**

Data on total catch and total number of fishing trips by the HL/TL vessels by year, obtained from PPN Palabuhanratu Port Authority for the 2008 - 2016 period enabled determination of CPUE in kg/trip (Table 7.11). The lowest CPUE was 461 kg/trip in 2010, the year when total number of trips was the highest. The highest CPUE of this period was in 2008, four years after the commencement of HL/TL operations at Palabuhanratu.

Table 7.11. Trends in effort, catch and CPUE for HL/TL vessels in PPN Palabuhanratu.

Year	Effort (Trips)	Catch (Kg)	CPUE (Kg/trip)
2008	350	292,167	835
2009	940	601,221	640
2010	1,927	888,403	461
2011	1,695	1,023,659	604
2012	1,032	852,040	826
2013	1,287	888,043	690
2014	1,211	613,143	506
2015	902	603,353	669
2016	504	320,855	637

Table 7.12 provides details of cost components of HL/TL with FADs for the vessels based at Palabuhanratu. The average amount of capital invested amounted to USD 20,639. This capital component included the cost of purchasing a vessel (USD 12,820), the main engine (USD 2,186), auxiliary machinery (USD 969), fishing gear (250) and costs FADs construction (USD 4,413). The average fix cost for 1 year was USD 429. The average variable cost of the vessel for one fishing trip, was USD 720.

Table 7.12. Cost components of HL/TL fishing with FADs in Palabuhanratu

Cost Variable	Average	Minimum	Maximum
Capital investment	20,639	9,496	37,138
Boat	12,820	3,846	26,923
Engine	2,186	923	3,462
Auxiliary 1	969	923	1,154
Fishing gear	250	77	538
Permit	0	0	0
FAD	4,413	3727	5,062
Fix Cost	**429**	**154**	**758**
Boat Maintenances	115	38	231
Main Engines Maintenances	231	77	385
Auxiliary Maintenances	48	15	81
Fishing gear Maintenances	35	23	62
Variable Cost	720	432	1201
Fuel	272	160	446
Lubricant	47	8	146
Spare part	57	3	186
Fishing gear	35	23	62
FAD Maintenances	19	8	31
Stone/Weight	33	31	35
Ice	121	85	135
Logistic/Food	136	115	160

The profit sharing system for the HL/TL vessels in Palabuhanratu is illustrated in Figure 7.10. The gross income from the catch is based on the total catch at time of return to port, less the 5 fish per person taken home by crew. Net income is determined by gross income less 20%; 5% for maintenance costs, 3% for tax *('retribusi')*, 5% for those persons *('juru batu')* in port who facilitate departure to sea and unloadings of catch, 5% for engine technicians *('juru mesin')*, and 2% for others. Accounting for the costs associated with the fishing operations at sea, the average net income is IDR 8 – 9 million. That net income is divided into 2 equal parts; half goes to the vessel owner and the other half is distributed to the vessel's captain and crew. The half of net income that goes to the captain and crew is further divided according the numbers of persons, with the captain receiving 2 persons worth and each crew member receiving 1 persons worth.

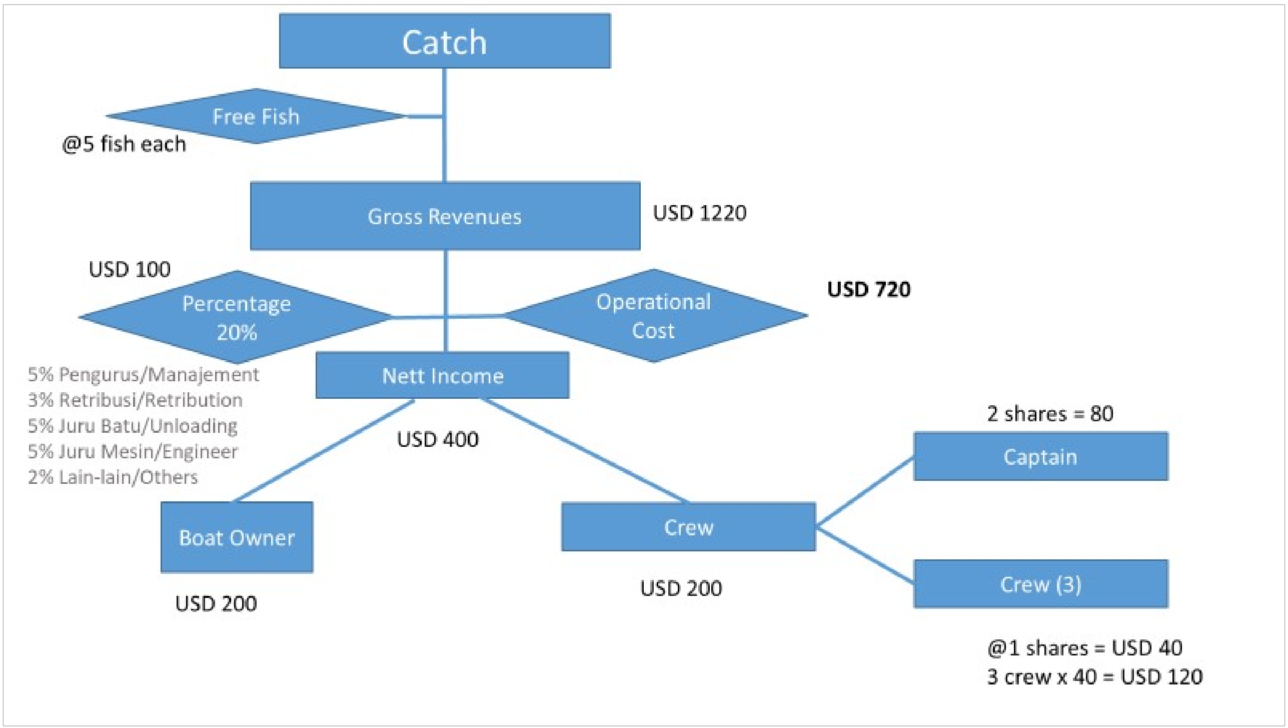

Figure 7.10. Sharing system of income of HL/TL in PPN Palabuhanratu

7.2.4 Trial acoustics and video research on fish aggregations on FADs

Acoustic trials

A total of 88 fish aggregations were observed during the acoustic surveys, ranging between 0.71 - 42881.66 m^2/nmi^2. Spatial distribution of fish aggregations varied from less than 0.1 to 1.4 nmi from the FAD, while the aggregations were distributed in the depth range of 10 to 245 m. The density of fish aggregations by depth and distance detected in the surveys are shown in Figure 7.11. Target Strength (TS) values were recorded for every fish aggregation; the lowest TS value was -59.6 and the highest value was -31.44 dB. Due to the high variability of TS values it was not possible to define the fish size without length-weight data, unless we assume a homogeneous distribution of the fish species around the FADs.

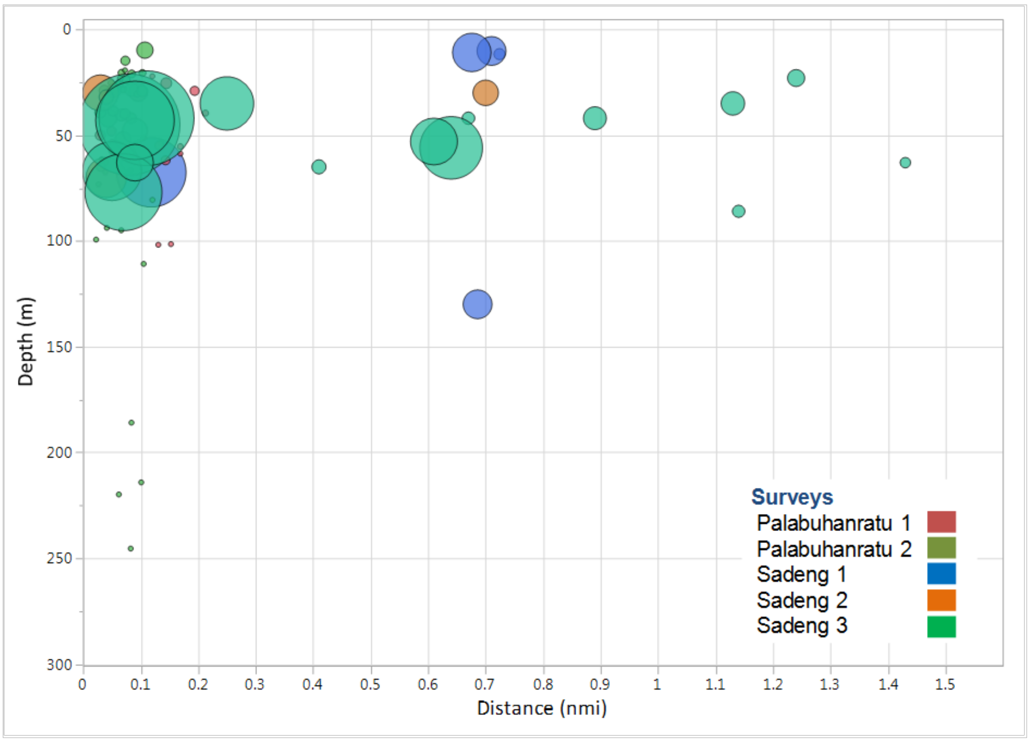

Figure 7.11. All aggregations of fish per depth and distance strata from the FADs.

Generalized linear models (GLMs) analysis showed that the variables of distance, depth, latitude, and longitude appear to be significant in the model and the full model (distance + depth + latitude + longitude) gives the lowest AIC value. The highest density of fish was found less than 0.2 nmi from the FADs and in a relative shallow layer of less than 100 m depth. A high number of fish aggregations were also found between 0.6 - 0.7 nmi from FADs in less than 100 m depth.

Temperature measurements in the acoustic surveys showed the lowest temperatures were observed during the Sadeng 1 survey on 23 August 2016 (southeast monsoon), while the other surveys had relatively similar temperature patterns. The thermocline layer in Sadeng 1 survey was shallowest at around 75 m and at 27°C. On average, the thermocline layers for other surveys were deeper than 90 m with temperature at around 28°C. The results showed that fish prefer to aggregate above and below the thermocline layer, however the highest density aggregations were found above the thermocline layer.

Camera trials

Several species of fish were observed and able to be identified to species in the trials using 360° camera. The species included dolphin fish (*Coryphaena hippurus*), rainbow runner (*Elagatis bipinnulata*), trigger fish (Balistidae), scads (*Decapterus spp.*), and juvenile yellowfin tuna (*Thunnus albacares*). Our trials of use of video camera for acoustic data verification showed there were depth limitations, where there is reliance on natural light. The estimate of this limit is around a maximum of 30 m depth, in best conditions. Also, the strong currents in open sea become a significant obstacle during the camera deployment. This was particularly true for the GoPro 360° video camera, where the camera frame rotated in the current as a result of the frame not being a streamlined and this made fish identification quite challenging. The Nikon KeyMission 360° had the advantage of its streamlined shape and it was possible to attach an additional wing to reduce rotations. However, the quality of video from the Nikon KeyMission 360° was poor by comparison to the clearer footage from the GoPro 360°. Another negative feature of the Nikon KeyMission 360° is that its underwater lens does not produce a full round field-of-view, with the edge impacted by a dark border.

Full details of the acoustic and camera trials are provided in the FAD fisheries study final report (in prep).

Overall, the trials of acoustic and visual survey methods on the FADs were successful in that they demonstrated that:

- With the appropriate equipment, and with a research vessel or with good cooperation from fishing vessel owners, skippers and crew, it should be possible to conduct acoustic and visual assessment of fish aggregations around the FADs;
- More extensive research with acoustic and visual surveys around the Indonesian FADs is recommended to do species characterisations, fish biomass estimates of fish aggregations, examine species' spatial behaviours, residency times, and aggregation 'recovery rates' following fishing events by the various fishing gears. The results of such research would benefit in the development of improved management for the FAD-based fisheries;
- Achieving video of sufficient quality to use as validation of fish species detected in acoustic census will require overcoming the problems of camera stability under influence of the strong water currents commonly experienced in the areas where the anchored tuna FADs are deployed;
- The trials did provide opportunity for capacity building in skills and knowledge associated with the fish aggregation associated research, and this will aid in enabling further research in this area.

7.3 Communications

Project objectives, activities, and outcomes were communicated through presentations and discussions at stakeholder and technical workshops, at scientific and industry meetings, via formal papers submitted to the RFMO meetings, the annual reports posted to the ACIAR website, a Fact Sheet, a newsletter, and disseminated through direct engagement with stakeholders in the field.

Internal project workshops and discussion forums

There were three main coordination meetings during the project's 5 year period: 1st Project Coordination Meeting on 28 - 30 April 2014, Hotel Seruni 3, Puncak (West Java); 2nd Project Coordination Meeting on 25 – 26 February 2016 (preceded by a 2 day Data Coordination Meeting), at RITF (Bali); and the Final Coordination Meeting (including project review) on 8 – 9 November 2016, at RITF.

In addition, throughout the project there were several less formal meetings between project staff to review progress and for planning. These included a 1 day workshop at CSIRO Hobart in March 2015 during the visit by 3 senior Indonesian project members, and another 1 day workshop to discuss the project's write-up at CSIRO Hobart in mid-Dec 2017. Both these workshops included video conference participation by the Indonesian team and by Prof. Bob Lester.

The project's Australian project leader, Craig Proctor, made 23 visits (average length 2 weeks) to Indonesia during the project's period and during the majority of those visits round-table discussion meetings with project members were held at Centre for Fisheries Research[16] (Jakarta) and at RITF (Bali). In addition, smaller group discussions were a regular occurrence between Mr Proctor, his Co-project Leaders (there were 4 different Co-Project Leaders during the course of the project), and other senior members of the Indonesian team.

[16] Formerly *Research Centre for Fisheries Management and Conservation,* at commencement of the project.

Scientific and industry meetings

Important communication and dissemination opportunities for the project included:

1. *Harvest Strategy (HS) development workshops*

This included 4 Technical HS Workshops and 7 Stakeholder HS Workshops between Oct 2014 and Nov 2017 (all workshops were 2 – 3 days). These workshops provided opportunities for our project to update participants on the project's objectives, activities and overall progress. Of particular importance was the updating participants on the status of data from the project's enumeration of the FAD-based fisheries at 4 ports. Regular participants in the workshops included project members, Campbell Davies (who had key roles in leading the meetings), Craig Proctor, and several from the Indonesian project team. Other participants included those from the RFMO WCPFC and IOTC, various sections of DGCF, NGOs (MDPI, WWF, ISSF, SFP), and representatives from various sectors of fishing industry;

2. *Presentations to stakeholders in fishing ports*

Various presentations (listed in Section 7.3) were given by project members during the course of the project as part of stakeholder meetings at fishing ports. Some of these were done early in the project (delivering project objectives) during the sampling for the Population Structure Study and others were given later in the project (delivering project outcomes) at the focus ports for enumeration, Kendari and Palabuhanratu. Stakeholders at these meetings included representatives of fishing industry (fishing associations, companies, vessel owners, fishers), local fisheries offices, and port authorities. These meetings were considered extremely important to the project's goals because, in addition to providing opportunity for disseminating information from the project, they provided opportunity to hear directly from stakeholders about the state of the fisheries, current issues/problems, and their views on best ways forward;

3. *International Coastal Tuna Business Forums*

During 2012 – 2016 there were 5 International Coastal Tuna Business Forums, jointly organised by IPNLF and DGCF. The project was well represented at all of these forums, and project members Campbell Davies, Prof. Wudianto, and Craig Proctor were invited to give presentations and be panel participants at 3 of these large meetings. The forums brought together representatives from all sectors of the tuna fisheries, across industry, management (including the RFMOs WCPFC and IOTC), and research. As such they afforded excellent networking opportunities for disseminating the project's activities;

4. *FAD Management Workshops*

The project assisted in the planning and convening of a 1 day FADs Management Discussion Workshop, held at RITF in February 2017. This was in collaboration with DGCF, TNC, and MDPI. A second important workshop for discussion on the FADs situation in Indonesian waters was the *National Forum on the Management of Fish Aggregating Devices (FADs)*, held in Bogor in October 2017. Craig Proctor was a participant at both workshops as were several of the project's Indonesian team members;

5. *RFMO Meetings*

Two papers (Widodo *et al.* 2016a and Lestari *et al*. 2016) as direct outputs from the project were submitted to the Scientific Committee Meeting of WCPFC in Bali in August 2016, and another submitted to the same meeting (Grewe *et al.* 2016) had strong links to the project (with several project members as authors). In November 2016, project member Anung Widodo (CFR) presented a paper (Widodo *et al.* 2016b) on the project's FAD study results to the IOTC Working Party for Tropical Tunas in the Seychelles;

6. *Science meetings of the International Pole and Line Foundation (IPNLF)*

In 2013 Craig Proctor was appointed to the Scientific and Technical Advisory Committee (STAC) of IPNLF. During 2013 – 2017 the annual meetings of the STAC provided opportunity for Craig to disseminate the project's objectives and activities to fellow STAC members; scientists from a range of disciplines in fisheries science including fisheries assessments, population dynamics, biology, and social economics. IPNLF's goals for sustainable 'one-by-one' line caught tuna fisheries (pole and line, troll-line, hand-line) in Indonesia have strong synergies to the sustainability goals of our project.

7. *Conferences*

Ms Pratiwi Lestari and Prof. Wudianto gave presentations on the project's Population Structure Study and FAD Fisheries Study respectively at the Australian Marine Sciences Association Conference in Darwin in July 2017 (details below).

List of oral communications

The following lists, in chronological order, the oral presentations given by project members during the project period (but not including the many presentations given by project members at the Project Coordination Meetings and in other internal meetings):

*Natsir, M. and Proctor, C. (2011) An overview of FAD-based fisheries and FAD issues in Indonesian archipelagic waters. Presentation to the International FADs 2011 Conference. Tahiti, December 2011;

Proctor, C. (2012). RFMOs – Benefits to Indonesia. Presented at the 1st International Coastal Tuna Business forum, Jakarta, 4 September 2012;

Proctor, C., Lestari, P. and Nurdin, E. (2013). Presentation on the project's objectives and methodologies, to Port Authority of Prigi Fishing Port (south coast East Java). April 2013;

Proctor, C., Lestari, P. and Nurdin, E. (2013). Presentation on the project's objectives and methodologies, to Municipal of Fisheries and Marine Affairs in Padang (West Sumatera). April 2013;

Proctor, C., Lestari, P. and Nurdin, E. (2013). Presentation on the project's objectives and methodologies, to Port Authority of Palabuhanratu Fishing Port (West Java). May 2013;

Proctor, C. (2014). A brief on issues of Indonesian pole and line fisheries. A presentation to Scientific and Technical Advisory Committee of International Pole and Line Foundation. Kuala Lumpur, February 2014;

Proctor, C. (2014) Current ACIAR capture fisheries projects and lessons from Australian experience in implementing long-term research plans. Presentation to Priority Identification Workshop for the strategic plan for ACIAR's Fisheries Program engagement in Indonesia. Bogor, March 2014;

Widodo, A. and Proctor, C. (2014) Presentations on fish identification at DGCF/IOTC/OFCF Enumerators Workshop, Bali, October 2014.

Proctor, C. (2014). Fisheries data collection in Indonesia. A presentation to Scientific and Technical Advisory Committee of International Pole and Line Foundation. Kuala Lumpur, November 2014;

Proctor, C. (2015) Developing research capacity for management of Indonesia's pelagic fisheries resources. Presentation to high level group from Gajah Mada University; visitors to CSIRO Hobart. March 2015;

Proctor, C. (2015). Presentation on the project's objectives, methodologies and status of data collection to Harvest Strategy Development Workshop, IPB Convention Centre, Bogor, May 2015;

Widodo, A. (2015). A brief of pole and line fisheries and the estimates of bait fish used (a case study in Sorong). Presentation to Baitfish Data and Management Workshop. Bali, May 2015;

Proctor, C. and Widodo, A. (2015). Characteristics of FADs in Indonesian waters. A presentation to Scientific and Technical Advisory Committee of International Pole and Line Foundation. Bangkok, November 2015;

Proctor, C., Widodo, A., Mahiswara, Sedana, I.G.B., and Wudianto (2015) Overview of FADs in Indonesian waters. Presentation to 3rd Harvest Strategy Stakeholder Workshop. Bali, November 2015;

Proctor, C. and Widodo, A. (2016). A presentation on the project's objectives and status of outcomes, to stakeholders (fishing industry, port authority, local fisheries officers) at Palabuhanratu Fishing Port. April 2016;

Proctor, C. and Natsir, M. (2016). A presentation on the project's objectives and status of outcomes, to stakeholders (fishing industry, port authority, local fisheries officers) at Kendari Fishing Port. April 2016;

Proctor, C., Widodo, A., Mahiswara, Sedana, I.G.B., and Wudianto (2017) Overview of FADs in Indonesian waters. Presentation at FADs Management Workshop, Bali, February 2017;

Lestari, P., Taufik, M., Wujdi, A., Proctor, C., Wudianto, Lester, R., Clear, N., Grewe, P., Eveson, P., Davies, C., Moore, B., Lansdell, M., Hill, P., Dietz, C., and Thompson, J. (2017) A multi-technique investigation of population structure of tunas in Indonesian archipelagic waters. Presentation to Australian Marine Sciences Association Conference. Darwin, July 2017;

Widodo, A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I. and Cooper, S. (2017) Characteristics of tuna fisheries associated with FADs in Indonesian waters. Presentation to Australian Marine Sciences Association Conference. Darwin, July 2017 (presented by Prof. Wudianto);

Widodo, A., Wudianto, and Proctor, C. (2017) Characteristics of tuna fisheries associated with anchored FADs in Indonesian waters. ACIAR Project FIS/2009/059. Presentation to National FADs Management Workshop. Bogor, October 2017.

*A presentation given prior to commencement of the project but considered an important preliminary communication of the project.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project's significant scientific impacts are summarised as follows:

- Impacts from the project have already been realised through direct inputs of data and information into the development of the Harvest Strategy (HS) Framework for Indonesian tuna fisheries which began with the first Stakeholder workshop on October 2014. There have since been 7 Stakeholder HS workshops and 4 Technical HS Workshops. The project has had strong representation in all these meetings. The HS development is a key component of Indonesia's draft National Tuna Management Plan;
- The project's population structure study is the most comprehensive for the tropical tuna species to date and has provided an improved understanding of the degree of mixing of tuna across the Indonesian archipelago and connectivity to adjoining oceans. Although, as we emphasise, this was a 'first look' at the level of connectivity of the populations across the region, and that follow-up research on other life-stages (larvae, adults) is recommended, the outcomes of the study will benefit the current discussions and decision making on management of the species at both domestic and international levels;
- The project's enumeration program for the FAD fisheries study was selected in the HS development process as one of four key sources of data for analysis in the development process The project's data have already been used in Management Strategy Evaluation (MSE) development as part of the HS process;
- The population structure study has enabled road testing of next generation sequencing technologies; expanding of the sampling region has permitted a greater perspective on the global population structure of yellowfin tuna. The outputs from this study and current work in other projects[17] will contribute within 5 years to an globally significant knowledge base on the population structure of tropical tuna in the Indo-Pacific region;
- The population structure study has also provided direct evidence of the benefits of using a multi-technique approach over a single technique;
- The project's sampling protocol for the population structure study has been adopted as protocol by other large-scale stock structure studies (see footnote, this page);
- The project's enumeration program protocol and experiences, with focus on FAD-based fisheries, are contributing to the development of protocols for DGCF's One Data program, with nationwide enumeration, logbook and observer programs;
- The project's FAD fisheries study has provided DGCF with an improved understanding of the 'dynamics' of the FAD-based fisheries which, together with the findings of other research programs and initiatives of other agencies, will assist Indonesia with development of more effective FAD regulations and fisheries monitoring programs;
- A key element of the previous point is the improved understanding of the scale of catch of juvenile YFT and BET, and bycatch species caught by the FAD-based fisheries. This information is essential to the design of effective fisheries regulations and important to the Indonesia's tuna industry's goals of achieving market certification for sustainable fisheries;

[17] *Including two current projects under leadership by CSIRO: Provenance and Chain of Custody of Tropical Tuna in the NE Indian Ocean (funded by DFAT and CSIRO), and Population structure of IOTC species in the Indian Ocean: Estimation with Next Generation Sequencing Technologies and Otolith Microchemistry (Project PSTBS-IO) (funded by the European Union through FAO and IOTC).*

- The project's *Bibliography of FAD studies* revealed a wealth of scientific research from Indonesia's waters with focus on, or with links to, FAD fisheries. Previously the majority of the 116 studies collated in the bibliography were largely unknown outside of Indonesia because of only being published in Bahasa Indonesia, and many as graduate and postgraduate student theses;
- Scientific impact has also been achieved through scientific papers and presentations by Indonesian and Australian team members on project outcomes to meetings of the RFMOs, IOTC and WCPFC, and to other forums such as the Scientific and Technical Advisory Committee of the International Pole and Line Foundation (see Sections 10.2 and 7.3 for lists of project publications and presentations respectively).

8.2 Capacity impacts – now and in 5 years

The project's significant capacity impacts are summarised as follows:

- Provided capacity development for Indonesian scientists in genetics, otolith chemistry, and parasites research techniques and associated data analyses. This included training delivered at CSIRO Hobart, University of Queensland, and in Indonesia. The scientists involved[18] now have lead roles in their respective institutes, applying their knowledge and enabling the institutes to expand into new areas of research;
- Provided capacity development for 11 Indonesian scientists from 3 institutes within AMAFRHR, in the planning and execution of field sampling of multiple species for population structure studies. This will enable Indonesia to engage in current and future fisheries population studies without the need for major inputs from CSIRO or other external agencies. CFR is applying their capacity as a participating partner in the current project *Population Structure of Tuna, Billfish and Sharks – Indian Ocean*;
- Supported (through funding and as participating trainers) the training of Indonesian scientists and DGCF staff on principles of HS/MSE, at CSIRO Hobart in 2016. The scientists who received this training, Dr Lilis Sadiyah (CFR) and Ms Tri Ernawati Sarwono (RIMF), now have principal technical and advisory roles in the HS development process for tuna fisheries and are likely to have increasingly important roles into the future;
- The project participated in organisation (including contributing to funding support) and running of a Crawford Fund Master Class[19] *"Methods for assessing data-poor fisheries"* in Bogor in 2015, involving 39 participants from government, research institute, university, NGO, and industry sectors. The skills acquired, by the scientist participants in particular, are being applied in the HS development process, for tuna and other fisheries as part of the annual stock assessment process;
- Improved capacity of Indonesian scientists in fisheries information gathering, through development and application of sampling protocols, and establishment and running of an enumeration program at 4 major tuna ports. The enumeration program has provided key lessons in what can and cannot be achieved through targeted data and information collection; lessons that will benefit establishment of future monitoring programs;

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[18] Ms Pratiwi Lestari (RIMF) as the project's trainee for fish parasites, Mr Muhammad Taufik (RIMF) as trainee for genetics, and Mr Arief Wujdi (RITF) as trainee in otolith chemistry. Both Ms Lestari and Mr Taufik have been playing key roles in sampling for follow-on stock structure projects since this project concluded, and have already passed on their knowledge to several of their institute colleagues in RIMF.

[19] Crawford Fund Master Class[19] "Methods for assessing data-poor fisheries", done in collaboration with Murdoch University, DGCF, and Institut Pertanian Bogor (Bogor Agricultural University), 24 – 28 August 2015.

- Linked to the previous point, increased capacity within CFR in design and implementation of databases and data quality control, through Mr Bayu Merta (Data Manager at CFR) working with Mr Scott Cooper (database scientist at CSIRO) in development of a bilingual database to accommodate the data and information collected in the FAD fisheries study. AMAFRHR's involvement in monitoring of fisheries is increasing, with more and more locations being added to the list of ports being monitored under the WPEA[20] and other programs, and database requirements are increasing accordingly. The importance of databases will continue to rise as the HS development continues for tuna and other fisheries;
- Improved capacity of Indonesian scientists in bio-/socio-economic assessments of fisheries. This capacity development is particularly timely, with increasing importance of such assessments to the HS development process. The impact is immediate, with at least one scientist within AMAFRHR, Mr Mohamad Natsir (CFR), now able to lead bio-/socio-economic surveys and assessments. He will undoubtedly transfer his knowledge to colleagues in his and other AMAFRHR institutes;
- Improved capacity of Indonesian scientists for doing targeted research on FADs. Although done primarily as trial research, the project developed new capacity for Indonesian scientists in acoustic and visual assessments of fish aggregations. This will be important for current and future research capacity and development of FAD's management;
- In doing her Masters of Applied Sciences (achieving First Class Honours) under this project as holder of a John Allwright Fellowship (JAF), Ms Ririk Sulistyaningsih[21] achieved capacity development in several areas of fisheries science, through coursework and her research project year. The latter provided her with skills in research planning and implementation, data gathering, statistical analyses and scientific writing. This builds on training she received in our earlier ACIAR project FIS/2002/074. She now has expanded knowledge on fish age and growth, and her research enabled the project to explore the potential for otolith shape as a tool for population structure analysis. Ms Sulistyaningsih is well positioned to be a key participating scientist and potential leader of her institute's collaboration in the new ACIAR project, FIS/2016/116, in which age/growth and reproductive biology of tuna are major foci;
- Dr Lilis Sadiyah (CFR), as recipient of a John Dillon Fellowship linked to this project, received capacity development in research leadership and management in 2016. This development builds on that she obtained through her JAF supported PhD at University of Tasmania-CSIRO in 2008 – 2011, under the earlier project FIS/2002/074. Dr Sadiyah has already demonstrated her abilities as AMAFRHR's lead mathematical scientist, a role with increasing importance as the HS development process continues and Indonesia become more active in the scientific committees and commissions of the three tuna RFMOs of which they are members. With her capacity development and widening experience she is also well positioned to take on more senior leadership roles within AMAFRHR and continue to recruit quantitatively trained staff to these important roles;
- This project has afforded opportunity for capacity building in scientific writing and presentation skills for several of the project's participating Indonesian scientists (and also for scientists on the Australian side). This includes the papers submitted to the meetings of the RFMOs and to other forums, the contributions to this Final

[20] *Western Pacific and East Asia program, funded by Global Environment Facility, and under coordination by WCPFC, in collaboration with AMAFRHR and the Pacific Community.*

[21] *Ms Ririk Sulistyaningsih, scientist of Research Institute for Tuna Fisheries, as a recipient of a John Allwright Fellowship , completed a Masters of Applied Sciences and achieved First Class Honours, at University of Tasmania in 2016 – 2017.*

Report (in particular, in regards to Indonesian scientists, the reports included in Appendix 12), journal papers, and presentations to conferences. See the presentations and publications listed in Sections 7.3 and 10.2 respectively. The impacts from these areas of capacity building are invaluable in the broadening of the communication of AMAFRHR's research outcomes beyond domestic boundaries and increasing Indonesia's scientific participation in the tuna RFMOs.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

- Indonesia is currently developing new strategies for management of its tuna fisheries. The outcomes from this project's population structure study and the FAD fisheries study have been and continue to be significant contributions to the HS development process. Contributing to the HS process and towards the goal of improved sustainability of the fisheries will assist in achieving improved economic stability for all sectors of these fisheries; both for the industrial/commercial and small-scale/artisanal sectors. The YFT and BET components of Indonesia's pelagic fisheries were valued, as international export and domestic product, at AU$690 million in 2015 (MMAF 2016) and together comprised around 6.3% of total value of Indonesia's marine capture fisheries commodities in that year;
- In wishing to ensure continuity and security of overseas markets for tuna product, Indonesia's fishing industry and fisheries management (i.e. the relevant Directorates within MMAF) recognise the importance of achieving Marine Stewardship Council and/or other sustainable fisheries certifications. The outputs of information from both the population structure study and the FAD fisheries study will assist those pursuing certifications in the application process. In particular, the improved information on catch compositions reported for the handline/troll-line and pole and line fisheries will assist fishing companies and the industry associations in providing details such as the proportions of target and non-target species in their overall catches;
- Information from the project provided to DGCF, on the scale of movements of YFT and BET within the Indonesian archipelago and connectivity to populations in the adjoining oceans will place MMAF in a stronger position to make decisions on effective management measures to better ensure sustainability of the tuna stocks, while also taking into account the economic impacts of such measures. And armed with this information will also enhance DGCF's position for communicating to stakeholders on the economic benefits that will accrue from improved management;
- Similarly, the information from the project's socio/bio-economic study will assist DGCF in assessing the likely impacts to the livelihoods of all fisheries sectors to any new management measures, including those relating to installation and use of FADs. This is of particular importance in considering the longer term priorities of ensuring stock conservation while maintaining economic viability of the fishing fleets of both large- and small-scale fishers (the latter voiced as highest priority by MMAF);
- The project's recommendations around need for improved FAD regulations (in terms of being more realistically implementable, enforceable, and more clearly defined) will assist DGCF in their development of revised and new regulations, while highlighting the potential economic impacts.

8.3.2 Social impacts

- The most obvious social impacts from the outcomes of this project are those that will flow to fisheries communities and all sectors of the tuna fishing industry from improved sustainability of the fisheries; most notably security of livelihoods and food supply;
- The project's preliminary socio-/bio-economic assessment of the FAD fisheries has been extremely timely, given the increased importance being voiced, by all involved (and in particular scientists within AMAFRHR's Research Centre for Marine and Fisheries Socio-Economic and the NGOs) on the socio-economic considerations around development of harvest strategies for the tuna fisheries and movement towards new management measures. The outcomes of the assessments for fisheries at Kendari and Palabuhanratu are being included in the initial review of the follow-on project, FIS/2016/116;
- This project's outcomes are unlikely to have any new impacts in respect to gender balance in Indonesia's fishing industries and fisheries communities. Within all sectors of the tuna fishing activities, with the exception of the fishers that go to sea, there is across-the-board strong representation by women. From the owners and senior staff of fishing companies, to senior representatives of the tuna fishing associations, to staff of processing companies and associated industries, and to those involved at all levels from point of catch landing to market, women are well represented;
- Similarly, among scientist ranks of fisheries research institutes within AMAFRHR, and among staff of DGCF and other Directorates within MMAF, gender imbalance does not appear, in general, to be a significant issue, with strong representation by women (both in terms of number of persons and seniority). However, at the higher levels of Heads and Directors of AMAFRHR institutes and Directorate Generals within MMAF, females are still few in number.

8.3.3 Environmental impacts

- In delivering information to provide a better understanding of Indonesia's FAD fisheries, the project outputs are currently assisting Indonesia in assessing what needs to be done to make the practices more environmentally sustainable, both in terms of catch (impacts to non-target species, impacts to stocks of juvenile tuna), but also in terms of marine pollution (FAD loss, FAD 'waste');
- As reported in Section 7.2.2, FADs have an average 'life' of 2 years and are frequently lost to natural and unnatural events. Although current fisheries regulations require that only biodegradable materials be used in FAD construction, in reality this regulation has not been adhered to. The scale of the FADs waste issue has not yet been investigated nor sufficiently addressed for Indonesian waters and we hope that highlighting the issue in this report will raise its importance;
- The use of FADs as a tool in the tuna fisheries carries some positive environmental benefits through significantly reduced fuel use, as a result of fishing vessels having to expend less effort in the search for fish schools;
- Similarly positive, an issue for FAD use that has attracted much attention worldwide, with the inadvertent catch and death/injury of non-target species (most notably turtles) in the submersed attractors, is not an issue for the Indonesian tuna FADs. The attractors used on the deep-water anchored FADs in Indonesia are non-entangling i.e. natural materials such as palm branches and not netting materials. By highlighting these positive aspects we hope the

project will assist in achieving a balanced discussion for the overall FADs management situation in Indonesia.

8.4 Communication and dissemination activities

The project’s communication and dissemination activities have been covered above in Section 7.3, in addressing the Communication objective.

9 Conclusions and recommendations

9.1 Conclusions

Population structure study

- The results for the three techniques that were, overall, consistent, suggesting multiple populations for both species across the geographic range;
- The outcomes of the genetics analyses suggested at least 2 or 3 genetic groupings ("a subtle genetic structure") for both YFT and BET, with clines of genetic variation across the geographic range;
- The patterns of prevalence and abundance of parasites suggested limited to no movement of fish (both species) westwards from the Indonesian archipelagic waters (IAW) into the eastern and central Indian Ocean, and also little movement from the Western Pacific Ocean westwards into the Indonesian archipelago. These results indicate at least three groups (populations) for each species, and the overall patterns were similar across years;
- The overall outcome from the otolith chemistry analyses, using both stable isotopes and elemental chemistry, was that the YFT and BET had not moved large distances in their first 4 - 6 months of life;
- These conclusions need to be qualified by the fact that the population structure study was based on samples from young-of-the-year tuna and the assumption that these individuals had not migrated substantial distances from the areas in which they were spawned. Further studies on other life history stages (ideally mature fish, and/or larvae) are required to substantiate, or refute, these conclusions;
- These results suggest that the current national and regional governance arrangements are likely to be consistent with the structure and connectivity of YFT and BET populations. That is, the Indian and Western Central Pacific Oceans being managed as separate stocks, by the respective Commissions, and IAW having higher connectivity (as indicated by estimates of gene flow) with adjacent WCPO waters, than with EIO waters;
- With respect to structure and connectivity in IAW, the results do not allow firm conclusions to be drawn on the appropriate scale of assessment management of its tuna fisheries within IAW (by FMA, multiple FMAs, or other scale). However, given the scale of movements documented from previous conventional tagging studies and the estimated level of gene-flow among neighbouring FMAs in IAW (713,714,715) and those bordering the WCPO (716, 717) reported here, it is likely that connectivity between these FMAs for both species is sufficiently high that they should be assessed and managed as a single management unit, consistent with current arrangements.
- An important outstanding question, which is not adequately resolved by this study, is the level of connectivity between IAW and adjacent areas of the WCPO. This connectivity is an important component of estimating the contribution of recruitment and adult biomass in the different areas to the populations overall and the relative impacts and sustainability of harvests in each area. Addition sampling over a number of years and use of other methods, such as Close-kin Mark Recapture have the potential to address this question directly.
- The population structure study engaged participating Indonesian scientists in planning, design and execution of large-scale field sampling, new methods in genetics, otolith chemistry, otolith morphology, and parasite characterisations, and for four of them this

included substantial training in Australian institutions. Individual scientists have already been using these new skills to participate in new projects, both independently and as part of new collaborative projects with CSIRO.

FAD fisheries study

- The tuna FAD situation in Indonesia is complex; perhaps the most complex of anywhere in the world. Multiple types of anchored FAD, multiple vessel types of various sizes and fishing gears, different forms of FAD ownership and operations, and high rates of FAD turn-over: a truly ‘dynamic’ FAD environment;
- The FADs are an important efficiency tool for both large-scale (purse-seine, some of the pole & line) and small-scale (smaller pole & line and hand-line/troll-line) fishers. Prohibiting use of the deepwater anchored FADs, or severely restricting their use, is likely to have largest impact to the small-scale fishers who have become heavily reliant on them. The productivity of free-school fishing, as an alternative to FAD-based fishing, for the small-scale vessels requires further study;
- The results of the project’s enumeration study confirm observations from other monitoring programs (including the concurrent WPEA program and of MDPI) that juvenile YFT and BET comprise significant proportions of the catch of the gears fishing on Indonesian deepwater anchored FADs; HL/TL in particular;
- As expected, obtaining a good estimate of FAD numbers in Indonesian waters proved difficult in the current unregulated environment (i.e. no accurate registry of operational FADs). This was true for Indonesian waters as a whole but also for smaller regions (e.g. determining the number of FADs within an individual FMA);
- Although Indonesia has had FAD regulations in fisheries law since 1997, with multiple upgrades and additions to the regulations since then (most recent regulations are Peraturan Menteri KP No.26/PERMEN/2016 of 2016), to date these regulations have not achieved adequate implementation nor enforcement. A low level of understanding by the fisher community on how the laws are intended to operate and on the benefits that the laws will achieve for the fishers, through improved sustainability of the fisheries, have been key contributing factors to the lack of ‘sign-on’ and adherence to them;
- The FAD fisheries study provided opportunity for extending Indonesia’s capacity for socio- and bio-economic assessments of fisheries, at a time when such capacity is increasingly in demand (e.g. in current and future tuna harvest strategy development, wider development of fisheries management plans for each FMA);
- The study also provided opportunity for participating scientists to explore methods of assessing FAD-based fishing operations, and to extend earlier research on the dynamics of fish aggregations on deepwater anchored FADs in Indonesian waters.

Overall project

- This project was large and complex. It involved a broad range of research methods and capacity development activities within both key components; the population structure study and the FAD fisheries study. In many ways it could have sat nicely as two projects - a separate project for each of those studies. However, as identified during the project’s planning phase, there were sufficient linkage points between the two studies, and large overlaps in personnel on the Indonesian team, to provide many operational benefits under the one project ‘umbrella’;
- The project achieved most of its objectives and has provided outcomes that have already proved useful in the development of Indonesia’s tuna fisheries management. There has been keen interest from the international scientific and management community in the results of both components of the project. The stand-alone final reports for the population

structure study and FAD fisheries study (in prep and close to completion), the scientific papers to follow, and the extension materials, will significantly extend the project's performance and overall achievements;

- The project's capacity development components produced some of its strongest outcomes, building on those provided by earlier ACIAR projects for Indonesia's tuna fisheries (FIS/2002/074 in particular). Several of the project's scientists from the three primary partner institutes (CFR, RIMF, and RITF) received training that have significantly enhanced their career paths. As noted, a number are using the skills and experience gained through this project to deliver important national projects, participate in independent international collaborations as well as playing key roles in new collaborative initiatives with the CSIRO team. For most, their training will have strong influence on their future research directions, and provide valuable expertise for their respective institutions.

9.2 Recommendations

- This study has demonstrated that the question of connectivity between IAW and WCPO and IO can be addressed through a combination of populations structure methods. Refining and extending the approach to include multi-year sampling of spawning adults and or larvae and methods that provide more direct estimates of connectivity, such as close-kin Mark Recapture, should be a high priority for future work;
- Results from the population structure study should be combined with those of current and future studies to determine appropriate management strategies for the two tuna species, both domestically within the Indonesian archipelago and other waters within the Indonesian EEZ, and for the broader Indo-Pacific region. As otolith chemistry and genetic approaches continue, samples collected in this project should be included and Indonesian scientists encouraged to participate, where possible, to value-add to the outputs achieved so far;
- As a next phase of examining the population structures of these important tuna species, future studies should extend to include other life-history stages of the tuna; larvae and large, mature fish in particular;
- With an ever increasing number of initiatives (most notably those of eNGOs) involved in the 'tuna space', assisting Indonesia with achieving improved fisheries management, there needs to be a high level of coordination among them and with Indonesian government (the Directorates within MMAF and AMAFRHR) to ensure maximum benefits, strongest outcomes, minimal duplication of efforts and effective use of resources;
- As the harvest strategy development for Indonesia's tuna fisheries continues, the current information gaps in life-history parameters for the key tuna species needs to be addressed[22]. Population biology research is needed to determine/validate size and age of fish at maturity, fecundity, seasonality of spawning, level of synchronicity of spawning across the region, spawning areas (spatially discrete or broad?), and growth-rate parameters, recognising the potential for significant differences in growth rates regionally;
- With increasing recognition of the importance of including socio-economic impacts to fishing communities (in particular impacts to small-scale fishers) in development of new management measures, the capacity development of Indonesian scientists in socio-/bio-economic assessment skills should continue and, if possible, be expanded;

[22] To a large extent this is being addressed by the ACIAR follow-on project FIS/2016/116 *"Harvest strategies for Indonesian tropical tuna fisheries to increase sustainable benefits"*.

- Similarly, there is need for an ongoing capacity development[23] for Indonesia's fisheries scientists and relevant staff within the Directorates of MMAF in all aspects of developing and implementing harvest strategies, including operating models, Management Strategy Evaluation, and identifying realistic and practical management measures for the complex Indonesian fisheries;
- Further capacity development opportunities for Indonesian scientists in population genetics, otolith chemistry, and parasites research should also be explored and pursued; Stock assessment and management strategy are also fields identified as areas that can be strengthened and enhanced;
- Further research on the FAD fisheries is required to determine 'realistic' FAD management options and the likely impacts of FAD-based management measures e.g. restrictions on FAD numbers by region, regulated FAD sharing within and between gear-types, seasonal closures (as has been operating for PNA countries in the Pacific Ocean);
- There is a need to address the question of whether free school (i.e. FAD-free) tuna fishing by 'One by One fishing gears' (pole & line and hand-line/troll-line) is likely to achieve the operational efficiencies, sufficient catch and sustainable incomes for the communities and industries associated with those gears;
- In association with the above, if a move away from FAD-based fishing were to be pursued, capacity development for fishers in free-school fishing techniques is most likely required;
- To extend the preliminary acoustics and visual census research done in this project, research on fish aggregation behaviours on the Indonesian tuna FADs is required to better understand the dynamics of deepwater FAD fishing, and catch success. The outcomes of such may prove to be different to the findings of studies elsewhere. As example, if considering FAD-sharing as a management measure, it is important to determine recovery times following fishing events by the different gears;
- Continued and, ideally, increased participation by vessel owners, skippers and fishers associations in the discussions around new management measures to ensure their 'sign-on';
- Investigate community-based enforcement options to supplement government-based enforcement or even to be the primary method of enforcement/regulation;
- Development of improved designs to achieve FADs that are environmentally friendly, able to comply with fisheries regulations, while maintaining affordability for fishing communities. This could include development of FAD constructions that are more robust and which are less susceptible to loss;
- Research is required to develop effective, affordable methods of FAD detection and monitoring (e.g. new satellite technologies, radar) to enable those enforcing the regulations the ability to monitor FAD numbers and locations in their region;
- With the ongoing 'roll-out' of logbooks by DGCF to the tuna fishing industry, there should be inclusion of information gathering on all aspects of FAD use and catch success;
- In addressing the ever increasing number of deepwater anchored FADs in Indonesian waters, and the little to no current adherence to the regulation of a minimum inter-FAD distance of 10 nmi, fishers need to be better informed of the benefits that will accrue from not having FADs at high density.

[23] *Also being addressed by the follow-on ACIAR Project FIS/2016/116.*

10 References

10.1 References cited in report

Allendorf, F.W., Hohenlohe, P.A. and Luikart, G. (2010) Genomics and the future of conservation genetics. Nat. Rev. Genet. 11, 697–709.

Anon (2008) West Sumatra Tuna Tagging Project 2006 – 2007. Final Report. 27pp.

ANOVA (2011) Port sampling protocol for artisanal handline tuna: Indonesia. 51pp.

Appleyard, S., Grewe, P., Innes, B., and Ward, R. (2001) Population structure of yellowfin tuna (*Thunnus albacares*) in the western Pacific Ocean, inferred from microsatellite loci. Marine Biology 139, 383-393.

Appleyard, S.A., Ward, R.D., and Grewe, P.M. (2002) Genetic stock structure of bigeye tuna in the Indian Ocean using mitochondrial DNA and microsatellites. J. Fish Biol.,60, 767-770.

Arnason, R. (2015) Lecture notes for United Nation University – Fisheries Training Program UNU-FTP. Iceland (unpublished).

Battese, G.E., & Coelli, T. (1995) A model for technical inefficiency effect in a stochastic frontier production function for panel data. Empirical Economics, 20, 325-332.

Brogan, D. (2002) Port sampling manual. Secretariat of the Pacific Community. 67pp.

Buckworth, R.C., Newman, S.J., Ovenden, J.R., Lester, R.J.G. and McPherson, G.R. (2007) The stock structure of northern and western Australian Spanish mackerel. Final report, Fisheries Research and Development Corporation Project 1998/159. Department of Primary Industry, Fisheries & Mines, Northern Territory Government, Australia. Fishery Report 88, i–vi, 225 pp.

Bush, A.O., Lafferty, K.D., Lotz, J.M. and Shostak, J.M. (1997) Parasitology meets ecology on its own terms: Margolis et al. revisited. Journal of Parasitology 83: 575–583.

Chiang, H-C., Hsu, C-C., Wu, G.C-C., Chang, S-K. and Yang, H-Y. (2008) Population structure of bigeye tuna (*Thunnus obesus*) in the Indian Ocean inferred from mitochondrial DNA. Fish. Res. 90, 305 – 312.

Dammannagoda, S.T., Hurwood, D.A. and Mather, P.B. (2008) Evidence for fine geographical scale heterogeneity in gene frequencies in yellowfin tuna (*Thunnus albacares*) from the north Indian Ocean around Sri Lanka. Fish. Res. 90, 147–157.

Davies, N., Hoyle, S., Harley, S., Langley, A., Kleiber, P., and Hampton, J. (2011) Stock assessment of bigeye tuna in the Western and Central Pacific Ocean. Report to Scientific Committee of Western and Central Pacific Fisheries Commission, 7th Regular Session, 9 – 17 August 2011, Pohnpei, FSM. WCPFC-SC7-2011/SA-WP-02, 133pp.

Davies, N., Shelton, H., Hampton, J., and McKenzie, S. (2014) Stock assessment of the yellowfin tuna in the western and central Pacific Ocean. WCPFC-SC10-2014/SA- WP-04. (2014).

Davey, J.W., Hohenlohe, P.A., Etter, P.D., Boone, J.Q., Catchen, J.M. and Baxter, M.L. (2011) Genome-wide genetic marker discovery and genotyping using next-generation sequencing. Nat. Rev. Genet. 12, 499–510.

Diaz-Jaimes, P. and Uribe-Alcocer, M. (2006) Spatial differentiation in the eastern Pacific yellowfin tuna revealed by microsatellite variation. Fisheries Science 72, 590-596.

Grewe, P.M., Krueger, C.C., Aquadro, C.F., Bermingham, E., Kincaid, H.L., and May, B. (1993) Mitochondrial DNA variation among lake trout (*Salvelinus namaycush*) strains stocked into Lake Ontario. Can. J. Fish. Aquatic. Sci. 50, 2397-2403.

Grewe, P.M. and Hampton, J. (1998) An assessment of bigeye (*Thunnus obesus*) population structure in the Pacific Ocean, based on mitochondrial DNA and DNA microsatellite analysis. School of Ocean and Earth Science and Technology Publication 98-05*,* Joint Institute for Marine and Atmospheric Research Contribution, 98-320.

Grewe, P.M., Appleyard, S.A. and Ward, R.D. (2000) Determining genetic stock structure of bigeye tuna in the Indian Ocean using mitochondrial DNA and DNA microsatellites. Report for the Fisheries Research and Development Corporation FRDC No. 97/122. Hobart: FRDC.

Grewe, P.M., Feutry, P., Hill, P.L., Gunasekera, R.M., Schaefer, K.M., Itano, D.G., Fuller, D.W., Foster, S.D., and Davies, C.R. (2015) Evidence of discrete yellowfin tuna (*Thunnus albacares*) populations demands rethink of management for this globally important resource. Scientific Reports, *5*, 16916. doi:10.1038/srep16916.

Grewe, P.M., Irianto, H.E., Proctor, C.H., Adam, M.S, Jauhary, A.R., Schafer, K., Itano, D., Evans, K., Killian, A. and Davies, C.R. (2016) Population structure and provenance of tropical tunas: recent results from high throughput genotyping and potential implications for monitoring and assessment. Submitted to the 12th Scientific Committee Meeting of Western and Central Pacific Fisheries Commission, Bali, 3 – 11 August 2016. WCPFC-SC12-2016-SA WP-01. 6pp.

Gunn J.S., Clear N.P., Ward R.D., Appleyard S.A., Grewe P.M. and Innes, B.H. (2002) The origins of recruits to the east coast yellowfin tuna fishery and the delineation of the structure of yellowfin stocks in the western Pacific. Final Report to the Fisheries Research Development Corporation, FRDC Project 94/022, 141 pp.

Hallier, J-P and Million, J. (2009) The contribution of the Regional Tuna Tagging Project – Indian Ocean to IOTC stock assessment. Report presented to the Indian Ocean Tuna Commission Working Party on Tropical Tuna, 15 – 23 October 2009, Mombasa, Kenya. IOTC-2009-WPTT-24.

Itano, D.G. and Coan, A.L. (2003) An assessment of the accuracy of yellowfin and bigeye tuna species identification by American Samoa port samplers. Report prepared for the 16th Standing Committee on Tuna and Billfish, Fishing Technology Working Group, July 9-16, 2002, Mooloolaba, Australia.

Itano, D.G. and Holland, K.N. (2000) Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in relation to FADs and natural aggregation points. Aquatic Living Resources 13, 213-223.

IOTC (2010) Report of the Thirteenth Session of the IOTC Scientific Committee. Victoria, Seychelles, 6 –10 December 2010. IOTC–2010–SC13–R: 224 pp.

IOTC (2011) Report of the Fourteenth Session of the IOTC Scientific Committee. Mahé, Seychelles, 12–17 December 2011. IOTC–2011–SC14–R[E]: 259 pp.

Josse, E., Bertrand, A., and Dagorn, L. (1999) An acoustic approach to study tuna aggregated around fish aggregating devices in French Polynesia: methods and validation. Aquatic Living Resources 12(05), 303-313.

Langley, A., Harley, S., Hoyle, S., Davies, N., Hampton, J. and Kleiber, P. (2009) Stock assessment of yellowfin tuna in the western and central Pacific Ocean. Submitted to 5th Regular Session of the Scientific Committee of Western and Central Pacific Fisheries Commission, 10 – 21 August 2009, Port Vila, Vanuatu. WCPFC-SC5-2005/SA-WP-03. 125 pp.

Langley, A., Hoyle, S., and Hampton, J. (2011) Stock assessment of yellowfin tuna in the Western and Central Pacific Ocean. Report to Scientific Committee of Western and Central

Pacific Fisheries Commission, 7th Regular Session, 9 – 17 August 2011, Pohnpei, FSM. WCPFC-SC7-2011/SA-WP-03, 132 pp.

Lester, R.J.G. and MacKenzie, K. (2009) The use and abuse of parasites as stock markers for fish. Fish. Res. 97,1–2.

Lester, R.J.G., Thompson, C., Moss ,H. and Barker, S.C. (2001) Movement and stock structure of narrow-barred Spanish mackerel as indicated by parasites. J. Fish Biol. 59, 833–842.

MMAF – RI (2016) Capture Fisheries Statistics of Indonesia by Province, 2015. Publication of Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Indonesia. 401 pp.

MMAF – RI (2017) Indonesia's Annual Report to the Western and Central Pacific Fisheries Commission. Submitted to the 12th Regular Session of the WCPFC Scientific Committee. Rarotonga, Cook Island, 9 -17 August 2017. 34 pp.

McKechnie, S., Pilling, G., and Hampton, J (2017) Stock assessment of bigeye tuna in the western and central Pacific Ocean. Report to Scientific Committee of Western and Central Pacific Fisheries Commission, 13th Regular Session, 9 – 17 August 2017, Rarotonga, Cook Islands. WCPFC-SC13-2017/SA-WP-05, 149pp.

Moore, B.R., Welch, D.J., Newman, S.J. and Lester, R.J.G. (2012) Parasites as indicators of movement and population connectivity of a non-diadromous, tropical estuarine teleost: king threadfin *Polydactylus macrochir*. J. Fish Biol. 81, 230–252.

Moreno, G. (2014) Collection of data and processing methodologies for artisanal fisheries in the provinces of Bali and East Java, Indonesia: issues and recommendations. Study commissioned by the Indian Ocean Tuna Commission and the Overseas Fishery Cooperation Foundation of Japan. IOTC Secretariat, May 2014, 31 pp.

Moreno, G. (2015) Implementation report for the project collection of data from tuna fisheries in the Provinces of West Sumatra and North Sumatra, Indonesia. Study commissioned by the Indian Ocean Tuna Commission and the Overseas Fishery Cooperation Foundation of Japan. IOTC Secretariat. 55pp.

Nielsen, E.E., Cariani, A., Aoidh, E.M., Maes, G.E., Milano, I., Ogden, R., Taylor, M., Hemmer-Hansen, J., Babbucci, M., Bargelloni, L., Bekkevold, D., Diopere, E., Grenfell, L., Helyar, S., Limborg, M.T., Martinsohn, J.T., McEwing, R., Panitz, F., Patarnello, T., Tinti, F., Van Houdt, J.K.J., Volckaert, F.A.M., Waples, R.S., FishPopTrace, c., Albin, J.E.J., Vieites Baptista, J.M., Barmintsev, V., Bautista, J.M., Bendixen, C., Bergé, J.-P., Blohm, D., Cardazzo, B., Diez, A., Espiñeira, M., Geffen, A.J., Gonzalez, E., González-Lavín, N., Guarniero, I., Jeráme, M., Kochzius, M., Krey, G., Mouchel, O., Negrisolo, E., Piccinetti, C., Puyet, A., Rastorguev, S., Smith, J.P., Trentini, M., Verrez-Bagnis, V., Volkov, A., Zanzi, A., and Carvalho, G.R. (2012) Gene-associated markers provide tools for tackling illegal fishing and false eco-certification. Nature Communications 3, 851.

Oksanen, J., Blanchet F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R.B., Simpson, G.L., Solymos, P., Steven, M.H.M., Szoecs, E. and Wagner, H. (2017) Vegan; community ecology package. R package version 2.4-2. https://CRAN.R-project.org/package=vegan

Peterson, B.K., Weber, J.N., Kay, E.H., Fisher, H.S. and Hoekstra, H.E. (2012) Double Digest RADseq: An inexpensive method for DeNovo SNP discovery and genotyping in model and non-model species. Plos One 7, e37135.

P4KSI and ACIAR (Centre for Fisheries Research and Development, Indonesia, and Australian Centre for International Agricultural Research) (2015) Strategic plan for ACIAR engagement in capture fisheries research and capacity development in Indonesia, 2015–25. ACIAR Technical Reports No. 88. ACIAR: Canberra. 28 pp.

Proctor, C.H., Merta, I.G.S., Sondita, M.F.A., Wahju, R.I., Davis, T.L.O., Gunn, J.S. and Andamari, R. (2003) A review of Indonesia's Indian Ocean tuna fisheries. ACIAR Country Status Report. 106 pp.

Proctor C., Mahiswara, and Widodo, A. (2018) Port sampling protocol for a FAD fisheries study. Technical manual for Australian Centre for International Agricultural Research Project FIS/2009/059. 94 pp.

Proctor C. H., Lester R. J. G., Clear N. P., Grewe P. M., Moore B. R., Eveson J. P., Lestari P., Wujdi A., Taufik M., Wudianto, Lansdell M. J., Hill P. L., Dietz C., Thompson J. M., Cutmore S. C., Foster S. D, Gosselin T. and Davies C. R. (2019a). Population structure of yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*T. obesus*) in the Indonesian region. Final Report as output of ACIAR Project FIS/2009/059. Australian Centre for International Agricultural Research, Canberra. 139 pp.

Proctor C. H., Natsir M., Mahiswara, Widodo A. A., Utama A. A., Wudianto, Satria F., Hargiyatno I. T., Sedana I. G. B., Cooper S. P., Sadiyah L., Nurdin E., Anggawangsa R. F. and Susanto K. (2019b). A characterisation of FAD-based tuna fisheries in Indonesian waters. Final Report as output of ACIAR Project FIS/2009/059. Australian Centre for International Agricultural Research, Canberra. 111 pp.

PT Hatfield Indonesia (2016) FAD (Fish Aggregating Device) Fishing in Indonesia. Report prepared for The Nature Conservancy – Fisheries Conservation Program. 17 pp.

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Australia. http://www.R-project.org/.

Ripley B., Venables B., Bates D. M., Hornik K., Gebhardt A. and Firth D. (2016) Support functions and datasets for Venables and Ripley's MASS. R package version 7.3. https://cran.rproject.org/web/packages/MASS/MASS.pdf

Rooker, J.R., Secor, D.H., Zdanowicz, V.S., De Metrio, G., Relini, L.O. (2003) Identification of Atlantic bluefin tuna (*Thunnus thynnus*) stocks from putative nurseries using otolith chemistry. Fish. Oceanogr. 12, 75–84.

Rooker, J.R., Secor, D.H., DeMetrio, G., Kaufman, A.J., Rios, A.B., and Ticina, V. (2008) Evidence of trans-Atlantic movement and natal homing of bluefin tuna from stable isotopes in otoliths. Mar. Ecol. Prog. Ser., 368, 231–239.

Ruchimat, T., Wudianto, Fahmi, Z., Setyadji, B. and Sadiyah, L. (2017) Indonesia National Report to the Scientific Committee of the Indian Ocean Tuna Commission. IOTC-2017-SC20-NR09.

Ruttenberg, B.I., Hamilton, S.L., Hickford, M.J.H., Paradis, G.L., Sheehy, M.S., Standish, J.D., Ben-Tzvi, O., and Warner, R.R. (2005) Elevated levels of trace elements in cores of otoliths and their potential for use as natural tags. Mar. Ecol. Prog. Ser., 297, 273-281.

Schaefer, M.B. (1957) A study of the dynamics of the fishery for yellowfin tuna in Eastern Tropical Pacific. Bulletin of Inter-America Tropical Tuna Commision, 2, 247-285.

Schaefer, K., Fuller, D., Hampton, J., Caillot, S., Leroy, B. and Itano, D. (2015) Movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus*) tagged and released in the equatorial Central Pacific Ocean, with conventional and archival tags. Fish. Res. 161, 336–355.

Schloesser, R.W., Neilson, J.D., Secor, D.H., and Rooker, J.R. (2010) Natal origin of Atlantic bluefin tuna (*Thunnus thynnus*) from the Gulf of St. Lawrence based on d13C and d18O in otoliths. Can. J. Fish. Aquatic Sci., 67, 563–569.

SPC (2012) Indonesian Tagging Report. Unpublished. 31 pp.

Stobberup, K. and Geehan, J. (2015) Collection of data from tuna fisheries in West Sumatra and North Sumatra Provinces, Indonesia. Final Project Report. Study commissioned by the

Indian Ocean Tuna Commission, Overseas Fishery Cooperation Foundation of Japan, Bay of Bengal Large Marine Ecosystem and Directorate General of Capture Fisheries (Indonesia). IOTC Secretariat. 87 pp.

Subani, W. and Barus, H.R. (1989) Alat penangkapan ikan dan udang laut di Indonesia (Fishing gears for marine fish and shrimp in Indonesia). No. 50 Th 1988/1989. Special edition of J. Mar. Fish. Res. ISSN 0216 – 7727. 248 pp.

Tremblay-Boyer, L., McKechnie, S., Pilling, G. and Hampton, J. (2017) Stock assessment of yellowfin tuna in the western and central Pacific Ocean. Report to Scientific Committee of Western and Central Pacific Fisheries Commission, 13th Regular Session, 9 – 17 August 2017, Rarotonga, Cook Islands. WCPFC-SC13-2017/SA-WP-06, 125 pp.

Ward, R.D., Elliott, N.G., Innes, B.H., Smolenski, A.J., Grewe, P.M. (1997) Global population structure of yellowfin tuna, *Thunnus albacares*, inferred from allozyme and mitochondrial DNA variation. Fish. Bull. 95, 566-575.

Welch D.J., Buckworth R.C., Ovenden J.R., Newman S.J., Broderick D., Lester R.J.G., Ballagh A.C., Stapley J.M., Charters R.A. and Gribble, N.A. (2009) Determination of management units for grey mackerel fisheries in northern Australia. Final Report, Fisheries Research and Development Corporation Project 2005/010, Fishing & Fisheries Research Centre Technical report No. 4, Fishing & Fisheries Research Centre, James Cook University, Townsville, Australia, 158 pp.

WCPFC (2010) Summary Report of the Sixth Regular Session of the Scientific Committee of Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Nuku'alofa, Tonga, 10–19 August 2010, 169 pp.

WCPFC (2011) The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Scientific Committee. 6th Regular session, Nuku'alofa, Tonga, 10-19 August 2010. Summary report. 193pp.

WCPFC (2012) The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Scientific Committee. 7th Regular session, Pohnpei, FSM, 9 - 17 August 2011. Summary report. 203 pp.

Wells, R.J.D., Rooker, J.R., and Itano, D.G. (2012) Nursery origin of yellowfin tuna in the Hawaiian Islands. Marine Ecology Progress Series 461, 187-196.

Widodo, A.A., Satria, F, Iskandar Prisantoso, B., Mahiswara, Sedana, I.G.B., Sadiyah, L. and Williams, P. (2013) East Indonesian Tuna Fisheries Port Sampling Protocol. 55 pp.

WWF (2008) Getting off the hook: Reforming the tuna fisheries of Indonesia and considerations for EBM. Eds. Pet-Soede, L. and Ingles, J. 229 pp.

Zeigler, J.M. and Whitledge, G.W. (2011) Otolith trace element and stable isotopic compositions differentiate fishes from the Middle Mississippi River, its tributaries, and floodplain lakes. Hydrobiologia 661, 289–302.

Zulbainarni, N. (2012) Teori dan Praktik Pemodelan Bioekonomi dalam Pengelolaan Perikanan Tangkap (Bioeconomic Modelling in Capture Fisheries Management; Theory and Practices) (Vol. 1). Bogor: PT Penerbit IPB Press.

10.2 List of publications produced by project

Moore, B.R., Lestari, P., Cutmore, S.C., Proctor, C., and Lester, R.J.G. (2019 – submitted to journal and accepted, awaiting publication) Movement of juvenile tuna deduced from parasite data. ICES Journal of Marine Science.

Lestari, P., Lester, R., and Proctor, C. (2016) Symbionts of bigeye and yellowfin tuna as potential stock markers for tuna in Indonesian archipelagic waters. Submitted to the 12th

Scientific Committee Meeting of Western and Central Pacific Fisheries Commission, Bali, 3 – 11 August 2016. WCPFC-SC12-2016-ST-IP-05.

Lestari, P., Lester, R., and Proctor, C. (2017) Parasites as potential stock markers for tuna in Indonesian waters. Ind. Fish. Res. J. 23 (1): 23 – 28.

Grewe, P.M.*, Irianto, H.E.*, Proctor, C.H.*, Adam, M.S, Jauhary, A.R., Schafer, K., Itano, D., Evans, K., Killian, A. and Davies, C.R.* (2016) Population structure and provenance of tropical tunas: recent results from high throughput genotyping and potential implications for monitoring and assessment. Submitted to the 12th Scientific Committee Meeting of Western and Central Pacific Fisheries Commission, Bali, 3 – 11 August 2016. WCPFC-SC12-2016-SA WP-01. 6pp.
Note: Although this paper includes results of research from outside the project, it does constitute a significant contribution from the project and several of the authors(*) are project members.

Natsir, M., Proctor, C., Wudianto, Nurdin, E., Sadiyah, L., Taufik, M. and Hargiyatno, I.T. (2017) A collection of abstracts of FAD fisheries research in Indonesia. A publication of Australian Centre for International Agricultural Research Project FIS/2009/059. Center for Fisheries Research. Agency for Marine and Fisheries Research and Human Resources. Jakarta. 308pp.

Proctor C., Mahiswara, and Widodo, A. (2018) Port sampling protocol for a FAD fisheries study. Technical manual for Australian Centre for International Agricultural Research Project FIS/2009/059. 94pp.

Widodo, A.A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I.T., and Cooper, S. (2016) Characteristics of tuna fisheries associated with Indonesian anchored FADs in waters of the West Pacific and the Indonesian archipelago. Submitted to the 12th Scientific Committee Meeting of Western and Central Pacific Fisheries Commission, Bali, 3 – 11 August 2016. WCPFC-SC12-ST-IP-06. 19pp.

Widodo, A.A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I.T., and Cooper, S. (2016) Characteristics of tuna fisheries associated with anchored FADs in the Indonesian Fisheries Management Areas 572 and 573 in the Indian Ocean. Submitted to the Indian Ocean Tuna Commission 18th Working Party on Tropical Tunas, Seychelles, 5 – 10 November 2016. IOTC-2016-WPTT18-29. 15pp.

Yong, R. and Lestari, P. (2016) Pictorial reference guide to didymozoids (Trematoda) of *Thunnus albacares* and *T. obesus* (Scombridae).

Appendix 1. Additional tables and figures for the results of the Parasites study (as summarised in Section 7.1.2)

Table A1-1. Mean fork length (FL) and parasite abundances (component species only) of A) bigeye tuna (*Thunnus obesus*) and B) yellowfin tuna (*T. albacares*) from all samples dissected, and site of infection. FMA = Fisheries Management Area, FL = fork length.

A) Bigeye tuna: Means, both years combined, all fish.

FMA	Sample size (total)	Mean FL (cm)	*Didymocystis bifurcata* Gills	*Didymozoon longicolle* Gills	*Koellikeria* type 1 Stomach wall	*Koellikeria* type 3 Pyloric caeca	*Koellikeria* type 4 Int. wall	*Bolbosoma* sp. All viscera	*Rhadinorhychus* sp.
Maldives	29	39.4	0.89	**3.22**	1.45	6.24	0.28	0.10	0.03
FMA 572	158	37.4	0.37	**0.25**	0.47	0.28	0.51	**0.08**	0.00
FMA 573	168	36.7	1.60	**0.00**	1.01	2.01	0.24	**0.08**	0.02
FMA 714	157	42.3	1.22	1.19	1.69	2.59	0.39	0.19	0.00
FMA 715	92	42.4	1.93	1.91	0.59	1.28	0.18	0.16	0.04
FMA 716	22	46.3	3.82	1.36	1.73	0.82	0.00	0.05	0.00
FMA 717	86	43.8	1.38	**2.84**	1.21	0.47	0.20	0.18	0.02
Solomon Is.	55	42.3	4.04	1.76	1.00	2.24	0.16	0.25	0.09

B) Yellowfin tuna: Means, both years combined, all fish.

FMA	Sample size (total)	Mean FL (cm)	*Didymocystis bifurcata* Gills	*Didymozoon longicolle* Gills	*Koellikeria* type 1 Stomach wall	*Koellikeria* type 3 Pyloric caeca	*Koellikeria* type 4 Int. wall	*Bolbosoma* sp. All viscera	*Rhadinorhychus* sp.
Maldives	52	38.0	2.16	**3.96**	2.08	2.08	0.10	0.15	0.02
FMA 572	137	36.3	2.83	**0.58**	0.63	0.77	0.25	0.06	0.02
FMA 573	287	36.1	2.61	**0.02**	1.05	1.45	0.20	0.02	0.01
FMA 714	255	39.4	2.45	3.14	1.96	3.64	0.20	0.07	0.00
FMA 715	193	39.1	1.80	1.88	0.68	1.72	0.06	0.04	0.03
FMA 716	74	40.7	8.03	3.55	1.86	2.74	0.00	0.05	0.00
FMA 717	148	39.1	2.14	**12.54**	2.58	3.63	1.56	**0.25**	0.02
Solomon Is.	51	37.1	4.35	4.78	0.67	2.06	0.39	0.08	0.06

Table A1-2. Results for one-way permutational analysis of variance pairwise tests of parasite abundance of BET (*Thunnus obesus*) from collection locations in and adjacent to Indonesian waters in 2013 (upper diagonal) and 2014 (lower diagonal) (component species only). The code in the table corresponds to the parasite species that is significantly different among regions at p = 0.01. D1 = *Didymocystis bifurcata*, D2 = *Didymozoon longicolle*, K1 = *Koellikeria* type 1, K3 = *Koellikeria* type 3, K4 = *Koellikeria* sp. 1, B = *Bolbosoma* sp. Note no significant differences were observed in the abundance of *Rhadinorhynchus* sp. among locations. '-' = no result due to small sample size.

Region	Maldives	FMA 572	FMA 573	FMA 714	FMA 715	FMA 716	FMA 717	Solomon Is.
Maldives		D2, K3	D2, K1	none	K3	-	K3	D1, D2
FMA 572	-		D1, K1, K3	D1, D2, K1, K3, B	D1, D2, B	-	D1, D2	D1, K3
FMA 573	-	D1, D2, K1, K3		D2, K1, B	D2, B	-	D2, B	D1, K1
FMA 714	-	K1, K3	D2		K1	-	D2, K1, K3	D1, D2
FMA 715	-	D1, K3	D2, K1	D1		-	D2	D1, D2, K3
FMA 716	-	D1, K1, K3	D2	none	none		-	-
FMA 717	-	D1, K1	D2	none	K3	none		D1, D2, K3
Solomon Is.	-	D1, D2, K1, K3	D2	D2	none	none	K3	

Table A1-3. Results for one-way permutational analysis of variance pairwise tests of parasite abundance of YFT (*Thunnus albacares*) from collection locations in and adjacent to Indonesian waters in 2013 (upper diagonal) and 2014 (lower diagonal) (component species only). The codes to the parasite species are provided in the caption to Table 2. Note no significant differences were observed in the abundance of *Rhadinorhynchus* sp. among locations.

Region	Maldives	FMA 572	FMA 573	FMA 714	FMA 715	FMA 716	FMA 717	Solomon Is.
Maldives		D2, K1	D2, K1, B	none	K1	D1, K3	D2, K4	D1, D2, K1
FMA 572	D2, K1		D1, K3	D1, D2, K1, K3	D2, K3	D1, D2, K1, K3	D1, D2, K3, K4, B	none
FMA 573	D2	D1, D2, K1		D1, D2, K1	D1, D2	D1, D2, K1, K3	D1, D2, K4, B	D1
FMA 714	D2	D1, K1	D2, K3, K4		K1	D1, K3	D2, K4, B	D1, D2
FMA 715	D2, K1	none	D2, K1	D1, K1, K4		D1, D2, K1, K3	D2, K4, B	D2
FMA 716	K3	D2, K3	D1, D2, K3	D1, D2, K3, K4	K3		D1, K1, K3, K4	D1, D2, K1, K3
FMA 717	none	D2, K1	D2, B	D2, K4, B	D2, K1, B	D1, K3, B		D1, D2, K4
Solomon Is.	none	D2	D1, D2	D1, D2	D1, D2	D2	D1	

Table A1-4. Summary of permutational multivariate analysis of variance tests to detect difference among tuna groups within Indonesian Fisheries Management Areas (FMAs). Pairwise test results that are significant at p = 0.01 are highlighted. See Supplementary Figure 1 for sampling sites.

Species	Year	FMA	Groups compared	F	P	df
BET	2013	FMA573	Palabuhanratu A vs. Prigi A	10.84	0.001	1, 59
		FMA714	Kendari A vs. Ambon	4.70	0.003	1, 73
		FMA715	Gorontalo A vs. Gorontalo C	0.78	0.541	1, 30
		FMA717	Sorong A vs. Jayapura	3.61	0.016	1, 36
	2014	FMA572	Padang A vs. Padang B	2.32	0.035	1, 59
		FMA573	Palabuhanratu B vs. Prigi B	1.59	0.187	1, 78
		FMA714	Kendari C vs. Ambon	0.97	0.411	1, 69
		FMA717	Sorong A vs. Jayapura	5.94	0.001	1, 44
YFT	2013	FMA573	Palabuhanratu A vs. Prigi A	3.77	0.018	1, 71
		FMA714	Kendari A vs. Ambon	4.65	0.008	1, 104
		FMA716	Bitung A vs. Bitung D	1.34	0.257	1, 32
		FMA717	Sorong A vs. Jayapura	7.75	0.001	1, 67
	2014	FMA573	Palabuhanratu B vs. Prigi B	0.75	0.510	1, 119
		FMA715	Kendari B vs. Gorontalo C	2.21	0.063	1, 75
		FMA715	Kendari B vs. Bitung G	2.58	0.049	1, 59
		FMA715	Gorontalo C vs. Bitung G	2.38	0.059	1, 72
		FMA717	Sorong A vs. Jayapura	12.20	0.001	1, 48

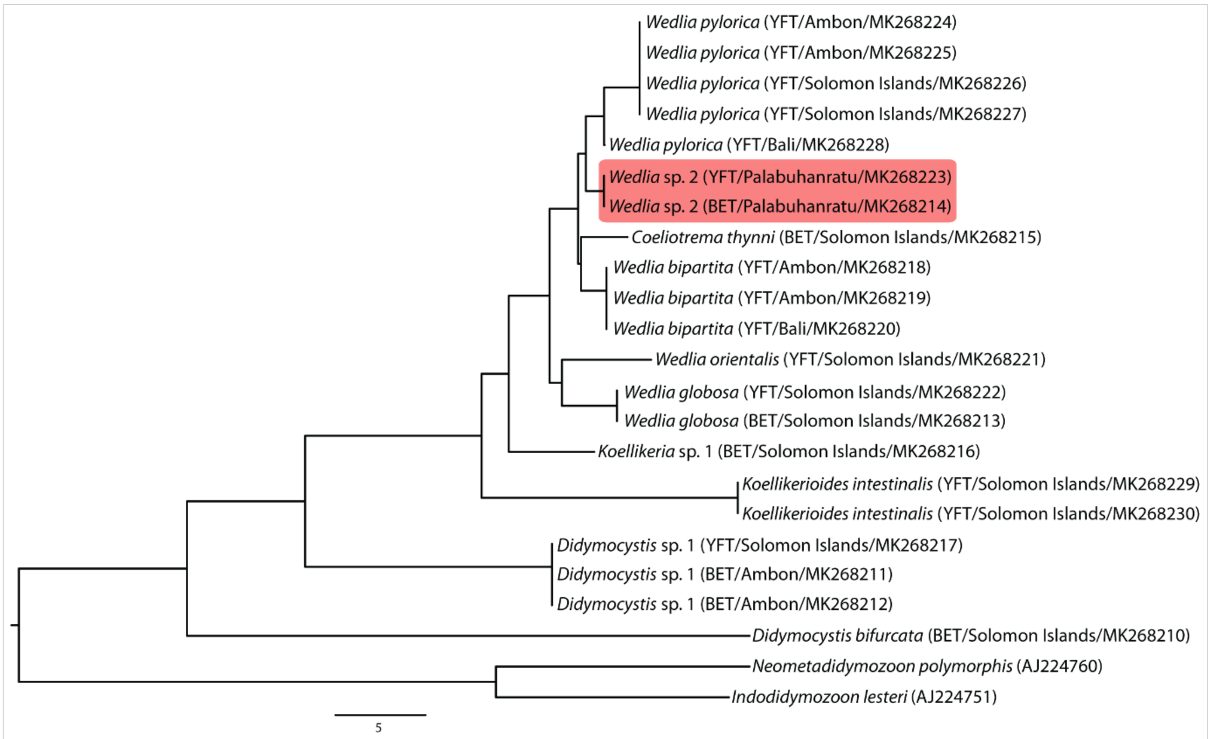


Figure A1-1. Phylogram based on neighbour-joining analysis of the ITS2 sequences of didymozoids from BET and YFT generated during this study. Outgroup taxa are from platycephalids. Highlighted pair is an example of the same parasite species occurring in both tuna species.

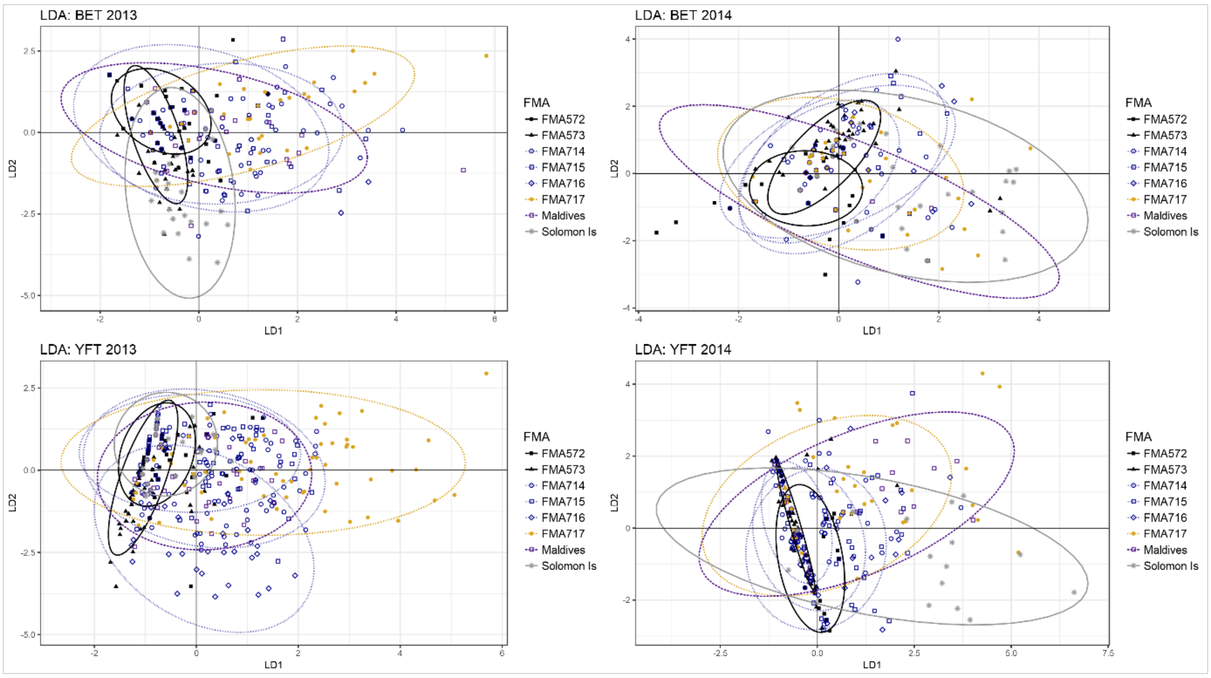


Figure A1-2. Results of Linear Discriminant Analyses (LDA) of component parasite species in BET (top row) and YFT (bottom row) in 2013 (left column) and 2014 (right column).

Appendix 2. Additional tables and figures for the results of the otolith chemistry study (as summarised in Section 7.1.3)

Table A2-1. Classification tables from leave-one-out cross-validation QDAs run on the isotope data for each species and season separately. Rows are the observed FMAs and columns are the predicted FMAs. Note for BET 2013, there were too few samples in FMA 716 for this area to be included in the models.

YFT, 2013

	111	572	573	714	715	716	717	999	% correct
111	20	2	0	0	0	0	0	2	83.3
572	1	21	0	5	0	4	0	0	67.7
573	1	11	8	3	6	8	5	8	16.0
714	3	21	9	9	5	6	0	2	16.4
715	2	6	12	6	5	3	2	4	12.5
716	0	7	2	1	1	6	0	6	26.1
717	1	6	6	0	3	4	9	10	23.1
999	0	1	0	0	1	5	3	15	60.0

YFT, 2014

	111	572	573	714	715	716	717	999	% correct
111	19	5	1	0	0	0	0	1	73.1
572	4	15	0	3	0	1	2	0	60.0
573	1	6	7	9	4	17	7	1	13.5
714	0	6	1	8	2	7	8	0	25.0
715	3	8	6	20	2	18	10	3	2.9
716	0	2	2	5	0	7	2	0	38.9
717	3	2	1	5	0	2	11	7	35.5
999	0	1	0	4	0	1	6	13	52.0

BET, 2013

	111	572	573	714	715	716	717	999	% correct
111	17	4	0	0	2	–	0	2	68.0
572	5	15	2	0	5	–	0	0	55.6
573	2	9	13	3	17	–	5	0	26.5
714	7	6	13	1	21	–	2	3	1.9
715	4	4	2	2	23	–	2	0	62.2
716	–	–	–	–	–	–	–	–	–
717	4	2	2	0	13	–	0	7	0.0
999	2	1	1	1	6	–	2	24	64.9

BET, 2014

	111	572	573	714	715	716	717	999	% correct
111	22	1	0	0	1	0	0	0	91.7

572	2	19	3	0	0	1	0	0	76.0
573	0	12	16	3	8	8	3	0	32.0
714	1	0	10	6	3	8	0	3	19.4
715	1	0	8	2	3	8	0	0	13.6
716	0	0	1	2	0	13	3	2	61.9
717	3	2	5	4	0	24	6	6	12.0
999	1	0	1	1	0	7	0	15	60.0

Table A2-2. Classification tables from leave-one-out cross-validation QDAs run on the element concentration data for each species, otolith position and season separately. Only results for positions 1 and 3 are shown. Rows are the observed FMAs and columns are the predicted FMAs. Note for BET 2013, there were too few samples in FMA 716 for this area to be included in the models.

YFT, Position 1, 2013									
	111	572	573	714	715	716	717	999	% correct
111	7	2	3	2	3	2	1	0	35.0
572	4	7	2	4	1	1	2	1	31.8
573	1	11	9	10	7	2	3	0	20.9
714	2	4	7	14	10	1	5	3	30.4
715	2	3	1	8	12	5	2	0	36.4
716	2	0	0	4	2	10	2	2	45.5
717	1	3	5	3	4	3	8	2	27.6
999	0	0	0	0	0	1	4	16	76.2

YFT, Position 1, 2014									
	111	572	573	714	715	716	717	999	% correct
111	9	0	1	3	2	1	4	1	42.9
572	0	11	2	1	0	3	3	1	52.4
573	0	7	7	3	7	1	4	5	20.6
714	3	0	4	7	5	5	2	1	25.9
715	1	1	3	12	18	5	10	4	33.3
716	2	0	0	4	2	5	3	0	31.3
717	2	1	0	6	6	1	6	2	25.0
999	3	3	3	1	1	0	0	5	31.3

YFT, Position 3, 2013									
	111	572	573	714	715	716	717	999	% correct
111	15	3	2	0	0	0	0	0	75.0
572	0	10	8	3	1	0	1	0	43.5
573	2	9	20	5	6	0	1	0	46.5
714	0	1	8	18	10	3	3	0	41.9
715	0	4	8	4	11	2	4	0	33.3

716	0	0	0	2	1	11	5	3	50.0
717	0	0	2	4	2	4	15	2	51.7
999	0	0	0	2	0	0	1	18	85.7

YFT, Position 3, 2014

	111	572	573	714	715	716	717	999	% correct
111	15	1	2	2	1	0	0	0	71.4
572	1	9	0	4	1	0	2	0	52.9
573	2	0	10	5	6	2	1	0	38.5
714	1	1	2	9	11	0	2	1	33.3
715	1	0	11	8	22	10	1	1	40.7
716	1	0	2	1	7	4	0	0	26.7
717	0	0	1	4	1	2	16	0	66.7
999	0	0	1	0	3	0	2	7	53.8

BET, Position 1, 2013

	111	572	573	714	715	716	717	999	% correct
111	7	1	7	4	1	–	0	1	33.3
572	1	10	7	1	1	–	0	0	50.0
573	1	8	17	2	6	–	4	2	42.5
714	5	0	7	14	11	–	2	1	35.0
715	3	0	6	5	8	–	4	1	29.6
716	–	–	–	–	–	–	–	–	–
717	2	1	4	2	1	–	13	1	54.2
999	1	0	2	1	0	–	2	15	71.4

BET, Position 1, 2014

	111	572	573	714	715	716	717	999	% correct
111	6	0	2	6	0	0	3	2	31.6
572	0	11	6	0	2	1	1	1	50.0
573	3	8	19	0	0	4	4	3	46.3
714	3	0	2	9	2	3	4	1	37.5
715	1	1	2	3	4	2	4	0	23.5
716	0	1	2	3	2	6	2	3	31.6
717	2	0	4	5	5	3	15	3	40.5
999	0	0	0	4	0	4	4	8	40.0

BET, Position 3, 2013

	111	572	573	714	715	716	717	999	% correct
111	11	2	1	5	1	–	0	0	55.0

572	1	9	5	1	1	–	0	2	47.4
573	1	5	23	4	3	–	0	3	59.0
714	0	3	9	19	9	–	1	0	46.3
715	0	1	1	5	14	–	6	0	51.9
716	–	–	–	–	–	–	–	–	–
717	0	1	5	3	3	–	6	3	28.6
999	0	3	1	2	0	–	2	14	63.6

BET, Position 3, 2014

	111	572	573	714	715	716	717	999	% correct
111	7	2	1	7	0	0	1	0	38.9
572	0	9	3	1	1	1	3	2	45.0
573	1	4	19	2	2	3	6	3	47.5
714	0	0	5	8	3	5	3	0	33.3
715	0	2	4	7	0	0	2	0	0.0
716	2	1	4	3	1	5	1	0	29.4
717	1	4	8	4	0	1	16	3	43.2
999	2	2	3	0	0	0	7	6	30.0

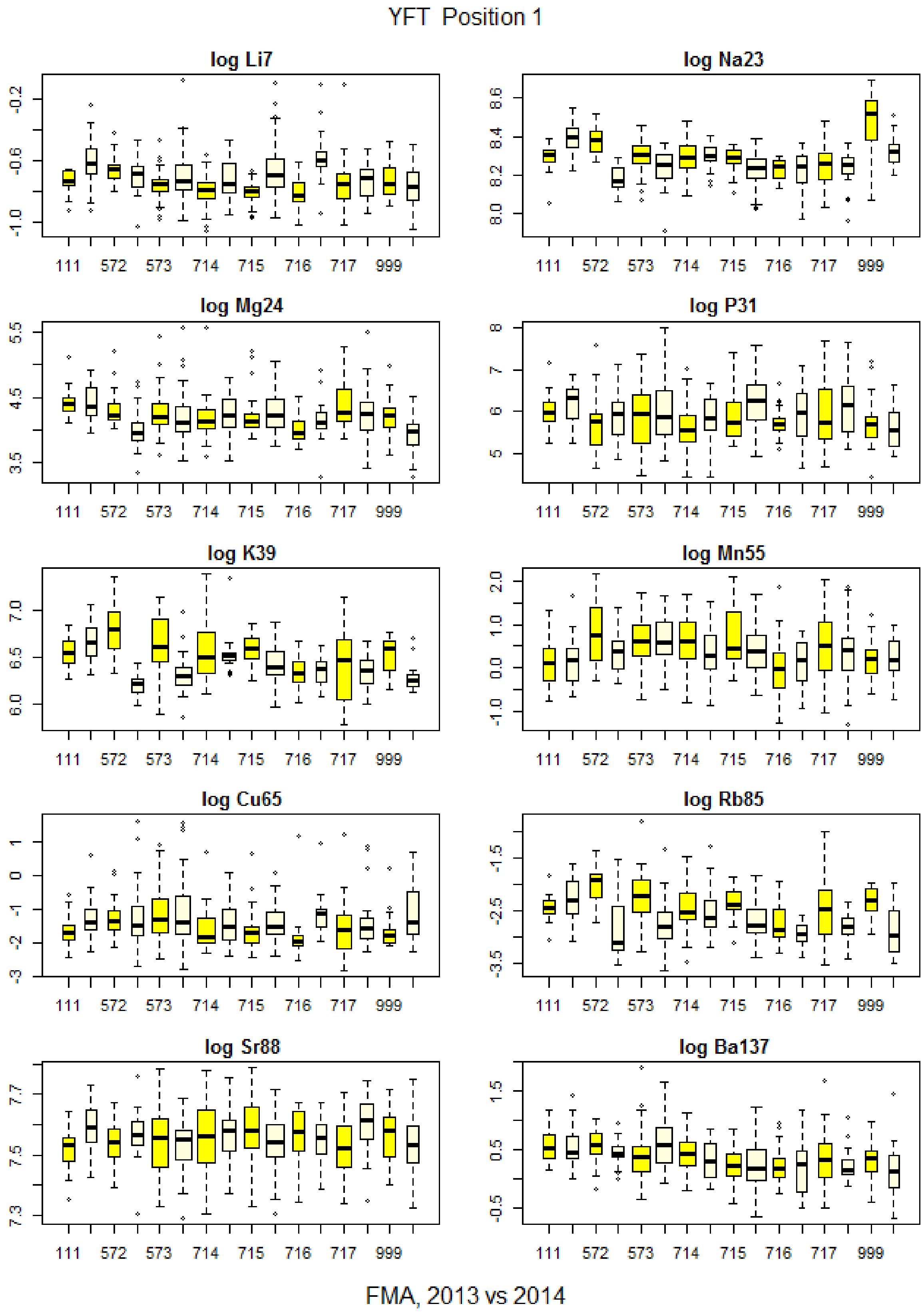


Figure A2-1. Boxplots of the log-transformed element data for YFT at otolith position 1, split by FMA and season, where dark yellow corresponds to 2013 and light yellow to 2014.

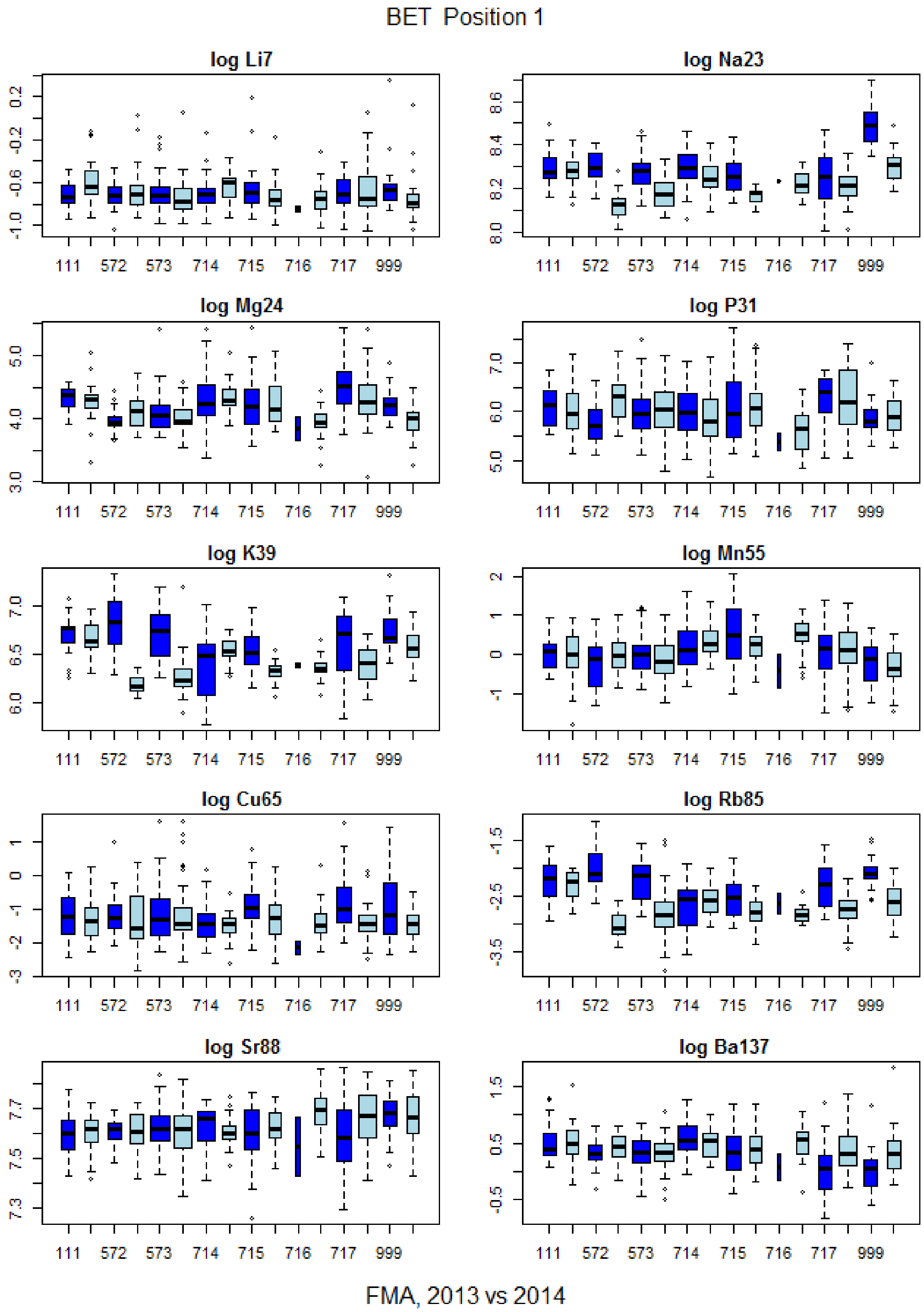


Figure A2-2. Boxplots of the log-transformed element data for BET at otolith position 1, split by FMA and season, where dark blue corresponds to 2013 and light blue to 2014.

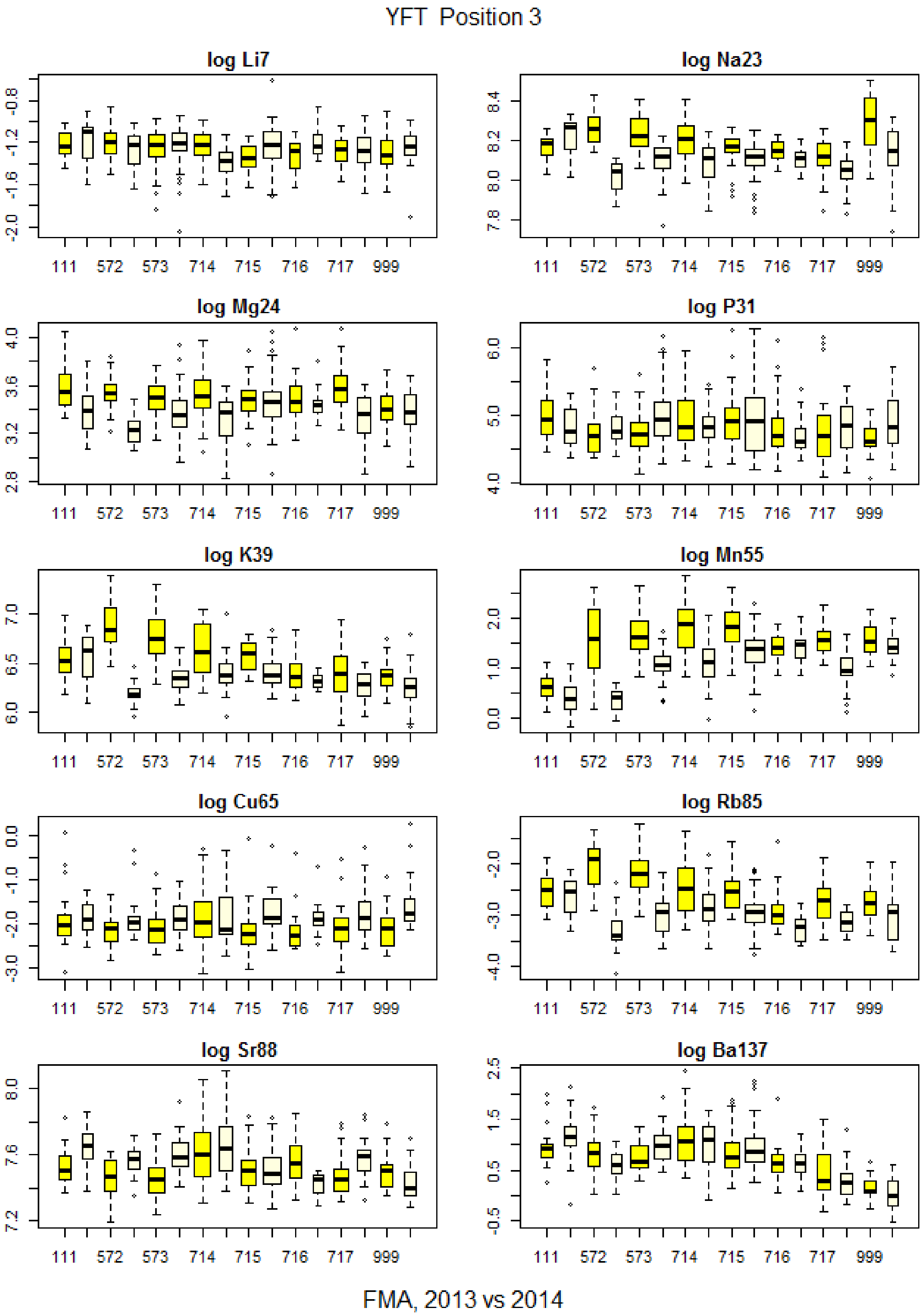


Figure A2-3. Boxplots of the log-transformed element data for YFT at otolith position 3, split by FMA and season, where dark yellow corresponds to 2013 and light yellow to 2014.

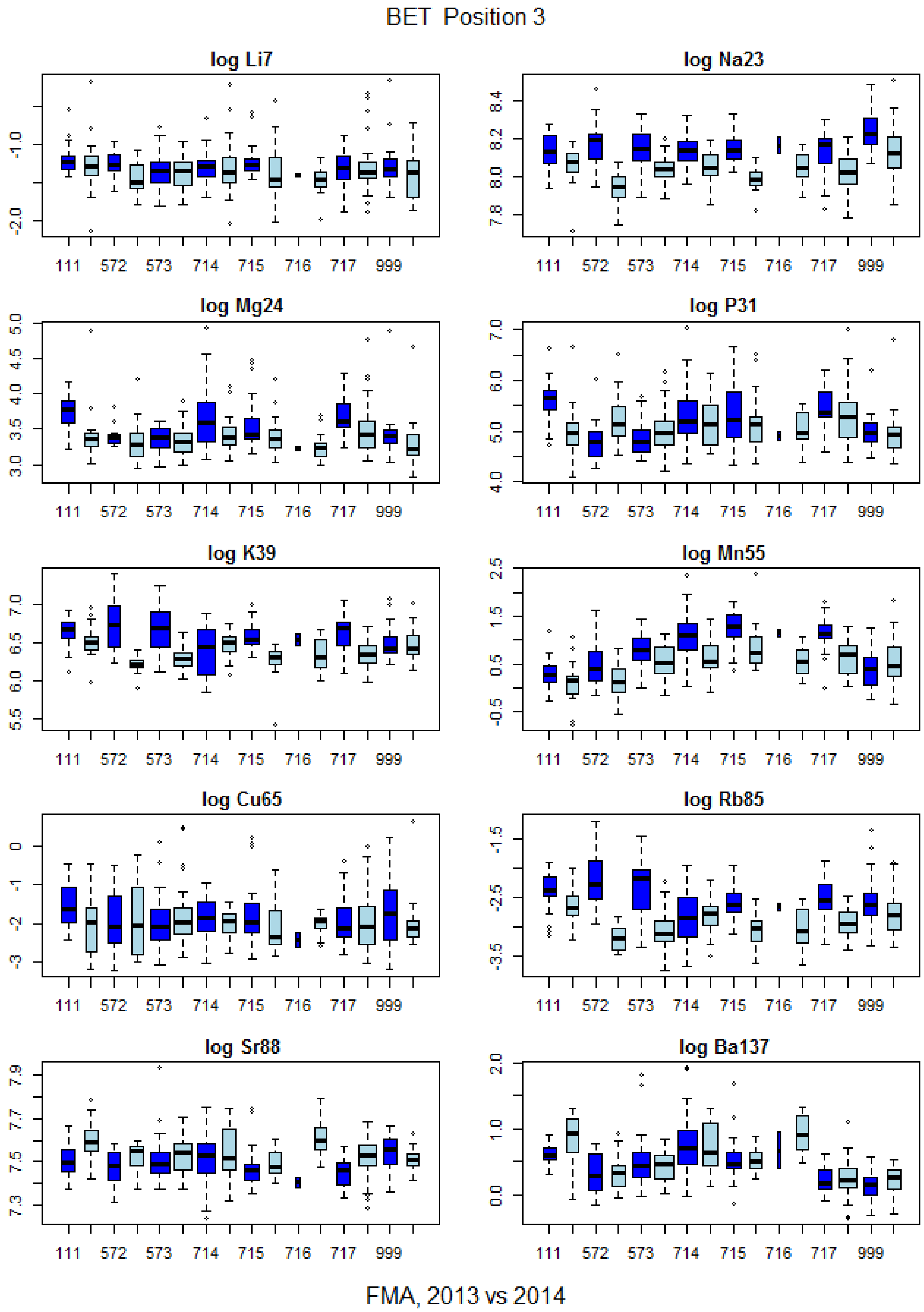


Figure A2-4. Boxplots of the log-transformed element data for BET at otolith position 3, split by FMA and season, where dark blue corresponds to 2013 and light blue to 2014.

Appendix 3. Supplementary information for the results of the FAD Fisheries Study

A3 – 1. General information on tuna FADs in Indonesian waters

Deepwater, anchored FADs have been a common feature of Indonesia's tuna fisheries since the 1970s. Until now, drifting FADs have not been used in the Indonesian tuna fisheries, even by purse-seine vessels. Developments in Indonesian FAD construction, including region specific designs, were first detailed by Subani and Barus (1989) and many studies have since described FAD types and FAD construction for those used in Indonesia's waters (Harjono 1991, Itano *et al.* 2004, Monintja 1993, Yusfiandayani 2013, Yusfiandayani et al. 2015). In common with anchored tuna FADs employed by fisheries of other countries, the Indonesian FADs have four key components: the surface float, the mainline to seafloor, a subsurface attractor, and the anchor (Figure A3-1).

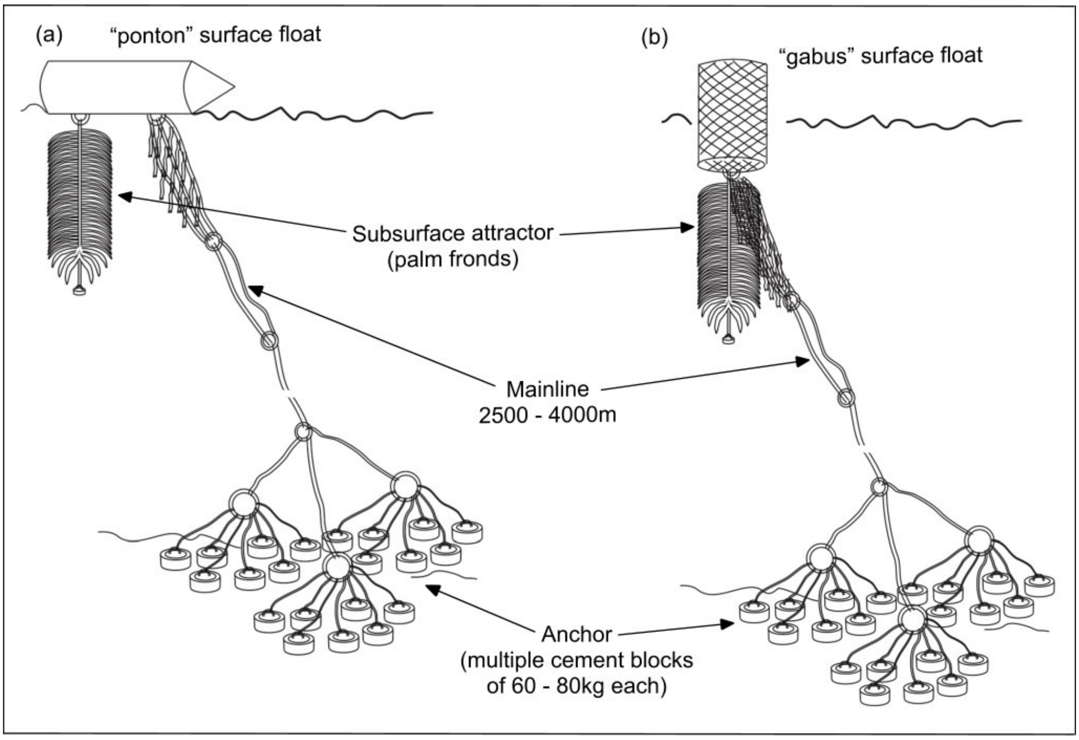


Figure A3-1 Typical FAD construction for (a) steel *ponton* type, and (b) polystyrene *gabus* type. From: Widodo *et al.* (2016).

The FAD surface floats are of three main types (Figure A3-2):

1. steel cylinder of 2 – 3 m length and approximately 0.8 m diameter, with generally one end is conical. These are called pontoon type or *"ponton"*, and were, until recent years, the most common type of FAD float in western and southern Indonesia;
2. bamboo raft, the most sophisticated version having a bungalow ("*rakit*") in which the fishers and/or caretakers of the FAD reside, for weeks or even months. Fresh supplies of food and water, and other necessities for the persons staying at the FAD are brought by fishing vessels or carrier vessels. FADs with *rakit* are found in eastern Indonesia, but to date, have not extended to western Indonesia;
3. large cylinders or blocks of styrene foam, encased in cloth and often bound by rope and used-motorcycle tyres, and strengthened by a wooden frame. These are commonly called "*gabus*" type FAD. This type of FAD has replaced *ponton* as the most common FAD type, due to its lower cost.

In general, the FAD surface floats are not equipped with navigation aids (no radio signal emitters or radar reflectors), but in some cases have an attached superstructure to make the FAD more visible.

Figure A3-2. Types of anchored FAD floats in Indonesia (a) & (b) steel *ponton*, (c) bamboo raft with *rakit*, and (d) polystyrene *gabus* (photos: C. Proctor).

The FAD mainline, of up to 4000m in length for FAD deployment in water depth of 2000 – 3000m (but sometimes as deep as 6000m), is most commonly a 2.5 – 4.0 cm diameter synthetic rope (Figure A3-3), sometimes with wire core, but other types of synthetic rope of lesser diameter and less cost are also not uncommon, particularly with *gabus* FADs. The subsurface attractors are most commonly branches of nipa palm (*Nypa fruticans*) or coconut palm (*Cocos nucifera)*, which are usually attached as a hanging cluster to the underside of the surface float. Attractors made of plastic strips (synthetic *raffia*) have also been encountered on FADs during this study, but current regulations prohibit the use of non-biodegradable materials. Nets and netting-like materials are not used as subsurface attractors on the FADs, and therefore Indonesian tuna FADs pose minimal risk of entanglement of turtles or other marine fauna.

FAD anchors are most commonly comprised of 60 – 80 kg concrete blocks or cylinders (Figure A3-3), with embedded ropes or motorcycle tyres as attachment points in each block, and 25 – 40 blocks linked together to form an anchor of total weight 2 – 3 tonnes (Figure A3-1).

Tuna fisheries that operate in association with FADs in Indonesia include the gear types purse seine, pole and line, hand-line, troll-line, and surface fishing using kites and lures. Two types of purse seine fleet size operate in the waters of FMA 713 – 717: smaller vessels of <30 GT which are called "mini-purse-seine" (Figure A3-4a) of local name "*pajeko*", and larger purse seine vessels ("*kapal pukat cincin*") of > 30 GT (Figure A3-4b). Pole and line vessels operating around FADs are also of two main types: small size vessels of <20 GT, commonly called '*funae*' (Figure A3-4c) and larger vessels of > 20 GT, commonly called "*huhate*" (Figure A3-4d). The numbers of *funae* vessels are not increasing, but still operate in several areas in northern Sulawesi (e.g. Belang and Pulau Gangga).

Figure A3-3. Examples of components for Indonesian anchored FADs: (a) coils of rope used for FAD mainline, (b) 60-80 kg cement weights which are linked together to form the FAD anchor, and (c) coconut palm branches attached to mainline as subsurface attractor (Photos: C. Proctor). From: Widodo *et al.* (2016).

Figure A3-4. Examples of Indonesian vessel types that fish on FADs: (a) Mini purse-seine (*pajeko*), < 30 GT, at PPP Sodohoa; (b) larger purse-seine (*pukat cincin*), > 30 GT, at PPS Kendari; (c) small pole and line (*funae*) in Belang, North Sulawesi; (d) pole and line, >50 GT, in Sorong; (e) hand-line/troll-line (*penongkol*) at PPP Sodohoa; and (f) hand-line/troll-line

'mother-ship' carrying several small catcher boats (*sampan*) in Kendari (Photos: C. Proctor). From: Widodo *et al.* (2016).

Hand-line fishing, troll-line fishing and kite fishing are generally done by a single vessel type i.e. multi-gear vessels, which switch between gears depending on season, prevailing seas conditions and catch success. These vessels, commonly wooden-hull vessels of size 6 – 10 GT (Figure A3-4e), have different local names across regions, including "*penongkol*" in northern and south-eastern Sulawesi, and "*sekoci*" in Bali and east Java. These hand-line/troll-line vessels and their fishing methods originated from southern Sulawesi (Bugis fishermen) and have spread to many other areas of the Indonesian archipelago.

Another type of tuna hand-line vessel that have operated widely in the eastern Indonesian waters, and particularly in northern Sulawesi, are *'pump boats*', which operate as a 'mother-vessel' servicing several small catcher boats (*sampan*) which are carried on board during travel. Some Indonesian HL/TL vessels, primarily in southern Sulawesi (e.g. in Bone) and SE Sulawesi (Kendari) have adopted this style of fishing, routinely carrying as many a 6 – 8 of the *sampan*, from which both large (up to 100 kg yellowfin tuna) and small tunas are caught (Figure A3-4f).

A3–2. Enumeration program at focus ports

Vessel trips enumerated and data entry

The four ports chosen for enumeration were Padang (West Sumatra), Palabuhanratu (West Java), Kendari (SE Sulawesi), and Sorong (West Papua) – for their locations see Figure 5.1. Their selection was based on geographical coverage (two ports in western Indonesia and two ports in eastern Indonesia) and on gear types. These 4 ports were considered appropriate for information gathering on all the key gears/vessel types that fish for tuna on FADs in Indonesian waters; purse-seine, pole and line, troll-line, and hand-line.

Two enumerators were recruited at each port. Some of the recruits had prior experience as enumerators in other programs e.g. the Western Pacific and East Asia (WPEA) program of RCFMC/WCPFC, whereas others were new to fisheries monitoring. At one port, Palabuhanratu, the enumerators were existing staff of the port authority (*Pelabuhan Perikanan Nusantara Palabuhanratu*). In Padang, one of the recruits was staff of the local fisheries office (*Dinas Kelautan dan Perikanan Kota Padang*).

A sampling protocol (Proctor *et al.* 2018) and data collection sheets were developed, both as Bahasa Indonesia and English versions, in the months prior to the commencement of enumeration in October 2013. The sampling protocol was largely based on that developed for the WPEA program (Widodo et al. 2013), but with additions tailored to the FAD-based operations. As example, the enumerators were tasked with obtaining information from skippers at time of a vessel's return to port, on FAD types used, FAD locations, and numbers of FADs visited in the fishing trip. In-field training was provided by the project's scientists to the enumerators at each port.

The combination of direct observations by the enumerators of catch unloadings from vessels, data they collected from fish auction places (*Tempat Pelelangan Ikan*) and processing companies, and information collected via interviews with vessel skippers enabled adequate completion of the data collection sheets in most cases.

For the first year of the enumeration program, the enumerators submitted their completed data collection sheets (landings forms and biological sampling forms) to Jakarta via mail, for data entry by RCFMC staff, Okta Ria Yunita, Puji Rahmadi, and Sunny Apriyani. Following training provided at the Enumerators Training Workshop in Bali in October 2014, and with provision of laptop computers to the enumerator teams at each focus port, data entry was done by the enumerators themselves.

Entry of the data and information collected by the program was done to an Oracle-Apex database, named the *FAD Fisheries Database* (*Database Perikanan Rumpon*), with internet-interface, which was developed and established by project member Scott Cooper (CSIRO), with inputs from Indonesian counterpart, Bayu Sedana (RCFMC), and from Craig Proctor. The database provided both Bahasa Indonesia and English options and was designed to capture and validate all the information collected by the enumerators on the landings and biological sampling forms. A *Data Entry User Manual* was prepared and used as the basis for the training delivered to the enumerators at the Enumerators Training Workshop.

Enumeration of a total of 2564 fishing trips was achieved across the four focus ports during period October 2013 – December 2016 (Table A3-1). The original plan was for the program of data and information collection to run for a minimum of 15 months. At Padang and Sorong the program ran for 18 months, and at Palabuhanratu and Kendari for 39 months, thereby exceeding expectations.

Table A3-1 Summary of enumeration of fishing vessel trips, by vessel type, at the four focus ports. HL/TL = Hand-line/Troll-line, PL = Pole & Line, PS = Purse Seine, CV = Carrier Vessel, NA = source gear Not Available.

			Vessel type						
						CV			
Location	Period	Total Trips	HL/TL	PL	PS	CV-PL	CV-PS	CV-HL/TL	CV-NA
Padang	Oct 2013 - Apr 2015	182	177		5				
Palabuhanratu	Oct 2013 - Dec 2016	1,152	1,152						
Kendari	Oct 2013 - Dec 2016	1,188	547	29	4	459	94	2	53
Sorong	Oct 2013 - Apr 2015	121	1	98			16		6
	Total	**2564**							

The majority (~75%) of the enumerated trips were for HL/TL vessels. Carrier vessels (CV) for both PL and PS vessels, operating out of Kendari and Sorong, accounted for 630 of the enumerated trips. In some cases the enumerators were unable to determine whether the source of fish landed by the CV was PL or PS or from a mix of both vessel types, hence use of “CV-NA”.

The enumeration activity shown for Padang included 5 trips of PS vessels that unloaded catch in port of PPS Bungus, approximately 16 km to south of Padang city. The remainder of the Padang enumeration was done at two small landing places (each with an auction centre, *Tempat Pelelangan Ikan*) at Muara Padang[24], the base for the majority of the HL/TL fleet. A smaller number of HL/TL vessels were based at PPS Bungus.

The enumeration activity shown for Kendari included landings at the main fishing port, Pelabuhan Perikanan Samudera Kendari (PPSK), but also landings at Pelabuhan Pantai Sodohoa (PP Sodohoa), a fish landing centre on the northern side of Kendari Bay, directly opposite the location of PPS Kendari on the southern side. Located on the northern shore of Kendari Bay, almost directly opposite PPSK. PP Sodohoa was established in 1978 and has a landing wharf (est. 50 x 3m), fish auction area (TPI), and fish market. Vessels that land and unload catch at PPI Sodohoa are primarily HL/TL (local name = *penongkol*), and mini purse-seine (local name = *gae*, pronounced “gay-eh”). Catch from these vessels is sold locally through the fish auction centre and fish market at Sodohoa, but some is trucked to other centres for wider distribution. Most unloading activity at Sodohoa is early morning,

[24] *Muara* = estuary, and *Muara Padang* is the estuary located in the southern area of Padang city and is the waterway fed by the rivers *“Padangbesi”* and *“Padangidah”* (source: Army Map Service T5II, dated 1944).

between 0530 and 0900 hrs. PL and PS vessels do not unload at PPI Sodohoa, only at PPSK. Of the 573 HL/TL vessel trips enumerated at Kendari, 401 of those were for vessels that unloaded catch to PP Sodohoa and the remaining 172 were for vessels unloading to PPSK.

A3-3. Catch characteristics – average catch by volume and species compositions

The following presents catch compositions, by location and by gear, based on information collected through the enumeration program.

Padang

Table A3-2. Catch composition of enumerated landings from HL/TL vessels at Muara Padang, 2014 – 2015.

Species		Total Catch Enumerated (kg)			
Common name	Scientific name	2014 n = 74	2015 n = 78	Total 152 trips	%
Skipjack tuna	*Katsuwonus pelamis*	17,945	28,800	46,745	34.61
Yellowfin tuna (small)	*Thunnus albacares*	12,685	19,250	31,935	23.65
Bigeye tuna (small)	*Thunnus obesus*	8,103	9,500	17,603	13.03
Yellowfin/Bigeye tuna nei	*Thunnus sp.*	3,490	7,400	10,890	8.06
Common dolphinfish	*Coryphaena hippurus*	4,362	5,770	10,132	7.50
Frigate/Bullet tuna nei	*Auxis spp.*	1,000	5,450	6,450	4.78
Rainbow runner	*Elagatis bipinnulata*	1,481	2,370	3,851	2.85
Frigate tuna	*Auxis thazard*	3,400		3,400	2.52
Eastern little tuna (kawakawa)	*Euthynnus affinis*	850	1,900	2,750	2.04
Yellowfin tuna (large)	*Thunnus albacares*	430	550	980	0.73
Bigeye tuna (large)	*Thunnus obesus*	100	150	250	0.19
Black marlin	*Makaira indica*	70		70	0.05
	Total	**53,916**	**81,140**	**135,056**	**100**

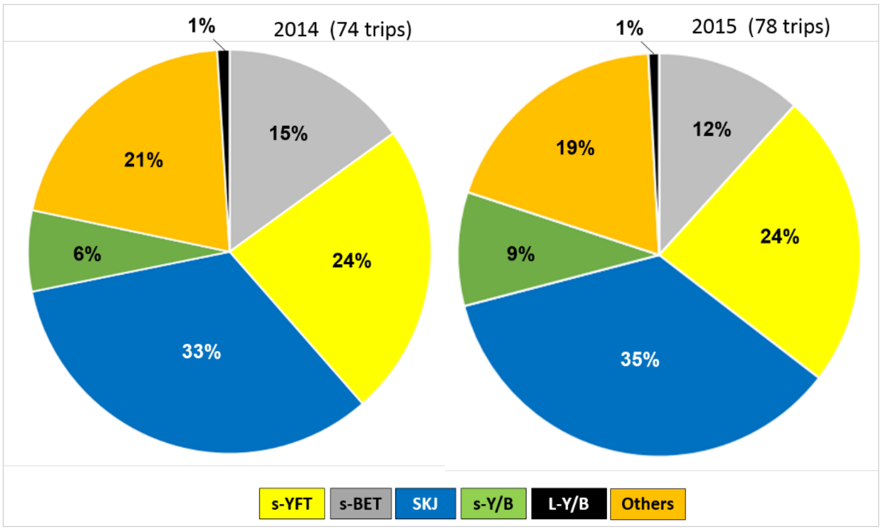


Figure A3-5. Catch composition of enumerated landings from HL/TL vessels at Muara Padang, 2014 – 2015. s-YFT = small YFT, s-BET = small BET, s-Y/B = small YFT/BET nei[25], L-Y/B = large YFT + large BET combined. For species that comprise "Others" see Table A3-2.

A conspicuous feature of the catch composition data collected for the HL/TL vessels at Muara Padang in the 2014 and 2015 enumerations is the high proportion (39% and 36% respectively) of juvenile YFT and juvenile BET (the two species combined) in the total catch

[25] *nei* = not enough information i.e. where fish were not able to be identified confidently to species due to small size or for other reason (e.g. poor fish condition).

(Table A3-2, Figure A3-5). These were of similar proportions to that of SKJ in both years. Interestingly, the proportion of juvenile BET in the total catch (15% and 12% in 2014 and 2015 respectively) was highest for catches by any gear at the four surveyed locations, and this result concurs with the relative ease with which the juvenile BET sampling targets were achieved at Muara Padang for the project's populations structure study in 2013 and 2014.

Palabuhanratu

Table A3-3 Catch composition of enumerated landings from HL/TL vessels at PPN Palabuhanratu, 2013 – 2016.

Species		Total Catch Enumerated (kg)					
Common name	Scientific name	2013*	2014	2015	2016	Total	%
		n = 165	n = 548	n = 263	n = 176	1152 trips	
Skipjack tuna	*Katsuwonus pelamis*	16,824	84,451	77,047	36,972	215,294	32.97
Yellowfin tuna (small)	*Thunnus albacares*	41,617	97,476	45,479	28,395	212,967	32.61
Yellowfin tuna (large)	*Thunnus albacares*	7,984	53,393	17,866	21,496	100,739	15.43
Striped Marlin	*Tetrapturus audax*	5,011	24,212	21,071	13,719	64,013	9.80
Bigeye tuna (small)	*Thunnus obesus*	5,159	14,798	13,380	6,143	39,480	6.05
Common dolphinfish	*Coryphaena hippurus*	1,621	6,940	3,165	2,594	14,320	2.19
Yellowfin tuna (small/large nei)	*Thunnus albacares*	1,528	858	979	168	3,533	0.54
Other fish nei	Other fish nei	520	665	285	170	1,640	0.25
Bigeye tuna (large)	*Thunnus obesus*		173	252	47	472	0.07
Albacore	*Thunnus alalunga*		252		145	397	0.06
Barracuda	*Sphyraena spp.*	106				106	0.02
Southern Bluefin Tuna	*Thunnus maccoyii*			49		49	0.01
Rainbow runner	*Elagatis bipinnulata*	24				24	0.00
	Total	**80,394**	**283,218**	**179,573**	**109,849**	**653,034**	**100**

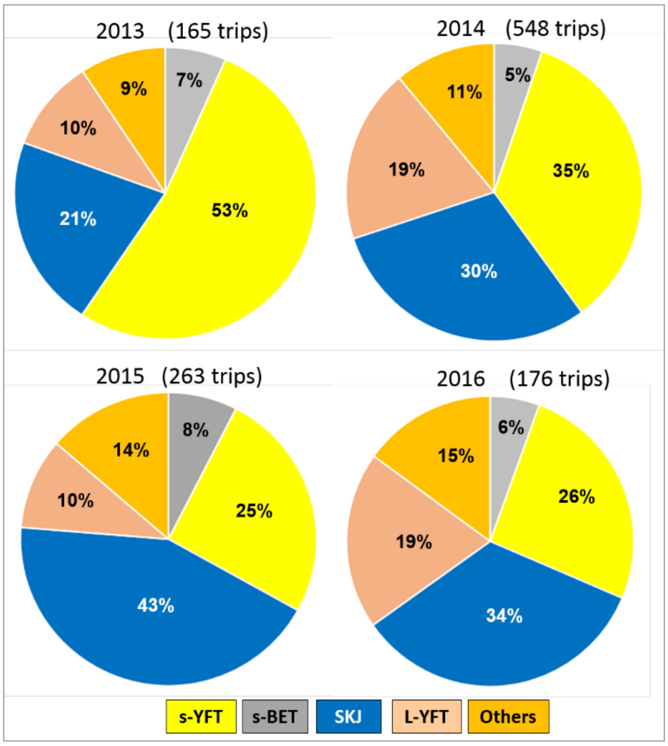


Figure A3-6. Catch composition of enumerated landings from HL/TL vessels at PPN Palabuhanratu, 2013 – 2016. s-YFT = small YFT, s-BET = small BET, L-YFT = large YFT. For species that comprise "Others" see Table A3-3.

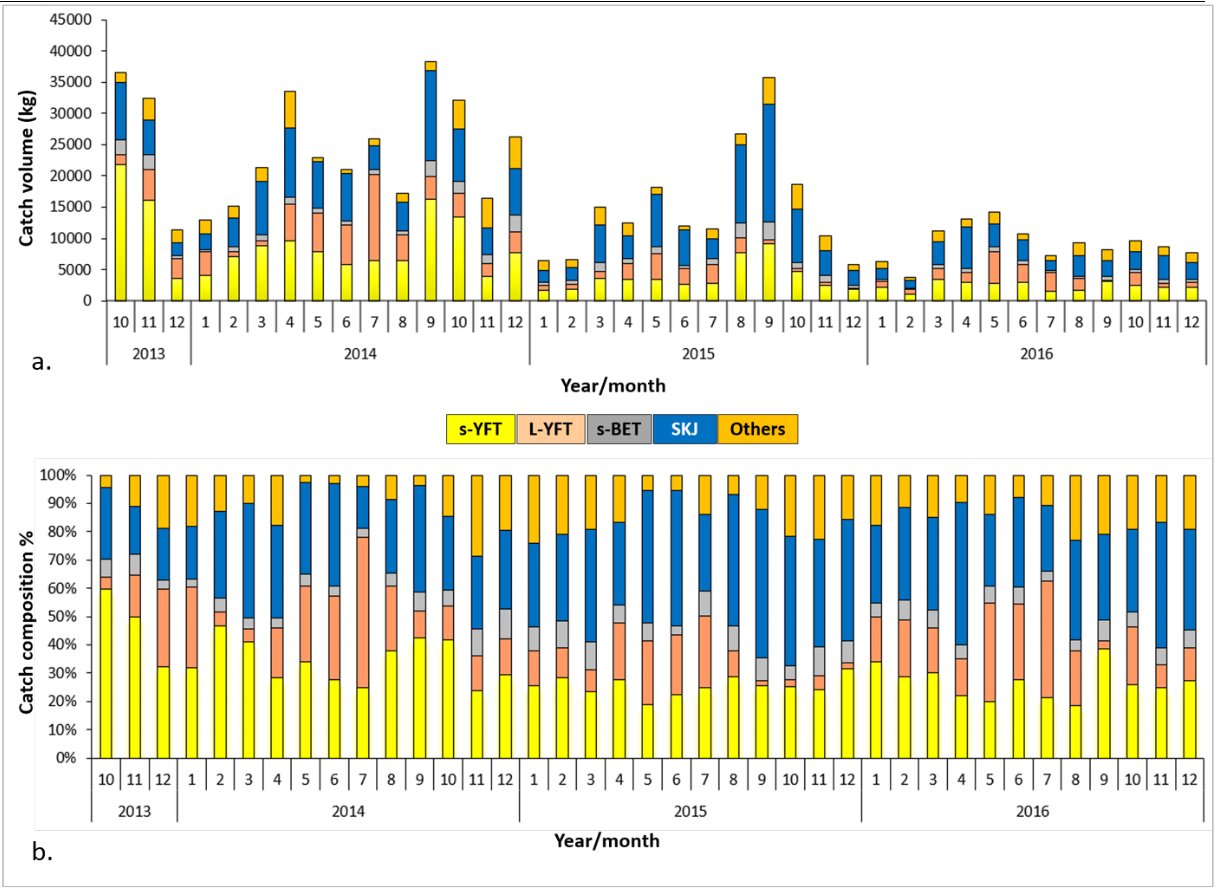


Figure A3-7. Catch composition by (a) volume (kg) and (b) % of total catch of enumerated landings from HL/TL vessels at PPN Palabuhanratu, 2013 – 2016. s-YFT = small YFT, s-BET = small BET, L-YFT = large YFT. For species that comprise "Others" see Table A3-3.

In common with the HL/TL fishery at Padang, the combined proportions of juvenile YFT and juvenile BET in the total catch in the 2013 – 2016 period were similar to those for SKJ (Table A3-3, Figures A3-6 and A3-7). In the 3 months (Oct – Dec) of survey for the fishery in 2013, the juveniles of YFT and BET were at a combined 60% of total catch, well exceeding that of SKJ at 21%. Large YFT also make up a significant proportion (10 – 19%) of the HL/TL landings; fish that are generally caught around the FADs at depths of 150 – 200m on deep hand-line or by surface fishing, often including use of kite-fishing. The juvenile and adult components of the catch are clearly seen in the length frequency distribution for YFT for this fishery (Figure A3-15).

Kendari

Table A3-4. Catch composition of enumerated landings from HL/TL vessels at Kendari (PP Sodohoa and PPS Kendari), 2013 – 2016.

Species		Total Catch Enumerated (kg)					
Common name	Scientific name	2013*	2014	2015	2016	Total	%
		n = 76	n = 144	n = 162	n = 165	547 trips	
Yellowfin tuna (small)	*Thunnus albacares*	40,418	76,010	75,885	73,233	265,546	46.32
Skipjack tuna	*Katsuwonus pelamis*	31,954	74,405	64,805	56,978	228,142	39.80
Bigeye tuna (small)	*Thunnus obesus*	2,640	9,605	9,346	13,202	34,793	6.07
Frigate tuna	*Auxis thazard*	2,221	9,080		300	11,601	2.02
Eastern little tuna (Kawakawa)	*Euthynnus affinis*		600	1,620	6,927	9,147	1.60
Black marlin	*Makaira indica*	1,568	2,352	2,170	1,246	7,336	1.28
Yellowfin tuna (large)	*Thunnus albacares*	1,303	1,671	2,140	1,848	6,962	1.21
Frigate tuna/Bullet tuna nei	*Auxis spp.*		900	910	2,045	3,855	0.67
Bigeye tuna (large)	*Thunnus obesus*	222	858		615	1,695	0.30
Various sharks nei	NA		120	535	933	1,588	0.28
Common dolphinfish	*Coryphaena hippurus*	656	236	100	60	1,052	0.18
Tiger shark	*Galeocerdo cuvier*			700		700	0.12
Marlins, sailfish, spearfish etc. nei	Istiophoridae	163	100			263	0.05
Blue marlin	*Makaira nigricans*	233				233	0.04
Silky shark	*Carcharhinus falciformis*		130			130	0.02
Scads nei	*Decapterus spp.*	80				80	0.01
Blue shark	*Prionace glauca*	65				65	0.01
Striped marlin	*Tetrapturus audax*		65			65	0.01
Narrow-barred Spanish mackerel	*Scomberomorus commerson*	6	8			14	0.00
Rainbow runner	*Elagatis bipinnulata*				8	8	0.00
Barracuda	*Sphyraena spp.*		5			5	0.00
	Total	**81,529**	**176,145**	**158,211**	**157,395**	**573,280**	**100**

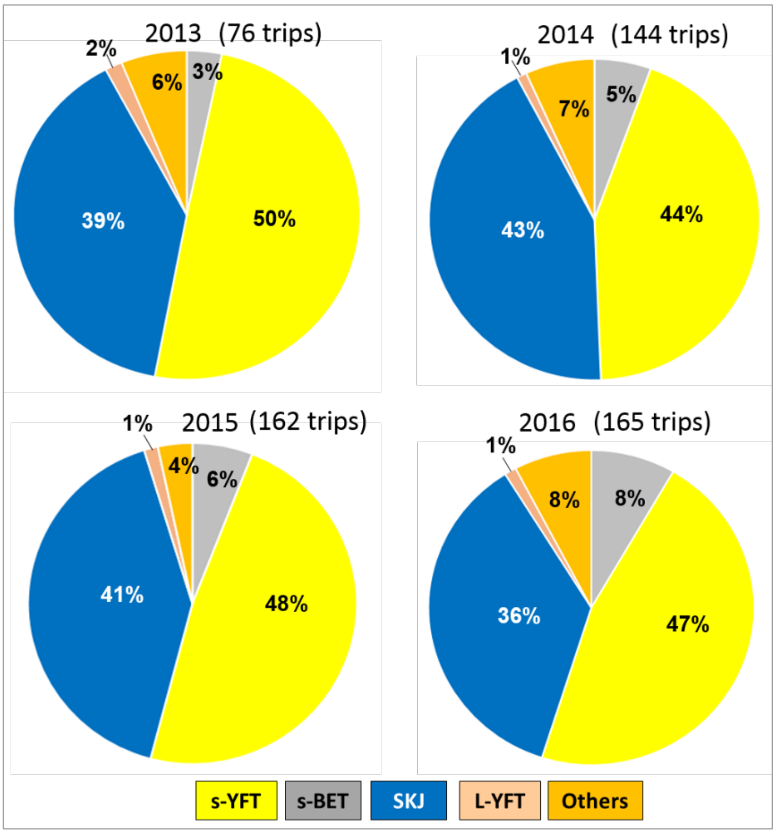


Figure A3-8. Catch composition of enumerated landings from HL/TL vessels at Kendari, 2013 – 2016. s-YFT = small YFT, s-BET = small BET, L-YFT = large YFT. For species that comprise “Others” see Table A3-4.

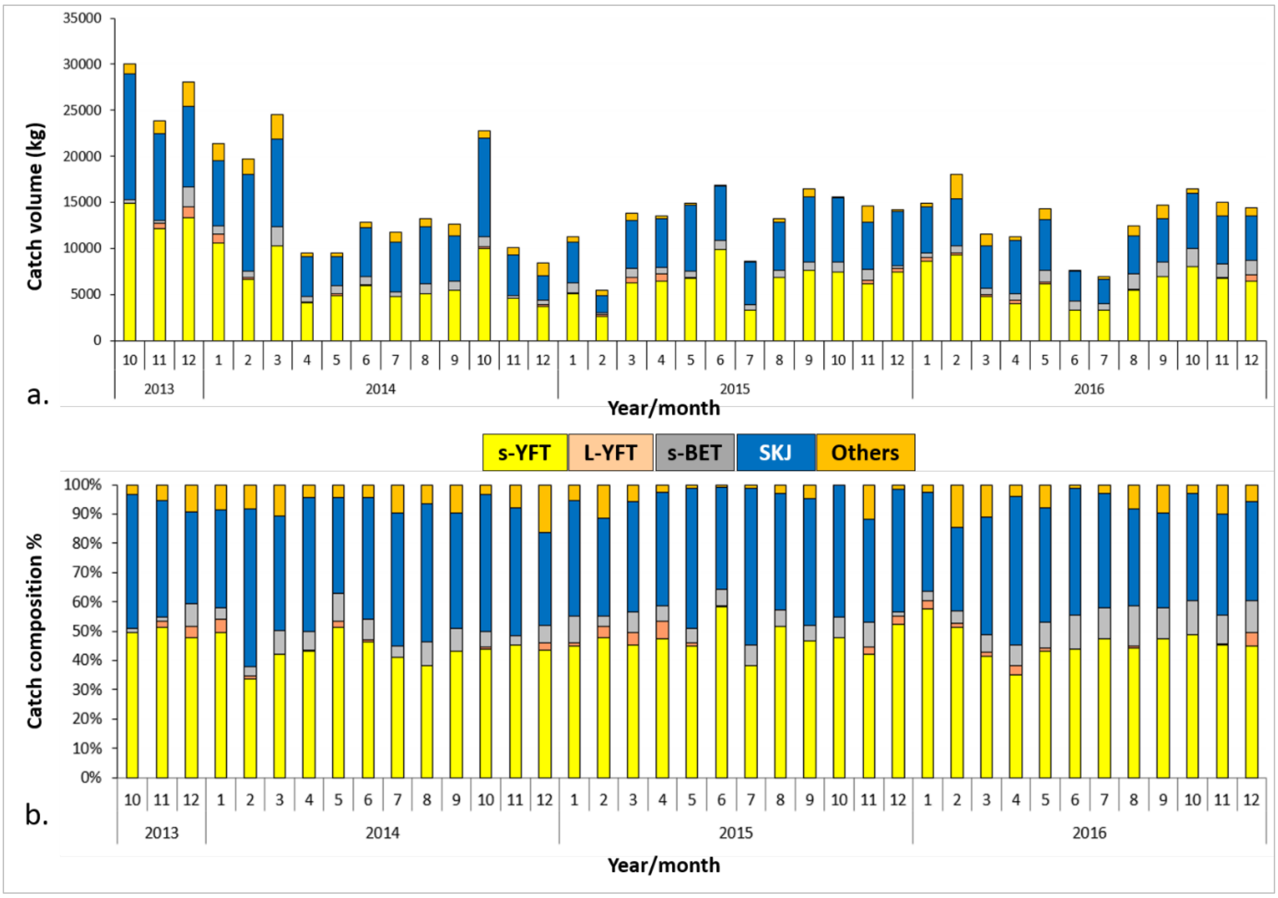


Figure A3-9. Catch composition by (a) volume (kg) and (b) % of total catch of enumerated landings from HL/TL vessels at Kendari, 2013 – 2016. s-YFT = small YFT, s-BET = small BET, L-YFT = large YFT. For species that comprise "Others" see Table A3-4

In common with the HL/TL landings at Muara Padang and Palabuhanratu, the proportions of juveniles of YFT and BET combined in the catches enumerated from HL/TL vessels at Kendari were large (49 – 55%), and exceeded the SKJ proportions (36 – 43%) across the 4 years (Table A3-4, Figures A3-8 and A3-9). However, the data from Kendari is complicated by the situation of large YFT. The proportions of these larger fish appear as only 1 – 2% of the total catch, which does represent the true situation. Large YFT are caught by the Kendari-based HL/TL vessels in similar ways to those at Palabuhanratu (i.e. by deepwater handline and surface kite-fishing) but were generally landed at PPS Kendari as fillets after processing at sea. Our enumeration program did not adequately 'capture' this component of the catches. At least one similar monitoring program, that of MDPI for the HL/TL fisheries in NTT, Banda Sea and Molucca Sea regions, instruct their enumerators to record data on measurements of fillet length and numbers of fillets in order to achieve estimates on the volume of adult fish in the catches. We see this as a worthy inclusion in any future enumeration if processing of the larger tuna at sea is allowed to continue. However, the level of confidence around estimates of whole fish volume based on fillet measures has yet to be determined.

Table A3-5. Catch composition of enumerated landings from carrier vessels at PPS Kendari, with catch from PL vessels, 2013 – 2016.

Species		Total Catch Enumerated (kg)					
Common name	Scientific name	2013* n = 39	2014 n = 99	2015 n = 158	2016 n = 160	Total 456 trips	%
Skipjack tuna	*Katsuwonus pelamis*	248,725	410,407	456,257	450,168	1,565,557	59.99
Yellowfin tuna (small)	*Thunnus albacares*	145,600	194,315	112,537	160,388	612,840	23.48
Frigate tuna	*Auxis thazard*	132,900	47,815			180,715	6.93
Scads nei	*Decapterus spp.*	150,200	26,300			176,500	6.76
Bigeye tuna (small)	*Thunnus obesus*	25,450	21,238	1,750	5,928	54,366	2.08
Common dolphinfish	*Coryphaena hippurus*		13,400		210	13,610	0.52
Indo Pacific sailfish	*Istiophorus platypterus*	4,800				4,800	0.18
Frigate tuna/Bullet tuna nei	*Auxis spp.*			200	1,000	1,200	0.05
	Total	**707,675**	**713,475**	**570,744**	**617,694**	**2,609,588**	**100**

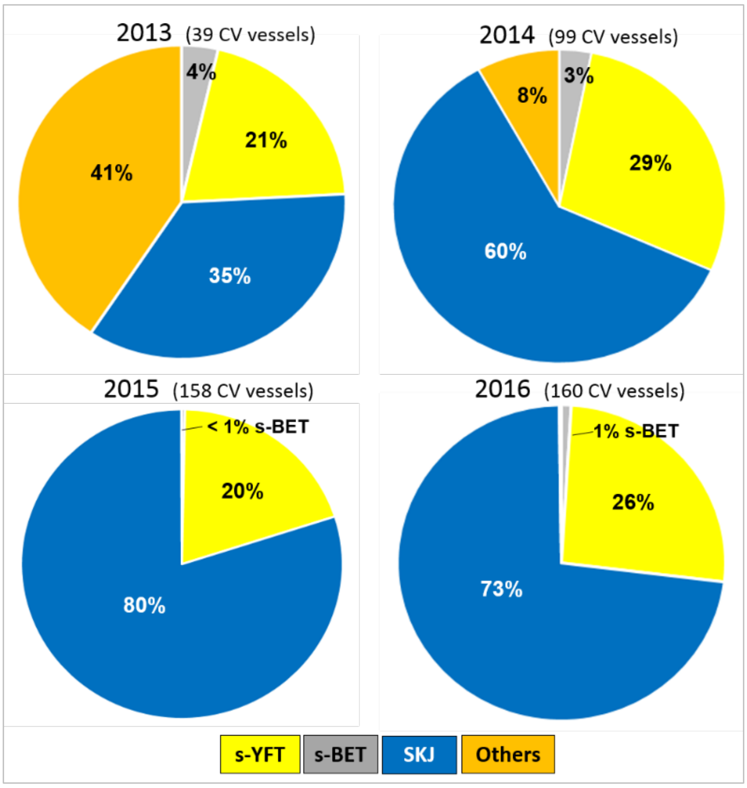


Figure A3-10. Catch composition of enumerated landings from carrier vessels at PPS Kendari, with catch from PL vessels, 2013 – 2016. s-YFT = small YFT, s-BET = small BET. For species that comprise “Others” see Table A3-5.

The catch compositions of carrier vessel landings of catch at PPS Kendari, collected at sea from PL vessels, were largely as expected, based on earlier reports for Indonesian PL fisheries and also results of the Indonesian component of the tagging program in 2009 – 2010. SKJ were the dominant component of the enumerated landings, at 60 – 80% for period 2014 – 2016, and juveniles of YFT and BET combined at 21 – 32% of total catch (Table A3-5, Figure A3-10). In contrast, the proportion of SKJ in the carrier vessel landings for the enumerated period of 2013 (Oct – Dec) was at only 35%; the result of unusually large catches of frigate tuna and scads (combined proportion of ~41%) in that period.

Table A3-6. Catch composition of enumerated landings from carrier vessels at PPS Kendari, with catch from PS vessels, 2013 – 2015 combined.

Species		Total Catch Enumerated (kg)	
Common name	Scientific name	2013 - 2015 n = 92 trips	%
Frigate tuna	*Auxis thazard*	745,405	27.343
Skipjack tuna	*Katsuwonus pelamis*	664,696	24.383
Yellowfin tuna (small)	*Thunnus albacares*	542,608	19.904
Scads nei	*Decapterus spp.*	524,099	19.225
Bigeye tuna (small)	*Thunnus obesus*	149,711	5.4918
Frigate tuna/Bullet tuna nei	*Auxis spp.*	88,262	3.2377
Eastern little tuna (kawakawa	*Euthynnus affinis*	11,300	0.4145
	Total	**2,726,081**	**100**

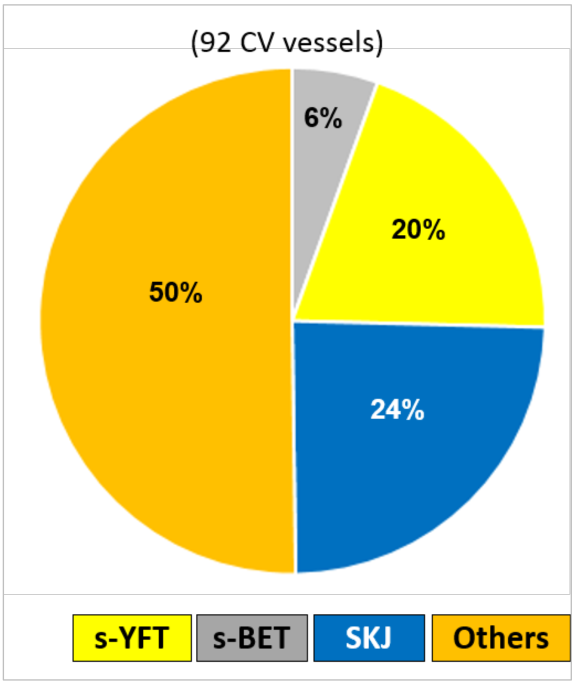


Figure A3-11. Catch composition of enumerated landings from carrier vessels at PPS Kendari, with catch from PS vessels, 2013 – 2015 combined. s-YFT = small YFT, s-BET = small BET. For species that comprise "Others" see Table A3-6.

The catches from PS vessels, collected at sea and landed by carrier vessels at PPS Kendari during the 2013 – 2015 enumeration period, were dominated in proportion by the "Others" category, which included frigate and bullet tuna (*Auxis thazard* and *A. rochei*), scads (*Decapterus spp.*), and kawakawa (*Euthynnus affinis*) (Table A3-6, Figure A3-11). Juveniles of YFT and BET combined were at 26% of the catch.

Table A3-7. Catch composition of enumerated landings from PL vessels at Sorong, 2013 – 2015 combined.

Species		Total Catch Enumerated (kg)	
Common name	Scientific name	2013 - 2015 n = 98 trips	%
Skipjack tuna	*Katsuwonus pelamis*	805,092	75.636
Yellowfin tuna (small)	*Thunnus albacares*	199,268	18.721
Bigeye tuna (small)	*Thunnus obesus*	37,271	3.5015
Yellowfin tuna (large)	*Thunnus albacares*	7,037	0.585
Yellowfin/Bigeye tuna nei	*Thunnus spp.*	6,227	0.0447
Frigate tuna	*Auxis thazard*	3,036	0.0775
Eastern little tuna (kawakawa)	*Euthynnus affinis*	2,575	0.2852
Yellowfin tuna (small/large nei)	*Thunnus albacares*	1,906	0.2419
Rainbow runner	*Elagatis bipinnulata*	825	0.1791
Rays bream (pomfret)	Bramidae *spp.*	711	0.6611
Common dolphinfish	*Coryphaena hippurus*	476	0.0668
	Total	**1,064,424**	**100**

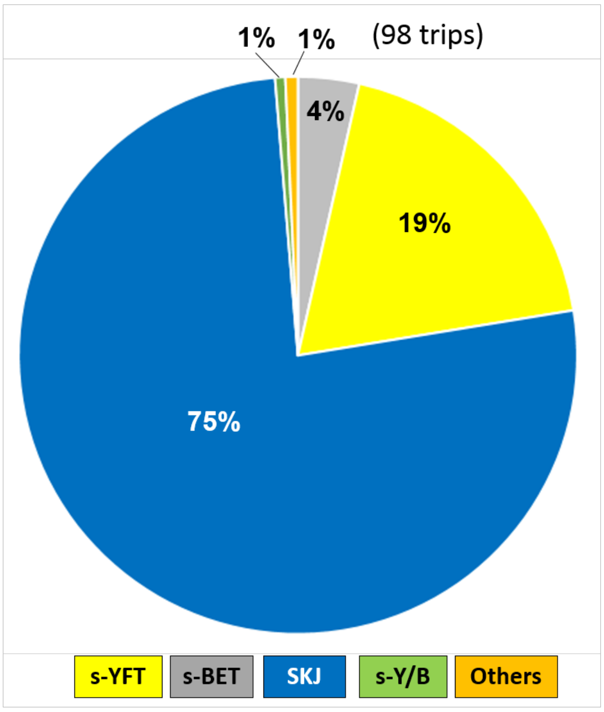


Figure A3-12. Catch composition of enumerated landings from PL vessels at Sorong, 2013 – 2015 combined. s-YFT = small YFT, s-BET = small BET, s-Y/B = small YFT/BET nei. For species that comprise "Others" see Table A3-7.

The enumerated landings of PL vessels at Sorong showed, unsurprisingly, a similar catch composition (all enumerated landings combined for 2013 – 2015, Table A3-7, Figure A3-12) to the PL landings at PPS Kendari, with SKJ dominating at 75%, and the juveniles of YFT and BET combined at 23% of total catch.

Table A3-8. Catch composition of enumerated landings from carrier vessels at Sorong, with catch from PS vessels, 2013 – 2014 combined.

Species		Total Catch Enumerated (kg)	
Common name	Scientific name	2013 - 2014 n = 16 trips	%
Skipjack tuna	*Katsuwonus pelamis*	443,950	78.39
Yellowfin tuna (small)	*Thunnus albacares*	90,167	15.92
Bigeye tuna (small)	*Thunnus obesus*	14,813	2.62
Frigate tuna	*Auxis thazard*	8,534	1.51
Eastern little tuna (kawakawa)	*Euthynnus affinis*	4,974	0.88
Rainbow runner	*Elagatis bipinnulata*	2,186	0.39
Common dolphinfish	*Coryphaena hippurus*	1,735	0.31
	Total	**566,359**	**100**

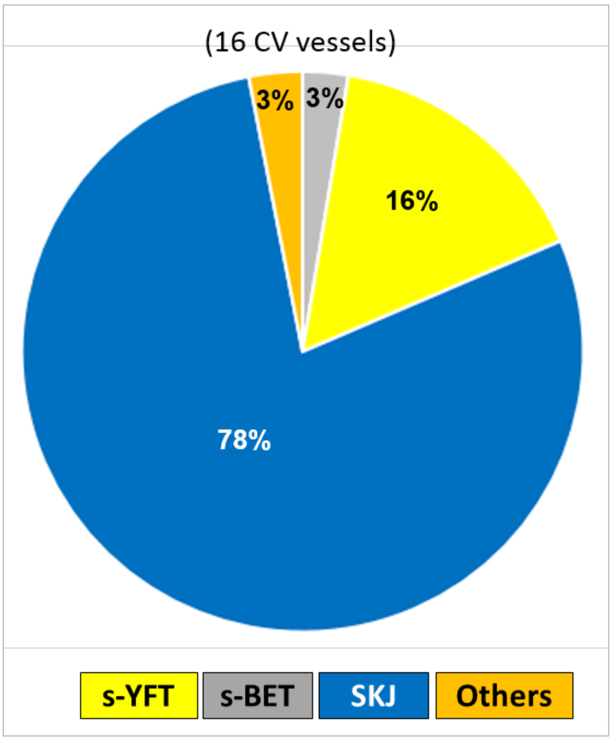


Figure A3-13. Catch composition of enumerated landings from carrier vessels at Sorong, with catch from PS vessels, 2013 – 2014 combined. s-YFT = small YFT, s-BET = small BET. For species that comprise "Others" see Table A3-8.

Only 16 landings of carrier vessels at Sorong with catches from PS vessels were enumerated. In the absence of a large "Others" component that was a feature for PS catches landed in Kendari, the catch composition for PS in Sorong was similar to that of PL; 78% SKJ, and 19% for juveniles of YFT and BET combined (Table A3-8, Figure A3-13).

The enumeration program included an attempt to obtain a course measure of fishing success (i.e. a course measure of CPUE) by having the enumerators request information in their interviews with vessel captains on the numbers of FADs visited in the recently completed fishing trip and the number of those FAD visits that yielded fishing success. A successful FAD visit was loosely defined as any visit yielding catch, with no actual ranking of catch success. The number of FAD visits included return visits to FADs within a trip (i.e. the total number of FAD fishing events in the trip).

Perhaps the most interesting outcome of this assessment of fishing success (albeit coarse) is the result of only 34.5% FADs success for the HL/TL fleet at Padang, compared to significantly higher levels for the HL/TL fleets at Palabuhanratu and Kendari (85% and 68% respectively) (Table A3-9). This may be explained by the FADs used by the Padang HL/TL fleet being those owned by PS vessels based in Sibolga (west coast of North Sumatra). It is possible the low success rate (i.e. low rate of fish encounters on FAD visitation) is due to the PS vessel fishing activity and the ‘recovery’ periods required for fish numbers to rebuild around the FADs following PS sets.

Table A3-9. Details of FAD visitation and fishing success rates by location and by gear type; information collected through post-trip interviews with vessel captains. Average catch per trip determined from enumerated catches. Number of vessel trips refers to those trips where FAD visitation information was able to be collected by the enumerators.

Location	Gear Type	No. Vessel Trips	Average No. Fishing (days)	Av. Number of FADs visited	Av. Number of FADs with success	FADs Success rate	Average Catch (kg) per trip
Padang	HL/TL	166	12.6	12.9	4.0	34.5%	1,169
Palabuhanratu	HL/TL	1,142	7.6	1.4	1.0	85.0%	588
Kendari	HL/TL	537	7.1	12.9	8.3	67.7%	1,110
Kendari	PL	22	2.4	2.3	1.1	64.4%	3,167
Sorong	PL	91	5.8	4.5	3.9	84.9%	13,462

A3-4. Biological sampling and length frequencies of tuna species

The enumeration program included biological sampling, primarily to provide information on the species diversity and size of species caught and landed by the vessels fishing on tuna anchored FADs in the region of the four focus ports. The enumerators were instructed, via the training and the sampling protocol (Proctor et al. 2018; based on WPEA sampling protocol Widodo et al. 2013), to achieve, as best as possible, a representative sample from each vessel’s catch landing. The sampling targets were:

1. For landings from PS vessels, to do length measurements on about 1% of the catch (randomly selected prior to any sorting of catch by species and size);
2. For landings from PL vessels, to sub-sample at least 50 kg of fish (a randomly selected sample) for every 1 tonne of catch landed;
3. For landings from HL/TL vessels, to sub-sample at least 50 kg of fish (a randomly selected sample) for every 1 tonne of catch landed, and to measure all large tunas and large bycatch species (e.g. billfish and sharks).

An additional key objective of the biological sampling activity was to provide capacity development to the enumerators in the techniques of subsampling of catches from fishing vessels, the actual methods of measurement with callipers and measuring boards, in species identification skills, and in all steps of data recording, data processing, and reporting.

Across the four focus ports, a total of 51,610 fish in the “small” (i.e. $\leq$ 100 cm) category and 2,187 in the “large” (i.e. > 100 cm) category were measured during the enumeration program (Table A3-10). All data collected by the enumerators were recorded on the *Catch Sampling Form* for the relevant vessel gear type and subsequently entered into the *Biological Sampling (Small)* and *Biological Sampling (Large)* modules within the FAD Fisheries Database.

Table A3-10. Details of the numbers of fish measured, by species, for length in the enumeration program (all ports combined). nd = not able to be differentiated.

English	Scientific name	Number
SMALL (< 100 cm)		
Skipjack tuna	*Katsuwonus pelamis*	25,268
Yellowfin tuna	*Thunnus albacares*	16,312
Bigeye tuna	*Thunnus obesus*	4,874
Common dolphinfish	*Coryphaena hippurus*	1,825
Frigate/Bullet tuna (nd)	*Auxis thazard/A. rochei*	985
Yellowfin/Bigeye tuna (nd)	*Thunnus albacares/T. obesus*	618
Frigate tuna	*Auxis thazard*	520
Rainbow runner	*Elagatis bipinnulata*	502
Eastern little tuna, Kawakawa	*Euthynnus affinis*	432
Scads nei	*Decapterus* spp.	209
Various sharks nei		25
Narrow-barred Spanish mackerel	*Scomberomorus commerson*	17
Albacore tuna	*Thunnus alalunga*	12
Other fish nei		5
Silky shark	*Carcharhinus falciformis*	3
Black marlin	*Istiompax indica*	2
Striped marlin	*Kajikia audax*	1
LARGE (> 100 cm)		
Yellowfin tuna	*Thunnus albacares*	1,478
Striped marlin	*Kajikia audax*	665
Common dolphinfish	*Coryphaena hippurus*	15
Marlins, sailfish, spearfish nei		13
Black marlin	*Istiompax indica*	10
Swordfish	*Xiphias gladius*	2
Bigeye tuna	*Thunnus obesus*	2
Various sharks nei		1
Albacore tuna	*Thunnus alalunga*	1
Blue shark	*Prionace glauca*	1

The length frequency histograms for SKJ, YFT, and BET, as determined from the biological sampling conducted at the four ports are provided below. As already highlighted in the catch composition section above, juvenile YFT and juvenile BET comprised significant proportions of the landings from all enumerated gear types (HL/TL, PL, and PS). The red lines in each frequency distribution (Figures A3-14 to A3-20) indicate the approximate lengths at maturity (L*m*) for the three tuna species, based on information from Fishbase[26] and other sources. However, it should be emphasised that the L*m* reported for each of SKJ, YFT, and BET does appear to vary across the species' geographic range, and that to date, determining this key population parameter for these species in Indonesian waters has not been rigorously examined[27].

Padang

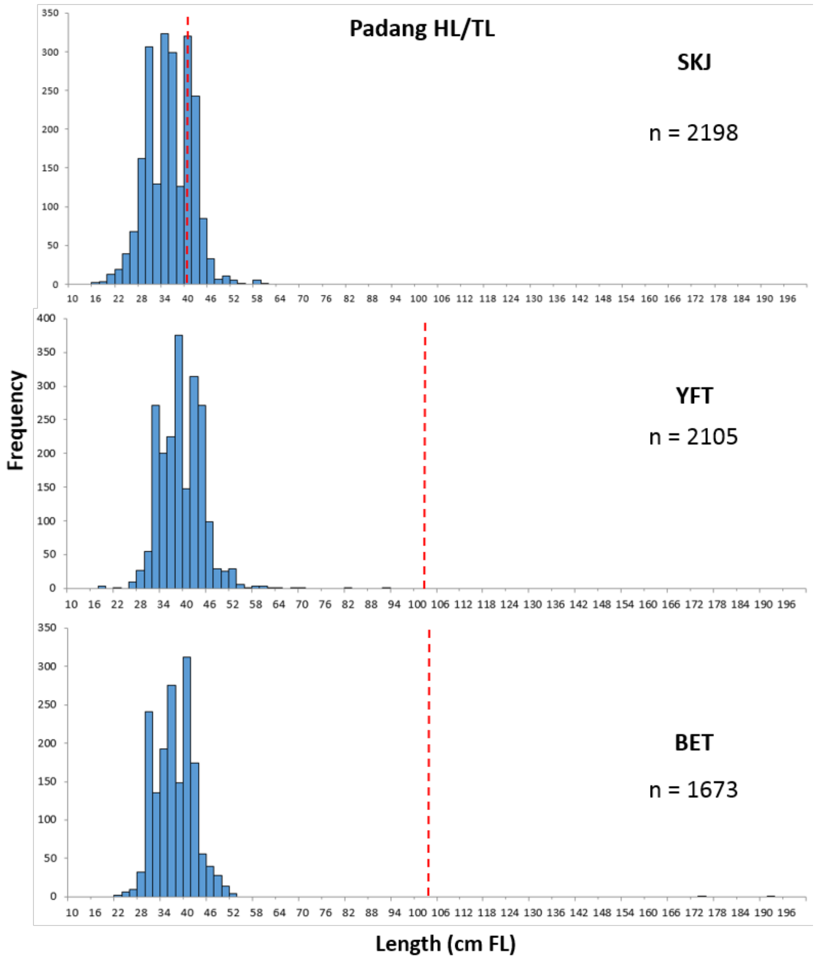


Figure A3-14. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Muara Padang from HL/TL vessels, 2013 – 2015 combined. Red dashed line indicates approximate L*m* for each species.

[26] Fishbase: https://www.fishbase.in

[27] Determining L*m* for SKJ, YFT, and BET in Indonesian waters is a key objective on the follow-on ACIAR project FIS/2016/116.

Palabuhanratu

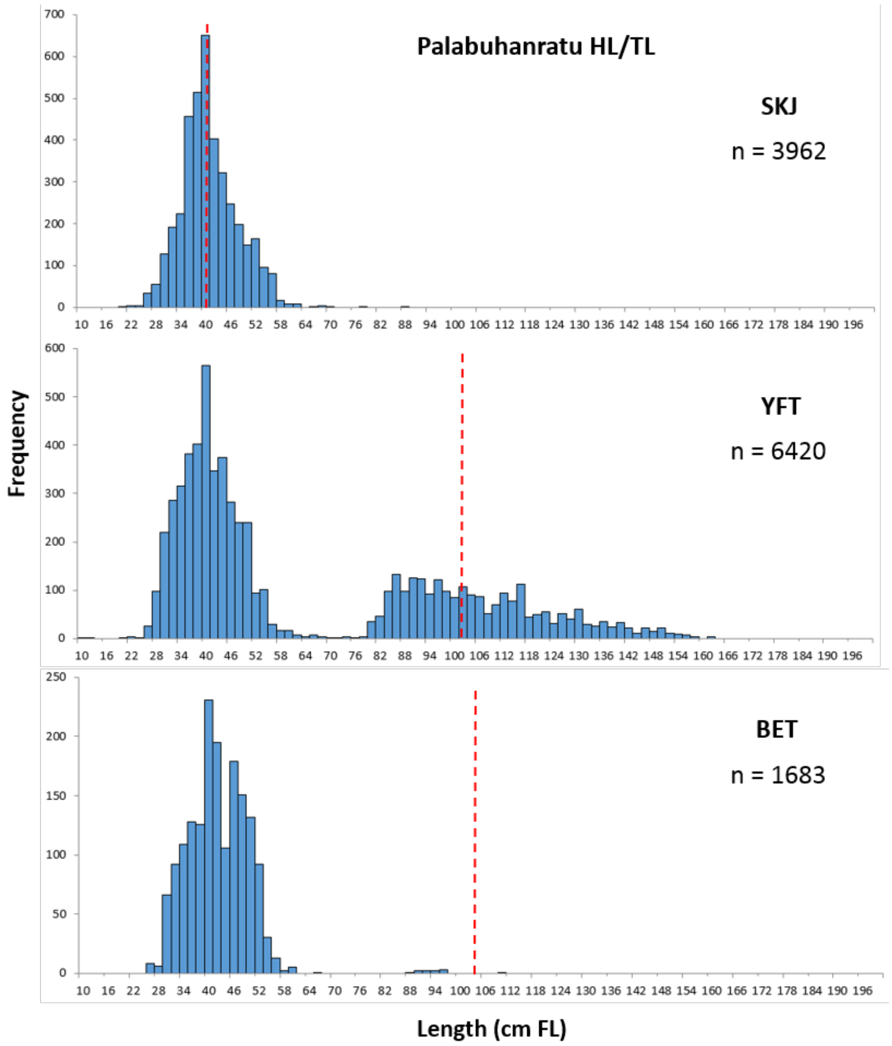


Figure A3-15. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Palabuhanratu from HL/TL vessels, 2013 – 2016 combined. Red dashed line indicates approximate L*m* for each species.

Kendari

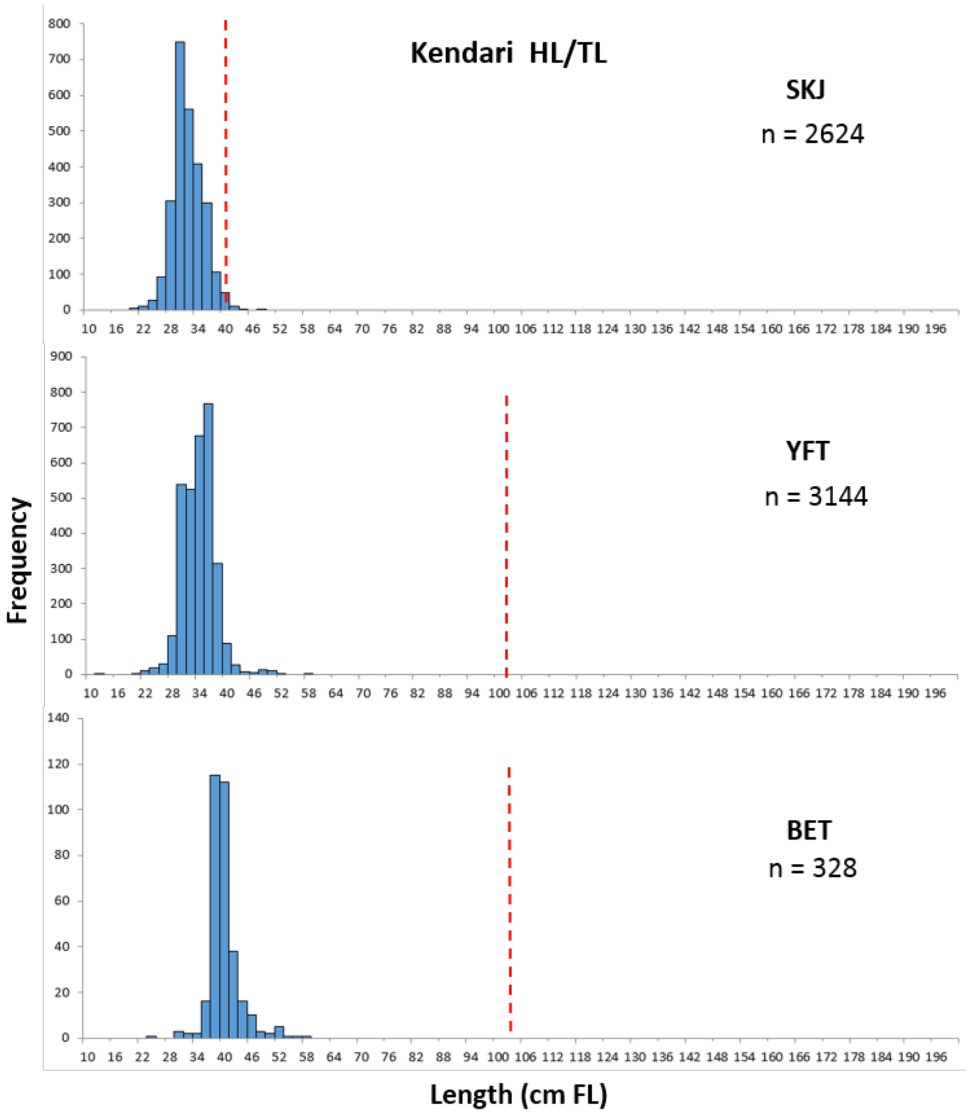


Figure A3-16. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Kendari from HL/TL vessels, 2013 – 2016 combined. Red dashed line indicates approximate L*m* for each species.

As mentioned in the catch composition section A3-3, the enumeration program did not achieve 'capture' of the adult YFT component of landings from HL/TL vessels in Kendari, because of the processing of these larger fish into fillets that occurs at sea.

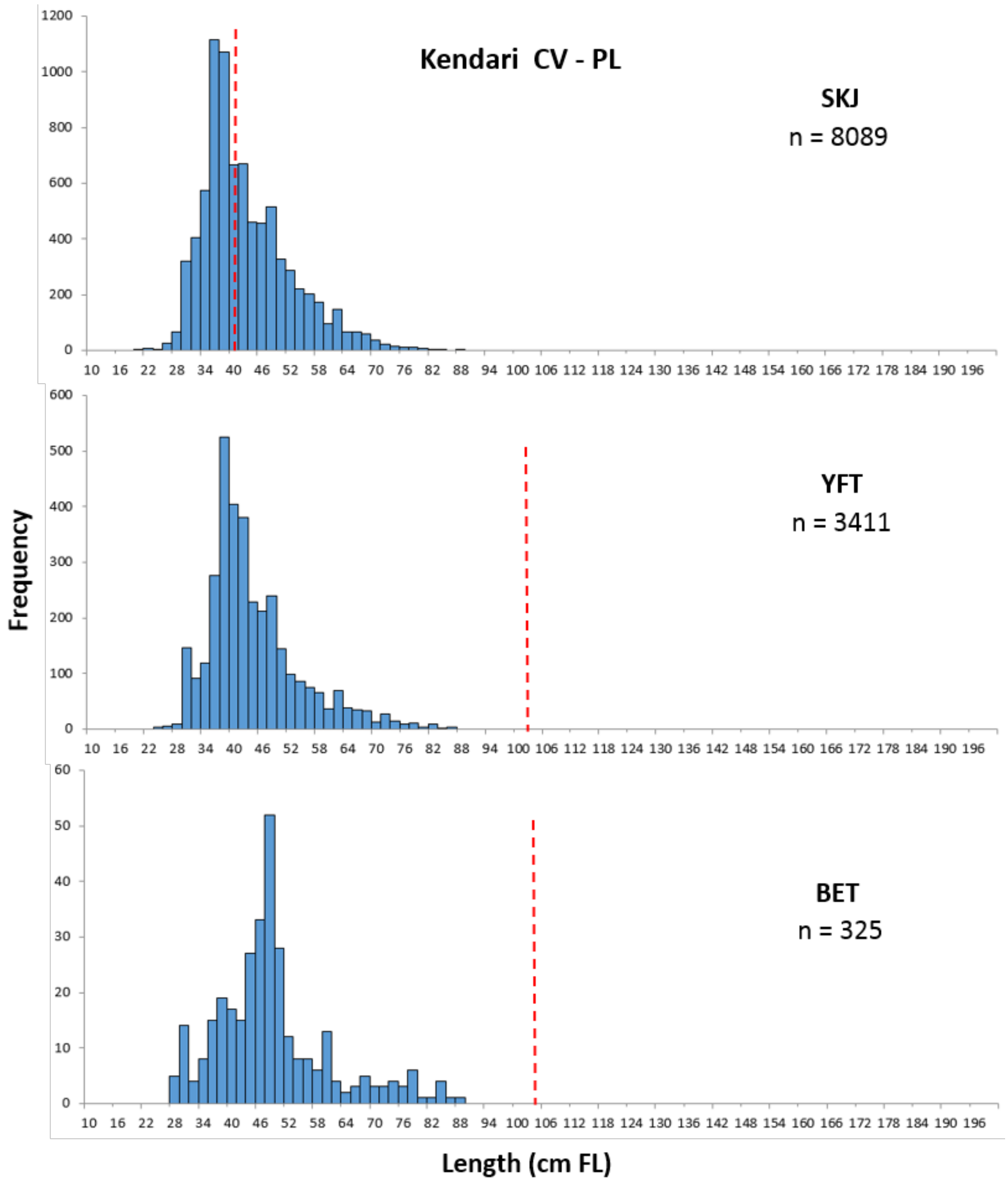


Figure A3-17. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Kendari from PL vessels, landed by carrier vessels, 2013 – 2016 combined. Red dashed line indicates approximate L*m* for each species.

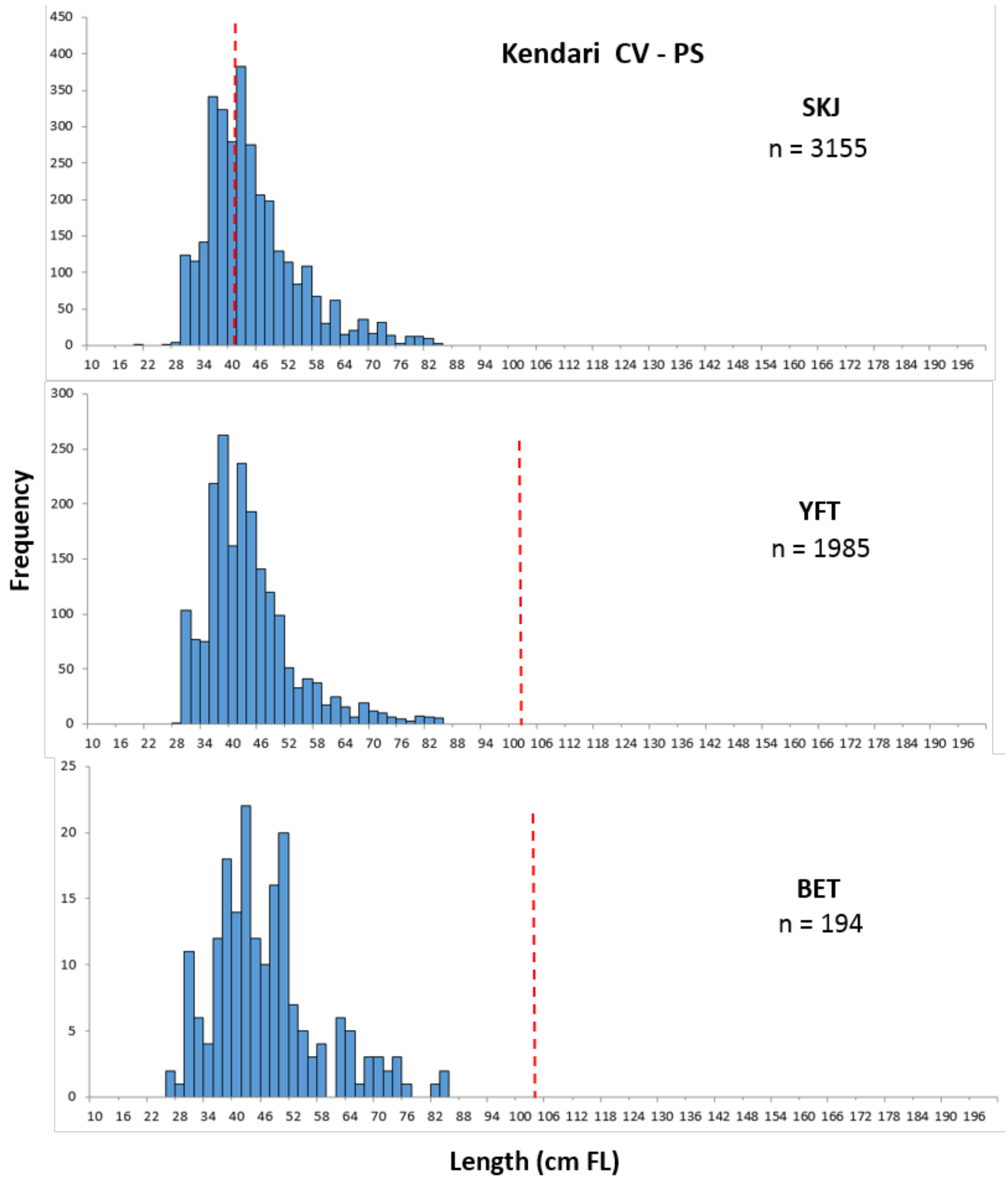


Figure A3-18. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Kendari from PS vessels, landed by carrier vessels, 2013 – 2014 combined. Red dashed line indicates approximate L*m* for each species.

Sorong

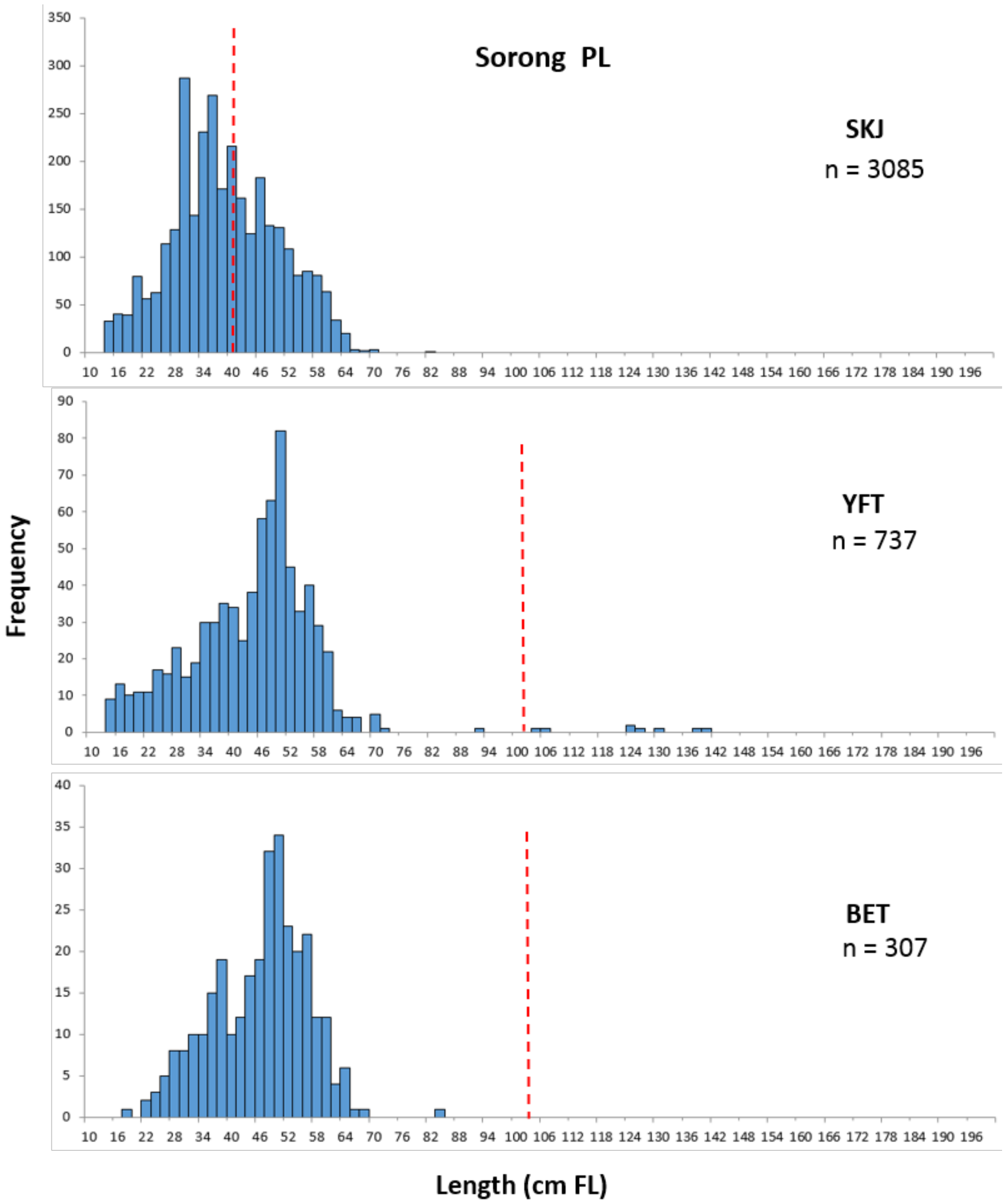


Figure A3-19. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Sorong from PL vessels, 2013 – 2015 combined. Red dashed line indicates approximate L*m* for each species.

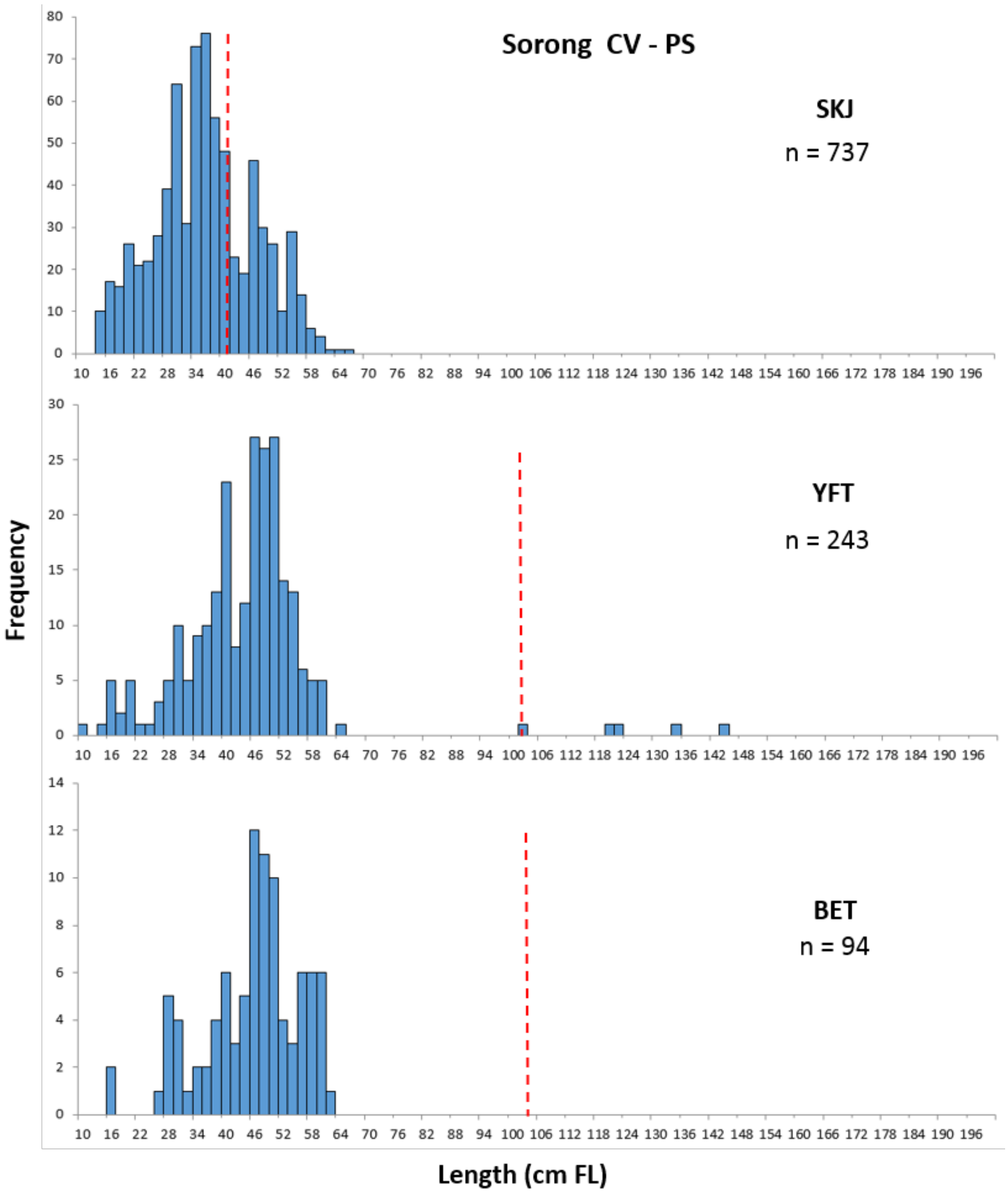


Figure A3-20. Length frequency distributions of SKJ (top), YFT (middle), and BET (bottom) subsampled from catches at Sorong from PS vessels, landed by carrier vessels, 2013 – 2014 combined. Red dashed line indicates approximate L*m* for each species.

A3-5. FAD ‘dynamics’ – numbers, locations, ownership and usage

In this section we present the results of information obtained through interviews performed by the enumerators with vessel captains post-fishing trips and from information gathered by project scientists visiting the four focus fishing ports and the other ports for the sampling of the project’s population structure study.

FAD types

As reported in Section A3-1, the surface floats of anchored tuna FADs in Indonesian waters vary in construction. Vessel Captains were asked in interview “What type of FADs were visited by your vessel during this fishing trip?”. Table A3-11 shows the types of FADs used by location and vessel gear type, and the styrofoam type (“*gabus*”) were in the majority for western Indonesia, whereas in eastern Indonesia it was common for vessels to have used/visited FADs of multiple types in the one fishing trip.

Table A3-11 Types of FADs visited, by number of fishing trips, by location. Information obtained via post-trip interviews with vessel captains. S = styrofoam (i.e. *gabus*), P = steel pontoon, B = bamboo raft, B+B = bamboo raft + bungalow. Multiple FAD types

Location	Gear type	Trips	FAD Type												
			S	P	B	B+B	Multiple FAD types								
							S, P	S, B	S, B+B	S, B, B+B	S, P, B	S, P, B+B	S, P, B, B+B	B, B+B	P, B+B
Padang	HL/TL	157	155				2								
Palabuhanratu	HL/TL	1119	1112	7											
Kendari	HL/TL	543		14	4	5	70	20	52	62	38	132	89	26	31
	PL	20				19							1		
Sorong	PL	74		50			23	1							

The styrofoam “*gabus*” type of FAD float had become increasingly popular because of its cheaper cost, ready availability of materials, and ease of construction compared to the steel pontoon and bamboo raft types. As example evidence of this change is that in 2006 – 2007, when our earlier ACIAR project FIS/2002/074 participated in a trial tuna tagging program in the West Sumatra region (Anon 2008), all of the ~56 FADs encountered in the Mentawai Strait were of the steel pontoon type. At time of this study, involving the same fleet of HL/TL fishing vessels based at Muara Padang, almost all FADs were *gabus* type.

FAD locations, numbers and density

At the beginning of the FAD study we anticipated that it would be difficult to obtain an accurate ‘picture’ of the numbers and distribution of tuna FADs by region, mainly because of lack of any effective registration system for the FADs at that time but also because of the dynamic nature of the FAD situation and the of the FADs themselves. This proved to be true. There is a high turn-over of the anchored tuna FADs, for various reasons including:

- FADs are often lost to natural forces such as storms and strong currents - breaking FAD lines or moving FADs significant distances if insufficient anchor weight;
- FADs are also lost through ‘unnatural forces’. It is not uncommon for FAD lines to be cut through conflicts with other fishing gear types e.g. by longline and gill-net vessels whose fishing gears are prone to entanglement on FAD floats and FAD lines;
- Conflicts between the vessels that fish on FADs, involving cutting of FAD lines, were also reported to have occurred - primarily between purse-seine vessels and hand-line/troll-line vessels, and even vessels of the same gear type from rival fishing companies;
- FAD lines deliberately cut by cargo vessels or other vessels encountering FADs in navigation lanes;

- As the FAD surface floats are most often poorly marked and difficult to see, loss of FADs can also occur through accidental, direct ‘hits’ (impacts) from other vessels;
- FADs degrade in condition at sea and the life-span of an Indonesian anchored tuna FAD will be, on average, a maximum of 2 years, but often less;
- FADs are constantly being replaced, and also new FADs installed, with still no effective implementation of a FAD registration system in most regions (see discussion on current FAD regulations in Section 7.2.2).

In the absence of an effective FAD registration system, obtaining FAD numbers and locations from port authorities or other offices linked to fishing vessel activity proved difficult. This was through no reluctance by these offices to provide the information and was only due to the non-existence of such information. Some vessel captains were willing to provide the way points from their GPS units for the positions of FADs they were using, but others were reluctant to do so for fear of giving up information viewed as too confidential in competing with rival fishers.

The majority of vessel captains interviewed post-fishing trip by the enumerators were, at least, willing to mark the grid-square (1° x 1°) positions for the FADs used in their trip, on the map provided on the back of the enumerator’s data collection sheet. These records enabled a ‘visitation frequency map’ to be generated for the four focus regions (Figure A3-21).

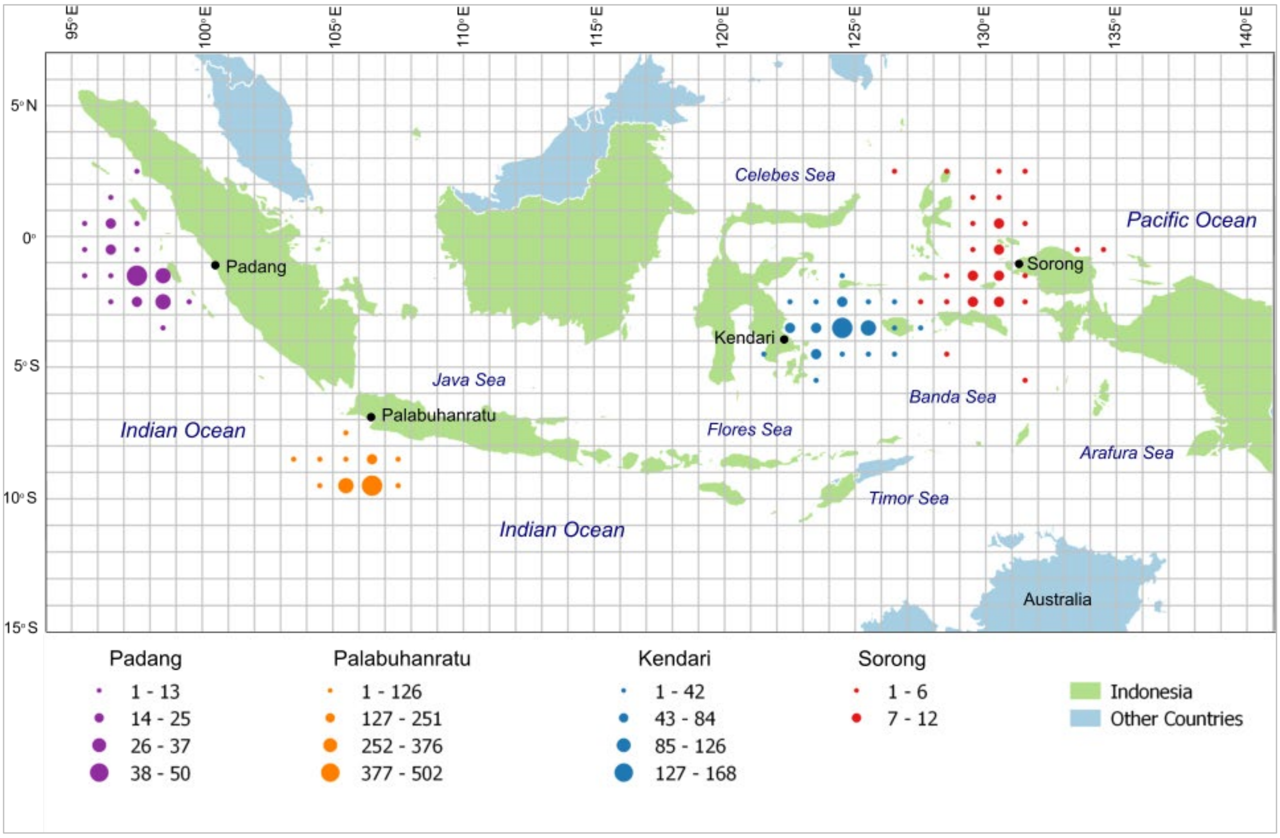


Figure A3-21 Map showing the distribution of FAD-based tuna fishing activity, based on numbers of fishing trips recorded with activity in 1° x 1° grid squares (information provided by vessel captains in post-trip interviews with enumerators). The coloured spot markers indicate the level of activity within the areas bound by the grid squares, and not the exact location of fishing activity. The activity shown is for the four focus regions of the project’s study for vessels operating out of Padang (purple), Palabuhanratu (orange), Kendari (blue), and Sorong (red). Note that this is not a representation of all the FAD ‘hot spots’ in Indonesian waters – there are others.

Information collected through this study concurred with information available from other sources (ABPC pers. comm. 2014, Hargiyatno et al. 2013 and 2015, Nurdin et al. 2012, Nurdin 2017, Satrioajie et al. 2017), in showing that the Indonesian anchored tuna FADs are often installed in close proximity to each other. The most recent FAD regulations (No.26/PERMEN-KP/2014) and DGCF FADs Management Plan of 2015 – 2017 (DGCF 2014) include the stipulation that "the distance between FADs must not be less than 10 nmi and must not be installed in a fence-effect (i.e. in a zig-zag pattern). There is clear evidence of this regulation not being adhered to nor enforced, at least in respects of inter-FAD distance. Our data presented in Figure A3-22 shows that many of the FADs used by the vessels in enumerated trips in the four focus regions, had inter-FAD distances of ≤ 10 nmi, and a significant number at ≤ 5 nmi. We do acknowledge the difficulty in obtaining a 'snapshot' of FAD positions to do such inter-FAD distance assessments, given the mobility of FAD surface floats. Anchored tuna FADs are commonly installed in deepwater (1500 – 5000 m) locations and subject to strong currents. FAD surface floats 'swing' on the FAD lines under the influence of these currents and can change position by as much as 2 or more nmi.

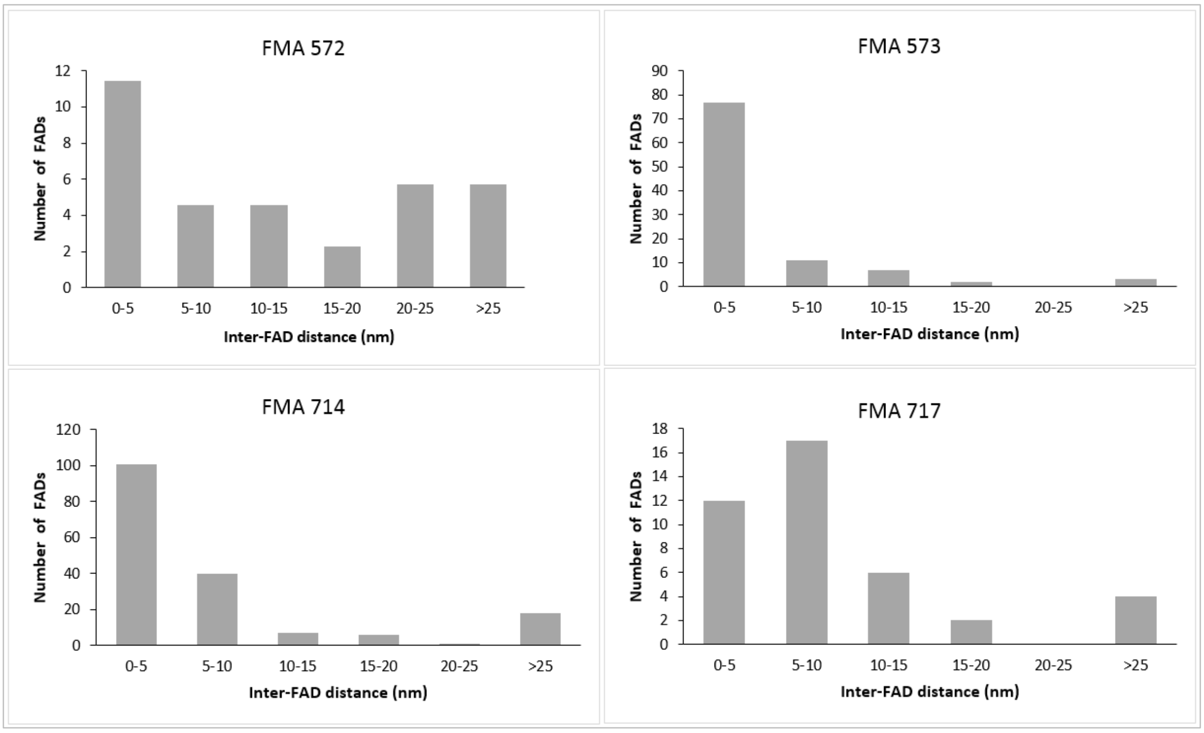


Figure A3-22 Histograms to show the frequency of inter-FAD distance (nm) for the FADs recorded by the enumeration program in each on the four Fisheries Management Areas (FMAs).

Information reported by Australia's Border Protection Command[28] (ABPC pers. comm. 2014) of hundreds of FAD sightings, detected in aerial surveillance conducted close to the Australian-Indonesian maritime border in the Timor Sea, to south of West Timor, showed that "many Indonesian FADs are arranged in grids, with regular spacing of between three and seven nautical miles apart". Similarly, the results of a detailed study of anchored tuna FADs in the Celebes and Molucca Seas by Satrioajie et al., presented to the FADs Fisheries Management Workshop in Bali in early 2017, reported a high incidence of inter-FAD

[28] *Information provided in 2014 by Australian Border Protection Command, from a confidential internal report on results of aerial surveillance in the region of the Australian - Indonesian maritime border in the Timor Sea.*

distances of <10 nmi, and “within ~ 7km (3.78 nmi) from each other” (Satrioajie et al. 2017, and in prep). Their study, which drew on positional information sourced from fishers logbooks, interviews with fishers, and direct observations of FAD positions, did acknowledge the likelihood of some level of ‘double counting’ of FADs due to the mobile nature of the FAD surface floats.

Table A3-12 provides a summary of information from several earlier studies on numbers of FADs in particular regions of Indonesian waters (within and outside the internal archipelagic waters). The majority of the estimates of FAD numbers are based on GPS position coordinates obtained directly from skippers through interview and/or from their notebooks/logbooks.

Table A3-12 Summary of FADs in various regions of Indonesian waters as reported by earlier studies. HL/TL = hand=line/troll-line, PL = pole & line, PS = purse-seine.

Region	**Approx. Lat/Long Coord. of area**	**No. of FADs** (Main users)	**Year**	**Study**	**Source of FAD positions**
W, SW, S, SE of Palabuhanratu West Java) - NE Indian Ocean	6.8 – 9.7 °S 105.0 – 107.4 °E	**112** (HL/TL from PPN Palabuhanratu)	2013	Hargiyatno et al. (2013)	Information from PSDKP Palabuhanratu and from skipper.
As above	As above	**85** (HL/TL from PPN Palabuhanratu)	2015	Nurdin (2017) – unpublished PhD thesis.	GPS coordinates from skipper.
S, SW of Prigi (East Java) - NE Indian Ocean	8.5 – 9.4 °S 110.6 – 112.0 °E	**54** (HL/TL from PPN Prigi)	2011	Nurdin et al. (2012)	GPS coordinates from skipper.
NE of Kendari (SE Sulawesi) - norther n Banda Sea	2.0 – 3.0 °S 124.0 – 127.0 °E	**83** (PS from PPS Kendari)	2015	Hargiyatno et al. (2015)	GPS coordinates from skippers.
NE, SE, S, SW of Kendari (SE Sulawesi) – Banda Sea, northern Flores Sea	2.5 – 6.0 °S 121.0 – 125.0 °E	**51** (HL/TL from PPS Kendari and PP Sodohoa)			GPS coordinates from skippers.
SE, S, NW from Ambon – Banda Sea, Arafura Sea	4.0 – 8.0 °S 125.0 – 134.0 °E	**39** (PS from PPN Ambon)			Fishing company in Ambon
N, S from Maumere – Flores Sea, Savu Sea	7.5 – 9.0 °S 122.5 – 124.0 °E	**5** (PL from Maumere)			GPS coordinates from skippers.
Molucca Sea	2.0 °N – 2.0 °S 123.0 – 128.0 °E	**673** (PL, HL/TL, PS from PPS Bitung and smaller ports)	2013 - 2015	Satrioajie et al. (2017)	GPS coordinates from skippers.
Celebes Sea	1.0 – 5.0 °N 120.0 – 126.0 °E	**289** (PL, HL/TL, PS from PPS Bitung and smaller ports)			
Ceram Sea (south of Misool Is.) and southern Halamahera Sea (north of Waigeo Is.)	0.5 °N – 2.0 °S 129.5 – 131.0 °E	**37** (PL from Sorong)	2018	WCPFC-WPEA-SM Program (2018) (A. Widodo pers. comm. Report in prep.)	Fishing company in Sorong (PT Citra Raja Ampat)

FAD positions unknown but in West Papua region.	na	**75** (Deepwater HL from Sorong)	2018		Fishing company in Sorong (UD. Jangkar Emas)

Scott and Lopez (2014), in their EU report on anchored and drifting FADs in countries worldwide, list Indonesia as having a total of 3858 anchored FADs, a number that had been reported by Natsir and Proctor (2011). Wibisono (2015) (as mentioned by PT Hatfield report 2016) referred to these 3858 FADs as being “official FADs”, suggesting they had been officially registered. The figure of 3858 was provided to Natsir by DGCF, but it was and still is unclear how that figure was derived, and whether it was a measure of officially registered FADs at that time. Based on the numbers of FADs reported by the earlier studies, and the number of regions where anchored tuna FADs are known to be used across the Indonesian archipelago, we (the authors of this FAD fisheries study) consider a total figure in the range of 5,000 – 10,000 to be ‘realistic’.

FAD ownership and operations

The various ways in which FADs are owned and operated for the fisheries based in Palabuhanratu and Kendari are reported in Section 7.2.3 (*Preliminary socio- and bio-economics surveys of FAD-based tuna fisheries at two key ports*). A following is a summary for the Indonesian tuna FADs more generally:

1. **FADs provided by local government (Province, Regency)**

   - for use by local fishers (one or more gear types);

   - all associated costs of FAD production, installation, and maintenance are borne by local government, or by fishers, or mix of both;

   - in some cases, support also provided through vessel assistance schemes;

2. **FADs owned by local fishing association or fishers ‘group’**

   - all costs of installation and maintenance borne by the association/group;

3. **FADs privately owned**

   - installed by private fishing company or vessel owner and only used by vessels of that company/owner and/or by ‘contracted’ vessels in *mitra kolaborasi*[29] arrangement;

   - sometimes use a ‘rolling system’ of vessels to guard FADs against use by other fishers/companies (i.e. a vessel using a FAD does not leave until a ‘sister’ vessel arrives to maintain a presence at the FAD);

   - installed by private fishing company for their company vessels but they also allow use by vessels of other fishers/companies;

   - FAD ‘time sharing’ by unwritten agreement e.g. HL/TL vessels can use the FADs owned and installed by PS vessel companies, but the former must depart the FAD if a PS vessel arrives;

   - ‘outside’ vessels permitted to use the FAD but must pay a fee (often % catch fee), or provide payment by acting as ‘watch-dog’ and reporting use of FADs by other

[29] Mitra kolaborasi – An arrangement also known as “nuclear estate for small stakeholders” or “small holders nucleus system” (Soepanto and Nikijuluw 1999), a system of cooperation between a commercial fishing company and small scale fishers as suppliers, pioneered by company PT Usaha Mina for small scale tuna fishers in Irian Jaya (now known as West Papua), beginning around 1985.

vessels to FAD owner (e.g. HL/TL vessels allowed to ‘anchor to’ FADs owned by PS or PL vessel companies in return for ‘watch-dog’ reporting);

- all costs of installation and maintenance are borne by owner company.

Until a few years ago, FADs provided by provincial and regency governments, to support local fishers and local fisheries, were a common occurrence. However, in recent times, the great majority of the deepwater tuna FADs, deployed in Indonesian waters, are privately owned i.e. owned by fishing companies, fishing vessel owner/operators, or by entrepreneurial persons who manufacture and install FADs as a business.

Large numbers of FADs (*payaos*) were introduced into the Indonesian EEZ in the early 1990s by Philippine purse-seine vessel operators; deployed primarily in Celebes Sea, west of the Sangihe Islands, in the area between Sangihe and Talaud Islands, and in the Maluku Sea (Naamin et al 2006). Indonesian fishing vessels were reportedly actively excluded from using these FADs and they were the cause for considerable ill feeling by Indonesian fishers towards those on the foreign vessels and their foreign fishing companies. There was a strong belief that the Philippine purse-seine activity, and the ‘walls of FADs’ installed by them, were significantly impacting on availability of tuna to the Indonesian fishers and were a major threat to the sustainability of the Indonesian fisheries (Mathews and Monintja 1996). However, these foreign owned FADs have since disappeared with the introduction of Indonesian Government strict laws in 2014 banning fishing by foreign owned vessels in Indonesian territorial waters.

References

Anon (2008) West Sumatra Tuna Tagging Project 2006 – 2007. Final Report. 27pp.

DGCF (2014) Indonesia Fish Aggregating Devices Management Plans in Western Pacific Ocean. (FADs Management Plan for 2015 – 2017). Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries. 5 pp.

Hargiyatno I T, Anggawangsa R F, and Wudianto (2013) Perikanan pancing ulur di Palabuhanratu: Kinerja teknis alat tangkap. J. Lit. Perikan. Ind. Vol.19 No. 3 September 2013, 121 – 130.

Hargiyatno I T, Anggawangsa R F, Samusamu A S, and Widodo A A (2015) Distribusi dan jarak pemasangan rumpon laut dalam, in Upaya Pengelolaan Perikanan Tuna yang Berkelanjutan (Studi Kasus di Kendari, Maumere, Ambon dan Pelabuhan Ratu) Proc. Simposium Nasional Pengelolaan Perikanan Tuna Berkelanjutan 10-11 December 2014 Bali, p 1238.

Harjono (1991) Indonesia’s experience of fish aggregating devices (FADs).

Itano, D., Fukofuka, S. and Brogan, D. (2004) The development, design, and recent status of anchored and drifting FADs in the WCPO. Submitted to the 17th Meeting of the Standing Committee on Tuna and Billfish, Majuro, Marshall Islands, 9 – 18 August 2004. SCTB17 INF-FTWG-3, 26pp.

Mathews, C.P. and Monintja, D.R. (1996) Assessment of the role of foreign and industrial tuna fishing in Indonesia’s EEZ, archipelagic and territorial waters. Report of Central Research Institute for Fisheries Research, Jakarta.

Monintja, D.R. (1993) Study on the development of rumpon as Fish Aggregating Devices. Mar. Technol. Bull. ITK, 3(3), 1 – 137.

Naamin, N., Mathews, C.P. and Monintja, D. (1996) Studies of Indonesian tuna fisheries, part 1: Interactions between coastal and offshore tuna fisheries in Manado and Bitung, North Sulawesi. FAO Fisheries. Technical Paper; Shomura, R.S; Majkowski, J; Harman, R.F; FAO Fisheries Technical Paper. No. 365. Available as: Status of Interactions of Pacific Tuna interactions of Pacific Tuna Fisheries in Proceedings of the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. Shimizu, Japan, 23-31 January, 1995. 1996. p. 282-297.

Natsir, M. and Proctor, C. (2011) An overview of FAD-based fisheries and FAD issues in Indonesian archipelagic waters. Abstract submitted (and presentation delivered) to FADs 2001 International Conference, Arue, Tahiti, 28 November – 2 December 2011.

Nurdin, E., Taurusman, A.A. and Yusfiandayani, R. (2012) Optimasi jumlah rumpon, unit armada dan musim penangkapan perikanan tuna di perairan Prigi, Jawa Timur. J. Lit. Perikan. Ind. Vol.18 No. 1 Maret 2012, 53 – 60.

Nurdin, E. (2017) . FAD as a tool of sustainable fisheries management; yellowfin tuna (*Thunnus albacares*). Unpublished PhD Thesis. Bogor Agricultural University, Bogor, West Java, Indonesia. 145pp.

Proctor C., Mahiswara, and Widodo, A. (2018) Port sampling protocol for a FAD fisheries study. Technical manual for Australian Centre for International Agricultural Research Project FIS/2009/059. 94pp.

Satrioajie, W.N., van Zwieten, P.A., de Froe, E., Siahainenia, A.J. and Rijnsdorp, A.D. (2017). Strategies of deployment of anchored FADs in the small scale tuna fisheries of North Sulawesi, Indonesia. Presentation to FADs Fisheries Management Workshop, Bali, Indonesia, 21 February 2017.

Soepanto and Nikijuluw, V.P. (1999) Fishing and resource management partnerships undertaken by PT Usaha Mina (Persero), Indonesia. Country Paper in Report of the Workshop on Smart Partnerships for Sustainability in the Fishing Industry, 26 – 28 November 1997, Penang, Malaysia. Chong, K-C. and Madhu, S.R. (eds), 99 – 106.

Scott, G.P. and Lopez, J. (2014) The use of FADs in Tuna Fisheries. EU report. IPOL-PECH_NT(2014) 514002_EN. 70 pp.

Subani, W. and Barus, H.R. (1989) Alat penangkapan ikan dan udang laut di Indonesia (Fishing gears for marine fish and shrimp in Indonesia). No. 50 Th 1988/1989. Special edition of J. Mar. Fish. Res. ISSN 0216 – 7727. 248pp.

Wibisono (2015) Summary of information on the capture of juvenile tuna in Indonesia. Factsheet by The Nature Conservancy, Indonesia Fisheries Program. 9 pp.

Widodo, A.A., Satria, F, Iskandar Prisantoso, B., Mahiswara, Sedana, I.G.B., Sadiyah, L. and Williams, P. (2013) East Indonesian Tuna Fisheries Port Sampling Protocol. 55pp.

Widodo, A.A., Wudianto, Proctor, C., Satria, F., Mahiswara, Natsir, M., Sedana, I.G.B., Hargiyatno, I.T., and Cooper, S. (2016) Characteristics of tuna fisheries associated with anchored FADs in the Indonesian Fisheries Management Areas 572 and 573 in the Indian Ocean. Submitted to the Indian Ocean Tuna Commission 18th Working Party on Tropical Tunas, Seychelles, 5 – 10 November 2016. IOTC-2016-WPTT18-29. 15pp.

Yusfiandayani, R. (2013) Fish aggregating devices in Indonesia: Past and present status on sustainable capture fisheries. Galaxea J. Coral Reef Studies 15: 260 – 268.

Yusfiandayani, R., Baskoro, M.S. and Monintja, D. (2015) Impact of fish aggregating device on sustainable capture fisheries. KnE Life Sciences, [S.I.], p. 224-237, Feb. 2015.

Appendix 4. Supplementary information for the Preliminary socio-/bio-economics surveys of FAD fisheries (summarised in Section 7.2.3)

Socio economic aspects of FAD tuna fishery in Kendari

Revenue from the fisheries are split between crew and FAD owners according to fixed rules and arrangements (see Table A4-1). First some of the catch is set aside for the crew, and the amount of this ‘free fish’ depends on the number of crew and the amount of the catch. Normally each crew will get 5 - 10 fish to eat with their families or neighbours, then 10% of the revenue is deducted as investment costs. If a vessel has utilised the FAD(s) of others, 33% of the catch must be paid to the FAD owner(s). The remainder is shared between the vessel owner, the captain and the crew, according to the shares of each individual. 2% of revenue is also set aside for certain fees which include costs associated with unloading the catches. There are variations in formulating the shares of each positions, but normally the captain receives the highest share of that received by the crew, with average share 3.64 (range from 3-4 shares), with ordinary deck hands only getting a share of 1.0. The sharing systems for each of the gear types, PS, PL, and HL/TL, are shown in Figure A4-1.

Table A4-1. Cost and share arrangements of the 3 different tuna fleets in Kendari

Shares	Unit	Purse Seine	Pole and Line	Hand line/ Troll line
Free Fish for the Crew (5-10 fish for each crew)	Kg	176.25	30.00	19.44
Before Subtracted by the cost				
Investor and investment	percentage	10%	10%	11%
After Subtracted by the cost				
Vessel Owner (True Benefit)	percentage	49%	49%	49%
Captain + Crew	percentage	49%	49%	49%
Fees (include unloading)	percentage	2%	2%	2%
FAD (if utilized other vessel or companies FAD)	percentage	33%	33%	
Shares based on the position		Average (Range)	Average (Range)	Average (Range)
Captain	Shares allocation	3.64 (3-4)	2.5 (2-3)	2.15 (2-2.5)
Engineer	Shares allocation	2.08 (1.5-2.5)	1.96 (1.5-2)	1.50
Fishing Master	Shares allocation	1.50	2.31 (2-2.5)	
Boy-boy (bait thrower)	Shares allocation		1.85 (1.5-2)	
Net Thrower	Shares allocation	1.50		
Diver	Shares allocation	1.50		
Crew	Shares allocation	1.00	1.00	1.00

Source: Interviews with vessel owners and captains in 2014 and 2015.

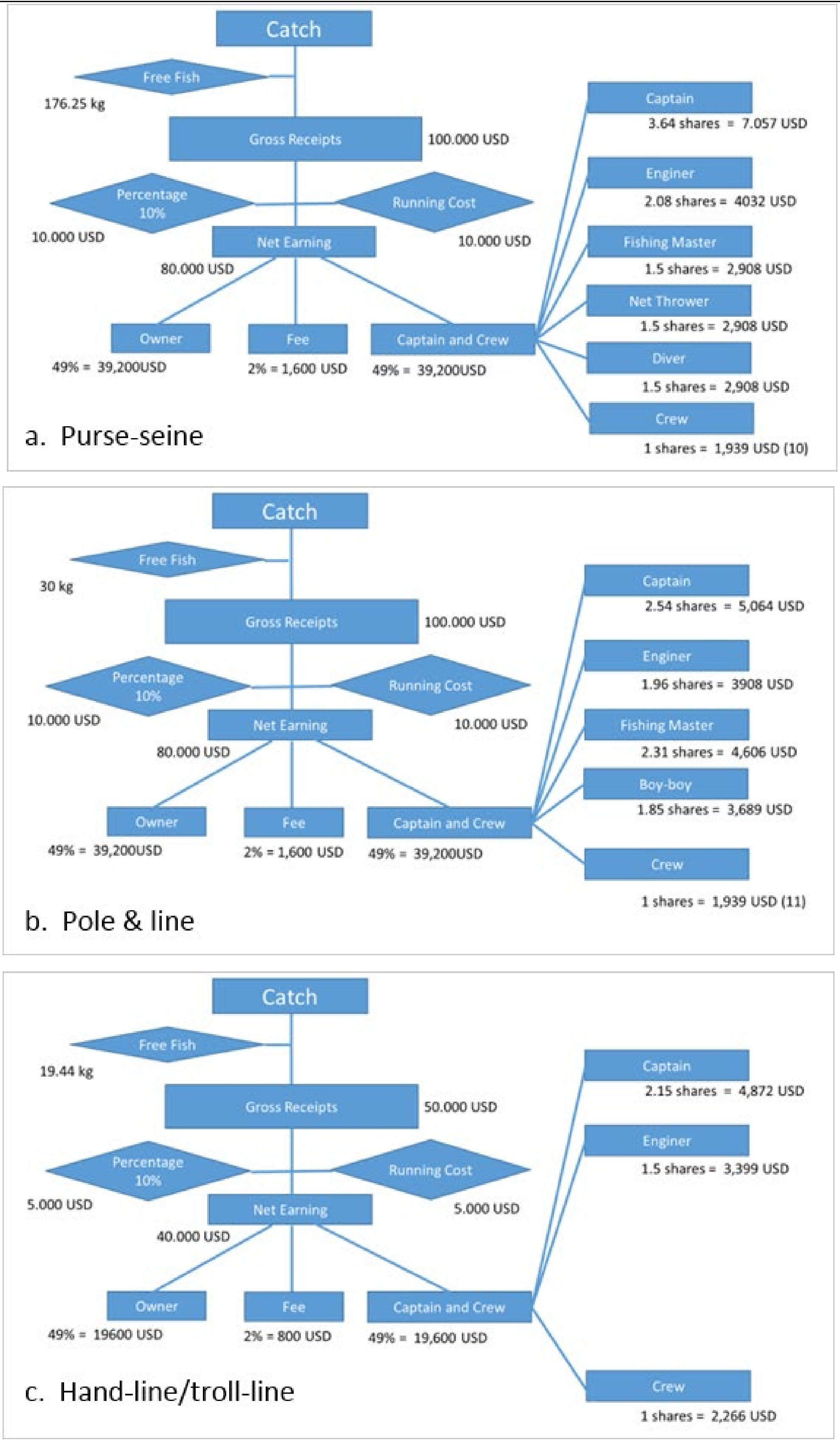


Figure A4-1. Cost sharing arrangements of (a) PS, (b) PL, and (c) HL/TL vessels in PPS Kendari.

Static equilibrium of bio economic model

Our bio-economic model for the FAD associated tuna fisheries based in Kendari was developed using the Schaefer (1957) surplus production model. The static equilibrium estimates from the bio-economic model showed that the current (i.e. 2015) exploitation level was below the MSY level, and the profit per trip for all the fishing gears was still high. Simulations were conducted to explore the effects of changes in fish price, fuel price and number of trips in a year. Result of these simulations are presented in Figure A4-2. In one scenario it was assumed that fuel increased in price by 40%, fish prices decreased by 10% and effort (fishing tips per year) decreased by 20%. In all three cases, the point representing MEY shifted to a lower level of effort and profits were reduced for all three gear types. PL vessels were most severely impacted in this scenario, as profits reduced by 34%. This can be explained by the fact that PL vessels use a large amount of fuel, far more than the other two vessel types. The average number of trips per year for the PL vessels is also less compared to the other fishing fleets, so the reduction of the number of trips per year will result in increases in their fixed costs.

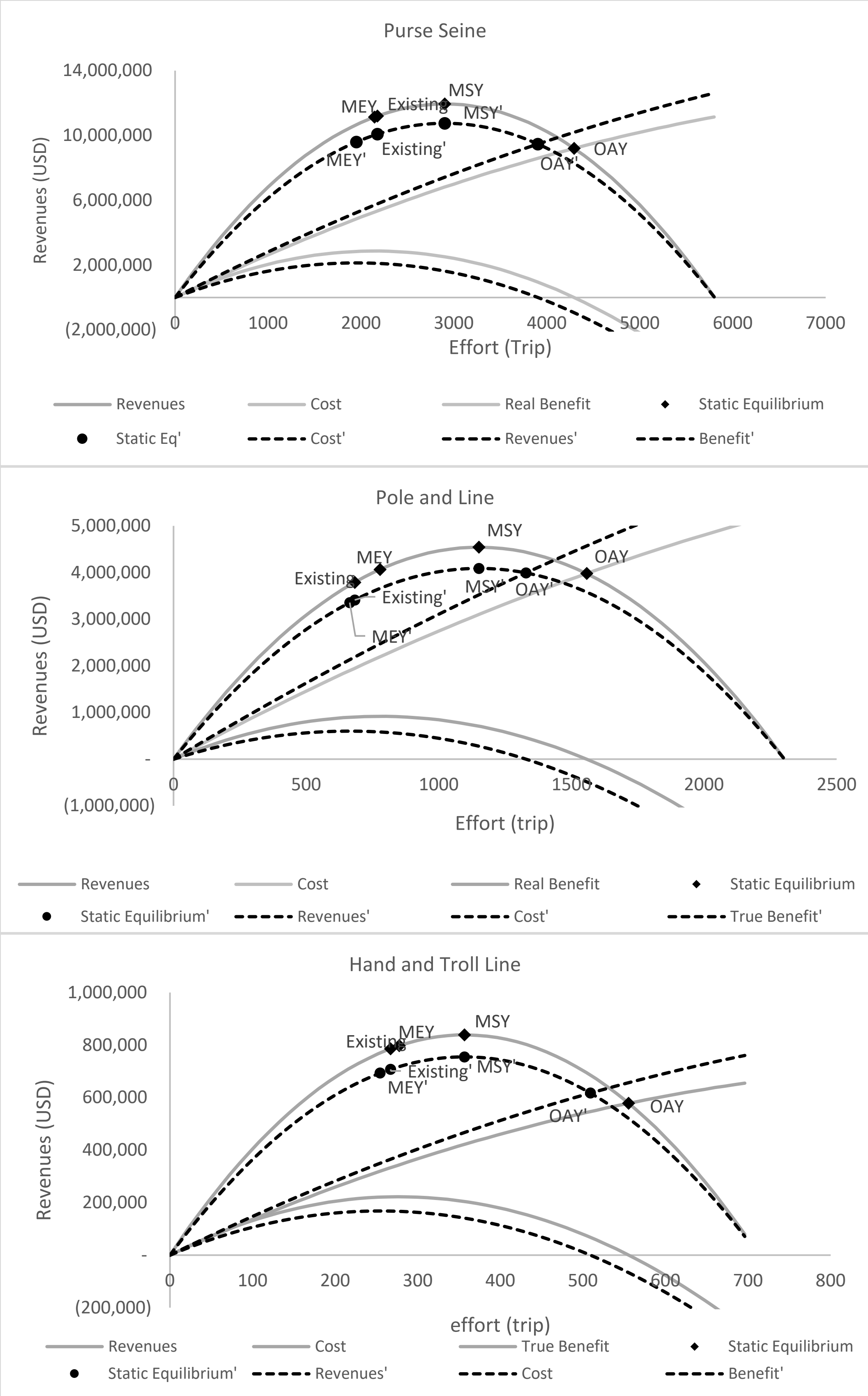


Figure A4-2. Bio-economic simulation for different scenarios for each gear type.

Appendix 5. A selection of project related photos

Photo 1: Enumerator Mr Ahmadrizal measuring juvenile tuna at Sodohoa in Kendari (SE Sulawesi).

Photo 2: Enumerators Mr Robi Hermawan and Mr Dedi Putra measuring juvenile tuna at Muara Padang (West Sumatra).

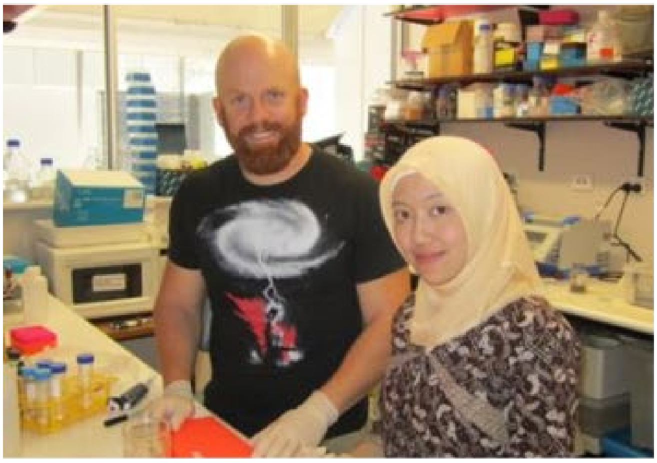
Photo 3: Prof. Wudianto (CFR) and Ms Pratiwi Lestari (RIMF) interviewing skippers of fishing vessels in Muara Padang.

Photo 4: Mr Mohamad Natsir (RIMF) with fishing vessel owner/operator Ibu Norma at Sodohoa, Kendari.

Photo 5: Stakeholders Meeting at PPN Palabhanratu for delivery of information on the project's FAD fisheries study, April 2016.

Photo 6: Enumerators Workshop, at Research Institute for Tuna Fisheries, Bali, October 2014.

Photo 7: Left - Mr Anung Widodo (CFR) in Noro (Solomon Islands) and Right - Mr Irwan Jatmiko (RITF) in Male (Maldives), doing sampling for the Population Structure Study.



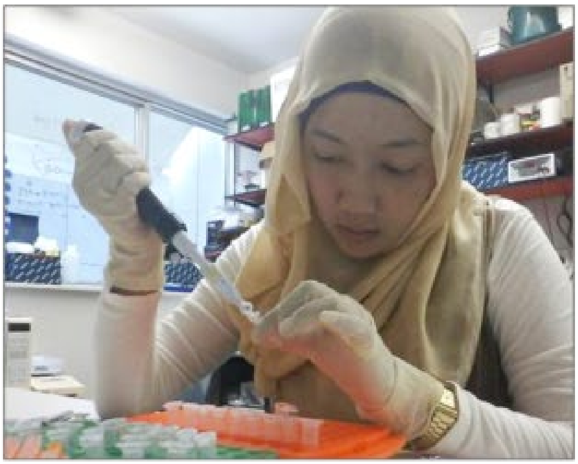


Photo 8: Ms Pratiwi Lestari (RIMF) receiving training at School of Biological Sciences, UQld. Left - with Dr Scott Cutmore, Right - processing samples for molecular characterisation of parasite species.

Photo 9: Mr Arief Wujdi (RITF) during training at CSIRO Hobart for otolith chemistry analyses, March 2015.

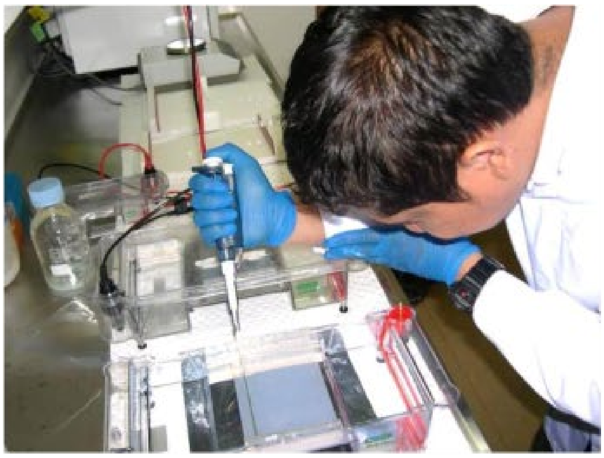


Photo 10: Mr Muhammad Taufik (RIMF) during training at CSIRO Hobart for genetics analyses, March 2015.

Photo 11: Prof. Bob Lester providing training on parasites at RIMF to scientists Mr Dimas Hedianto and Ms Pratiwi Lestari.

Photo 12: Dr Campbell Davies explaining finer points of Harvest Strategies at Technical Workshop in Bogor in April 2016.

Photo 13: Final Project Coordination Meeting at RITF in November 2016.