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Length-Based Assessment of Oceanic Tuna Fisheries in Indonesia Archipelagic Waters, Based on a Crew Operated Data Recording System (CODRS)

YKAN Technical Paper

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Executive Summary

This report presents summaries on catch composition and fleet characteristics of tuna fisheries in Indonesia's Archipelagic Waters (IAW), an area comprising Fisheries Management Areas (*Wilayah Pengelolaan Perikanan*, WPP) 713 (Makassar Strait), 714 (Banda Sea), and 715 (waters between east Sulawesi and west Papua). For yellowfin tuna (YFT, *Thunnus albacares*) and skipjack tuna (SKJ, *Katsuwonis pelamis*), this report also presents a length-based assessment based on the size composition of the total extraction (all gears combined) of these species from the IAW. Based on the results of the length-based assessment, we evaluated outcomes of various length-specific harvesting scenarios.

This report is part of the 2019-2021 Indonesia Tuna Consortium project, an initiative funded by Walton Family Foundation, which brings together various non-governmental organizations who support the Indonesia Ministry of Marine Affairs and Fisheries to develop a Harvest Scenario for tuna fisheries in the IAW. The purpose of this contribution to the Tuna Consortium project is to take a snapshot of tuna fisheries in the Indonesia Archipelagic Waters, and to illustrate how data on catch volume and length composition may be used to inform fisheries management. The primary audience for this report are researchers and managers at the Indonesia Ministry of Marine Affairs and Fisheries. We hope that this report will help the Ministry to explain the status of Indonesia's tuna fisheries to the Scientific Committee of the Western and Central Pacific Fisheries Commission.

Indonesia's tuna fisheries feature various gear types, boat sizes, and trade modalities. Even within a single gear type, handlines, variation is high: From small, multiple feathered hooks to catch small tunas at the surface to a single large hook with natural bait fished at a depth of up to 200 m to catch large tuna. Measured to global standards, the vessels of the tuna fleet operating in the IAW are mid-sized at most, and within that size bracket the IAW tuna fleet shows high variation: From canoes crewed by one or two fishers making day trips, to purse seiners of nearly 100 GT who stay out at sea for weeks at a time. Large vessels operate from Indonesia's fishing harbors (e.g., Bitung, Kendari, and Ambon), but small vessels may land their catch anywhere, often selling to small-scale traders who transport the fish to processing plants or to other traders at local hubs. The large majority of vessels, small and big, fish commercially—subsistence fishing is rare.

The diversity in gears and vessels and the dispersion of landings, poses a huge challenge for estimation of catch volume and catch composition. Selectivity varies between gears, hence size composition differs between gears. To get an estimation or the size composition of the *total* catch (all gears combined), one must not only measure catch characteristics by gear type, but also the contribution of each gear type to the total fleet. Unfortunately, data on fleet composition are not readily available, as registration and licensing of tuna fishing vessels is the responsibility of administrations at different levels: Vessels larger than 30 GT are licensed by national government, those between 10 and 30 GT by provincial government, and vessels smaller than 10 GT are only registered. Moreover, national and provincial records do not always clarify whether a fishing vessel participates in the tuna fishery or in another fishery. An assessment of the entire fishery, therefore, required a survey of the fleet and its composition (frame survey), as well as an assessment of catch volume and catch composition by gear type and vessel size.

We conducted the frame survey by enumerating all vessels that fish for tuna in the IAW. The frame survey comprised data from various sources, including direct observation

by a trained field team, official data (esp. Fishing Harbor Information Center, and fisheries surveillance posts, PPSKP) provincial fisheries agencies, data from other non-governmental organizations (esp. *Masyarakat Dan Perikanan Indonesia* and *Asosiasi Perikanan Pole & Line dan Handline Indonesia*). The catch assessment survey was conducted through the Crew-Operated Data Recording System (CODRS), which is a paperless logbook system combined with a low-cost tracking devices deployed on the vessels of fishers who participated in the CODRS program. Fishers who participated in the CODRS program agreed to take digital pictures of their catch while they are fishing at sea. In total, up to 110 vessels participated in the program. Our field technicians recruited crews for participation in the program based on representation in respect to boat size and gear. Crews received a modest fee for their participation, depending on the size of the vessel. The images from the fishers were analysed at the office by our team of field technicians.

Our frame survey found that there were close to 13,000 vessels fishing for tuna in the IAW. More than half of that number, some 6,800 boats, were "nano" handliners (i.e. vessels smaller than 5 GT). Most vessels were dedicated to tuna fishing, but 23% of the vessels were fishing seasonally, meaning that they participated in other fisheries for some part of the year.

The main tuna species caught by the fleer targeting oceanic tunas in the IAW in 2020 were yellowfin tuna *Thunnus albacares* (172,292 MT), bigeye tuna *Thunnus obesus* (8,511 MT), and skipjack tuna *Katsuwonus pelamis* (105,072 MT). Neritic tunas (*Euthyunnus affinus* and *Auxis spp*) caught by this fleet amounted to 14,820 MT, whereas catch of small pelagic scads (*Decapterus spp*), caught mainly by purse seine, amounted to 18,008 MT. Taken together, and including an "other species" group amounting to 9,945 MT, Indonesia's oceanic tuna fleet caught 328,650 MT of fish in the IAW in 2020.

Focusing on the two main species in this fishery, our study found that handline and trolling line are by far the most important gears for yellowfin tuna, and for skipjack tuna the most important gears were pole-and-line and purse seine. Handline and trolling line together caught 91% of all yellowfin tuna in terms of catch volume, but handline caught about 11 times as much as trolling line. Pole-and-line and purse seine together caught 95% of all skipjack tuna, and pole-and-line caught about 4 times as much as purse seine.

The relatively low contribution of the pole-and-line and purse seine to the yellowfin tuna catch does not mean these gears have a minor effect on the fishery. In contrast to handline and trolling line, most of the yellowfin tuna caught by pole-and-line and purse seine are small, between 15 and 35 cm fork length (FL) for purse seine, and between 20 and 50 cm FL for pole-and-line—far smaller than the size of maturity (103 cm FL). We asked ourselves whether the yellowfin tuna fishery as a whole (i.e., all gears combined) would benefit from a reduction in extraction of juvenile tuna. Ultimately, the outcome of this analysis depends on assumptions on natural mortality and growth. We found that extraction of juvenile yellowfin tuna by pole-and-line resulted in an annual loss of spawning stock biomass of 47,000 MT, whereas purse seine resulted in an annual loss of spawning stock biomass of 9,400 MT. These losses are substantial, as we estimated current spawning stock biomass at 295,000 MT.

Most skipjack tuna caught in IAW in 2020 were immature (less than 50 cm FL). This was true for all gears. The skipjack tuna catch by purse seine comprised 100% juveniles, with a median length of 28 cm FL—this corresponded to a an annual loss in spawning stock biomass of 23,000 MT. Pole-and-line catches comprised over 90% juveniles, with a median length of 36 cm FL, corresponding to an annual loss in spawning stock biomass of 80,000 MT. These losses were very high compared to the estimated current spawning stock biomass of only 100,000 MT.

Using published values on natural mortality, growth, and maturity, and combining these values with the length-frequency of the total catch (all gears combined) in 2020, we estimated current, length-dependent fishing mortality for yellowfin tuna and for skipjack tuna. Using a conventional population dynamics model based on Von Bertalanffy growth, exponential decay, and constant recruitment, we estimated current spawning stock biomass as a fraction of the spawning stock biomass in an unfished (pristine) situation ($SSB/SSB_{F=0}$). For yellowfin tuna, this value was 43%, and for skipjack tuna this value was 32%. With a generally accepted target reference value of 40%, and a limit reference value of 20%, these values indicate that there is modest scope for improvement of the yellowfin tuna fishery. In contrast, skipjack tuna is seems to be over-exploited in the IAW.

We applied aforementioned population dynamics model to assess the effect of size-specific fishing mortality reductions, where effort of all gears is reduced by 20%, 40%, and 50%. We also assessed the effect of a structured harvest scenario, which includes the following two interventions: (1) a reduction of fishing mortality by 70% of very small yellowfin tuna ("small tuna", 15-65 cm FL) and of all sizes of skipjack tuna, and (2) a reduction in fishing mortality with 10% for larger tuna. Finally, we assessed the effect of a more extreme version of the structured harvesting scenario, to evaluate whether this would result in significant gains compared to the more modest structured harvesting scenario. We evaluated these scenarios in terms of $SSB/SSB_{F=0}$ and in terms of volume and value of the fishery. Estimation of the value of the fishery was based on an off-vessel price of 1.5 US$ - 6 US$ per kg for yellowfin tuna, and 0.83 US$ - 2 US$ for skipjack tuna. For both species, bigger fish fetch higher prices.

For yellowfin tuna, across-the-board (all gear) effort reductions with 20%, 40%, and 50% resulted in a reduction of volume with up to 24%, and a reduction in value of up to 19%. In terms of volume and value, therefore, these interventions would be undesirable. Note, however, that a reduction in effort also implies a reduction in costs of fishing, and therefore these interventions would improve profitability of the sector. These interventions would also improve the status of the stock. In contrast to the modest gains from across-the-board effort reductions, a *structured* effort reduction would result in substantial gains. The total volume of the catch would slightly increase compared to 2020, and total *value* would increase with 12% or close to US$ 103 million. The increase in value was caused by a shift from a catch dominated by smaller tuna to a catch dominated by larger yellowfin tuna, resulting in a better price per kg. Under the structured scenario, $SSB/SSB_{F=0}$ would rise to 55%, very safely above the target reference point.

For skipjack tuna, across-the-board (all gears) effort reductions up to 50% would lead to catch volume reductions up to 33% compared to the baseline (2020) level, as well as a loss of value value of up to 30%, while of course costs would be reduced very significantly as well and profitability may in fact be increased. These interventions would improve status of the stock, as indicated by $SSB/SSB_{F=0}$, to 57% from a baseline (2020) level of 32%, and these improvements would be insufficient to get the stock beyond the target reference point. For SKJ, our model predicted that an effort reduction by 70% under HS4 would lead to a loss of gross revenue in the SKJ fisheries of almost US$ 79 million, which is a loss of half the gross revenue compared to the 2020 baseline scenario. These losses however would be more than compensated through increased revenue from the YFT fisheries, while profitability in both fisheries would be greatly improved. With a 70% reduction of fishing effort in the SKJ fisheries, a massive reduction in costs, carbon footprint, baitfish depletion and other undesirable impacts of overfishing would be mitigated. The net economic and fisheries conservation gains from such intervention therefore appear to be worth consideration.

We concluded that an intervention leading to size-specific adjustment of fishing mortality, i.e. a reduction in the fishing on juvenile yellowfin tuna and on all size classes of skipjack tuna, was most promising in terms of outcome of the fishery (catch volume and value) and in terms of stock status. Size-specific adjustment of fishing mortality would increase the value of both fisheries combined (yellowfin tuna and skipjack tuna) with around 24 million US$ per year in total.

Benefits of across-the-board adjustment of effort (all gears) appeared modest at best. This leaves the important question how such size-specific adjustment can be achieved, keeping in mind the differences in size selectivity between gears. We provided the following suggestion:

- Reduce fishing effort of pole-and-line with 70%, to address current growth overfishing of skipjack tuna and reduce fishing mortality of small tuna
- Disallow purse seining for small yellowfin tuna and skipjack tuna, shifting the purse seine fishery to scads and other small pelagic species
- Disallow commercial landing of juvenile yellowfin tuna by handline and trolling line gears (excepting minor amounts for use as bait or home consumption)
- Discourage use of anchored Fish Aggregating Devices (FADs) for catching juvenile tuna, instead only allow FADs for fishing deep with large hooks, targeting large yellowfin tuna.

Note that adjustment of size-specific fishing mortality would require *all* of the measures listed above. Whereas implementation of these measures will be challenging, and perhaps not even desirable for socio-economic or political reasons, one should not disregard the ecological reality that improvement of the fishery must involve a substantial adjustment one way or the other. Finally, we suggest that such adjustment is best implemented gradually to allow the sector to adjust.

1 Introduction to Tuna Fisheries in Indonesian Archipelagic Waters

This report presents summaries on catch composition and fleet characteristics of tuna fisheries in Indonesia's Archipelagic Waters (IAW), an area comprising Fisheries Management Areas (*Wilayah Pengelolaan Perikanan*, WPP) 713, 714 and 715 (Fig. 1.1). For yellowfin tuna (YFT, *Thunnus albacares*) and skipjack tuna (SKJ, *Katsuwonis pelamis*), we also present a length-based stock assessment based on the length composition of the total extraction of these species from the IAW.

Producing about 7% of the world's yellowfin tuna of 1,462,540 MT (FAO, 2018), the IAW is of global importance. Yellowfin tuna and skipjack tuna production from the IAW amounted to 103,291 and 239,039 MT respectively in 2016 according to official reports (Satria et al., 2017; MMAF, 2018b), whereas reported landings from all of Indonesia totalled 209,227 MT for yellowfin tuna, and 440,812 MT for skipjack tuna (MMAF, 2017a). This means that 43% of Indonesia's yellowfin tuna and 54% of Indonesia's skipjack tuna came from the IAW (MMAF, 2017a). The main fishing grounds in this area are located in the Molucca Sea, Seram Sea, Banda Sea, Flores Sea and Makassar Strait.

Indonesia's yellowfin tuna production is about four times higher than production of bigeye tuna *Thunnus obesus*. The other two large tuna species caught in Indonesia are albacore *Thunnus alalunga* and southern bluefin tuna *Thunnus maccoyii*, which are mostly caught in the Indian Ocean (WPP 572 and 573).

In the context of tuna management, "Indonesia Archipelagic Waters" has become a term that differentiates WPPs 713, 714, and 715 from WWPs that are part of the open oceans (i.e., 572 and 573 in the Indian Ocean, and 716 and 717 in the Pacific Ocean). Also, the IAW excludes other FMAs that are in between Indonesia's islands (571, 711, 712, and 718), even though these could be characterized as "archipelagic waters" as well. The reason for this distinction is that the latter WPPs comprise mostly shallow seas, which are not important for tuna fisheries.

Vessels operating in the IAW originate from various ports throughout the country, and may also operate in other WPPs. Larger vessels, ranging from 15 to 100 GT, commonly make trips to distant fishing grounds located 1,000 kilometers or more from port. Smaller boats around 5 to 15 GT range up to 150 km from their home base, while the smallest boats of less than 5 GT commonly range up to 50 km from their landing sites. Gear types in these fisheries include pole and line, purse seine, handline, trolling line and long line in many different sizes and varieties (Fig. 1.3- 1.7). The use of anchored Fish Aggregating Devices (aFADs) is widespread.

The relatively high production of tuna from the IAW, combined with indications for residential behaviour for yellowfin and skipjack tuna in this area ("stickiness", Natsir et al., 2012), has encouraged Indonesia to prioritize management for these two species in the IAW (Anon., 2017; Anon., 2018; Satria and Sadiyah, 2018). Within a wider international context, the IAW is part of the area managed by the Western and Central Pacific Fisheries Commission (WCPFC), which is therefore an important partner for Indonesia in planning and implementation of tuna fisheries management.

The Ministry of Fisheries and Marine Affairs (MMAF) developed a framework for harvest strategies (HS) for tropical tuna in the IAW (MMAF, 2018a) through a science-based and participatory process, which included data collection and analysis, expert consultations, workshops, and modelling in support of decision-making (Satria and Sadiyah,

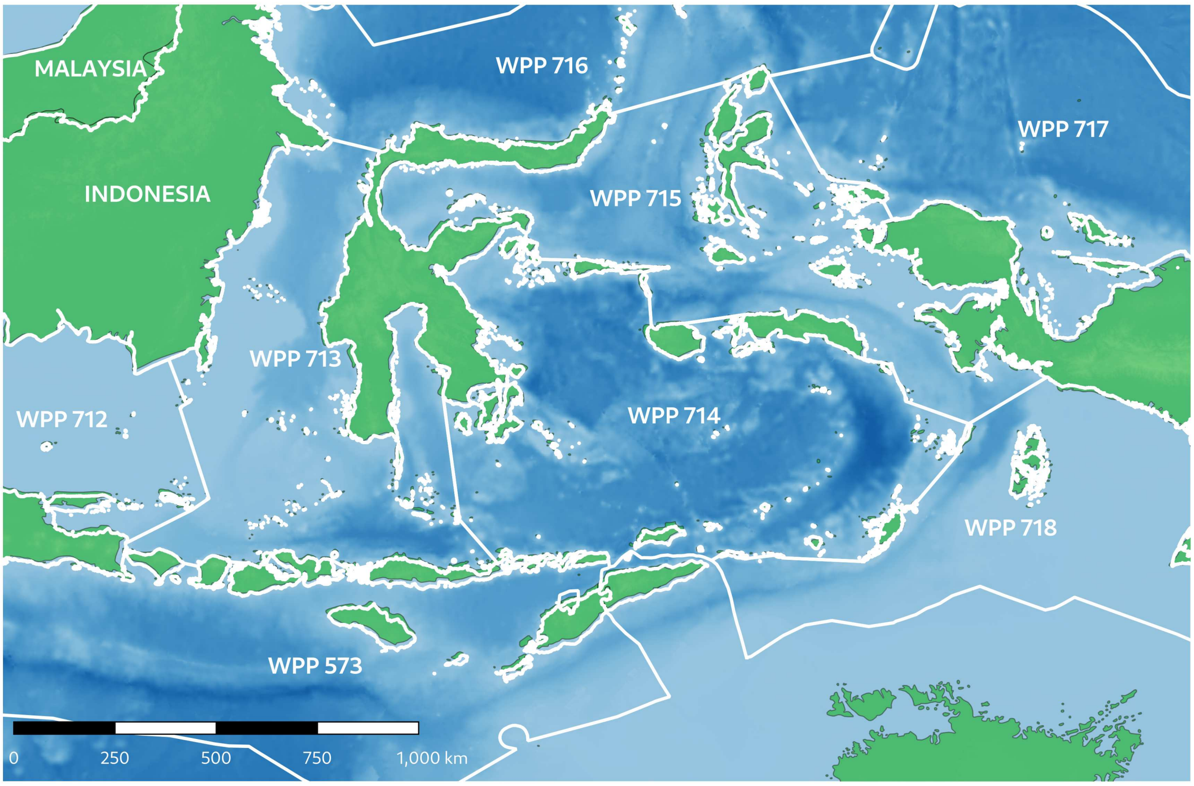


Figure 1.1: Location of the area known as Indonesia Archipelagic Waters (IAW), comprising Fisheries Management Areas (WPPs) 713, 714, and 715. Surrounding WPPs (712, 716, 717, 718, and 573) are indicated as well.

2018). MMAF has committed to continue collaboration with experts, fishers, fishing associations, industry and NGOs, to develop and implement a harvest scenario (Satria and Sadiyah, 2018). In support of the harvest scenario, the Indonesian government and CSIRO developed an operating model for evaluation of fishery management scenarios in the IAW (Anon., 2018; Hoshino et al., 2018). Implementation of the harvest scenario and parameterization of the operating model require accurate data on catch volume and on the species and size distribution of the catch. Data collection, however, presents a substantial challenge, as the IAW tuna fishery is a widely dispersed multi-gear fishery. For that reason, the Ministry invited partner organizations to contribute data on catch volume and catch composition for the tuna fisheries that they work on.

YKAN has been supporting government and industry with the development of cost-effective, scientifically sound, and scalable approaches to data collection that rely on participation by fishers. Data presented in this report is from catches of over 110 small-scale and medium-scale vessels operating in the IAW (Mous et al., 2021). We worked with the crews of these 110 fishing vessels to collect data through the Crew-Operated Data Recording System (CODRS), which is essentially an image-based logbook system operated on boats that have a tracking device (SPOT Trace) (Fig. 1.8 and 1.9).

The reason that we applied a new data collection method rather than more conventional methods (port sampling, on-board observers, pen-and-paper logbooks) relates to the characteristics of the tuna fishery in the IAW. As in many other tropical small- to medium-scale fisheries, the IAW tuna fisheries are characterized by multiple gear types and a fleet that is dispersed over remote stretches of coastline. In such situations, conventional catch- and effort-based methods suffer from problems with limited access to landing sites, species identification, gear identification, and lack of resources for implementation by qualified enumerators and observers.

Port sampling requires the presence of well-trained enumerators at the site and time of landing, which poses a logistical challenge even when vessels do land in ports instead of remote landing sites. Many fleet segments in tropical small-scale fisheries, however, land their fish in a very dispersed manner, outside the main ports, making enumeration almost impossible. Furthermore, for longer fishing trips, it is difficult to determine actual fishing grounds at the time of landing, and the enumerator can only note down the fishing grounds in general terms. Furthermore, port sampling relies on the assumption that the vessel returns to port with its entire catch. This is an over-simplification that disregards the dynamics in small-scale fisheries. Fishers often pool catches from various small boats into one fishing vessel for landing, and often parts of the catch are landed at different times and different places. It is not always transparent for the enumerator whether the landed batch of fish represents one full catch, or whether the batch comprises graded fish from various boats. In Indonesia, the standard catch and effort monitoring system, which is mostly based on port sampling, (Yamamoto,1980) has not been successful in capturing data with sufficient resolution for accurate stock assessment in small- to medium-scale fisheries (Dudley and Harris, 1987).

Observer programs can only be implemented on larger vessels, they are expensive, require substantial technical expertise, and can be unsafe due to bad working conditions. The logistics of getting an observer on board a fishing vessel that plans to depart is sometimes prohibitively complex. It is likely that these logistical challenges made observer programs more vulnerable to disruptions caused by the covid-19 pandemic compared to other data collection methods. Some observer programs were put on hold (Blaha 2021, FAO 2021), and consequently some authorities and organizations waived observer requirements (e.g., Rauch 2020). In the Western Central Pacific East Asia (WPEA) project “Improved Tuna Monitoring”, the observer program was more severely affected compared to other monitoring methods (McDonald & Williams 2021). In contrast, fishing itself continued, and it follows that approaches where fishers independently collect data are less affected than methods that require more intensive support. NOAA researchers note that the covid-19 pandemic provides some justification to rely more on fishery-dependent research (as opposed to fishery-independent surveys) in the future (Link et al., 2021). As we will show in this report, covid-19 did not interrupt data collection with CODRS, it only caused delays in transmitting the data from the fishers to the database.

It is our experience that pen-and-paper logbooks are unsuitable for small to medium-scale fisheries in developing countries, even though boats that must have a fishing license (SIPI) are required by law to submit logbooks (see Ministerial Regulation 48 of 2014). Partly, this is because events and practices at sea cannot always easily be transcribed to the tabular format of most logbooks. For example, the fisher may find it difficult to fill in a fishing position if he fished multiple locations. The level of education varies between fishers, and whereas some fishers are quite capable to fill in logbook forms, others may find this difficult. Getting precise information on species composition from pen-and-paper logbooks is almost impossible, since fishers use local names which vary widely throughout the Indonesia archipelago. Finally, a fisher has little to gain from filling in the logbook accurately, and convenience often trumps accuracy. In some areas where official quality control is weak, logbooks have become a purely administrative requirement that is completed by an agent together with the rest of the ship’s paperwork. It is ironic that some fishers keep very accurate records of their fishing positions and their catch for their own purposes (Fig. 1.2), but of course they do so in a format of their own choosing, and they do not necessarily intend to share this information.

Figure 1.2: Notebook of a snapper fisher in Java (Karang Serang, February 2018), showing fishing positions (blurred by the authors of this report). Picture by Rani Ekawaty.

For port sampling, observer programs, and pen-and-paper logbooks, species identification remains a major problem. This is partly due to insufficient training, but also due to the fact that observations, once noted down on paper, cannot be verified. Even observers who have participated in a species identification training still mis-identified about 50% of 26 species common in the tuna fishery (MMAF, unpublished training report).

For the reasons explained above, and noting that fishers tended to communicate with each other and with project staff through images sent by messaging applications (esp. Whatsapp), we decided to develop an image-based logbook system that we now refer to as the Crew-Operated Data Recording System (CODRS).

This report presents catch composition information on various species and species groups in 2020, based on data collected through the CODRS program, combined with a survey of boats that are active in the tuna fishery in the IAW. The resulting length-frequency distributions are balanced according to the number of active fishing vessels for each fleet segment, meaning that these length-frequency distributions provide an impression of the total extraction from the IAW. Based on these balanced length-frequency distributions, this report presents length-based stock assessments for yellowfin and skipjack tuna for that same year.

In addition, we present findings from a population dynamics model that was initially developed for yellowfin tuna in the IAW (Pet et al., 2019), and which is now also adjusted and applied for skipjack tuna in the same region. The model is based on parameters obtained from length-based stock assessments of yellowfin and skipjack tuna and it serves two purposes. Firstly, we used the model to highlight some of the most important uncertainties around model input parameter values. Secondly, we used the model to explore ways forward for management of the IAW tuna fisheries. Results from modelling of yellowfin and skipjack tuna fisheries in the IAW must always be combined, as skipjack tuna fisheries feature a substantial bycatch of juvenile yellowfin tuna (Baily et al. 2013, Itano 2005, and this report). The exploratory management measures evaluated through the population dynamics model presented in this report may be useful to guide more comprehensive evaluation of harvest strategies with the operating model (Anon., 2018; Hoshino et al., 2018).

Figure 1.3: Pole-and-line fishing gear. The hooks are not baited, but this fishery still relies on baitfish. Fishers toss baitfish over the side of the vessel, and together with water squirted from the boat this simulates a feeding frenzy, with tuna eager to strike the feathered hooks.

Figure 1.4: Purse seine, typical for IAW. Most of the purse seines used in Indonesia are small, only a fraction of the size of those deployed from industrial purse seiners operating on the high seas.

Figure 1.5: Handlines used for vertical fishing, lowering the bait to depths up to 100 m.

Figure 1.6: Trolling gear. The fishers tow the bait behind a moving vessel, keeping the bait close to, or even at, the surface. Sometimes, fishers use a kite to “play” the bait at the surface.

Figure 1.7: Typical long line gear used in Indonesia’s Archipelagic Waters (IAW).

Figure 1.8: Large yellowfin tuna photographed by fishing crew on board as part of CODRS.

Figure 1.9: Skipjack tuna (top two fish) and small (juvnenile) yellowfin tuna (bottom two fish) photographed by fishing crew who participate in CODRS.

2 Methods

2.1 Data collection on tuna catch, fleet size, fishing grounds and effort

This study focuses on the Indonesian Archipelagic Waters (IAW), including Fisheries Management Areas (FMAs) 713, 714 and 715 (Satria and Sadiyah, 2017; Satria and Sadiyah, 2018; Hoshino et al., 2020), in an ecosystem-based approach that addresses all fleet segments operating in this archipelagic, deep-water ecosystem, regardless of home base of vessels. A major challenge with understanding any fishery in Indonesia is that there is no comprehensive database of all fishing vessels that target a specific group of species. Only recently, the Ministry of Marine Affairs and Fisheries developed the Database of Indonesian Vessels Authorized to Fish for Tuna (DIVA-TUNA), which takes its data from licensing databases. The fishing licensing databases, which are maintained by national and provincial agencies, are not consolidated at the national level however, and the records in these databases do not identify which group of species each vessel targets. Moreover, a large part of Indonesia's tuna fleet is smaller than 10 GT, and these vessels are not subject to the licensing system at all. As there were no complete data available on the fleet targeting tuna in the IAW, we conducted a frame survey over the years 2018-2020, bringing together data on active tuna vessels from:

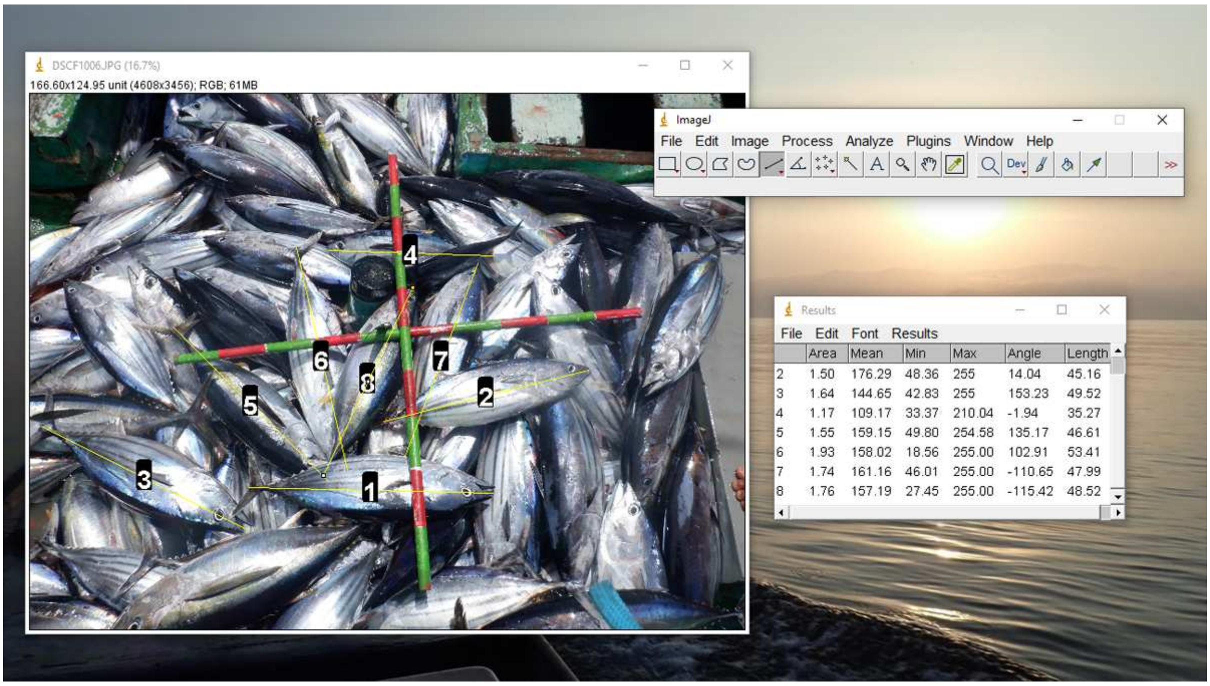
- Reports and websites.
- Satellite images from Google Earth and Google Maps to identify concentrations of fishing vessels, followed by ground truthing to confirm activity in the tuna fisheries.
- Reports on fleet size and structure from fishing harbors (e.g., at the website of the Fishing Harbor Information Center *Pusat Informasi Pelabuhan Perikanan*).
- Records of departures and arrivals of fishing vessels provided by governmental fisheries surveillance posts at fisheries harbors *Pangkalan Pengawasan Sumberdaya Kelautan dan Perikanan* (Pangkalan PSDKP). Even though these records may not cover all trips, they do give an accurate overview of the number of vessels active throughout the year at these ports.
- Verbal information from officials, academics, fishers, fish traders, sharing their knowledge on the fisheries situation in specific areas.
- Data from partner organizations who conduct sustainable fisheries programs in the IAW (NB: *Masyarakat Dan Perikanan Indonesia*, and *Yayasan IPNLF Indonesia*).
- Direct observations and broad verification of all information by our field technicians.

We cross-checked all information and filled in remaining gaps to develop a complete and detailed data base on the fleet as active in the IAW tuna fisheries in 2020. For each vessel we recorded boat size, gear type, estimated effort allocation inside versus outside the IAW, port of registration, home district (*Kabupaten*), allowed FMAs (according to license), boat name, and contact details. For smaller vessels (less than 5 GT), boats numbers were often counted in groups with similar characteristics (size, gear, etc.), leaving blank the attributes that are meaningful only for single boats (e.g. name of the boat). Following practices by fisheries managers in Indonesia, we distinguished 4 boat size categories: “nano” (<5 GT), “small” (5-<10 GT), “medium” (10-30 GT), and “large” (>30 GT). We distinguished 5 major gear types including pole-and-line, purse seine, handline, trolling line, and long line. Each of these gears come in many different sizes and varieties, which we analyzed separately. Within the tuna fleet we differentiated between dedicated and seasonally active fishing boats, to improve the accuracy of catch calculations.

We collected data on catch composition and fishing practices through collaboration with the crews of 110 fishing vessels participating in our CODRS (Crew-Operated Data Recording System) program, which remained active throughout 2020 (longitudinal survey). We used information on allowed FMAs to plan selection of vessels participating in the CODRS program, aiming to get adequate representation for each boat size - gear combination operating in the IAW. We summarized fleet information by registration port and home district, while we determined actual fishing grounds and fishing activity by placing SPOT Trace units on all fishing boats participating in the CODRS program. Each of the participating boats contributed data on spatial and temporal behavior from the tracking devices onboard, while the crews of the vessels collected catch information by taking pictures of the fish. We selected the 110 crews with a goal to represent all the major fleet segments (boat size - gear combinations) in the fleet. The CODRS approach is similar to logbooks as it relies on collaboration by the crew of the fishing vessel. We originally developed this method for the Indonesia snapper fishery (Dimarchopoulou et al., 2021, Wibisono et al., 2022), and we adjusted part of the data collection process to high catch volumes that are common in some of the fleet segments in the tuna fisheries.

We recruited crews for the CODRS program in all areas from where fleets are operating into the IAW, across the full range of boat size and gear type categories (fleet segments) in the fleet, aiming to involve at least one and where possible multiple vessels within the same segment. We provided captains with a digital camera, a fish measuring board and length reference sticks, and a SPOT Trace unit for tracking. As participation in the CODRS program requires the crew to do additional work, we provided crews with compensation varying between US$1000 and US$2,250 per year, depending on the size of the boat. We then trained captains or some of their crew in properly photographing their catch, and how to operate the SPOT Trace units, which were set to transmit positions every hour. Whereas SPOT Trace can accommodate higher transmission frequency, this drains the battery, and we found that a transmission frequency of one hour is an acceptable compromise between spatial resolution and power drain. SPOT Trace stops reporting positions when the vessel is stationary, and if the crew switch off the device it generates a “power-off” message with the last-known position. Data recording for each CODRS fishing trip begins when the boat leaves port, with the GPS recording the vessel track while it is steaming out. After reaching the fishing grounds, fishing will start, changing the track of recorded positions into a pattern that shows fishing instead of steaming. We used these tracks and fishing patterns to assign an FMA to each fishing trip and catch.

On vessels that typically catch only a limited number of fish on each fishing day, the crew photographed each fish caught with a measuring board in the background, usually before storing the fish on ice. To further record details on the gear, the crew also included in the frame the bait that they used, or they included a sign that identifies the gear type with which they caught each fish. On pole-and-line and purse seine vessels, which are characterized by large catches of small fish, we asked crew to take pictures of unsorted batches of fish, directly after capture, with length reference sticks put on top at a square angle (Figure 2.1). This means that the images still give information on the length composition, but not on the total catch. We asked captains to include a picture of their sales receipts to record the weight of the total catch, and of receipts of any supplies they bought for the trip, to record expenses. If the captains did not have a sales receipt, we asked them to note down their total catch (weight of all species combined, in kg) on a piece of paper, and to take a picture of that note. At the end of each fishing trip, which varies from a single day for small boats up to several weeks for the largest vessels, captains handed the memory cards containing the photographs of their catch and receipts and other notes to the technicians on shore. Images could then be analyzed by technicians in the lab, to generate species-specific length frequency distributions of the catches.



	Area	Mean	Min	Max	Angle	Length
2	1.50	176.29	48.36	255	14.04	45.16
3	1.64	144.65	42.83	255	153.23	49.52
4	1.17	109.17	33.37	210.04	-1.94	35.27
5	1.55	159.15	49.80	254.58	135.17	46.61
6	1.93	158.02	18.56	255.00	102.91	53.41
7	1.74	161.16	46.01	255.00	-110.65	47.99
8	1.76	157.19	27.45	255.00	-115.42	48.52

Figure 2.1: Mixed Small Yellowfin and Skipjack Tuna from Pole and Line measured using ImageJ.

For each fishing event during the trip, we also asked fishers to take a picture of the prevailing situation during fishing. These "situations" depend on the type of gear and on the conditions under which actual catching took place. For handline, troll line, and pole-and-line, we asked the crews to take a picture of the FAD if they were fishing on or near a FAD (or any other floating object), and we asked them to take a picture of the pod of dolphins or the flock of sea birds if they were fishing on a free-swimming, surface-feeding school of tuna. For purse seine, we asked the fishers to take a picture of the FAD if they were fishing near a FAD, and if they were not fishing near a FAD we asked them to just take a picture of the setting. We asked long liner vessels to take a picture of the longline (i.e., the basket with the hooks) before setting. These pictures helped our technicians to interpret the images of the catch, while the time stamps of these images indicated when fishing actually took place. Based on the quality of the images, technicians provided feedback to the fishers to improve data quality on subsequent trips. Sets of images from fishing trips with unacceptable low-quality photographs, or sets that only represent a very small part of a multi-day fishing trip were not further processed or included in the dataset.

Technicians identified the species and fork length of each fish displayed on measuring boards from the images, or used ImageJ software and the reference sticks in the images of pole-and-line and purse seine catches to obtain size frequencies by species from those catches. Length measurement was done as Fork Length (FL), to the nearest cm. For hand line, troll line, longline, and gillnet, where images usually featured only one or a few fish on a measuring board, the technicians measured all fish on-screen. For purse seiners and pole-and-liners, where each image usually featured a spread of unsorted fish with length reference sticks put on top of the fish, technicians measured all fish in the frame that showed from head to tail, and that were not covered by other fish, irrespective of species. In that way, technicians measured up to 15 fish in each image, aiming to measure a total of at least 500 fish from each trip. Field technician uploaded data to an online data management portal for quality control by senior technicians who reviewed the species identification and length measurement data for accuracy, before adding each submission to the database.

To estimate body weight (kg) from length measurements of individual fish, we obtained species-specific allometric length-weight relationships from the literature. In this way, we obtained the combined weight of all fish that were measured. For hand line, troll line, gillnet, and longline, where fishers could take images of each fish caught, we compared the total weight of all fish measured to the total weight on the receipts. If the total weight of all measured fish was more than 90% of the weight that the captain declared on the receipt, we labelled data from that trip as "complete". If the total weight of all fish measured for the entire trip was lower than 90% of the total weight of catch reported by the captain on the receipts, but higher than 30%, we labelled the data as "incomplete". If the estimated weight of all measured fish was lower than 30% of the total catch weight according to the receipt, we labelled the data from that trip as "bias".

Trips with "incomplete" and even "bias" data were common, since it was not always possible to get pictures during each fishing day, for example because of bad weather. For this report, we only used data from trips that were "complete" or "incomplete", and we excluded data from trips that were labelled as "bias". For purse seiners and pole-and-liners, we used the weight of the total catch from the receipts to calculate a sub-sample factor. We used that sub-sample factor to raise the measured length-frequency distribution in the sub-sample to a length-frequency distribution that represents the total catch of that trip. Since crews could only take pictures of part of the catch, it was not meaningful to label catches as "complete", "incomplete" or "bias". This means that for purse seiners and pole-and-liners we exclusively relied on the receipts to get estimates for the total catch of that trip.

We calculated Catch-per-Unit-Effort (CpUE) as catch volume (kg) per size unit of the vessel (GT) per active fishing day (in kg/GT/day), using only those days from the trip when images were actually collected, from either "complete" or "incomplete" trips. Medium size and large vessels (10 GT and larger) make longer trips, and there may be some days on which weather or other conditions are such that images cannot be collected. Usually, however, a sufficient number of days with images remain to allow for CpUE estimation. For boats of 10 GT and above, catch data from trips labelled as "incomplete" (i.e., images represent 30% to 90% of the catch on the receipt) were still used for analysis, using only those days on which all necessary images were collected. For boats below 10 GT (doing day trips or trips of just a few days) only catch data from trips labelled as "complete" were used for CpUE calculations.

Active tuna fishing dates were defined as days when vessels were operating in waters off the continental shelf (where water depths exceed 200 meters), with vessel speeds below 5 km/hr to filter out steaming to and from fishing grounds, as well as anchoring in shallow waters. Data on vessel positions and speeds were collected by SPOT Trace for each segment of the fleet, except for a few segments for which no CODRS contracts were active. For non-CODRS fleet segments we estimated the number of active fishing days from the average of all CODRS boats in the same size class and we estimated the CpUE from the nearest size class within the same gear type category and for the same species of fish. We estimated total annual catch for each fleet segment from (a) the CpUE per species in the fleet segment, multiplied with (b) the total capacity of the fleet in the fleet segment (in GT), and (c) the annual number of active fishing days in the fleet segment. For vessels which were not full time dedicated to fishing for oceanic tunas inside the IAW, we corrected with spatial and temporal effort allocation information representing seasonality of tuna fishing and allocation of effort inside or outside the IAW.

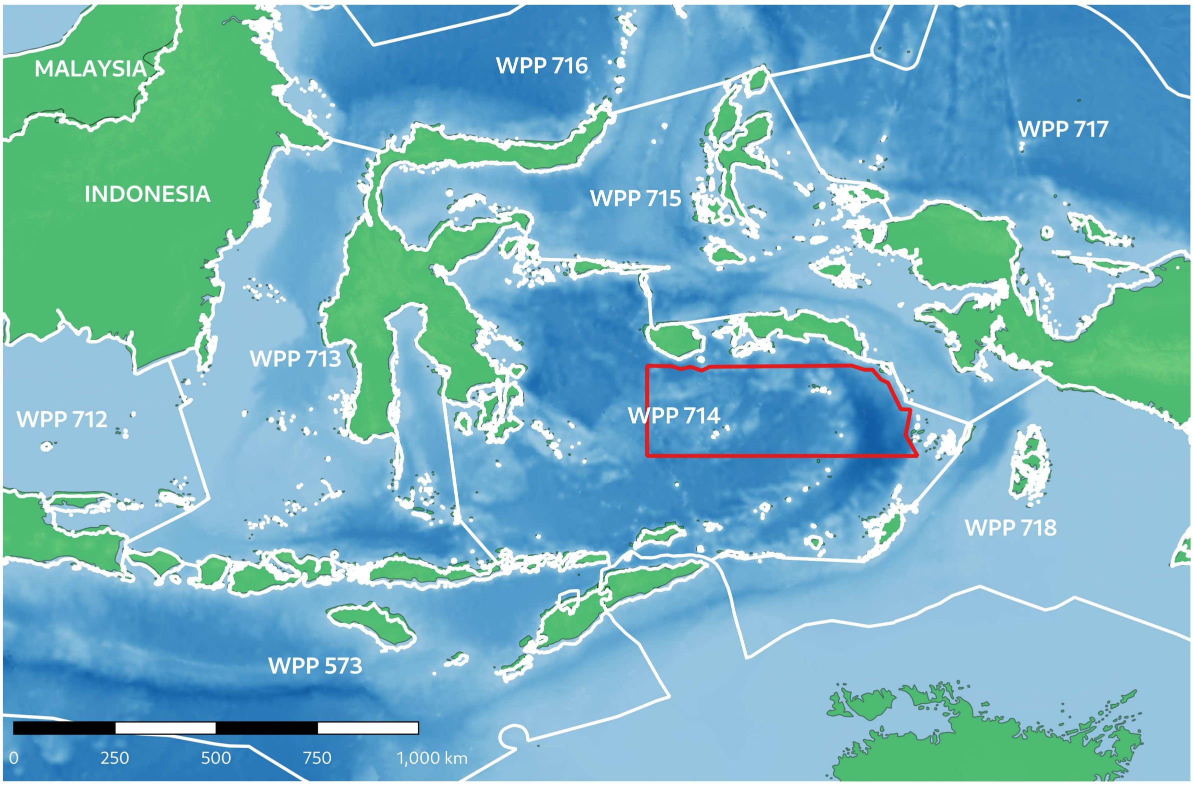


Figure 2.2: Location of the Banda Sea seasonal closure (red outline) in WPP 714 of the Indonesia Archipelagic Waters (IAW). According to Ministerial regulation (PERMEN-KP) 26 of 2020, the closure only pertains to yellowfin tuna *Thunnus albacares* for the period October-December.

Fishing grounds by fishing gear were indicated by plotting the positions reported by the SPOT Trace units for the year 2020. These positions include tracks (steaming) as well as actual fishing positions. Since SPOT Trace only reports one position if the vessel is stationary (or nearly stationary) over a time period longer than one hour, the resulting map with recorded positions is not completely representative of fishing grounds. On the other hand, during steaming, SPOT Trace reports an hourly position, so to some extent these tracks obscure fishing positions. For each fleet segment we estimated the relative activity (percentage of effort) applied inside and outside the IAW. This information was then used when total effort and catches were calculated strictly for IAW waters. To get a rough indication of the level of compliance with a seasonal closure for yellowfin tuna fishing in the Banda Sea (Figure 2.2), see Regulation of the Minister of Marine Affairs and Fisheries (PERMEN-KP 26 of 2020), we filtered out the fishing positions for the closed period (October-December), and we assessed by eye whether there was any indication that fishers participating in the CODRS program avoided the closed area during those months.

2.2 Estimating life-history parameters, fishing mortality, and SPR

Our length-based assessments for yellowfin and skipjack tuna are based on the essential length-based life-history parameters; instantaneous rate of growth (K), asymptotic length (Linf), length at maturity (Lmat), optimum harvest length (Lopt), and length-dependent instantaneous rate of natural mortality (M). Lmax is the maximum length a species can attain in the local population, whereas Linf is the mean length of the fish in the cohort at infinite age. Lmat is the smallest length at which 50% of the fish in a cohort are sexually mature. The optimum harvest size (Lopt) can be determined for each species as the length class with the highest biomass in an un-fished population (Beverton, 1992). Natural mortality (M) is the share of the cohort in each size class that dies and exits the population (per unit of time) due to natural causes, like predation, disease, starvation, or exhaustion from spawning. Fishing mortality (F) is the share of the cohort in each size class that is removed by fishing. Total mortality (Z) by size class follows from addition of natural and fishing mortality.

Growth parameters for various species of tuna have been estimated in many studies, by using length at age data to fit the Von Bertalanffy growth equation (Sparre and Venema, 1992) with growth parameters Linf, K and t_0, with t_0 the hypothetical age at size 0 cm, where the fitted curve cuts the age axis. In the present study we used the best available information on length at age to fit growth curves and estimate von Bertalanffy growth parameter values for yellowfin (YFT) and skipjack tuna (SKJ). To verify our estimate for Linf, we estimated the Lmax by species from Linf based on a known life history invariant, or relationships between Linf and Lmax (Nadon and Ault, 2016). For many families of fish combined, the life history variant Lmax/Linf was shown to equal roughly 0.9 so an estimate for Lmax could be calculated from the Linf we obtained after fitting growth curves to length at age information. This Lmax could then be compared with available literature to see if a reasonable estimate was indeed obtained. Estimates for Lmat were obtained from the literature and recent studies show a high degree of consensus on values for Lmat in YFT and SKJ. Biological studies on maturation have been shown to be more robust than studies on Linf (Brown-Peterson et al., 2011).

For natural mortality (M), we used the length-dependent estimates in Hampton (2000), which is the most widely referenced study on this topic for yellowfin and skipjack tuna. Natural mortality (M) is one of the most influential quantities in fisheries stock assessment and the calculation of management advice. Hampton (2000) points out that estimates of M are critical to stock assessments, specifically in relation to the issue of harvesting juvenile tuna. He notes: "*The higher M estimates for the small tuna would considerably dampen the estimated impacts of small tuna catches on fisheries targeting larger tuna*". It is clear that over-estimating M for pre-mature tuna would lead to under-estimating the impact of harvesting small tuna. And over-estimating M would under-estimate the potential gains for fisheries targeting large YFT from harvest scenarios that reduce fisheries mortality among juvenile YFT. Unfortunately, M is notoriously difficult to estimate from standard fisheries data (Maunder and Aires-da-Silva, 2012), but tagging studies as in Hampton (2000) represent a solid approach and have resulted in estimates that we will apply in the present study.

In data-poor fisheries, length-based assessment methods are a viable way to determine fishery status and pre-set management benchmarks (e.g. Sparre and Venema, 1992; Froese and Binohlan, 2000; Froese, 2004; Prince et al., 2014; Hordyk et al., 2015). Length-based assessments assume that the size distribution of fish populations can be deduced from the size distribution of the catch. This means that gear selectivity must be known, at least for part of the size range, or that the resulting fishing mortality (F), which is a combination of selectivity and effort, can be deducted in an iterative process on the basis of known catch size frequency distributions. In our standard population dynamics model we estimated an overall size dependent fishing mortality by species, directly in such iterative process. We have not attempted to separately reconstruct selectivity curves for each type of gear. We determined F by size class through iteration, selecting the size dependent values that resulted in the best fit of the modelled versus recorded catch size frequencies. Our model and iterative process for estimation of F by size class was implemented in a spreadsheet, and the fit was assessed by eye. For estimation of the optimum harvest size (Lopt), we used the same model to find the length at which the cohort biomass reaches its maximum. Lopt follows from Linf and M/K (natural mortality over growth rate) in the Beverton (1992) estimator, Lopt = Linf * 3/(3+(M/K)), with the size dependent natural mortality at Lopt as the value for M.

As an indicator for Spawning Potential Ratio (SPR, Quinn and Deriso, 1999), we used the estimated Spawning Stock Biomass (SSB) as a fraction of the spawning stock biomass of that population if it would have been pristine (Meester et al 2001), i.e., unfished (F=0). We estimated SPR in our model as the ratio between the modelled mature population biomass at estimated F and the modelled mature population biomass at F=0. Froese et al. (2016) considered a total population biomass B of half the pristine population biomass $B_{F=0}$ to be the desired reference point for stock size. The Froese et al. (2016) target reference point correlates with an SPR ($SSB/SSB_{F=0}$) of about 40%, not far from the reference point recommended by Wallace and Fletcher (2001). Therefore, we chose an SPR of 40% as a Target Reference Point for low risk. As a Limit Reference Point, i.e., the SPR below which the population is at high risk of unrecoverable deterioration, we selected an SPR of 20%. This value aligns with other studies on tuna (Hoshino et al., 2018;, Preece et al., 2011), and with the interim harvest scenario for tuna in Indonesian waters (MMAF, 2018a). We consider an SPR between 20% and 40% to represent a medium risk situation in tuna fisheries.

2.3 Modelling yellowfin and skipjack tuna fisheries in IAW

The model we used for simulating IAW YFT and SKJ fisheries is a straightforward population dynamics model that assumes equilibrium of the stock and the fishery. Under the equilibrium assumption, with constant annual recruitment, constant (but size dependent) rates of natural and fishing mortality, and constant growth, the production from one single cohort over its lifespan equals production from the entire population in a single year (Beverton and Holt, 1957). The population at any point in time is composed of all surviving fish from all cohorts, each at their specific age. Assuming equilibrium, we simulate population dynamics and fisheries production for a single year by simulating the dynamics in a single cohort over its lifespan (Gulland, 1983). Recruitment of YFT and SKJ in the Western Central Pacific Ocean (WCPO) is variable and influenced by environment conditions, but has remained relatively constant on average over a wide range of spawning stock biomass levels (e.g. Langley et al., 2009). We have therefore not included a stock-recruitment relationship in our model, and we assumed constant recruitment.

For our model, we assume a “closed system” in the IAW (Figure 2.3), comprising FMAs 713, 714, and 715, with all recruits originating from and remaining inside the region, without any inflow into this region from elsewhere. Our study was designed to support the Indonesia Ministry of Marine Affairs and Fisheries in their efforts to develop a Harvest Scenario for tuna fisheries in the IAW specifically (Satria and Sadiyah, 2017; Satria and Sadiyah, 2018). Most recently, Hoshino et al. (2020) also worked with the IAW as a unit for assessment and to develop empirical harvest strategies for oceanic tunas. In our model, we therefore disregard potential connectivity between the IAW, WPP 716, and WPP 717 and the implicit assumption is that exchange of biomass is negligible or that any emigration from the IAW is roughly balanced by immigration into the area. This is a simplification of the reality of course, but in fact WCPFC Region 7, which includes the IAW, is known for relatively low exchange flows with surrounding regions (Tremblay-Boyer et al., 2017). The IAW are assumed to hold specifically “sticky tuna” (Itano, pers. comm.), while some net in-flow may be occurring from directly neighboring regions (1 and 8) in the Western Pacific (e.g. Tremblay-Boyer et al., 2017). Recent findings from DNA research also suggest limited mixing among neighboring regions around the Philippines and the Bismarck Sea (Aguila et al., 2015). Information on movements between the Indian Ocean and IAW is scarce, but potential corridors are relatively narrow between the Banda and Savu Seas.

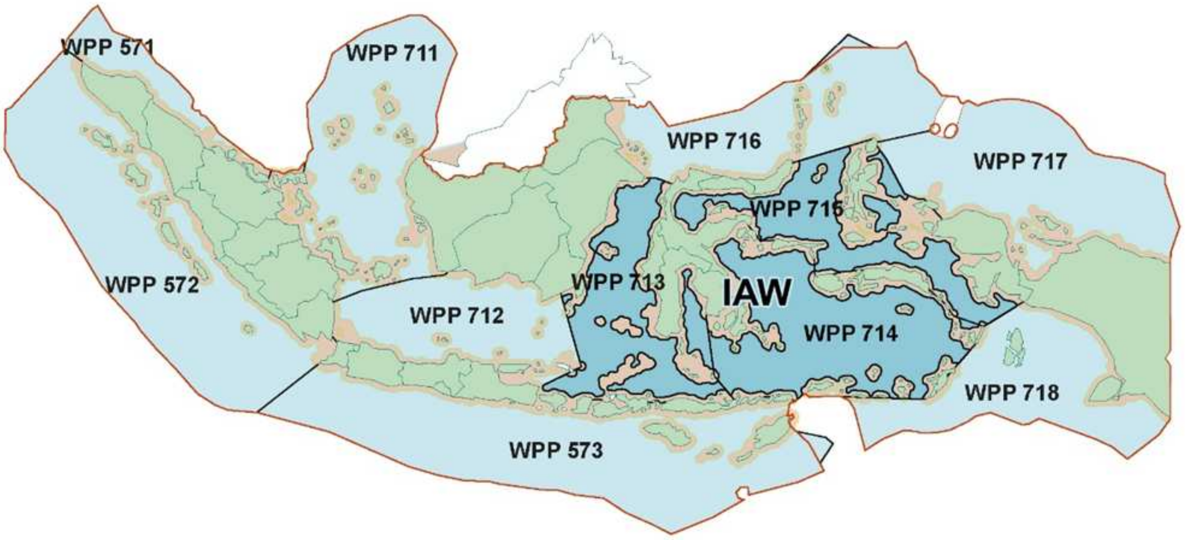


Figure 2.3: Indonesian Fisheries Management Areas (FMAs or WPPs) and details of deep Indonesia’s Archipelagic Waters (IAW).

As a unit for assessing the Indonesian part of WCPO region 7, Lewis & Davies (2021) more recently proposed to use a “Core Connectivity Zone” for YFT and SKJ, which includes the IAW (WPP 713, 714, and 715) as well as WPP 716 and 717. This begs the question how representative the results of an assessment in the IAW are for a wider area that would include FMAs 716 and 717. One way to shed light on this question is by comparing the importance of tuna fisheries in FMAs 716 and 717 to the tuna fisheries in the IAW. According to official statistics on landings in 2016, oceanic tuna from the IAW amounted to around 60% of the total catch from Indonesian waters. At the same time, tuna from the IAW amounted to more than 75% of the production from the “core connectivity zone”. FMA 715 by itself already represented around 50%) of the catch of the “core connectivity zone” (MMAF, 2017a). The importance of IAW, relative to the wider core connectivity zone, suggests that inclusion of 716 and 717 will not dramatically change the findings and conclusions of this report on the IAW.

To obtain model input parameter values, we reviewed literature on growth and natural mortality. We found that estimated parameter values vary in the literature, and that some estimates were not directly comparable, when different authors provided values for different, but overlapping, size ranges or ages. Therefore, we had to triangulate or interpolate between different sources to choose estimates that fit best with the combined information. We developed a size dependent fisheries mortality curve for all major gear types combined based on overall catch size frequency distributions recorded by CODRS. After estimation of parameter values for growth, natural mortality, and fishing mortality, and feeding our estimated values into the model, we calibrated recruitment so that the model predicts a catch that is consistent with recorded actual catch for 2020 from the IAW. The resulting model with estimated input parameter values represents our baseline scenario for the 2020 tuna fisheries in the IAW. To simulate effects of different management interventions, we changed age- (and size-) dependent fishing mortality, keeping all other parameters (growth, natural mortality, and recruitment) constant. Changes in fishing mortality are presented as alternative harvest strategies that are explained also in operational terms.

Input parameters and other assumption in this model, like in any model, are subject to discussion. Growth and mortality parameter values do affect predictions on the effects of alternative harvest strategies. Assuming or measuring a value for total mortality (Z), over-estimation of natural mortality (M) leads to under-estimation of fishing mortality (F). Under-estimation of potential growth could lead to under-estimation of the benefits from alternative harvest strategies. Uncertainties surrounding input parameter values are usually quantified through a sensitivity analysis. We performed a sensitivity analysis for a predecessor of this model, which had the same structure and where we assessed the same management scenarios. The conclusion from that sensitivity analysis was that the relative outcomes of the management scenarios were not affected by variation in input parameters for growth and mortality (Pet et al., 2019), and we felt that a sensitivity analysis for the model presented in this report would result in the same conclusion. We therefore did not perform a new sensitivity analysis for the model presented here. We acknowledge, however, that a sensitivity analysis should be performed if researchers plan to use this model for decision-making going forward.

3 Results from CODRS monitoring of IAW tuna fisheries

3.1 The tuna fishing fleet in Indonesian Archipelagic Waters

Frame survey results were compiled into a detailed survey report covering all the islands in and around the IAW (Yuniarta and Satrioajie, 2021a), and data from this report were transferred into a central data base for the tuna fishing fleet in the IAW (Table 3.1). This fleet data base includes information for each fishing boat in the fleet on boat size, gear type, port of registration, licenses for specific FMAs, main fishing grounds, captain contacts and other details. Origins of boats are not always overlapping with their fishing grounds, and trips to distant waters are common, especially for the larger vessels. The total tuna fishing fleet operating in the IAW includes almost 13,000 fishing boats (Table 3.2), representing a total of just over 86,000 Gross Tons (GT) combined vessel volume (Table 3.3).

We differentiated between dedicated and seasonally engaged fishing boats, which have a different average number of active fishing days per year (Table 3.4), to improve the accuracy of CpUE and total catch calculations. Effort in terms of "fishing vessel days" per year was calculated from the number of boats in each fleet segment multiplied with the average number of active fishing days per year, per fishing boat in that segment of the fleet. The average number of active fishing days per year, for each gear type and by boat size category, was derived from tracker data, looking at movement patterns and separating "steaming" from "fishing".

The percentage of fishing days allocated to IAW (versus outside waters) is estimated for each fleet segment down to the detail of registration port and used to further adjust the effort actually deployed inside the IAW. As a result, for example IAW catch volume from large longline vessels relatively low because some of them spend only about 10% of their fishing time inside IAW waters and the rest outside.

Figure 3.1: A typical tuna fishing boat used for pole-and-line fishing from Bitung, Sulawesi Utara, operating in the Molucca Sea (WPP 715) and on nearby fishing grounds.

Fishing boat sizes range from canoes of less than 1 GT, up to the larger vessels measuring close to 100 GT. Following practices by fisheries managers in Indonesia we distinguished 4 boat size categories including "nano" <5 GT), "small" (5-<10 GT), "medium"

(10-30 GT), and "large" (>30 GT). Gear types include pole-and-line, purse seine, handlines, trolling lines and long lines (Figures 3.1 to 3.5). Recruitment of captains from the overall fleet for the CODRS program (Table 3.5) was not exactly proportional to composition of the fleet in terms of vessel size, gear type and the FMA where the boat normally operates. Therefore, we estimated catch characteristics by fleet segment from the CODRS data, after which we combined catch characteristics by fleet segment with the effort by fleet segment to estimate total catch and species composition of the extraction from the IAW.

Figure 3.2: A typical tuna fishing boat used for trolling line fishing from Kota Ambon, Maluku, operating in the Banda Sea (WPP 714) and Molucca Sea (WPP 715).

Figure 3.3: A typical tuna fishing boat used for purse seine fishing from Kota Ambon, Maluku, operating in the Banda Sea (WPP 714) and Molucca Sea (WPP 715).

Figure 3.4: A typical tuna fishing boat used for handline fishing from Kota Tidore, Maluku Utara, operating in the Molucca Sea (WPP 715) and on nearby fishing grounds.

Figure 3.5: A typical tuna fishing boat used for longline fishing from Denpasar, Bali, operating in the Banda Sea (WPP 714) and on nearby fishing grounds.

Spatial patters of fishing vessels participating in the CODRS program showed that the program covered the entire IAW (Figure 3.6). Some fleet segments, like for example long line vessels from Bitung and Benoa, appeared to operate occasionally in the Banda Sea, with other trips going north to WPP 716 and WPP 717, or to the south, into the Indian Ocean. Reported vessel positions mostly depict steaming, moving slowly, and drifting, since SPOT Trace does not report positions if the vessels is stationary. Based on reported vessel positions, there was no evidence of any compliance with the Banda Sea seasonal closure (Figure 3.7). When we filtered vessel positions for the months that the closure was in effect (October 1 - December 31), it was clear that vessels participating in the CODRS program still fished in the closed area.

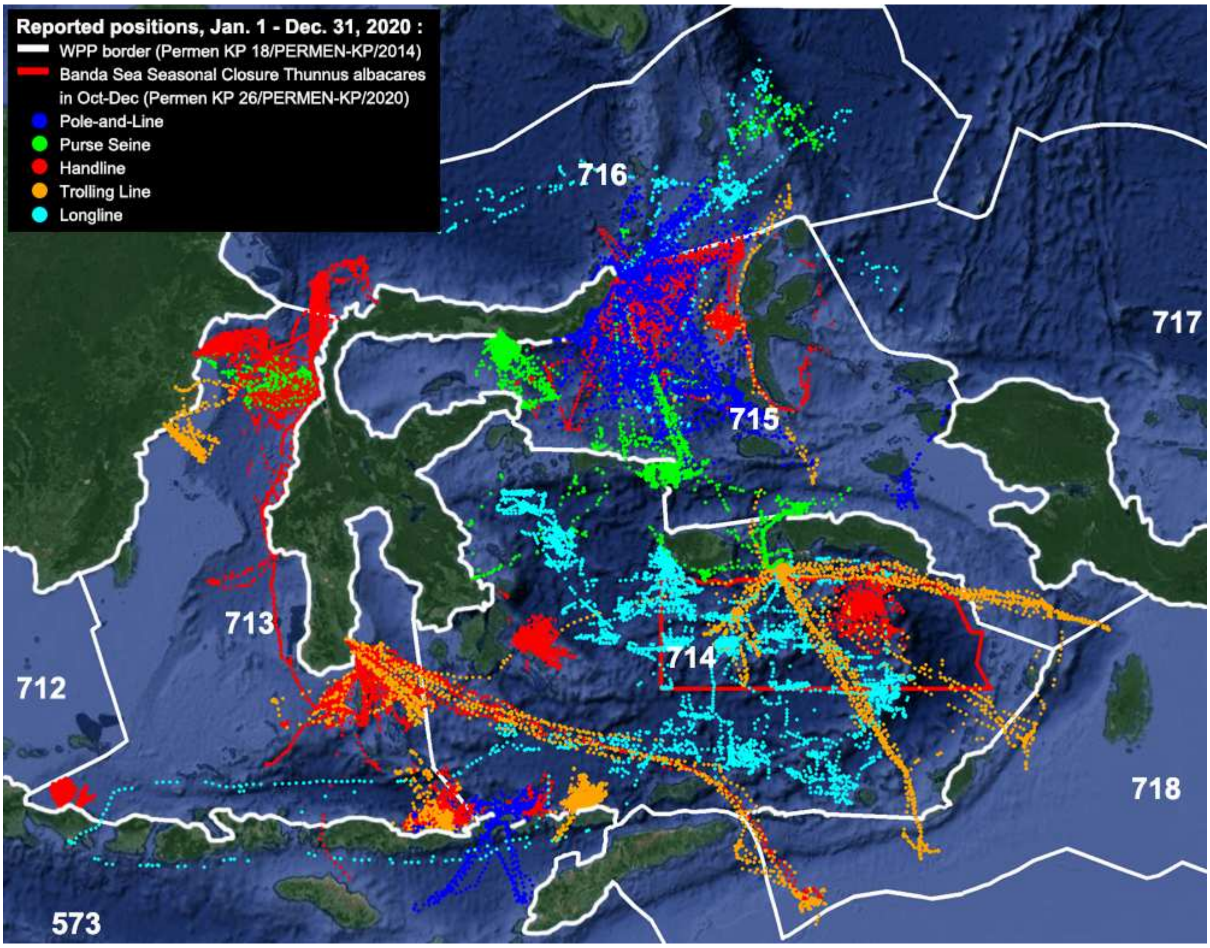


Figure 3.6: Spatial patterns of tuna vessels participating in the CODRS program, by gear type, in Indonesian Archipelagic Waters in 2020. The positions include SPOT Trace reports during steaming as well as fishing.

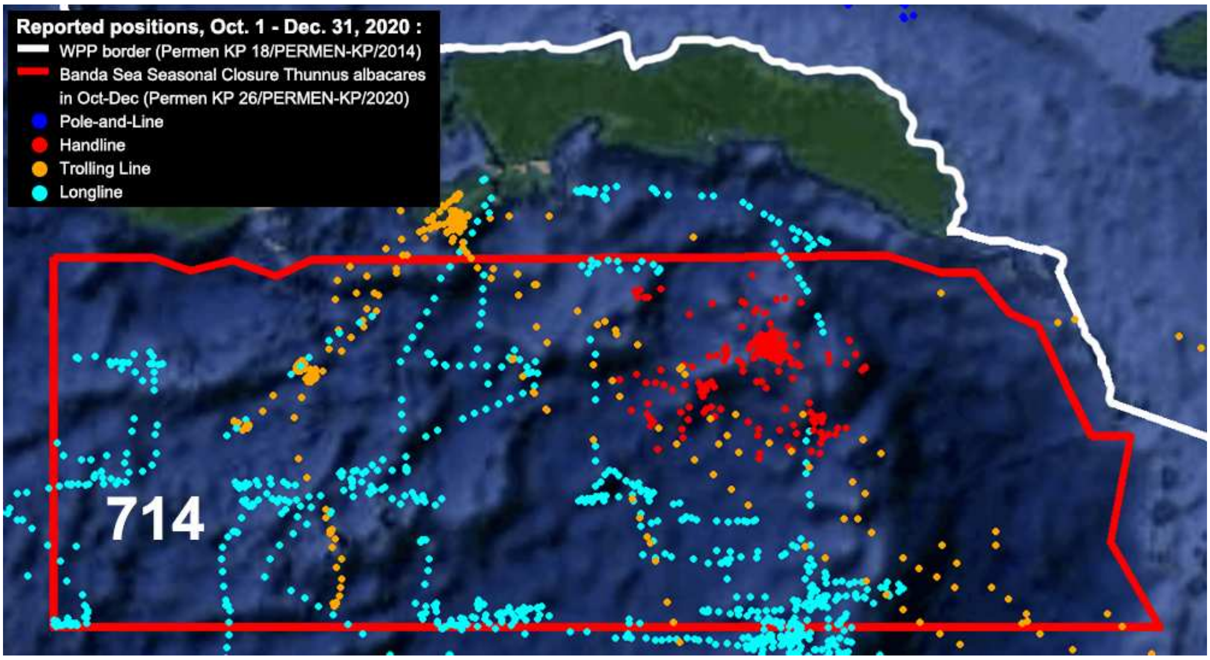


Figure 3.7: Spatial patterns of tuna vessels participating in the CODRS program, by gear type, in the Banda Sea Seasonal Closure between October and December 2020. The positions include SPOT Trace reports during steaming as well as fishing.

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
573 713	50	Badung	Badung	Medium D	PoleAndLine	1	28
573 714	20	Pelabuhan Benoa	Denpasar	Large D	LongLine	21	845
573 714	20	Pelabuhan Benoa	Denpasar	Medium D	LongLine	88	2142
573 713	20	Lombok Timur	Lombok Timur	Large D	TrollingLine	1	32
573 713	20	Lombok Timur	Lombok Timur	Medium D	TrollingLine	151	2703
573 713	20	Lombok Timur	Lombok Timur	Nano D	TrollingLine	1	2
573 713	20	Lombok Timur	Lombok Timur	Small D	TrollingLine	1	6
573 713	20	PP. Labuhan Lombok	Lombok Timur	Medium D	PoleAndLine	2	39
573 713	20	PP. Labuhan Lombok	Lombok Timur	Medium D	TrollingLine	47	833
573 713	20	PP. Labuhan Lombok	Lombok Timur	Nano D	TrollingLine	35	120
573 713	20	PP. Labuhan Lombok	Lombok Timur	Small D	TrollingLine	216	1494
573 713	20	PP. Tanjung Luar	Lombok Timur	Medium D	TrollingLine	6	100
573 713	20	PP. Tanjung Luar	Lombok Timur	Small D	TrollingLine	6	42
573 713	30	PP. Lappa	Sinjai	Medium D	TrollingLine	1	20
573 713	25	Desa Poto Tano	Sumbawa Barat	Nano S	Handline	21	20
713	100	Desa Kokar	Alor	Nano D	Handline	25	26
713 573	83	Desa Kokar	Alor	Nano D	Handline	5	8
713	100	Balikpapan	Balikpapan	Nano D	TrollingLine	2	4
713	100	PP. Manggar Baru	Balikpapan	Medium D	TrollingLine	7	127
713	100	PP. Manggar Baru	Balikpapan	Medium S	TrollingLine	5	80
713	100	PP. Manggar Baru	Balikpapan	Nano D	TrollingLine	4	4
713	100	PP. Manggar Baru	Balikpapan	Small D	TrollingLine	5	27
713	100	PP. Manggar Baru	Balikpapan	Small S	TrollingLine	4	23
713 716	60	PP. Manggar Baru	Balikpapan	Nano S	TrollingLine	1	2
713	100	PPI. Manggar Baru	Balikpapan	Small D	TrollingLine	2	12
713	100	registration_port	Balikpapan	Nano D	TrollingLine	1	1
713 712	50	PP. Banjarmasin	Banjarmasin	Medium S	PurseSeine	1	12
713	100	Desa Siddo	Barru	Medium S	PurseSeine	10	120
713	100	Desa Kore	Bima	Nano D	Handline	15	44
713	100	Kec. Tambora	Bima	Nano D	Handline	15	44
713	100	Kec. Wera	Bima	Nano D	Handline	20	53
713	100	PP. Sape	Bima	Medium D	PoleAndLine	15	393
713 714	100	PP. Lonrae	Bone	Medium D	Handline	9	122
713 714	100	PP. Lonrae	Bone	Medium D	TrollingLine	2	43
713 714	100	PP. Lonrae	Bone	Medium S	Handline	107	1492
713 714	100	PP. Lonrae	Bone	Small D	Handline	2	10
713 714	100	PP. Lonrae	Bone	Small S	Handline	205	1361
713	100	Desa Berbas	Bontang	Nano D	Handline	2	4
713	100	Desa Berbas Pantai	Bontang	Nano D	Handline	16	42
713	100	Desa Berbas Pantai	Bontang	Nano D	TrollingLine	1	1
713	100	Desa Berbas Pantai	Bontang	Small D	Handline	7	44
713 714	100	Desa Berbas Pantai	Bontang	Small D	Handline	1	6
713	100	Desa Berbas Tengah	Bontang	Nano D	TrollingLine	12	12
713	100	PP. Manggar Baru	Bontang	Nano D	Handline	1	3
713	100	PP. Tanjung Laut	Bontang	Nano D	Handline	3	8
713 716	70	PP. Tanjung Laut	Bontang	Small S	TrollingLine	1	6
713	100	PP. Tanjung Limau	Bontang	Small S	TrollingLine	1	6
713 716	70	PP. Tanjung Limau	Bontang	Medium D	TrollingLine	9	180
713 716	70	PP. Tanjung Limau	Bontang	Nano D	TrollingLine	3	6
713 716	70	PP. Tanjung Limau	Bontang	Small D	TrollingLine	5	26
713	100	PPN. Palipi	Bontang	Nano D	Handline	2	9
713	100	Desa Banjar	Buleleng	Nano S	TrollingLine	80	80
713	100	Desa Celukanbawang	Buleleng	Nano S	TrollingLine	80	80
713	100	Desa Les	Buleleng	Nano D	Handline	102	61
713	100	Desa Sangsit	Buleleng	Nano S	Handline	50	31
713	100	Lovina	Buleleng	Nano S	Handline	80	80
713	100	Pantai Penimbangan	Buleleng	Nano D	Handline	83	51
713	100	Penuktukan	Buleleng	Nano D	TrollingLine	50	50

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
713	100	Bulukumba	Bulukumba	Medium D	Handline	1	13
713	100	Bulukumba	Bulukumba	Nano D	Handline	4	10
713	100	Desa Basokeng	Bulukumba	Nano D	Handline	1	2
713	100	Pelabuhan Rakyat Parapara	Bulukumba	Medium D	Handline	76	953
713 714	100	PP. Beba	Bulukumba	Large D	PurseSeine	1	31
713 714	100	PP. Beba	Bulukumba	Medium D	Handline	2	28
713 714	100	PP. Beba	Bulukumba	Small D	Handline	1	10
713 714	100	PP. Benteng	Bulukumba	Large D	PurseSeine	1	30
713 714	100	PP. Bonto Bahari	Bulukumba	Medium D	Handline	4	46
713 714	100	PP. Bonto Bahari	Bulukumba	Nano D	Handline	1	5
713 714	100	PP. Bonto Bahari	Bulukumba	Small D	Handline	2	18
713 714	100	PP. Bonto Bahari	Bulukumba	Large D	PurseSeine	8	244
713 714	100	PP. Kajang	Bulukumba	Large D	PurseSeine	10	303
713 714	100	PP. Kajang	Bulukumba	Medium D	Handline	1	16
713 714	100	PP. Kajang	Bulukumba	Small D	Handline	1	6
713	100	PPI. Bonto Bahari	Bulukumba	Small D	Handline	1	9
713	100	PPI. Kajang	Bulukumba	Small D	Handline	50	335
713 714	100	PPI. Kajang	Bulukumba	Small D	TrollingLine	1	6
713	100	PPN. Palipi	Bulukumba	Nano D	Handline	2	6
713 714 573	100	Pelabuhan Benoa	Denpasar	Medium D	Handline	14	250
713 714	100	PP. Lappa	Denpasar	Medium D	Handline	39	751
713	100	Kec. Kilo	Dompu	Nano D	Handline	20	59
713	100	Desa Boneoge	Donggala	Nano D	Handline	396	1582
713	100	PP Donggala	Donggala	Small D	Handline	76	410
713	100	PP. Banggae	Donggala	Medium D	Handline	2	26
713	100	PP. Banggae	Donggala	Small D	Handline	1	6
713 716	80	PP. Banggae	Donggala	Small D	Handline	1	9
713	100	PPI. Donggala	Donggala	Medium D	Handline	1	12
713	100	PPI. Donggala	Donggala	Nano D	Handline	27	101
713	100	PPI. Donggala	Donggala	Small D	Handline	1	6
713	100	Desa Baturinggit	Karangasem	Nano S	Handline	20	10
713	100	Desa Sukadana	Karangasem	Nano S	Handline	60	30
713	100	Desa Tianyar	Karangasem	Nano S	Handline	60	30
713	100	Desa Tianyar Barat	Karangasem	Nano S	Handline	60	30
713	100	Desa Tulamben	Karangasem	Nano S	Handline	20	10
713	100	Desa Bontosungu	Kepulauan Selayar	Nano S	TrollingLine	30	39
713	100	Desa Mekar Indah	Kepulauan Selayar	Nano S	TrollingLine	40	52
713	100	Desa Patikarya	Kepulauan Selayar	Nano S	TrollingLine	19	32
713	100	PPI. Kayuadi	Kepulauan Selayar	Medium D	PoleAndLine	1	28
713	100	PPI. Kayuadi	Kepulauan Selayar	Medium D	TrollingLine	5	117
713	100	PPI. Kayuadi	Kepulauan Selayar	Small D	TrollingLine	1	6
713	100	TPI Bonehalang	Kepulauan Selayar	Medium S	PoleAndLine	1	28
713	100	TPI Bonehalang	Kepulauan Selayar	Medium S	PurseSeine	7	131
713	100	TPI Bonehalang	Kepulauan Selayar	Medium S	TrollingLine	1	18
713	100	TPI Bonehalang	Kepulauan Selayar	Small S	TrollingLine	2	19
713 714	100	Konawe	Konawe	Nano S	Handline	13	26
713 714	100	Konawe	Konawe	Small S	Handline	9	54
713	100	Kelurahan Kolo	Kota Bima	Nano D	Handline	20	59
713	100	Kota Makassar	Kota Makassar	Large D	TrollingLine	1	32
713	100	Kota Makassar	Kota Makassar	Medium D	TrollingLine	12	276
713	100	PPN. Untia	Kota Makassar	Large D	PurseSeine	1	33
713	100	PPN. Untia	Kota Makassar	Medium D	Handline	6	92
713	100	PPN. Untia	Kota Makassar	Medium D	PurseSeine	15	441
713 714 715	100	Kota Manado	Kota Manado	Large D	Handline	4	124
713 714 715	100	Kota Manado	Kota Manado	Medium D	Handline	14	196
713 714 715	100	Kota Manado	Kota Manado	Small D	Handline	6	36
713	100	PP. Cempae	Kota Parepare	Medium D	Handline	5	73
713	100	PP. Cempae	Kota Parepare	Medium D	PurseSeine	4	81

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
713	100	PP. Cempae	Kota Parepare	Nano D	Handline	20	49
713	100	PP. Cempae	Kota Parepare	Small D	Handline	3	17
713	100	PP. Cempae	Kota Parepare	Small D	TrollingLine	2	11
713	100	Lombok Utara	Lombok Utara	Nano S	Handline	108	54
713	100	Luwu	Luwu	Medium D	PoleAndLine	2	58
713 714	100	Luwu Utara	Luwu Utara	Medium D	PoleAndLine	3	87
713	100	Desa Berbas Pantai	Majene	Small D	Handline	6	35
713	100	Majene	Majene	Large D	Handline	3	94
713	100	Majene	Majene	Medium D	Handline	16	208
713	100	Majene	Majene	Nano D	Handline	23	46
713	100	Majene	Majene	Small D	Handline	3	17
713	100	PP Banggae	Majene	Medium D	Handline	54	702
713	100	PP. Tenda	Majene	Small D	Handline	1	6
713	100	PP. Kasiwa	Mamuju	Nano D	Handline	6	17
713	100	PP. Kasiwa	Mamuju	Nano S	TrollingLine	15	17
713	100	PP. Kasiwa	Mamuju	Small D	Handline	9	75
713	100	Desa Babana	Mamuju Tengah	Nano D	Handline	15	45
713	100	Pelabuhan Marapokot	Nagekeo	Nano D	Handline	20	50
713	100	TPI. Riung	Ngada	Nano D	Handline	15	38
713	100	Pasangkayu	Pasangkayu	Small D	Handline	20	148
713 714	100	Pinrang	Pinrang	Nano D	Handline	1	2
713	100	Desa Karama	Polewali Mandar	Nano D	Handline	349	1431
713	100	Desa Pambusuang	Polewali Mandar	Medium D	Handline	3	63
713	100	Desa Pambusuang	Polewali Mandar	Nano D	Handline	19	75
713	100	Desa Pambusuang	Polewali Mandar	Small D	Handline	28	180
713	100	PP Lantora	Polewali Mandar	Medium D	Handline	5	65
713	100	PP Lantora	Polewali Mandar	Nano D	Handline	57	208
713	100	Desa Kodia	Sikka	Nano D	Handline	50	62
713	100	Desa Nangahure	Sikka	Nano D	Handline	6	15
713 714	100	Desa Nangahure	Sikka	Nano D	Handline	100	300
713	100	Desa Parumaan	Sikka	Nano D	Handline	70	86
713	100	Desa Pemana	Sikka	Nano D	Handline	151	186
713 714	100	Desa Wuring	Sikka	Nano D	TrollingLine	80	80
713 714	100	PP Alok	Sikka	Medium D	PoleAndLine	1	28
713	100	PP. PP. Alok	Sikka	Large D	PoleAndLine	1	32
713 714	100	PP. PP. Alok	Sikka	Medium D	PoleAndLine	64	1590
713 714	100	PP. PP. Alok	Sikka	Nano D	Handline	88	98
713 714	100	PP. PP. Alok	Sikka	Nano D	TrollingLine	11	22
713	100	Sikka	Sikka	Large D	PoleAndLine	14	441
713	100	Sikka	Sikka	Medium D	PoleAndLine	22	550
713 714 573	80	PP. Benoa	Sinjai	Medium D	TrollingLine	11	258
713 714	100	PP. Kendari	Sinjai	Medium D	TrollingLine	1	23
713 714 573	80	PP. Kendari	Sinjai	Medium D	TrollingLine	1	21
713 714 573	80	PP. Labuhan Lombok	Sinjai	Medium D	TrollingLine	7	158
713	100	PP. Lappa	Sinjai	Medium S	TrollingLine	1	18
713 714	100	PP. Lappa	Sinjai	Medium D	Handline	4	82
713 714	100	PP. Lappa	Sinjai	Medium D	PurseSeine	1	28
713 714	100	PP. Lappa	Sinjai	Medium D	TrollingLine	10	203
713 714 573	80	PP. Lappa	Sinjai	Large D	PoleAndLine	1	30
713 714 573	80	PP. Lappa	Sinjai	Large D	PurseSeine	2	61
713 714 573	80	PP. Lappa	Sinjai	Medium D	Handline	4	92
713 714 573	80	PP. Lappa	Sinjai	Medium D	PoleAndLine	6	165
713 714 573	80	PP. Lappa	Sinjai	Medium D	PurseSeine	17	460
713 714 573	80	PP. Lappa	Sinjai	Medium D	TrollingLine	441	8620
713 714 573	80	PP. Lappa	Sinjai	Nano D	Handline	4	14
713 714 573	80	PP. Lappa	Sinjai	Nano D	TrollingLine	3	10
713 714 573	80	PP. Lappa	Sinjai	Small D	Handline	1	7
713 714 573	80	PP. Lappa	Sinjai	Small D	TrollingLine	1	9

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
713 714 573	80	PP. Oeba	Sinjai	Medium D	TrollingLine	11	269
713 714 573	80	PP. Pondok Dadap	Sinjai	Medium D	TrollingLine	4	84
713 714 573	80	Sinjai	Sinjai	Nano S	Handline	10	20
713 714 573	80	Sinjai	Sinjai	Small D	Handline	54	378
713 714 573	80	Sinjai	Sinjai	Small D	TrollingLine	23	209
713	100	Desa Labuhan	Sumbawa	Nano D	Handline	15	61
713	100	Pulau Bungin	Sumbawa	Nano D	Handline	10	27
713	100	Pulau Kaung	Sumbawa	Nano D	Handline	5	14
713	100	Pulau Medang	Sumbawa	Small D	Handline	50	268
713	100	Takalar	Takalar	Large D	Handline	5	158
713	100	Takalar	Takalar	Medium D	Handline	65	910
713 714	100	Takalar	Takalar	Small D	Handline	20	140
713	100	PP. Batulicin	Tanah Bumbu	Medium S	PurseSeine	3	58
713	100	PP. Kotabaru	Tanah Bumbu	Medium S	PurseSeine	18	302
714	100	Desa Kabir	Alor	Nano D	Handline	200	400
714	100	Desa Kokar	Alor	Nano D	TrollingLine	4	9
714	100	Desa Baliara	Bombana	Nano S	TrollingLine	59	77
714	100	Desa Baliara Kepulauan	Bombana	Nano S	TrollingLine	72	94
714	100	Desa Wamlana	Buru	Nano D	Handline	6	12
714	100	Buru Selatan	Buru Selatan	Nano D	Handline	99	198
714 713	100	Buton	Buton	Medium D	PoleAndLine	2	40
714 713	100	Buton	Buton	Nano D	Handline	92	92
714 713	100	PPI. Pasar Wajo	Buton	Nano D	TrollingLine	15	16
714	100	Buton Selatan	Buton Selatan	Medium D	PoleAndLine	3	60
714	100	Desa Napa	Buton Tengah	Nano S	Handline	15	16
714	100	Desa Wakambangura	Buton Tengah	Nano S	Handline	20	22
714	100	Desa Watolo	Buton Tengah	Nano S	Handline	40	44
714	100	Desa Waturambe	Buton Tengah	Nano S	Handline	15	16
714	100	Desa Malalanda	Buton Utara	Nano D	TrollingLine	43	47
714 713 718	90	PP. Ambon	Denpasar	Medium D	Handline	1	22
714 573	50	Kota Gorontalo	Flores Timur	Large D	PoleAndLine	1	32
714 573	50	PP Amagarapati	Flores Timur	Medium D	PoleAndLine	48	713
714 573 713	50	PP Amagarapati	Flores Timur	Medium D	PoleAndLine	1	15
714 573	50	PP. Amagarapati	Flores Timur	Medium D	PoleAndLine	6	97
714	100	Kolaka	Kolaka	Medium D	PoleAndLine	1	26
714	100	Konawe Kepulauan	Konawe Kepulauan	Nano S	Handline	274	442
714	100	Konawe Utara	Konawe Utara	Nano S	Handline	18	25
714	100	Desa Laha	Kota Ambon	Nano D	Handline	34	44
714	100	Desa Latuhalat	Kota Ambon	Nano D	Handline	238	309
714	100	Dusun Seri	Kota Ambon	Nano D	Handline	34	44
714	100	Dusun Seri	Kota Ambon	Nano D	TrollingLine	1	1
714 715	100	Kota Ambon	Kota Ambon	Large D	PoleAndLine	2	64
714 715	100	Kota Ambon	Kota Ambon	Medium D	Handline	15	352
714 715	100	Kota Ambon	Kota Ambon	Nano D	Handline	102	204
714 715	100	Kota Ambon	Kota Ambon	Small D	Handline	5	30
714 715	100	Kota Ambon	Kota Ambon	Small D	TrollingLine	1	6
714	100	Pangkalan Nusaniwe	Kota Ambon	Nano D	TrollingLine	1	1
714 715	100	Pelabuhan Benoa	Kota Ambon	Large S	PurseSeine	1	72
714	100	PP. Ambon	Kota Ambon	Large D	LongLine	1	44
714	100	PP. Ambon	Kota Ambon	Large S	PurseSeine	5	383
714	100	PP. Ambon	Kota Ambon	Medium D	Handline	1	15
714	100	PP. Ambon	Kota Ambon	Medium D	LongLine	12	245
714	100	PP. Ambon	Kota Ambon	Medium D	TrollingLine	2	31
714 713 718	90	PP. Ambon	Kota Ambon	Large S	PurseSeine	2	125
714 715	100	PP. Ambon	Kota Ambon	Large S	PurseSeine	6	475
714 715	100	PP. Ambon	Kota Ambon	Medium D	Handline	45	868
714 715	100	PP. Ambon	Kota Ambon	Medium D	LongLine	16	318
714 715	100	PP. Ambon	Kota Ambon	Medium D	PoleAndLine	8	187

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
714 715	100	PP. Ambon	Kota Ambon	Medium D	TrollingLine	3	55
714 718	90	PP. Ambon	Kota Ambon	Medium D	Handline	1	16
714	100	PPI. Wameo	Kota Bau-Bau	Medium D	PoleAndLine	20	232
714	100	Kota Kendari	Kota Kendari	Large S	Handline	9	405
714	100	Kota Kendari	Kota Kendari	Medium D	PoleAndLine	30	780
714	100	Kota Kendari	Kota Kendari	Nano S	Handline	64	128
714	100	Kota Kendari	Kota Kendari	Small S	Handline	45	270
714	100	PP. Kendari	Kota Kendari	Large D	PoleAndLine	2	93
714	100	PP. Kendari	Kota Kendari	Large S	Handline	5	201
714	100	PP. Kendari	Kota Kendari	Large S	PurseSeine	21	891
714	100	PP. Kendari	Kota Kendari	Medium D	Handline	42	961
714	100	PP. Kendari	Kota Kendari	Medium D	PoleAndLine	28	671
714	100	PP. Kendari	Kota Kendari	Medium S	Handline	73	1000
714	100	PP. Kendari	Kota Kendari	Medium S	PurseSeine	250	5481
714	100	PP. Kendari	Kota Kendari	Medium S	TrollingLine	2	23
714	100	PP. Kendari	Kota Kendari	Small S	Handline	11	60
714	100	Desa Balauring	Lembata	Nano D	Handline	43	56
714 573	83	Desa Balauring	Lembata	Nano D	Handline	7	9
714	100	Pelabuhan Balauring	Lembata	Nano D	Handline	2	2
714	100	Desa Lurang	Maluku Barat Daya	Nano D	TrollingLine	1	3
714	100	Desa Uhak	Maluku Barat Daya	Nano S	TrollingLine	6	6
714	100	Desa Biyau	Maluku Tengah	Nano D	Handline	4	7
714	100	Desa Dender	Maluku Tengah	Nano D	Handline	15	30
714	100	Desa Kampung Baru	Maluku Tengah	Nano D	Handline	45	91
714	100	Desa Lautang	Maluku Tengah	Nano D	Handline	39	93
714	100	Desa Nusantara	Maluku Tengah	Nano D	Handline	38	78
714	100	Desa Pagar Buton	Maluku Tengah	Nano D	Handline	10	18
714	100	Desa Pulau Ay	Maluku Tengah	Nano D	Handline	13	23
714	100	Desa Pulau Hatta	Maluku Tengah	Nano D	Handline	10	21
714	100	Desa Pulau Rhun	Maluku Tengah	Nano D	Handline	38	77
714	100	Desa Ruta	Maluku Tengah	Nano D	Handline	45	72
714	100	Desa Uring Tutra	Maluku Tengah	Nano D	Handline	3	5
714	100	Desa Waer	Maluku Tengah	Nano D	Handline	31	64
714	100	Desa Yainuelo	Maluku Tengah	Nano D	Handline	70	112
714	100	Dusun Aira	Maluku Tengah	Nano D	Handline	40	64
714	100	Dusun Ampera	Maluku Tengah	Nano D	Handline	50	80
714	100	Dusun Amrua	Maluku Tengah	Nano D	Handline	75	120
714	100	Dusun Pulau Pisang	Maluku Tengah	Nano D	Handline	4	7
714	100	Kec. Banda	Maluku Tengah	Small D	Handline	18	108
714	100	Maluku Tengah	Maluku Tengah	Medium D	PoleAndLine	2	46
714	100	Maluku Tengah	Maluku Tengah	Nano D	Handline	131	262
714	100	Maluku Tengah	Maluku Tengah	Nano D	TrollingLine	47	94
714	100	Maluku Tengah	Maluku Tengah	Small D	Handline	6	36
714	100	PP. Ambon	Maluku Tengah	Medium D	LongLine	1	22
714 715	100	PP. Ambon	Maluku Tengah	Medium D	LongLine	1	23
714 715	100	PP. Ambon	Maluku Tengah	Medium D	PoleAndLine	10	210
714	100	PP. Banda	Maluku Tengah	Nano D	Handline	58	104
714	100	PP. Salahutu	Maluku Tengah	Nano D	Handline	66	92
714	100	PP. Tehoru	Maluku Tengah	Nano D	Handline	53	85
714	100	Morowali	Morowali	Medium D	PoleAndLine	8	112
714	100	Kec. Pasir Putih	Muna	Nano D	Handline	60	100
714	100	Kec. Maginti	Muna Barat	Nano D	Handline	10	18
714	100	Kec. Napano Kusambi	Muna Barat	Nano D	Handline	40	74
714	100	Polewali Mandar	Polewali Mandar	Nano D	Handline	3	6
714	100	Polewali Mandar	Polewali Mandar	Small D	Handline	1	6
714	100	PP. Werinama	Seram Bagian Timur	Nano D	TrollingLine	41	57
714	100	PP. Kendari	Sinjai	Medium D	TrollingLine	1	18
714	100	PP. Lappa	Sinjai	Medium D	TrollingLine	1	22

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
714	100	PP. Oeba	Sinjai	Medium D	TrollingLine	2	52
714	100	PPN. Ambon	Sinjai	Medium D	TrollingLine	4	96
714	100	Desa Labuan	Tojo Una-Una	Nano S	Handline	56	73
714	100	Desa Podi	Tojo Una-Una	Nano S	Handline	60	78
714	100	Desa Tojo	Tojo Una-Una	Nano S	Handline	70	91
714	100	Desa Koroe Onowa	Wakatobi	Nano D	Handline	4	6
714	100	Desa Koroeonowa	Wakatobi	Nano D	TrollingLine	38	62
714	100	Desa Longa	Wakatobi	Nano D	TrollingLine	15	22
714	100	Desa Matahora	Wakatobi	Nano D	TrollingLine	26	43
714	100	Desa Mola Bahari	Wakatobi	Nano S	TrollingLine	104	165
714	100	Desa Mola Nelayan Bakti	Wakatobi	Nano S	TrollingLine	201	382
714	100	Desa Mola Samaturu	Wakatobi	Nano S	TrollingLine	82	119
714	100	Desa Mola Selatan	Wakatobi	Nano S	TrollingLine	118	111
714	100	Desa Patuno	Wakatobi	Nano D	TrollingLine	18	26
714	100	Desa Sombu	Wakatobi	Nano D	TrollingLine	81	49
714	100	Desa Waelumu	Wakatobi	Nano D	TrollingLine	59	106
714	100	Desa Waetuno	Wakatobi	Nano D	TrollingLine	20	28
714	100	Waha	Wakatobi	Nano D	TrollingLine	8	10
714	100	Wakatobi	Wakatobi	Nano D	Handline	10	26
714	100	Wapiapia	Wakatobi	Nano D	TrollingLine	30	35
715	100	Kec. Totikum	Banggai Kepulauan	Nano S	TrollingLine	26	29
715	100	Bitung	Bitung	Large D	Handline	6	181
715	100	Bitung	Bitung	Medium D	Handline	83	2158
715	100	Bitung	Bitung	Nano D	Handline	297	594
715	100	Bitung	Bitung	Small D	Handline	174	1044
715 716	90	PP. Belang	Bitung	Medium D	PurseSeine	1	23
715	100	PP. Bitung	Bitung	Large D	Handline	50	2738
715	100	PP. Bitung	Bitung	Large D	PoleAndLine	17	882
715	100	PP. Bitung	Bitung	Large D	PurseSeine	7	414
715	100	PP. Bitung	Bitung	Medium D	Handline	222	3948
715	100	PP. Bitung	Bitung	Medium D	PoleAndLine	1	23
715	100	PP. Bitung	Bitung	Medium D	PurseSeine	5	126
715	100	PP. Bitung	Bitung	Nano D	Handline	83	115
715	100	PP. Bitung	Bitung	Small D	Handline	137	740
715	100	PP. Kema	Bitung	Medium D	Handline	1	12
715	100	PPN. Ternate	Bitung	Medium D	Handline	1	13
715	100	PP. Tilamuta	Boalemo	Large D	Handline	2	69
715	100	PP. Tilamuta	Boalemo	Large D	PoleAndLine	2	84
715	100	PP. Tilamuta	Boalemo	Large D	PurseSeine	8	277
715	100	PP. Tilamuta	Boalemo	Medium D	PoleAndLine	3	56
715	100	PP. Tilamuta	Boalemo	Medium D	PurseSeine	3	63
715	100	PP. Dudepo	Bosel	Nano S	TrollingLine	50	10
715 714	100	Buru	Buru	Nano D	Handline	213	426
715	100	Desa Tongute Ternate	Halmahera Barat	Nano D	Handline	9	20
715	100	Halmahera Barat	Halmahera Barat	Nano D	Handline	5	10
715	100	PP. Loloda	Halmahera Barat	Nano D	Handline	5	11
715	100	Desa Awanggo	Halmahera Selatan	Nano D	Handline	20	40
715	100	Desa Indomut	Halmahera Selatan	Nano D	Handline	30	66
715	100	Desa Kubung	Halmahera Selatan	Nano D	Handline	30	54
715	100	Desa Kupal	Halmahera Selatan	Nano D	Handline	25	50
715	100	Desa Laluin	Halmahera Selatan	Nano D	Handline	5	11
715	100	Desa Laluin	Halmahera Selatan	Nano D	TrollingLine	1	2
715	100	Desa Mandopolo	Halmahera Selatan	Nano D	Handline	7	13
715	100	Desa Panambuang	Halmahera Selatan	Nano D	Handline	25	42
715	100	Halmahera Selatan	Halmahera Selatan	Large D	PoleAndLine	1	31
715	100	Halmahera Selatan	Halmahera Selatan	Small D	TrollingLine	1	8
715	100	PP. Bacan	Halmahera Selatan	Medium D	PoleAndLine	2	55
715	100	PP. Ternate	Halmahera Selatan	Large D	PoleAndLine	1	31

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
715	100	PP. Ternate	Halmahera Selatan	Medium D	PurseSeine	2	23
715	100	Pulau Bisa dan Bacan	Halmahera Selatan	Nano D	Handline	63	126
715	100	Desa Loleo	Halmahera Tengah	Nano D	Handline	5	11
715	100	Halmahera Tengah	Halmahera Tengah	Medium D	PoleAndLine	1	19
715	100	PP. Weda	Halmahera Tengah	Nano D	Handline	5	12
715	100	PP. Manitingting	Halmahera Timur	Nano D	Handline	7	14
715	100	PP. Manitingting	Halmahera Timur	Small D	Handline	1	9
715 716	70	Desa Dedete	Halmahera Utara	Nano D	Handline	9	12
715 716	70	Desa Dedete	Halmahera Utara	Nano D	TrollingLine	1	1
715	100	Desa Ngofagita	Halmahera Utara	Nano D	Handline	10	13
715 716	70	Desa Tobo Tobo	Halmahera Utara	Nano D	Handline	10	13
715	100	PP. Tobelo	Halmahera Utara	Nano D	Handline	23	65
715	100	PP. Tobelo	Halmahera Utara	Small D	Handline	9	55
715 717	90	PP. Tobelo	Halmahera Utara	Small D	PoleAndLine	15	138
715	100	Pelabuhan Sitaro	Kepulauan Sitaro	Medium S	Handline	1	17
715 714	100	Kec. Sanana	Kepulauan Sula	Nano D	Handline	113	226
715 714	100	PP. Ambon	Kota Ambon	Medium D	PoleAndLine	9	208
715	100	Kota Gorontalo	Kota Gorontalo	Large D	Handline	9	284
715	100	Kota Gorontalo	Kota Gorontalo	Nano D	Handline	4	11
715	100	PP. Inengo	Kota Gorontalo	Small D	Handline	1	6
715	100	PP. Tenda	Kota Gorontalo	Medium D	Handline	28	466
715	100	PP. Tenda	Kota Gorontalo	Medium D	PoleAndLine	1	24
715	100	PP. Tenda	Kota Gorontalo	Nano D	Handline	1	3
715	100	PP. Tenda	Kota Gorontalo	Small D	Handline	44	266
715	100	PP. Sorong	Kota Sorong	Large D	PoleAndLine	3	123
715	100	PP. Sorong	Kota Sorong	Large S	PurseSeine	1	68
715 717	90	PP. Sorong	Kota Sorong	Large D	PoleAndLine	23	1022
715 717	90	PP. Sorong	Kota Sorong	Large S	PurseSeine	1	68
715 717	90	PP. Sorong	Kota Sorong	Medium D	PoleAndLine	4	70
715	100	Desa Soasio	Kota Ternate	Nano D	Handline	18	27
715	100	Desa Soasio	Kota Ternate	Nano D	TrollingLine	2	9
715	100	Kota Ternate	Kota Ternate	Large D	Handline	1	32
715	100	Kota Ternate	Kota Ternate	Medium D	PoleAndLine	3	69
715	100	PP. Ternate	Kota Ternate	Large D	PoleAndLine	2	63
715	100	PP. Ternate	Kota Ternate	Medium D	Handline	3	51
715	100	PP. Ternate	Kota Ternate	Medium D	PoleAndLine	13	306
715	100	PP. Ternate	Kota Ternate	Medium D	PurseSeine	1	24
715	100	PP. Ternate	Kota Ternate	Nano D	Handline	3	6
715	100	PPN. Ternate	Kota Ternate	Large D	PoleAndLine	7	234
715	100	PPN. Ternate	Kota Ternate	Large D	PurseSeine	1	31
715	100	PPN. Ternate	Kota Ternate	Medium D	Handline	4	58
715	100	PPN. Ternate	Kota Ternate	Medium D	PoleAndLine	33	799
715	100	PPN. Ternate	Kota Ternate	Medium D	PurseSeine	3	74
715	100	PPN. Ternate	Kota Ternate	Small D	Handline	2	13
715	100	PPN. Ternate	Kota Ternate	Small D	TrollingLine	2	12
715	100	Ternate	Kota Ternate	Nano D	Handline	80	160
715	100	Desa Gurabati	Kota Tidore Kepulauan	Nano D	Handline	37	50
715	100	Desa Rum Balibunga	Kota Tidore Kepulauan	Nano D	Handline	51	70
715	100	PPI. Goto	Kota Tidore Kepulauan	Large D	PoleAndLine	3	92
715	100	PPI. Goto	Kota Tidore Kepulauan	Medium D	PoleAndLine	8	205
715	100	PPI. Goto	Kota Tidore Kepulauan	Nano D	Handline	3	7
715	100	Desa Malaku	Maluku Tengah	Nano D	Handline	20	28
715	100	Dusun Parigi	Maluku Tengah	Nano D	Handline	210	298
715	100	Minahasa	Minahasa	Medium D	Handline	1	24
715	100	Minahasa	Minahasa	Small D	Handline	2	12
715 716	50	Minahasa Selatan	Minahasa Selatan	Large D	Handline	4	124
715 716	50	Minahasa Selatan	Minahasa Selatan	Medium D	Handline	2	28
715	100	Minahasa Tenggara	Minahasa Tenggara	Medium D	Handline	10	140

Table 3.1: Total Number and Gross Tonnage of Tuna Fishing Boats by Main Target WPP, Registration Port, Home District (Kabupaten), Boat Size Category and Type of Fishing Gear. Nano < 5 GT, Small 5-<10 GT, Medium 10-30 GT, Large >30 GT. D Dedicated, S Seasonal.

WPP	%IAW	Registration Port	Home District	Boat Size	Gear	N	Total GT
715	100	Minahasa Tenggara	Minahasa Tenggara	Small D	Handline	3	18
715	100	PP. Belang	Minahasa Tenggara	Medium S	Handline	5	94
715	100	Minahasa Utara	Minahasa Utara	Medium D	Handline	1	14
715	100	Minahasa Utara	Minahasa Utara	Nano D	Handline	1	2
715	100	PP. Kema	Minahasa Utara	Medium D	Handline	1	24
715 716	50	Pangkajene	Pangkep	Medium D	Handline	1	14
715	100	Kec. Marisa	Pohuwato	Nano D	Handline	80	112
715	100	Pulau Morotai	Pulau Morotai	Nano D	Handline	152	304
715	100	Desa Gela	Pulau Taliabu	Nano D	Handline	9	12
715	100	Desa Gela	Pulau Taliabu	Nano D	TrollingLine	1	1
715	100	Desa Samuya	Pulau Taliabu	Nano D	Handline	10	13
715	100	PP. Bobong	Pulau Taliabu	Nano D	Handline	10	13
715	100	PP. Bobong	Pulau Taliabu	Small D	PoleAndLine	10	66
715	100	Aai Berar Besar	Raja Ampat	Nano D	TrollingLine	10	10
715 717	80	Arefi	Raja Ampat	Nano D	TrollingLine	25	29
715	100	Deer	Raja Ampat	Nano D	TrollingLine	20	22
715 717	80	Desa Samate	Raja Ampat	Nano D	TrollingLine	20	24
715	100	Desa Tolobi	Raja Ampat	Nano D	TrollingLine	25	28
715 717	80	Distrik Kota Waisai	Raja Ampat	Nano D	TrollingLine	70	83
715 717	80	Kampung Solol	Raja Ampat	Nano D	TrollingLine	15	20
715 717	80	Yensawai Timur	Raja Ampat	Nano D	TrollingLine	15	17
715 714	100	Desa Kawah	Seram Bagian Barat	Nano D	TrollingLine	138	179
715 714	100	PP. Piru	Seram Bagian Barat	Nano D	TrollingLine	14	18
715 714	100	PP. Pulau Buano	Seram Bagian Barat	Nano D	Handline	157	204
715	100	PP. Bula	Seram Bagian Timur	Nano D	Handline	140	197
715 716	50	Kep. Sitaro	Siau Tagulandang Biaro	Large D	Handline	2	62
715 717	90	PP. Sorong	Sorong	Large D	PoleAndLine	1	40
715	100	Sorong	Sorong	Nano D	Handline	5	10
716 713	30	PP. Sambaliung	Berau	Small D	Handline	16	109
716 715	10	PP. Bitung	Bitung	Large D	LongLine	1	41
716 715	10	PP. Bitung	Bitung	Medium D	LongLine	13	244
716 715	30	Kep. Sangihe	Kepulauan Sangihe	Large D	Handline	1	31
716 715	30	Kep. Sangihe	Kepulauan Sangihe	Medium D	Handline	6	84
716 715	10	Kota Manado	Kota Manado	Nano D	Handline	10	20
716 715	20	PP. Tumumpa	Kota Manado	Medium D	PurseSeine	1	14
717 715	10	PP. Sorong	Kota Sorong	Medium D	Handline	11	156
717 715	10	PP. Sorong	Kota Sorong	Small D	Handline	6	45
718 715	10	Kaimana	Kaimana	Nano D	Handline	30	40
718 714	30	Tanimbar Selatan	Kepulauan Tanimbar	Nano D	Handline	20	38
TOTAL						12979	86100

Table 3.2: Number of Boats in the IAW Fleet by Fishing Gear and Boat Size

Number of Boat	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano Dedicated	0	0	5656	1008	0	6664
Nano Seasonal	0	0	1134	983	0	2117
Small Dedicated	25	0	770	267	0	1062
Small Seasonal	0	0	270	8	0	278
Medium Dedicated	362	53	805	739	131	2090
Medium Seasonal	1	289	186	9	0	485
Large Dedicated	81	39	87	2	23	232
Large Seasonal	0	37	14	0	0	51
Total	469	418	8922	3016	154	12979

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

Table 3.3: Total Gross Tonnage in the IAW Fleet by Fishing Gear and Boat Size

Gross Tonnage	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano Dedicated	0	0	11675	1363	0	13038
Nano Seasonal	0	0	1276	1297	0	2573
Small Dedicated	203	0	4671	1875	0	6748
Small Seasonal	0	0	1746	54	0	1799
Medium Dedicated	7991	1357	14123	14309	2993	40774
Medium Seasonal	28	6103	2603	140	0	8874
Large Dedicated	3293	1425	3895	63	930	9605
Large Seasonal	0	2082	606	0	0	2688
Total	11515	10967	40595	19100	3923	86100

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

Table 3.4: Average number of Active-Fishing Days by Type of Gear and by Boat Size Category in the IAW Tuna Fisheries

Days / Year	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line
Nano Dedicated	NA	NA	264	278	NA
Nano Seasonal	NA	NA	63	65	NA
Small Dedicated	279	NA	273	291	NA
Small Seasonal	NA	NA	63	78	NA
Medium Dedicated	154	114	233	202	296
Medium Seasonal	38	14	50	41	NA
Large Dedicated	143	215	185	185	198
Large Seasonal	NA	31	23	NA	NA

Table 3.5: Tuna CODRS vessels by Gear Type and Boat Size Category in the IAW

Number of Boat	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano	NA	NA	38	15	NA	53
Small	0	NA	7	5	NA	12
Medium	3	8	14	6	2	33
Large	6	4	0	0	2	12
Total	9	12	59	26	4	110

3.2 Catch composition

Dedicated fishing boats on average were fishing actively between 150 and 300 days per year, depending on fleet segment (Table 3.4). Boats that operate only seasonally in the IAW tuna fisheries were fishing actively for a much lower number of days per year in these fisheries. Total effort by fleet segment is calculated from the total Gross Tonnage in the segment multiplied with the average number of active fishing days per year for that segment. We collected and maintained high resolution information on sub-categories within fleet segments (Yuniarta and Satrioajie, 2021b) to differentiate effort and CpUE by subcategory before weighing and grouping by major gear type and boat size in this report. The size frequency of the catch of each target species (Yuniarta and Satrioajie, 2021c) was converted into weight by using species-specific length-weight relationships, to determine Catch per Unit of Effort (CpUE) in kg per GT per active fishing day for each species by gear type and boat size category. CpUE by species and effort by in each segment of the fleet in 2020 were used to calculate the catch by species for each gear type and boat size category (Tables 3.6 to 3.8), adding up to the total catch by species from the IAW for that year (Table 3.9).

The estimated total catch from the IAW across all species landed by the oceanic tuna fishing fleet in 2020 was 328,650 metric tons (MT) of fish, including 93,637 MT by pole-and-line, 52,169 MT by purse seine, 163,249 MT by handline, 16,351 MT by trolling line, and 3,243 MT from long line fisheries. With productions of over 172,292 MT and 105,027 MT respectively, yellowfin tuna (YFT) and skipjack tuna (SKJ) were by far the most important species in the IAW tuna fisheries, together representing 84% of the total catch. The bulk of the YFT landings (by volume) from the IAW is caught with handline and trolling lines, with a smaller contribution in terms of weight from pole-and-line and purse seine gears. SKJ, on the other hand, is mainly caught with pole-and-line and purse seine. Purse seine is the only gear type for which oceanic tunas do not form the bulk of the catch. Purse seine vessels in the IAW are relatively small units that fish for a broad spectrum of small pelagic species, including scads (*Decapterus spp.*), neritic tunas (*Euthynnus* and *Auxis spp.*), juveniles of oceanic tunas and a range of other small pelagic species.

Table 3.6: IAW Thunnus albacares Catch (Metric Tons) by gear type and boat size in 2020

Vessel category	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano Dedicated	NA	NA	78679	3569	NA	82249
Nano Seasonal	NA	NA	4384	927	NA	5310
Small Dedicated	231	NA	10621	2122	NA	12974
Small Seasonal	0	NA	2046	110	NA	2155
Medium Dedicated	5048	244	37596	6129	1006	50024
Medium Seasonal	9	295	2926	50	0	3281
Large Dedicated	6133	1201	7862	25	245	15467
Large Seasonal	0	518	315	0	0	833
Total	11422	2259	144429	12932	1251	172292

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

Table 3.7: IAW Thunnus obesus Catch (Metric Tons) by gear type and boat size in 2020

Vessel category	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano Dedicated	NA	NA	3987	61	NA	4048
Nano Seasonal	NA	NA	183	2	NA	185
Small Dedicated	0	NA	8	0	NA	8
Small Seasonal	0	NA	4	0	NA	4
Medium Dedicated	0	0	1735	4	1895	3635
Medium Seasonal	0	0	142	0	0	142
Large Dedicated	0	0	380	0	96	476
Large Seasonal	0	0	15	0	0	15
Total	0	0	6452	68	1991	8511

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

Table 3.8: IAW Katsuwonus pelamis Catch (Metric Tons) by gear type and boat size in 2020

Vessel category	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Nano Dedicated	NA	NA	3015	1466	NA	4480
Nano Seasonal	NA	NA	160	474	NA	634
Small Dedicated	2440	NA	150	60	NA	2650
Small Seasonal	0	NA	41	0	NA	41
Medium Dedicated	53272	998	36	82	0	54388
Medium Seasonal	99	1208	0	4	0	1311
Large Dedicated	23849	12377	0	3	0	36229
Large Seasonal	0	5340	0	0	0	5340
Total	79660	19923	3401	2088	0	105072

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

Table 3.9: Catch in Metric Tons, by gear type and major species category, for the fleet that was specifically targeting oceanic tunas in the IAW in 2020.

Species	Pole and Line	Purse Seine	Handline	Trolling Line	Long Line	Total
Thunnus albacares	11422	2259	144429	12932	1251	172292
Thunnus obesus	0	0	6452	68	1991	8511
Katsuwonus pelamis	79660	19923	3401	2088	0	105072
Euthynnus & Auxis spp.	2519	10630	618	1054	0	14820
Decapterus spp.	0	17985	23	0	0	18008
Other	37	1372	8326	209	1	9945
Total	93637	52169	163249	16351	3243	328650

NB: Overall total production of neritic tunas, scads and other species was significantly higher in the IAW in 2020, as a result of effort purse seines specifically targeting small pelagic species only. Catches of oceanic tunas in this table represent estimates for overall totals from the IAW in 2020.

In our study we have only included those purse seine vessels that target oceanic tunas at least part of the time, so our results are not representative of the total purse seine fleet active in the IAW. Even in the purse seine catches of our selected group of vessels, scads formed the largest species category (by weight) in 2020. It is important to note the difference between these smaller archipelagic purse seine vessels that target a range of small pelagic species, versus the large ocean-going purse seine vessels that mainly target skipjack and juvenile yellowfin tuna. Within the tuna fishing fleet as we defined it here for the IAW, the purse seine segment is the main supplier to local markets, whereas fish from the other gear types either ends up in international canned tuna trade, or fresh and frozen tuna loins for international sashimi and tuna steak markets. The issue of species composition, together with size distribution, impact and target markets, needs to be carefully considered when harvest strategies and management interventions are considered for the IAW tuna fisheries.

A relatively large percentage of the YFT catch in 2020 was produced by vessels smaller than 30 GT, which has important consequences for management. Close to 60% of YFT landings, in terms of weight, came from nano and small-sized vessels using handline and trolling lines of a great diversity, targeting the complete size range of the species. Contributions by pole-and-line and purse seine do not seem to be that great in terms of weight, but these gear types catch large numbers of small to very small fish (Figure 3.8). Many types of handlines and trolling lines are either targeting small YFT with multiple small hooks and mostly artificial baits, or larger hooks and mostly natural baits. Longlines produce large YFT and BET, while handlines and to a lesser extend also trolling lines catch considerable numbers of smaller BET (Figure 3.9). SKJ is mostly caught by purse seine and pole-and-line vessels, with purse seines catching the smallest fish (Figure 3.10). Purse seines also catch by far the largest numbers of small neritic tunas, scads and other species.

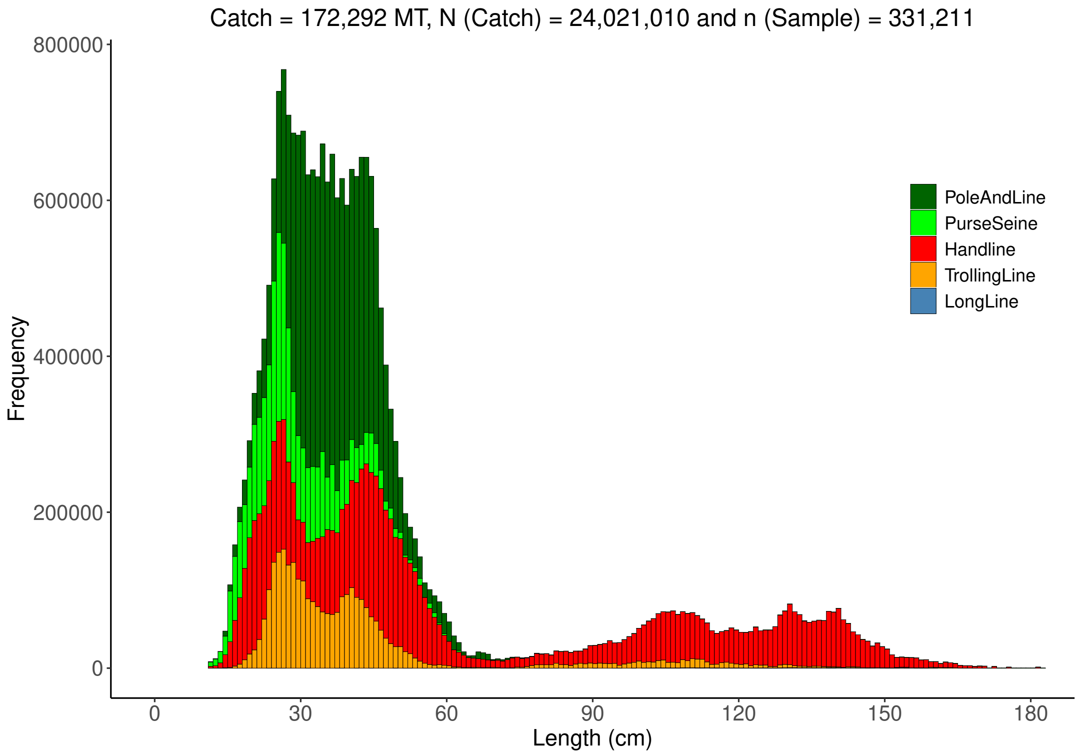


Figure 3.8: *Thunnus albacares* catch length-frequency distribution by gear type in the IAW in 2020

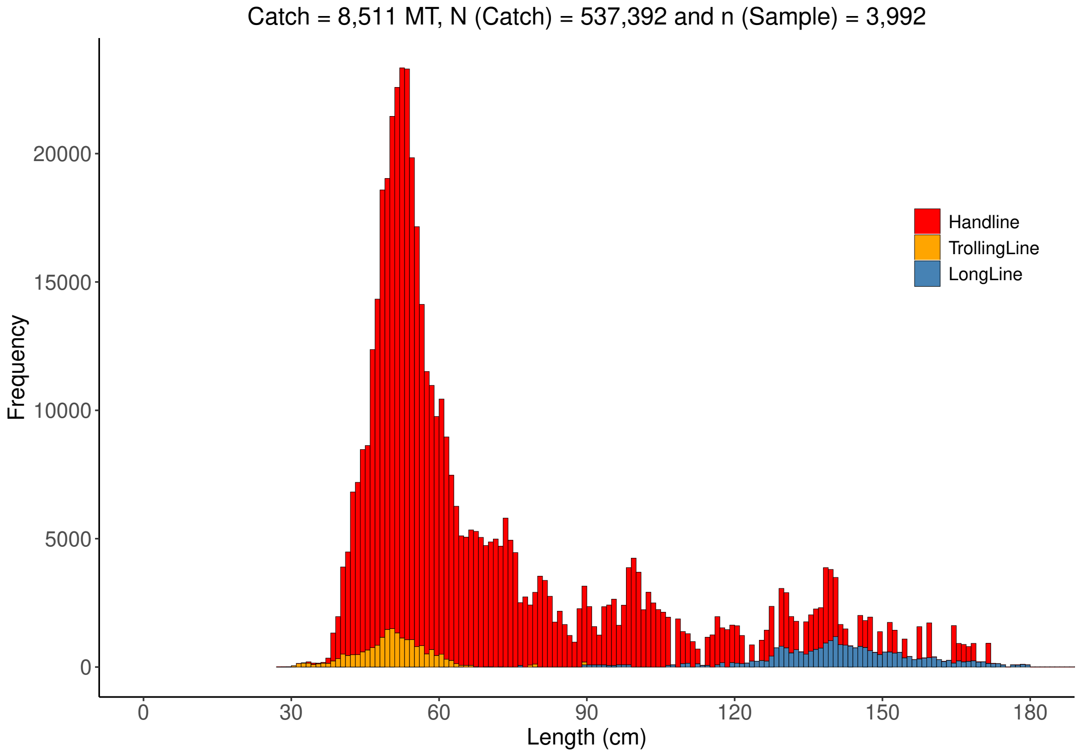


Figure 3.9: *Thunnus obesus* catch length-frequency distribution by gear type in the IAW in 2020

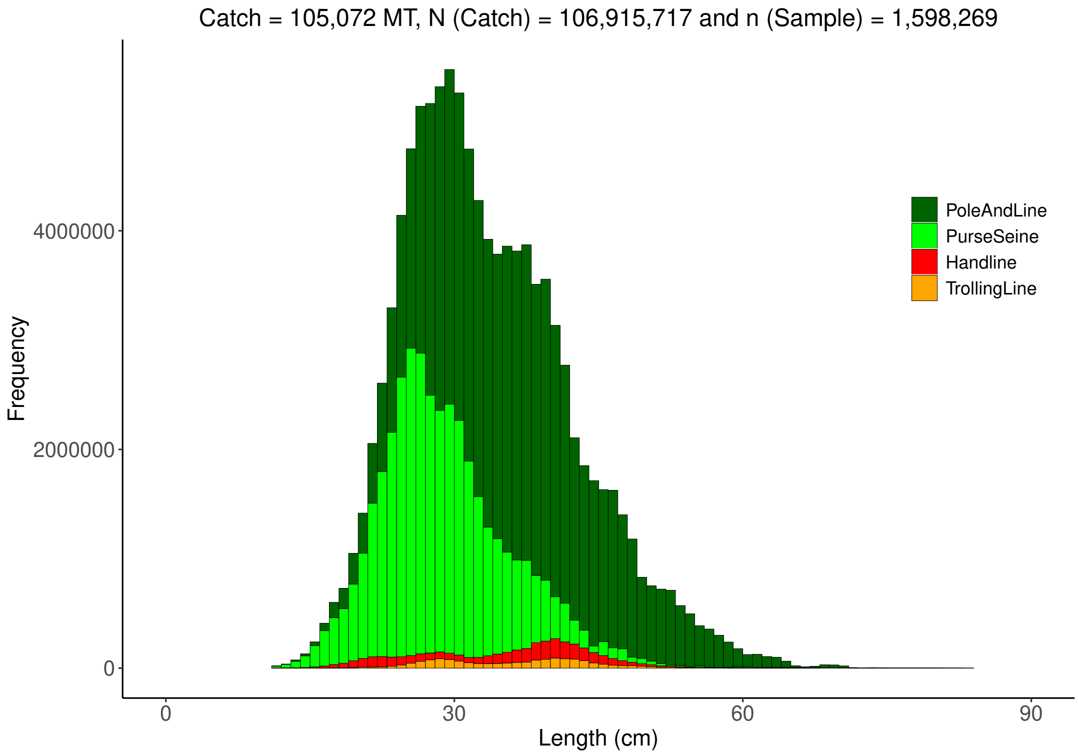


Figure 3.10: *Katsuwonus pelamis* catch length-frequency distribution by gear type in the IAW in 2020

3.3 Growth, maturation and natural mortality of yellowfin & skipjack tuna

3.3.1 Growth and maturation of yellowfin tuna

Age and growth of YFT from the Western and Central Pacific Ocean (WCPO) have been studied in detail on the basis of daily growth increments and tagging data (Lehodey and Leroy, 1999). There is also mention of potentially somewhat faster growth occurring in Philippine waters (Yamanaka, 1990), but slower growth rates have also been reported (Sun et al., 2003). Growth in YFT is not only known to vary between different areas but also between year classes in the same area (Kikkawa and Cushing, 2002). Based on studies of daily growth rings in otoliths, YFT can reach a length of about 30 cm when they are about one quarter of one year old, with fast growth reported especially from Southern Philippine waters (Yamanaka, 1990; Stequert et al., 1996; Lehodey and Leroy, 1999), close to the IAW. In a review of the biology and fisheries for YFT in the Western and Central Pacific Ocean (Suzuki, 1994), the Southern Philippine data (Yamanaka, 1990) are referred to for growth to 57 cm fork length in one year, while White (1982) is referred to for growth up to 64 cm in the first year of life, also for Philippine waters. Within the Lehodey and Leroy (1996) data plots, we can see a concentration of tag and recapture data points close to 60 cm fork length at 1 year of age. This size of close to 60 cm at 1 year (or 4 quarters) of age has also been reported for YFT across different regions (Shuford et al., 2007). Further direct reading of recapture data plots in Lehodey and Leroy (1999) reveals attainment of about 90 cm fork length in 2 years, close to 115 cm in 3 years, and about 135 cm at 4 years of age. After that hardly any data are plotted and just 2 data points for larger fish seem to be available from this specific tag and recapture study.

The growth rate of tagged yellowfin in the length range from about 25 to 100 cm fork length has been reported to be nearly linear (e.g. Wild, 1994), with growth increments of close to 3 cm per month or almost 9 cm per quarter. This results in 1 quarter year old fish (starting at 30 cm fork length) growing to about 57 cm at one year old and 93 cm at 2 years old, in line with readings from tag recapture plots by Lehodey and Leroy (1999). Wild (1986), using daily ring methods for YFT in the eastern Pacific, noted differences in growth rates between sexes in YFT, but showed growth curves to cross one another at around 2 years of age and about 90 cm in fork length. After 2 years of age, the growth in YFT slows down somewhat with about 115 cm obtained at 3 years of age (Yabuta et al, 1960; Lehodey and Leroy, 1999). Less reliable information is available on growth in larger fish, but YFT at 4 years of age seem to be reaching a size of around 135 cm according to tag return plots in Lehodey and Leroy (1999). Zhu et al. (2011) reported YFT in the Pacific Ocean to reach about 160 cm fork length at 6 years of age.

Historical catch length frequency distributions from YFT fisheries show that fish up to 175 cm were common in the past, while fish up to 185 cm fork length and larger have regularly been recorded in the Indo Pacific Oceans (Rohit et al., 2012; Damora and Baihaqi, 2013). A recent study on hand line fisheries in the Banda Sea, in IAW, contained a sample of 4,829 YFT with fork lengths up to 178 cm (Haruna et al., 2018). A sample from YFT landings in East Java in April and May of 2017 was reported to be dominated by very large fish between 151 and 180 cm while 4% of the sample was made up of fish longer than 180 cm (Hidayati et al., 2018). These largest fish can be assumed to be mostly males (Wild, 1986), which are reaching 170 and 175 cm at around 7 to 8 years old respectively (Marsac, 1991; Gascuel et al, 1992). Australian fisheries management assumes longevity of YFT to be around 9 years, with a mean size of 180 cm attained by these fish at that maximum age.

Based on the above review of literature, we are estimating size at age for YFT in IAW starting with 30 cm fork length at an age of one quarter of one year. This is then followed by sizes of about 59 cm at one year and 90, 115, 135, 148, 160, 170 and 175 cm fork length at 2, 3, 4, 5, 6, 7, and 8 years of age respectively. We have not included fish older than 8 years of age or larger than 176 cm fork length in our model. For our model, we fitted a von Bertalanffy growth curve through the above estimated “size at age” points with growth parameters Linf = 200 cm fork length, K = 0.25 per year and t 0 = -0.4 years (Figure 3.11). In comparison, Hampton (2000) found K = 0.25, but a lower Linf of 166 cm, based on length increment data from a tagging study that included 1,629 fish, most of which were recaptured at lengths below 100 cm FL. Rohit et al. (2012) estimated Linf at 197 cm, very close to ours, based on their sample of 6,758 YFT with lengths up to 185 cm from an Indian Ocean fishery.

The mean length at 50% maturity for YFT in the equatorial WCPO was estimated at 104 cm fork length over a range of samples from different areas and gear types (Itano, 2000). A very similar size of 102 cm for length at 50% maturity was estimated for yellowfin from the Indian Ocean (Zudaire et al., 2013) with the maturity threshold in that study defined as the presence of advanced vitellogenic oocytes. Studies from other ocean basins resulted in similar estimates for size at maturity, with for example 99 cm, just slightly smaller than in the Indo Pacific region, reported as the length at 50% maturity for YFT from the Eastern Atlantic (Diaha et al., 2016). Using length-at-age estimates as above, we are therefore assuming here that YFT in the equatorial Indo-Pacific mature during their third year of life, reaching a mean length at maturity (Lmat50%) at about 103 cm fork length and an age of 2.5 years. Following Itano (2000) and Zudaire et al. (2013) we are assuming maturation to start at 2 years of age and 90 cm body length and all YFT to be fully mature at 4 years of age and a body length of 135 cm. The estimated size at 50% maturity is used in our model to calculate SPR.

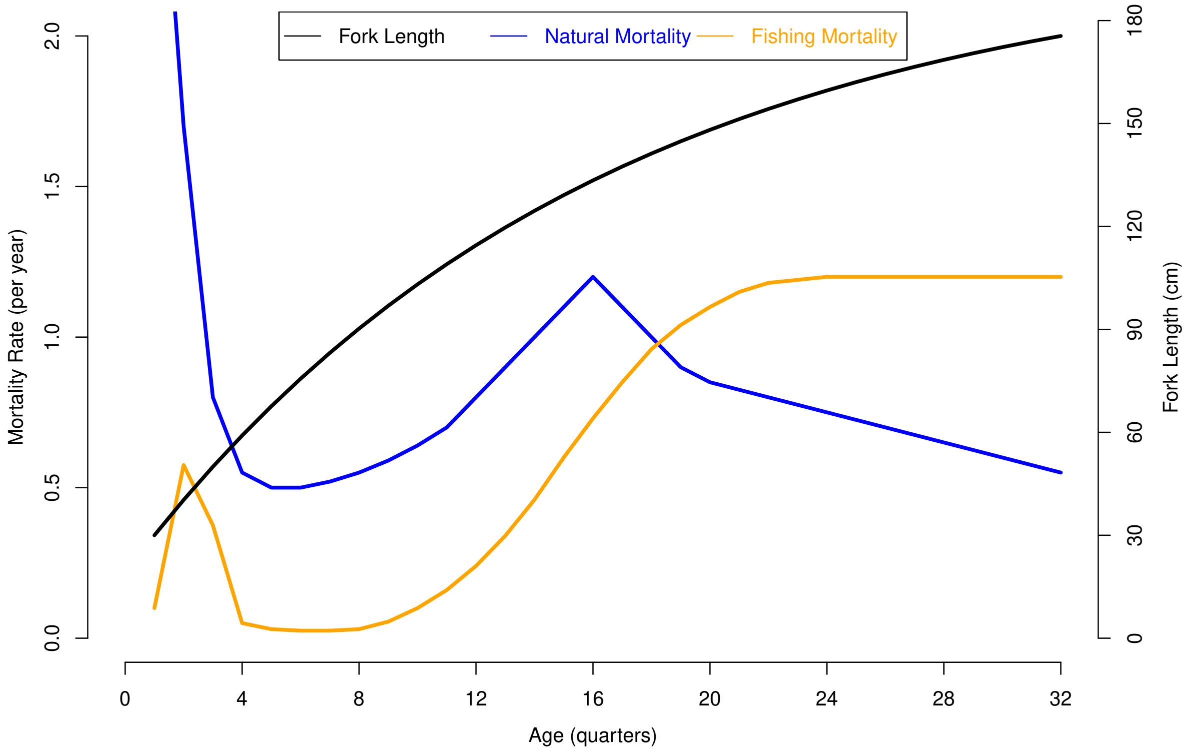


Figure 3.11: Mortality and length-at-age for *Thunnus albacares*

3.3.2 Natural mortality of yellowfin tuna

Natural mortality (M) in YFT depends on body size (Hampton, 2000; Hampton and Fournier, 2001). Like in other pelagic fishes, natural mortality is very high for the smallest size classes, mostly due to predation (Maunder and Aires-da-Silva, 2012). More specific to YFT is the bottoming out of natural mortality when these fish outgrow predation, followed by an increased natural mortality when they reach their size of sexual maturation (Schaefer, 1998; Harley and Maunder, 2003; Maunder and Aires-da-Silva, 2012). Natural mortality in adult YFT is believed to be high among spawning females, resulting in a reduced sex ratio of females versus males among size classes above 135 cm (Schaefer, 1998). In models that do not differentiate between sexes, the overall natural mortality by size group is assumed to be the average over the remaining males and females.

Pauly's empirical formula (Pauly, 1983) using growth parameters as estimated above, results in a value 0.5 per year for M, but this estimate is not size specific. A tagging study in Hawaii (Adam et al., 2003) estimated a value of 0.8 for M in the size class of 46 to 55 cm for YFT, which are about 3 quarters old. The Hawaii tagging study could not provide size specific estimates for M at any resolution for specific size classes above 55 cm (fish of 1 year and older) due to very high outward migration rates and very low tag return rates after only a few months at liberty (Adam et al., 2003). Hampton (2000) however reported an M of 0.44 per year for YFT in the size class 61 to 70 cm in the western tropical Pacific Ocean. Estimates for M in the range of 0.4 to 0.6 per year have also been reported earlier for premature YFT in the Pacific Ocean (Schaefer, 1967; Francis, 1977). For YFT stock assessment in the Indian Ocean, the IOTC used a value of ca. 0.55 per year (Fu et al., 2018; Nishida, et al., 2018) as the minimum level of M in 1 to 2 years old fish, based on tagging data. This level fits well with Hampton's (2000) estimate of M close to 0.5 per year between 1 year and 2 years of age at a fork length of about 61 to 70 cm, assuming an organic shape of the curve for M. Previously, lower estimates of M were used by the IOTC, on the basis of tagging data, with an average of 0.4 per year overall and with the dip in pre- mature natural mortality even further below that (IOTC, 2008). Estimates for overall levels of M were adjusted by the IOTC in 2015 and 2016 stock assessments, after sensitivity analysis and after comparison with levels estimated for the Pacific Ocean (Langley, 2012; 2015 and 2016).

The level of 0.5 per year for 61 to 70 cm YFT (Hampton 2000) comes down from 0.7 per year for 51 to 60 cm fish and about 1.3 per year for 41 to 50 cm YFT, and even higher values for the 30 to 40 cm recruits. Natural mortality in YFT exceeds 1.7 per year for sizes below 40 cm, and 3.0 per year for recruits of 30 cm fork length (Hampton, 2000). After accepting minimal values down to 0.5 for natural mortality to be reached in pre-mature fish, we will adopt a curve of increasing natural mortality with increasing size, attributed to female natural mortality during and after maturation. For pre-mature YFT ranging from 51 to 80 cm fork length, Hampton (2000) reports an average natural mortality level of 0.6 while Itano (pers. comm.) advised to work with an average M of 0.6 for 1- to 2-year old YFT and 0.7 for 3 to 5-year old fish. In a review of natural mortality in YFT, Maunder and Aires-da-Silva (2012) advised that "specifying M for pre-mature YFT at an average M of 0.1625 per quarter (or 0.65 per year) might be prudent", and they refer to Hampton (2000) for that advice. We therefore inferred an average level of 0.6 for M in pre-mature YFT of 4 to 10 quarters. For our model we will adopt a peak in natural mortality at around 16 quarters or 4 years of age, coinciding with 135 cm fork length (Schaefer, 1998).

We adopt an average M of about 1.3 per year for fish between 40 and 50 cm (Hampton, 2000), similar to what is used by the IOTC for 0+ fish of about 2 to 3 quarters old (Nishida et al., 2018; Fu et al., 2018). For 50 cm YFT, aged 3 quarters, we adopt an M of 0.8 per year, as estimated by Adam et al. (2003) for the range of 46 to 55 cm fish. For the size range of 50 to 59 cm (aged 3 quarters to 1 year old) we adopt an average M of 0.7 following Hampton (2000) and for YFT of 1 year old we adopt an estimated M of 0.55 (Nishida et al., 2018). Further following Hampton (2000), we adopt an M of 0.5 on average for YFT from 59 to 68 cm (4 to 5 quarters), with a lowest value for M at 0.5 at an age of 5 to 6 quarters. Natural mortality then rises again to a value of 0.55 per year at 2 years of age (Nishida et al., 2018) and maturing YFT are assumed to reach an M of about 0.8 per year at 3 years of age, at a fork length of 115 cm. For pre-mature fish between 59 and 103 cm (1 to 1.5 years old) the resulting curve (Figure 3.11) leads to an average M of around 0.6 per year (as per Itano, pers. comm.). For maturing fish from 2 to 3 years old, between 90 and 115 cm, this curve leads to an average M of 0.7 per year.

Natural mortality in Pacific YFT is assumed to increase from about 0.8 per year at 3 years of age to an estimated 1.2 per year for the combined sexes, at around 4 years of age and a size of 135 cm fork length (Maunder and Aires-da-Silva, 2012; Tremblay- Boyer et al., 2017). A significantly lower level in the peak of natural mortality in YFT is assumed however in stock assessments of YFT in the Indian Ocean (Fu et al., 2018). Estimated natural mortality of YFT in the WCPO (Tremblay-Boyer et al., 2017) drops again for fish older than 4 years, but remains at an average level of around 0.8 per year for fully matured YFT of combined sexes. For further comparison, the resulting average natural mortality by age and size group from the curve we have adopted for our model (Figure 3.11) is as follows:

- M(avg) = 2.4 per year for YFT of 1 to 2 quarters old juveniles (30 to 40 cm FL),
- M(avg) = 1.3 per year for YFT of 2 to 3 quarters old juveniles (40 to 50 cm FL),
- M(avg) = 0.7 per year for YFT of 3 to 4 quarters old juveniles (50 to 59 cm FL),
- M(avg) = 0.5 per year for YFT of 4 to 5 quarters old juveniles (59 to 68 cm FL),
- M(avg) = 0.6 per year for YFT of 4 to 10 quarters pre-matures (59 to 103 cm FL),
- M(avg) = 0.7 per year for YFT of 8 to 12 quarters old maturing (90 to 115 cm FL),
- M(avg) = 0.8 per year for YFT of 10 to 32 quarters matures (103 to 176 cm FL).

And a length based natural mortality curve was adopted as follows:

- 30 - 40 cm FL (1 to 2 quarters): M(avg) = 2.4 per year,
- 40 - 50 cm FL (2 to 3 quarters): M(avg) = 1.3 per year,
- 50 cm FL (45 to 55 cm, 3 quarters) M(avg) = 0.8 per year,
- 50 - 59 cm FL (3 to 4 quarters): M(avg) = 0.7 per year,
- 55 - 65 cm FL (ca. 4 quarters): M(avg) = 0.6 per year,
- 59 - 68 cm FL (4 to 5 quarters): M(avg) = 0.5 per year,
- 50 - 83 cm FL (3 to 7 quarters), pre-mature fish: M(avg) = 0.6 per year,
- 90 - 115 cm FL (2 to 3 years), maturing fish: M(avg) = 0.7 per year,
- 103 - 176 cm FL (2.5 to 8 years), mature fish: M(avg) = 0.8 per year.

3.3.3 Growth, maturation and natural mortality of skipjack tuna

Skipjack tuna in the Western and Central Pacific Ocean are reported to recruit to the population as 1 quarter year old at about 23 cm FL (Vincent et al., 2019) and they reach 45 cm FL at one year and 65 cm at 2 years of age (Tanabe et al., 2003). Mean length-at-age increases quickly until about 2 years of age and 65 cm FL, after which growth slows down to reach 77 cm FL at 3 years of age, until reaching a length of about 85 cm in 4 years old fish (Vincent et al., 2019). Our model includes fish op to 5 years old and 90 cm FL only. For our model, we have fitted a von Bertalanffy growth curve through the above estimated “size at age” points with growth parameters Linf = 99 cm fork length, K = 0.45 per year and t 0 = -0.35 years (Figure 3.12). Skipjack tuna reaches maturity around 50 cm FL in the WCPO (Ohashi et al., 2019; Vincent et al., 2019) including the IAW specifically (Susanto and Lumingas, 2014) and thus we are using 50 cm as the Lmat(50%) in our model for Skipjack tuna.

Estimates of natural mortality rate were based on a size-structured tag attrition model (Hampton, 2000), which indicated that natural mortality was substantially larger for small skipjack (21-30 cm FL) compared to larger skipjack (51-70 cm FL). The longest period at liberty for a tagged skipjack to date was 4.5 years. Based on these tagging data and after further modeling, a complete estimate for natural mortality at age was obtained for a stock assessment of skipjack tuna in the Western and Central Pacific Ocean (Vincent et al., 2019) and we have used these estimates directly for our model. Natural mortality of skipjack tuna in the Western and Central Pacific is estimated to be high at almost 2.5 per year for one quarter old recruits and 2.25 for 2 quarter old fish, and then decrease until ages 6 to 8 quarters by about half, before moderately increasing again with increasing age (Figure 3.12).

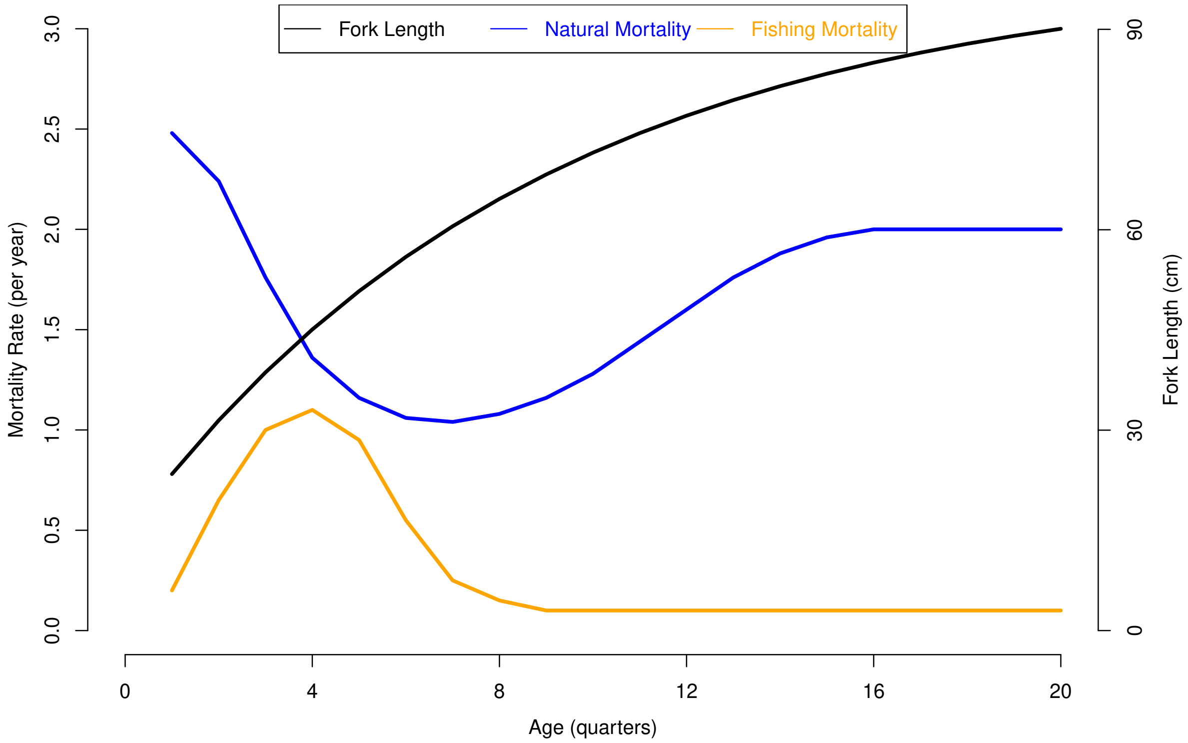


Figure 3.12: Mortality and Length at Age for Katsuwonis pelamis

3.4 Selectivity and fishing mortality in IAW tuna fisheries

To understand selectivity and fishing mortality in YFT in the IAW we have to recognize two distinct types of YFT fisheries operating in these waters. The first type includes the various fisheries for “baby tuna”, which is a trade name for small YFT (Nurani et al., 2014). The term “baby tuna” is widely used in Indonesia as a the trade name for very small YFT, sometimes mixed with BET, and the term is also used in some Indonesian fisheries regulations (MMAF, 2015). However, since size limits to this category are not always clear and we need to prevent using “emotive” terms in this report, we will use the term “small tuna” for the size category 15-65 cm fork length in our reporting. We will refer to “medium YFT” for the size category 66 to 106 cm fork length and to “large YFT” for the fish of 107 cm and larger. Fisheries for “small tuna” target 1 quarter to 1- year old juveniles with individual body weights of about 0.1 to 6 kg and a length range of about 15 to 65 cm fork length (Figure 3.8). These fisheries, especially the hand line fisheries with small hooks, also yield a significant number of small bigeye tuna (Figure 3.9).

The most important gear types in the small tuna fisheries include pole-and-line, small purse seines, and handlines and trolling lines with multiple small hooks. All of these gear types are used around FADs as well as around free surface schools. Pole-and-line fisheries are targeting both small tuna and SKJ, often in an opportunistic approach, simply going for the schools of small tuna and/or SKJ they run into first. None of the fleet segments in the IAW is currently exclusively targeting SKJ. Purse seiners as combined fisheries are targeting a wide range of small pelagic species, including SKJ and small tuna, but also *Euthynnus*, *Auxis*, *Decapterus*, *Rastrelliger*, *Sardinella*, and other small pelagics. Hook and line gear with multiple small hooks (hand lines and trolling lines) are targeting both small YFT and SKJ.

Gear types targeting small tuna are characterized by similar selection curves, jointly peaking somewhere between 30 cm and 45 cm FL, before fish reach 1 year of age, and dropping off sharply after that (Ernawati et al., 2018; Bailey et al., 2013). Differences in selectivity do exist though, and YFT and SKJ from purse seine catches are significantly smaller than from pole-and-line. Median sizes are both well under the size of maturity for both species in both these types of gear. Combined selectivity curve over all gear types targeting small tuna is somewhat similar to the individual curves, but significantly wider due to differences between the types of gear. Selectivity for all gear types targeting small tuna drops to very low levels by the age of 4 to 5 quarters for YFT (Davies et al., 2014).

The second important group of YFT fisheries in IAW are the fisheries for large YFT (Haruna et al., 2018), targeting adult fish with individual body weights larger than 25 and up to 110 kg, with sizes ranging from 107 cm to 175 cm fork length for those weights. These are mature fish, with ages ranging from just over 2.5 years to 6 or 7 years old. Important gear types in these fisheries, often used around FADs, on seamounts, and around dolphin pods, include deep droplines and drift lines with single large hook and large natural baits, trolling lines with large baited hooks or lures, surface handlines with live baits or dead baits under kites, and long lines with multiple large hooks and natural baits. Selectivity in the combined fisheries for large YFT rises sharply from about 3 years old when the fish measure about 115 cm (Ernawati et al., 2018; Davies et al., 2014). Handlines are catching most of the large YFT in the IAW.

A third category of tuna fisheries in the IAW can be described as harvesting medium YFT (Haruna et al., 2018), mainly juveniles, 1 year to 2.5 years old, weighing between 6 and 25 kg and measuring somewhere between 66 and 106 cm fork length. These fish are mainly just bycatch in the various hook-and-line fisheries. Medium-sized YFT are sometimes targeted specifically, when they are encountered in much greater numbers than small tuna or large YFT. Due to differences in price per kg though, fishers using various kinds of handlines prefer to target larger YFT, while pole-and-line as well as purse seine operations can fill their holds much quicker by targeting dense surface schools of small tuna or SKJ when these schools are present. It is often assumed (Lewis, pers. comm.) that catchability (availability to the gear) is significantly reduced for medium YFT compared to small tuna and large YFT, for reasons not well understood.

The shape of the overall selectivity curve for YFT in IAW, after combination of the selectivity curves for small tuna and large YFT, becomes a bimodal curve, as was also reported for the Philippines with all gears combined (Davies et al, 2014). A bimodal selectivity curve is also directly following from the combination of various selectivity curves reported for IAW (Ernawati et al., 2018), although peak selectivity for large YFT fisheries in Indonesia may be underestimated in some models. A bimodal shape of the overall selectivity curve has also been reported for other tuna fisheries, such as for example for Eastern Atlantic bluefin tuna (Restrepo et al., 2007).

For YFT fisheries in the Indian Ocean, the IOTC estimates F at over 0.6 per year for large YFT over all regions and gear types, with F peaking between ages of 15 and 24 quarters (Fu et al., 2018). When separated by region, a clearly higher F of at least 0.7 or up to 0.8 for large YFT is estimated for IOTC region 4, eastern equatorial, which includes Indonesia. The IOTC specifically notes that overall magnitude of the decline in YFT biomass is substantially higher in IOTC region 4 than in other regions (Fu et al., 2018). Even higher fishing mortality for YFT than described above for the eastern equatorial Indian Ocean, was reported for 2017 from the Eastern Pacific Ocean (Minte-Vera et al., 2018) with F = 0.4 for age groups of 1-10 quarters, F = 1.0 for age groups of 11-20 quarters and F = 0.8 for age groups of 20 quarters and above.

Total mortality for large YFT in Indonesia was reported for the Banda Sea and for EEZ waters south of Java. Total mortality Z was estimated at 1.5 from catch curve analysis over a large sample of hand line caught large YFT from the Banda Sea (Haruna et al., 2018). With an estimated M of 0.8 for large YFT as described above, this leads to an estimated F of 0.7 for these fish in IAW. For the south coast of Java, F was estimated at around 0.6 for large YFT (Nurdin et al., 2016). For large YFT from the Pacific Ocean a total mortality (Z) from catch curve analysis was estimated at 1.6 (Zhu et al., 2011) and this would lead to an estimated F of 0.8 using again the M of 0.8 as above. Davies et al (2014) reported F at 0.4 and sharply on the increase for adult YFT already in 2012 over all regions combined in the WCPO, with relatively much higher F reported from Indonesia and the Philippines.

WCPFC estimates F = 0.3 for juveniles as well as for adults by 2016 for the WCPO. A higher level and extremely sharp increase are shown for F in recent years, especially for adults, in WCPFC YFT region 7, which includes the IAW (Tremblay-Boyer et al., 2017). The estimated F for adults in YFT region 7 of the WCPO was exceeding 0.4 by 2016. Davies et al (2014) showed F at 0.4 and sharply on the increase for adult YFT in the WCPO by 2012 and Hampton et al. (2006) estimated F in the WCPO to exceed 0.6 for some age groups already by 2004. The shape of the F curve with separated peaks in fishing mortality for juveniles and adults is showing in YFT assessments for the WCPO since 2012 (Tremblay-Boyer et al., 2017). WCPFC stock assessments note that "A significant component of the increase in juvenile fishing mortality is attributable to the Philippines, Indonesian and Vietnamese surface fisheries" (Tremblay-Boyer et al., 2017).

Fishing mortality (F) is a combination of selectivity, catchability (availability to the gear) and fishing effort. We used the fitted curve and level of the F by age group as input for our models for YFT and SKJ (Figures 3.11 and 3.12). We fitted F by age and size group by comparing model outcomes for catch curves to actual catch curves as recorded by the CODRS program. For this, we use the total reconstructed catch curves by species, based on detailed information on catch curves by gear type and boat size category in combination with relative effort of each fleet segment as explained above. Keeping in mind information on selectivity, catchability, and fishing effort, we have fitted a curve for F by age group based on comparisons between modelled and recorded catch curves of YFT from the IAW specifically (Figure 3.14). The resulting average fishing mortality by age and size group of YFT, from the curve we have adopted, is as follows:

- F(avg) = 0.28 per year for small tuna of 1 to 4 quarters old (30 to 59 cm FL),
- F(avg) = 0.04 per year for medium YFT of 5 to 10 quarters old (68 to 103 cm FL),
- F(avg) = 0.14 per year for juvenile YFT of 1 to 10 quarters old (30 to 103 cm FL),
- F(avg) = 0.95 per year for large YFT of 11 to 32 quarters old (109 to 176 cm FL).

Estimated fishing mortality for SKJ in the IAW was also obtained from fitting to the complete reconstructed observed catch curve (Figure 3.26), and for small and medium sized SKJ (1 to 4 quarters) this fishing mortality is higher than what we found for small tuna in the same age group. This is possibly because fast and large growing YFT can quickly (before reaching one year of age) “grow out” of the selection curve of the combined fisheries targeting small tuna and SKJ, whereas SKJ remains vulnerable to those fisheries (mainly pole-and-line and purse seine) for the full first year of its life, throughout the limited boundaries of the IAW. Size dependent fishing mortality for SKJ follows a dome shaped curve for fish up to 60 cm and then remains low for larger SKJ, which seem to be much less available to the gear similar to medium sized YFT of the same size range which also experience relatively low fishing mortality in the IAW. The following estimated average fishing mortality by age and size group for SKJ resulted from our fitting procedure:

- F(avg) = 0.4 per year for Small SKJ of 1 to 2 quarters old (23 to 31 cm FL),
- F(avg) = 1.1 per year for Medium SKJ of 3 to 4 quarters old (39 to 45 cm FL),
- F(avg) = 0.2 per year for Large SKJ of 5 to 20 quarters old (51 to 90 cm FL).

3.5 Length-based stock assessment for yellowfin tuna

The overall catch size frequency distribution for YFT from the IAW (Figure 3.13), based on CODRS data from 2020, shows a very large proportion of small juveniles (88% of individuals) in the catch. With an optimum harvest size of 106 cm, just above the size at maturity of 103 cm, the bulk of the catch in terms of individual fish is caught well below that optimum size. The median size in the catch curve is only 38 cm FL, which is the size of a recruit less than 2 quarters old. Fish below and just around the median size still experience an extremely high natural mortality, but fish from 50 cm onwards, about 3 quarters old and older, already experience relatively low natural mortality. This raises the question what economic benefits could be had from letting these fish grow to a larger size, where prices per kg will be higher. We addressed that question in section 4 of this report.

The CODRS program measured 331,211 YFT and on the basis of effort information we reconstructed an overall catch curve comprising 24,020,765 individuals. Based on the overall catch curve, the total YFT catch from the IAW was estimated at 172,286 MT, including 24,918 MT small tuna, 20,906 MT medium YFT and 126,461 MT of large YFT. Fishing mortality currently mainly affects small tuna of 30 to 60 cm, far below the optimum harvest size, and large YFT, around and above the optimum harvest size (Fig. 3.14 and 3.15).

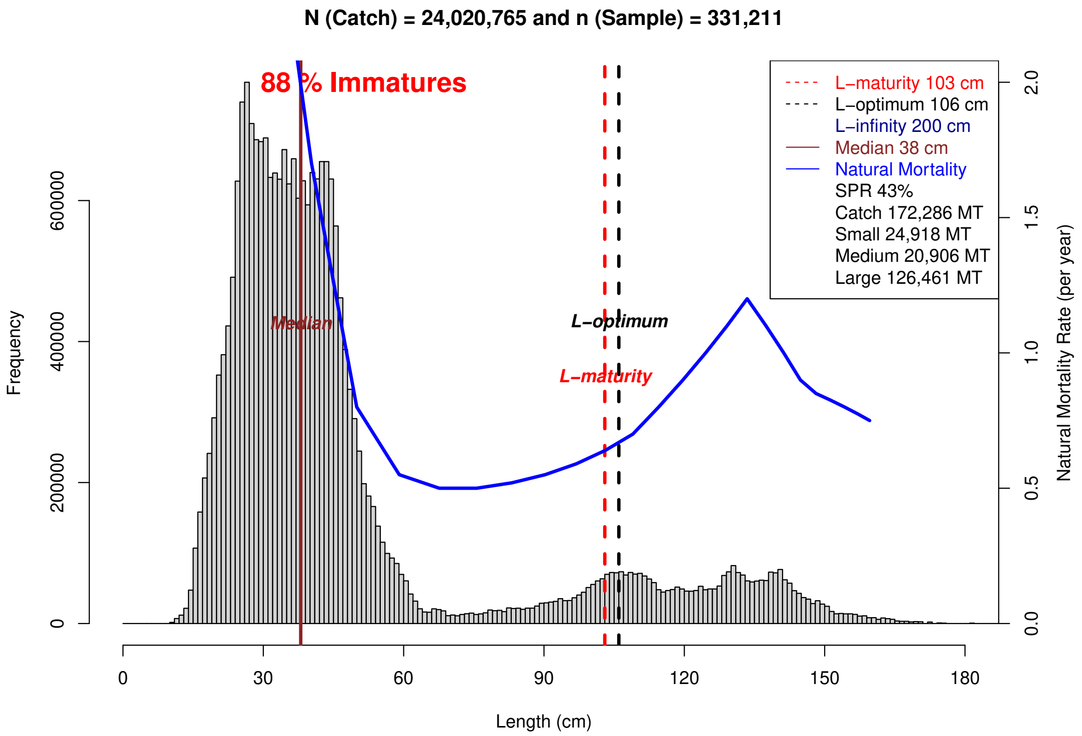


Figure 3.13: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, all gear types combined.

The length-based stock assessment for YFT is based on the overall catch curve from the IAW, combining information from all segments of the fleet that operates here. By fitting fishing mortality until a modelled catch curve best represented the shape of the actual recorded catch curve from CODRS data, we could estimate the Spawning Potential Ratio (SPR). For YFT in the IAW we thus estimated an SPR of 43%, so just above our target reference point of 40%, and thus achieving management objectives. It is however clear that spawning biomass can still be improved somewhat in this area, while the main question remains on potentially higher economic benefits from a fishery with more large and valuable fish in the population. The estimated SPR of 43% for YFT in the IAW is in line with the SPR reported for YFT Region 7 of the WCPO, one of the most depleted regions, according to a recent stock assessment by WCPFC (Vincent et al., 2020). The SPR of 43% is well below the average reported for the wider WCPO in the same assessment.

Looking at separate catch size frequencies and catch contributions by gear type for YFT, we see that pole-and-line contributes the largest part of the small tuna catch from the IAW, with 11,421 MT or 46% of small tuna in 2020 (Fig. 3.16). Purse seine contributed 2.258 MT or 9% in that same year (Figure 3.17), while handline and trolling line contributed the remaining 45%.

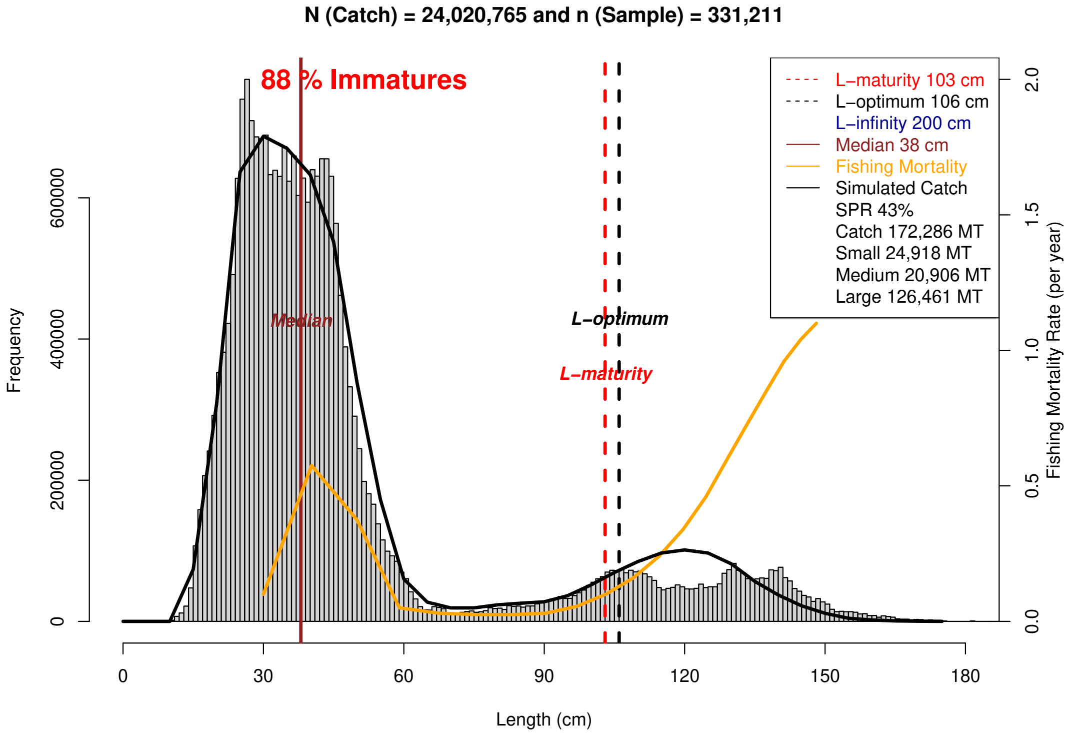


Figure 3.14: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, all gear types combined.

Figure 3.15: Yellowfin tuna by size category
(from the top: small tuna, medium-size tuna, and large tuna).

Pole-and-line and purse seine catches of YFT comprise 100% of immature fish, while some forms of handline and trolling line also produce larger YFT (Figures 3.18 and 3.19). For the latter two gear types it is the versions with multiple small hooks, often used with artificial feather like lures, which produce most of the small tuna (Fig. 3.20 and 3.21). Longlines catch almost exclusively large and mature yellowfin and bigeye Tuna (Fig. 3.22 and 3.23).

Pole-and-line catches small tuna in a narrow size range between 25 and 50 cm FL, from pre-recruits less than 1 quarter to about 3 quarters old, with a median size of just 37 cm FL and less than 6 months old. The largest fish in the pole-and-line catch are already experiencing a reduced natural mortality though, and would contribute significantly to spawning biomass if left to grow. Purse seine catches relatively small numbers of significantly smaller of small tuna in a range between about 20 and 40 cm FL and with a median size of only 27 cm, which is smaller than the size at recruitment used in WCPO and our own stock assessments. These very small fish are still experiencing very high rates of natural mortality and their extraction may only be causing a relatively small impact on spawning biomass. We will explore the comparison of impact from pole-and-line versus purse seine fisheries on YFT and SKJ stocks further in Chapter 5 and discuss implications for management also there.

With 144,428 MT in 2020, various types of handlines produced by far the largest part of the YFT catch volume in the IAW (Fig. 3.18), and the bulk of that catch (by weight) consisted of large adult fish. In terms of numbers though, 70% of the individual fish caught by handlines were immature fish and the median size in the handline catch in 2020 was only 50 cm FL. Looking closer at the various types of handline gears in the IAW, the vast majority of the small tuna from handline is caught with dedicated gear for small fish, with multiple small hooks and artificial baits (Fig. 3.20). Examining monthly catch size frequencies for this gear, there was no apparent modal progression (Fig. 3.24). It appeared that small tuna was available throughout the year, and this indicates that spawning was continuous, with some spawning events being more successful than others, causing irregular patterns over time. Trolling lines contributed a smaller amount of 12,931 MT to the YFT catch in 2020 (Fig. 3.19), with dedicated multiple small hook types with artificial lures catching mostly small tuna (Fig. 3.21). Longlines catch a relatively small amount of large YFT in the IAW as well as a slightly larger amount of large BET (Fig. 3.22 and 3.23).

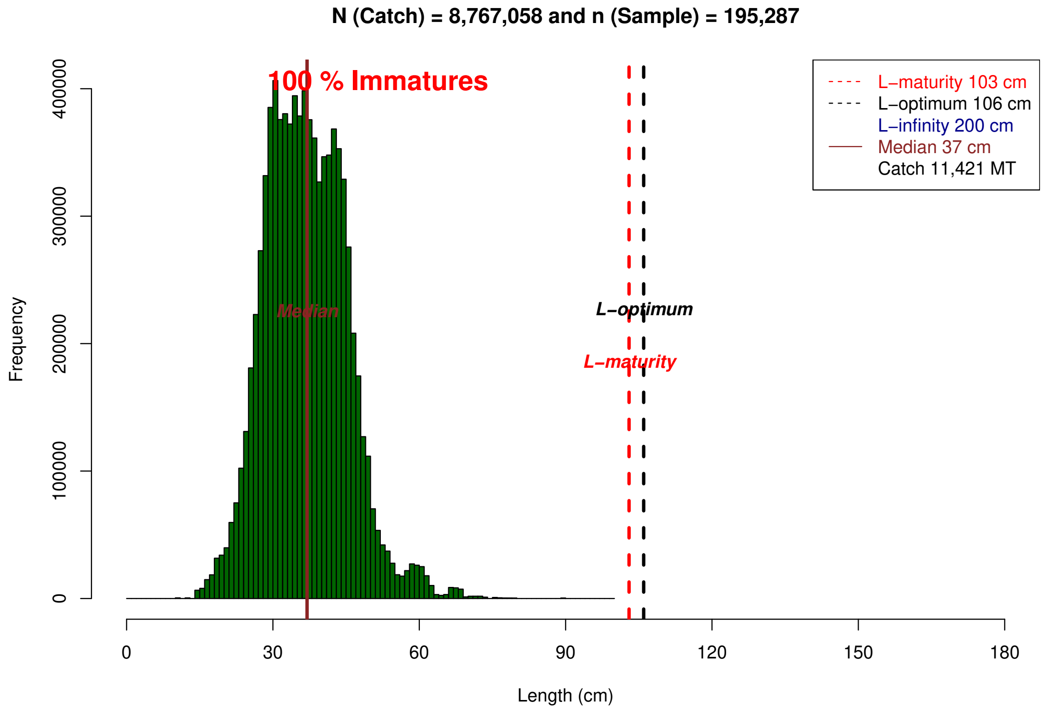


Figure 3.16: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, pole-and-line.

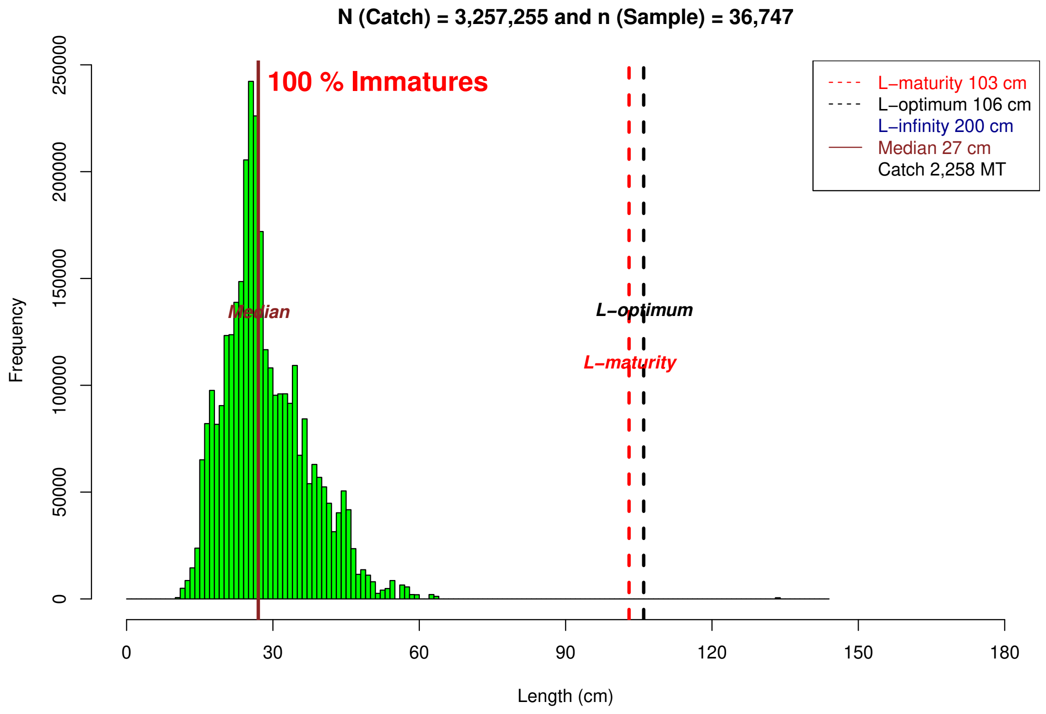


Figure 3.17: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, purse seine.

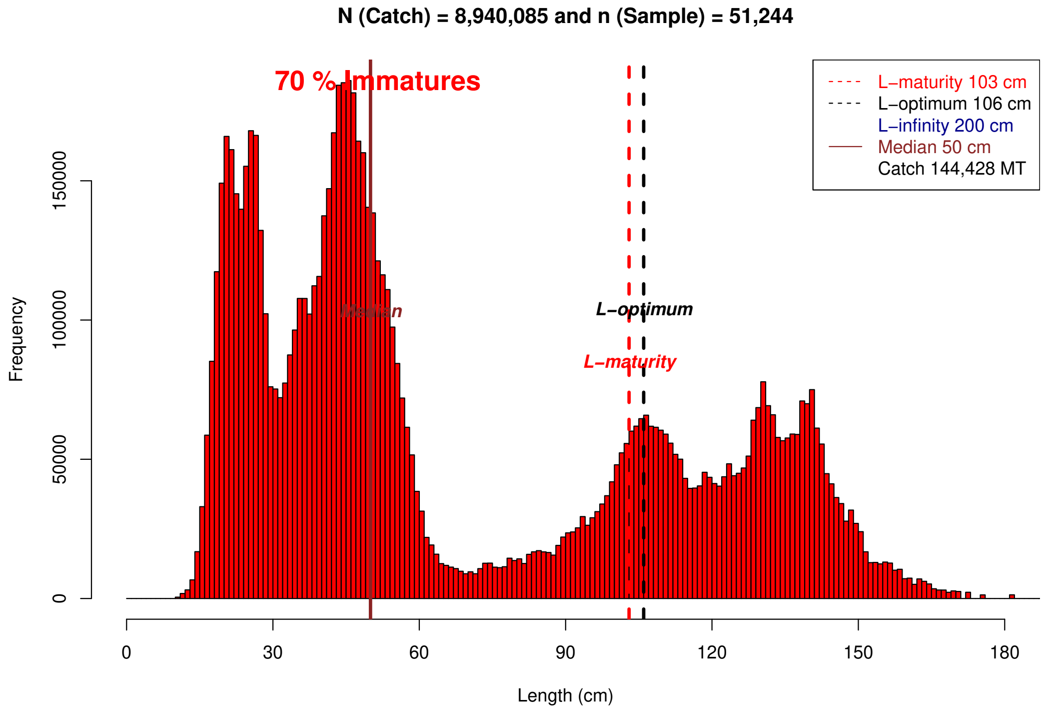


Figure 3.18: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, handline.

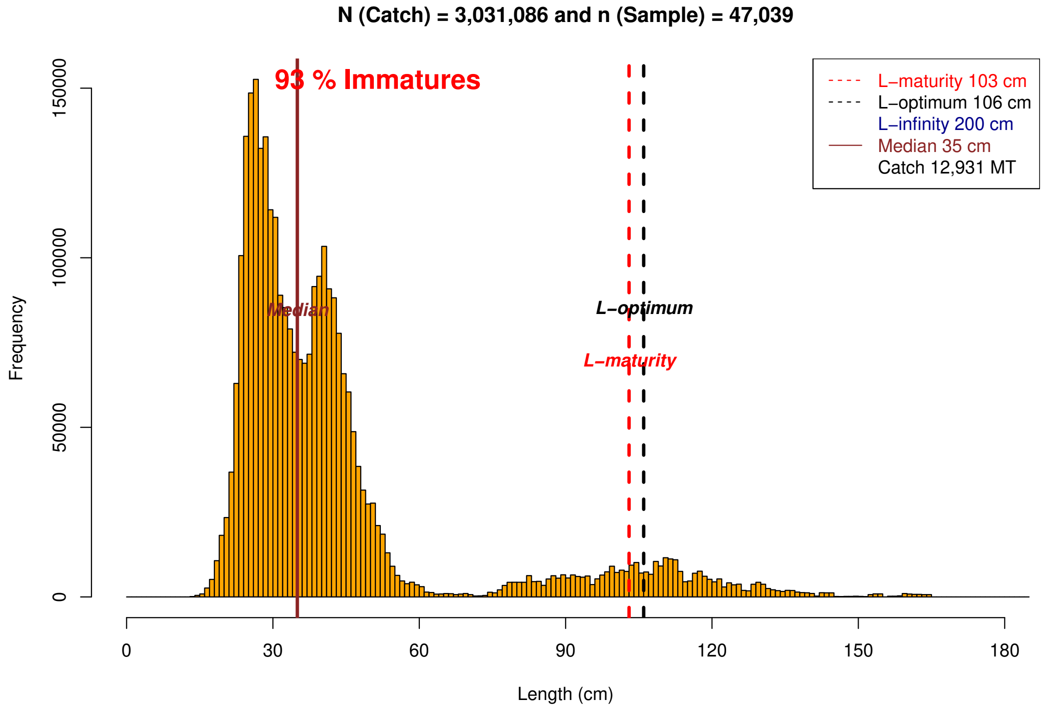


Figure 3.19: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, trolling Line.

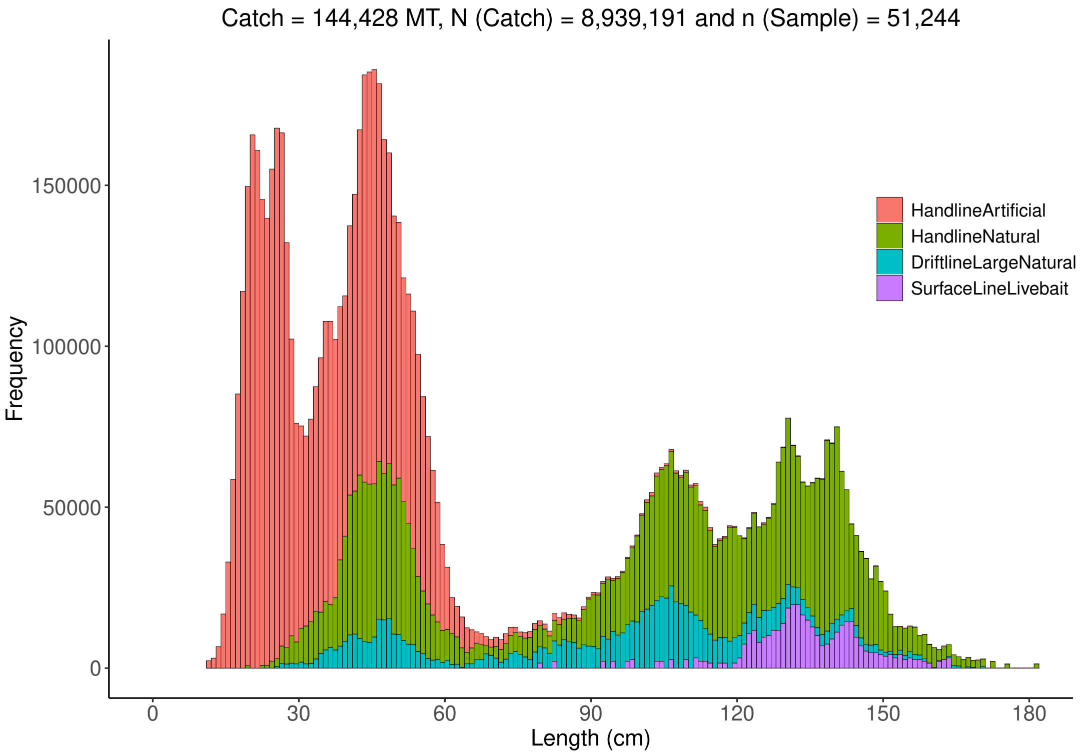


Figure 3.20: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, by gear types in handline category.

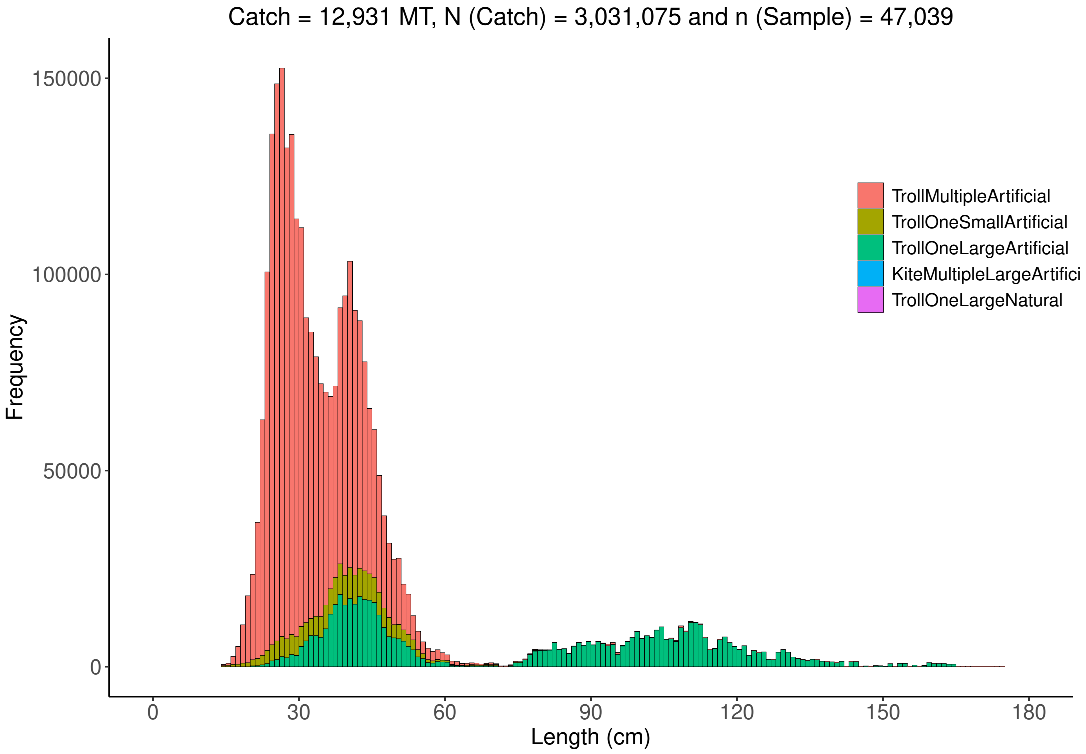


Figure 3.21: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, by gear types in the trolling line category.

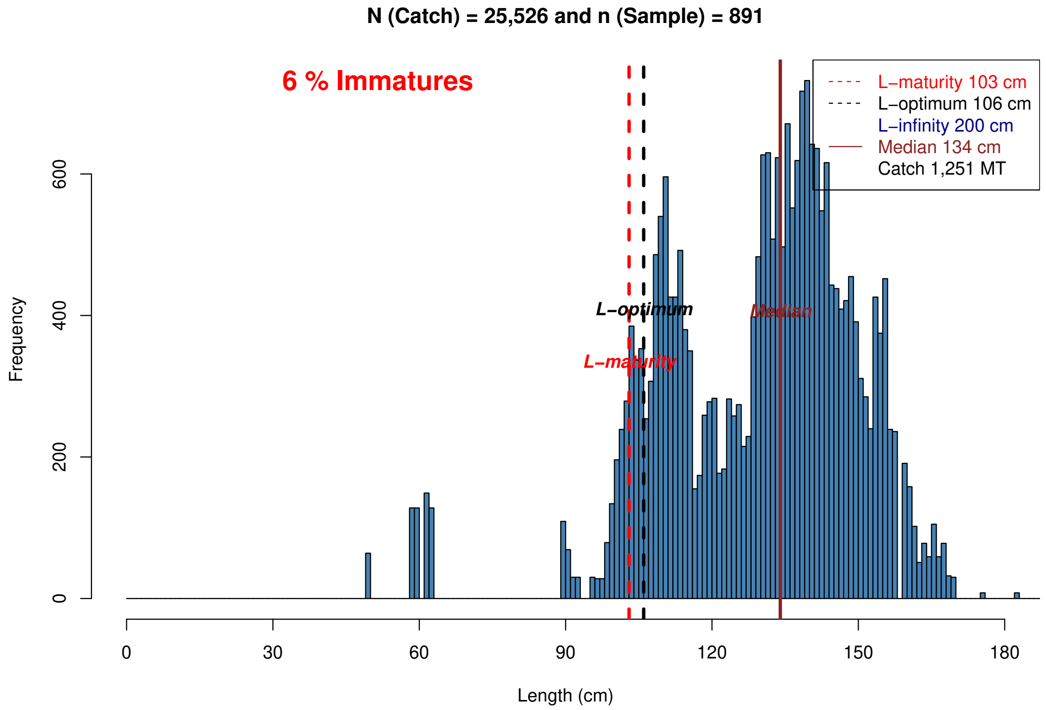


Figure 3.22: Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, longline.

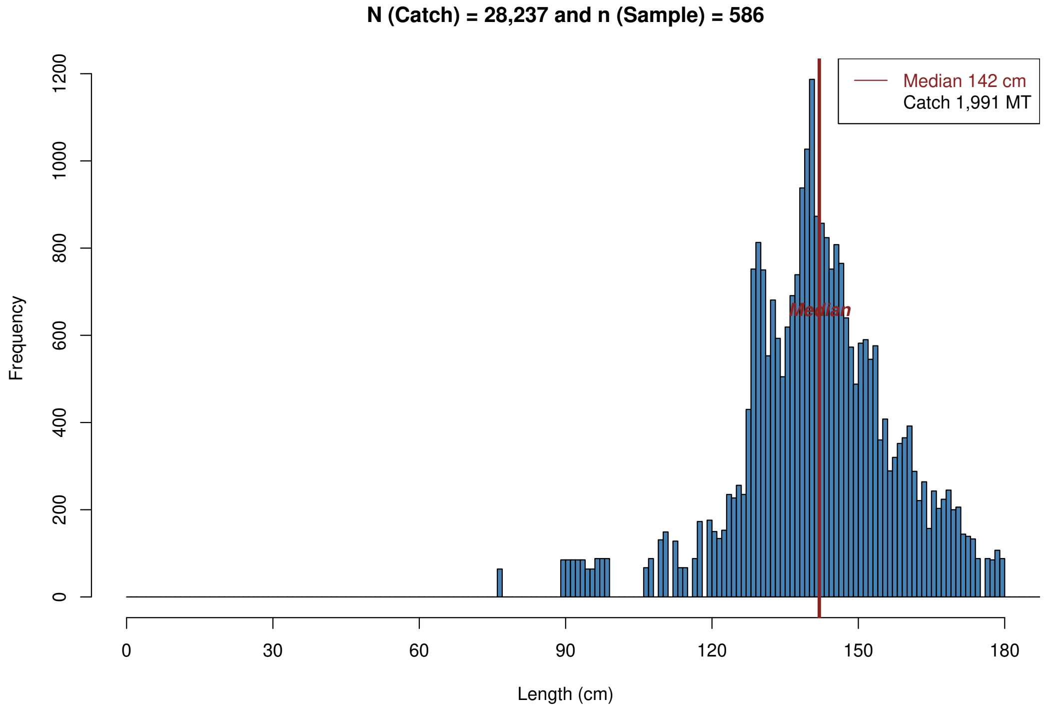


Figure 3.23: Catch size frequency distribution of *Thunnus obesus* in the IAW in 2020, longline.

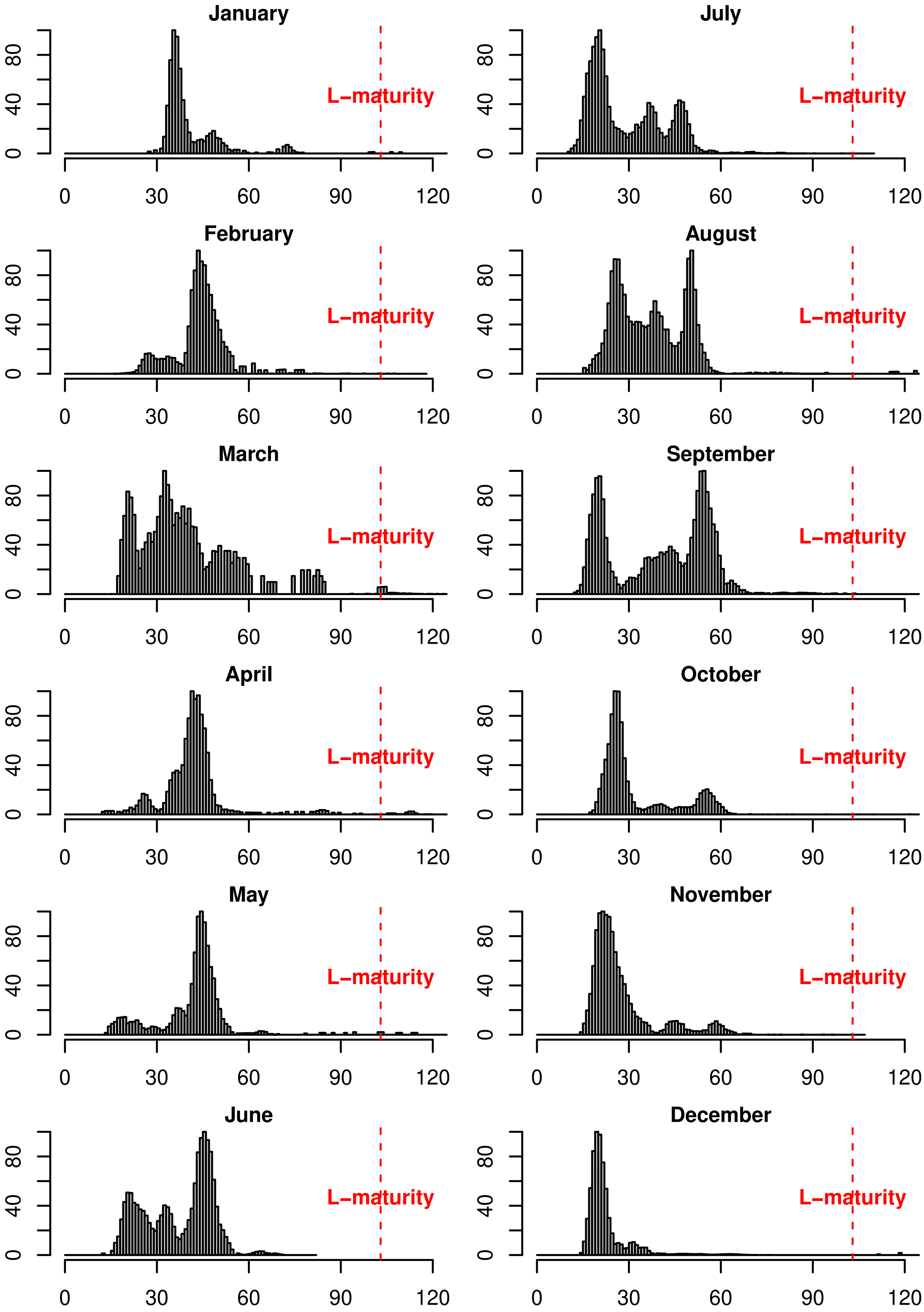


Figure 3.24: Relative Catch size frequency distribution of *Thunnus albacares* in the IAW in 2020, handlines with artificial baits.

3.6 Length-based stock assessment for skipjack tuna

The overall catch size frequency distribution for SKJ from the IAW (Figure 3.25), based on CODRS data from 2020, shows an extremely large proportion of small juveniles (94% of individuals) in the catch. With an optimum harvest size of 55 cm, just above the size at maturity of 50 cm, almost the entire catch in terms of individual fish is caught well below that optimum size. The median size in the catch curve is only 33 cm FL, at which size the SKJ is just over 6 months old. Fish below and just around the median size still experience a very high natural mortality, but SKJ from 40 cm onwards, about 3 quarters old and older, already experience relatively low natural mortality. This raises the question what benefits could be had from letting these fish grow to larger size before harvest, through reduction of fishing mortality. It would seem that each cohort could contribute much more to the adult (spawning) biomass, if the SKJ fishery were rationalized through a reduction of effort, aiming to provide at least the same revenues but at much lower costs, through increased CpUE and better prices for larger fish. We have addressed this question in Section 4.4.

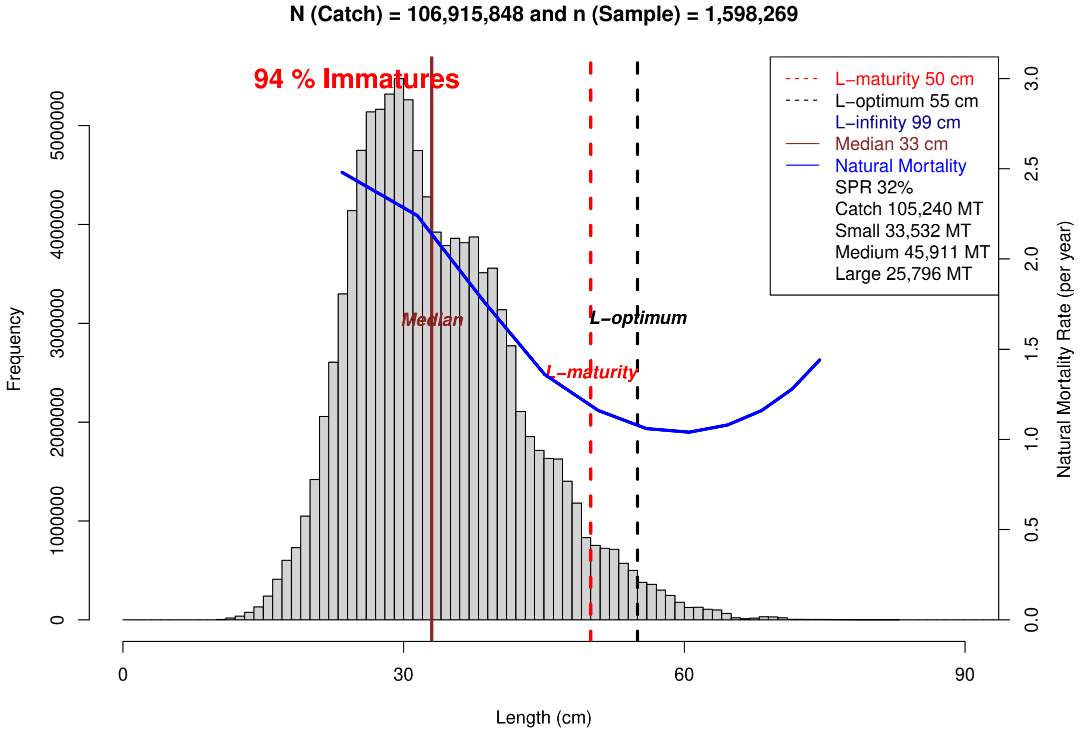


Figure 3.25: Catch Size Frequency Distribution of Katsuwonis pelamis in the IAW in 2020, all gear types combined.

The CODRS program measured a sample of 1,598,269 SKJ, and on the basis of effort information we reconstructed an overall catch curve including 106,915,848 individuals. Based on the overall catch curve, the total SKJ catch from the IAW was estimated at 105,240 MT, including 33,532 MT small SKJ, 45,911 MT medium SKJ and just 25,796 MT of large SKJ. Fishing mortality currently affects all size classes in the population of SKJ, starting at a high level of 0.65 per year already for 6 months old SKJ recruits of 31 cm FL and rising to 1.1 for 1 year old fish. Each cohort is decimated by fisheries well before it reaches the optimum harvest size (Fig. 3.26). Large adult SKJ, around and above the optimum harvest size, are rare in the catch (Fig. 3.27).

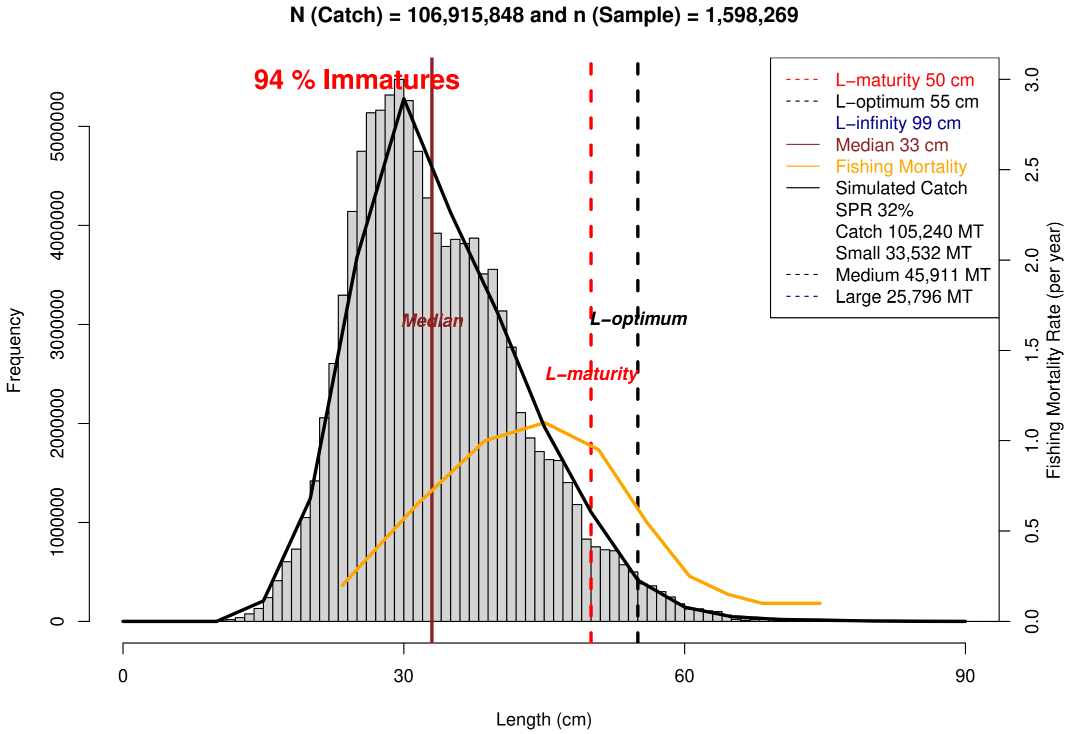


Figure 3.26: Catch size frequency distribution of *Katsuwonis pelamis* in the IAW in 2020, all gear types combined.

Figure 3.27: Skipjack Tuna by size category (from the top: small, medium and large).

The length-based stock assessment for SKJ is based on the overall catch curve from the IAW, combining information from all segments of the fleet that operates there. By calibrating fishing mortality until the modelled catch curve best fitted the shape of the actual recorded catch curve from CODRS data, we estimated the Spawning Potential Ratio (SPR) for SKJ in the IAW at 32%, well below our target reference point of 40%, and indicating a medium high risk of overfishing in this area. An SPR of 32% for SKJ in the IAW is in the middle of a range of SPR values estimated since 2010 for SKJ Region 5 of the WCPO (which includes the IAW) in stock assessments by WCPFC (Vincent et al., 2019; 8-Region Model), and significantly below what was reported for the complete WCPO.

Examining monthly catch size frequencies (Fig. 3.32), we did not discover any modal progression. Spawning may be continuous as there appear to be similar sized small SKJ throughout the year, with some spawning events probably being more successful than others, causing irregular patterns over time. Looking at separate catch size frequencies and catch contributions by gear type for SKJ, pole-and-line contributed the largest part of the catch from the IAW, with 79,659 MT or 76% of SKJ in 2020 (Fig. 3.28). Purse seine contributed 19,923 MT or 19% in that same year (Fig. 3.29), while other gear types were relatively insignificant for SKJ production (Fig. 3.30 and 3.31). Pole-and-line and purse seine catches of SKJ contain 91% and 100% immature fish respectively, while handline and trolling line also produce mainly immature fish. For the latter two methods it is the versions with multiple small hooks with artificial feather-like lures that produce most of the SKJ.

Pole-and-line currently mostly catches SKJ between 20 and 55 cm FL in the IAW, including 1 quarter old recruits up to fish 6 quarters old, with a median size of just 36 cm FL representing fish less than 9 months old. SKJ and YFT catch size frequencies from pole-and-line show almost the same median length. The largest SKJ in the pole-and-line catch (those over 40 cm FL) are already experiencing a reduced natural mortality, and would contribute significantly to spawning biomass if left to grow. Purse seine caught smaller numbers, and of significantly smaller size, in a range between about 20 and 40 cm FL, representing fish of 1 to 3 quarters old. The median size in the purse seine catch of just 28 cm is only just above the size at recruitment used in WCPO and our stock assessments. Also purse seine showed very similar sizes for SKJ and YFT in the catch.

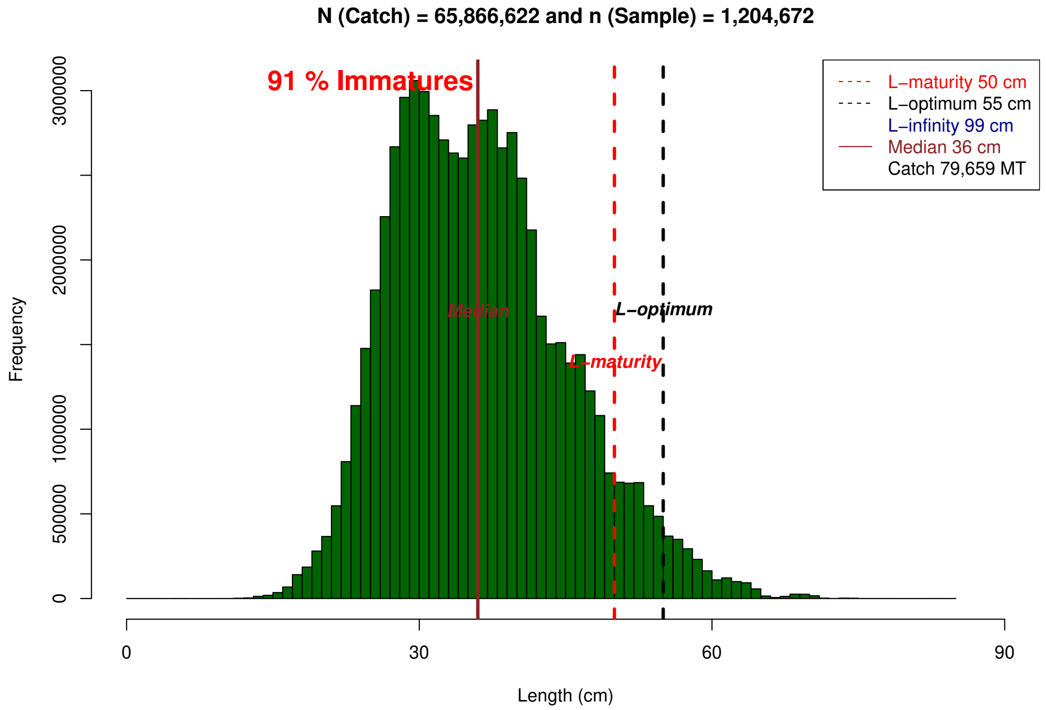


Figure 3.28: Catch Size Frequency Distribution of Katsuwonis pelamis in the IAW in 2020, Pole and Line.

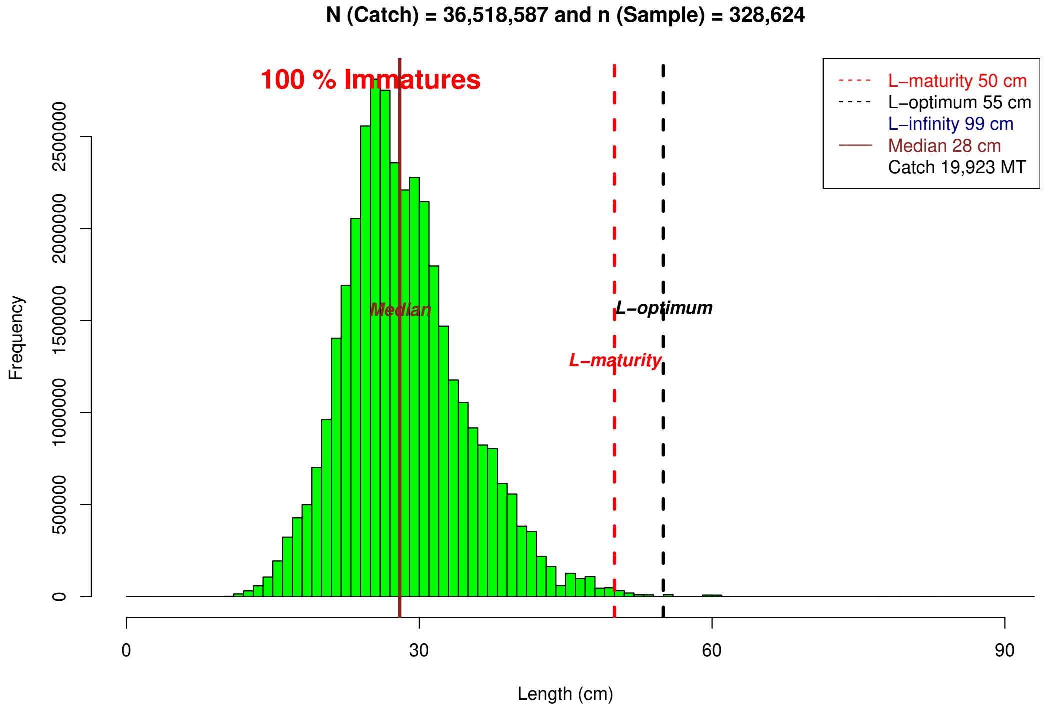


Figure 3.29: Catch Size Frequency Distribution of Katsuwonis pelamis in the IAW in 2020, Purse Seine.

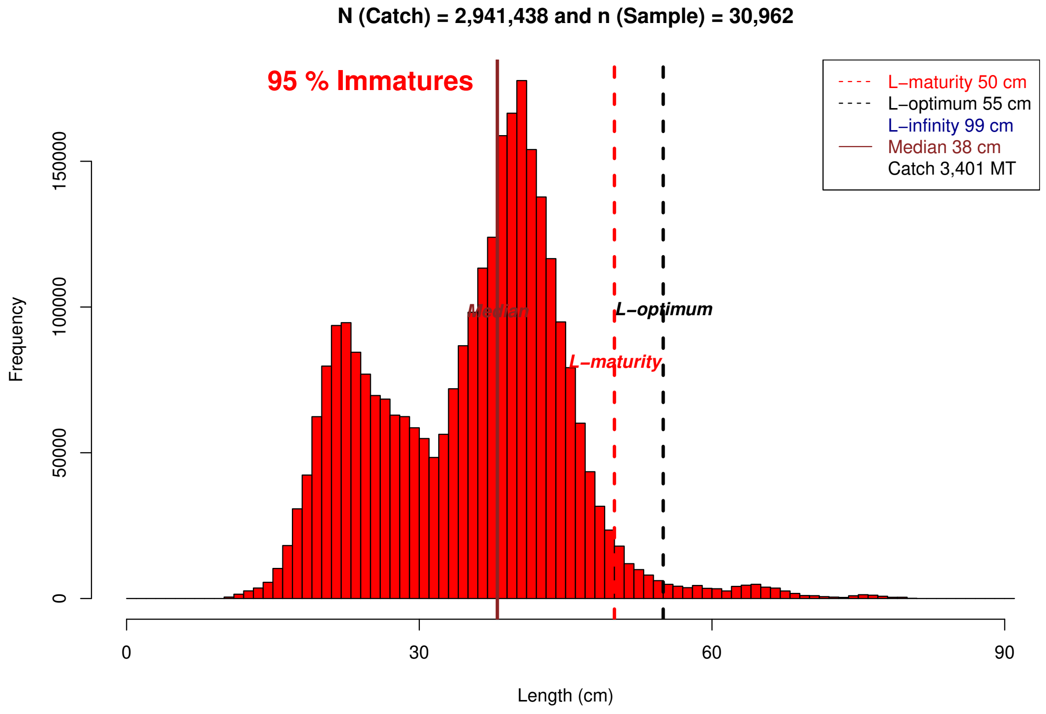


Figure 3.30: Catch Size Frequency Distribution of Katsuwonis pelamis in the IAW in 2020, Handline.

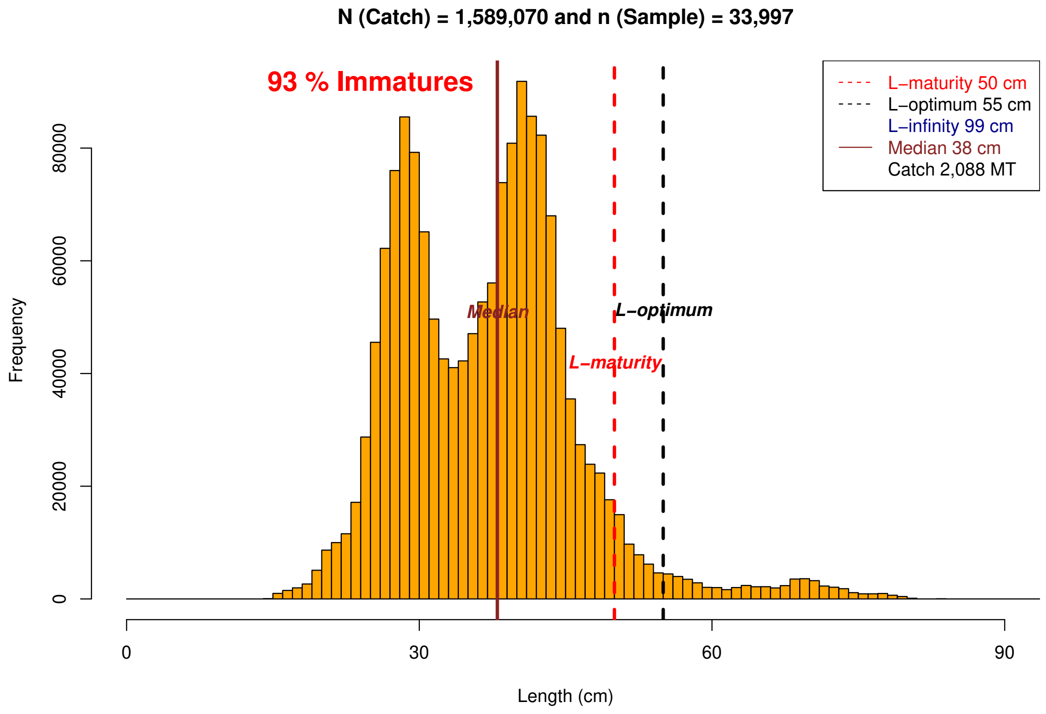


Figure 3.31: Catch Size Frequency Distribution of Katsuwonis pelamis in the IAW in 2020, Trolling Line.

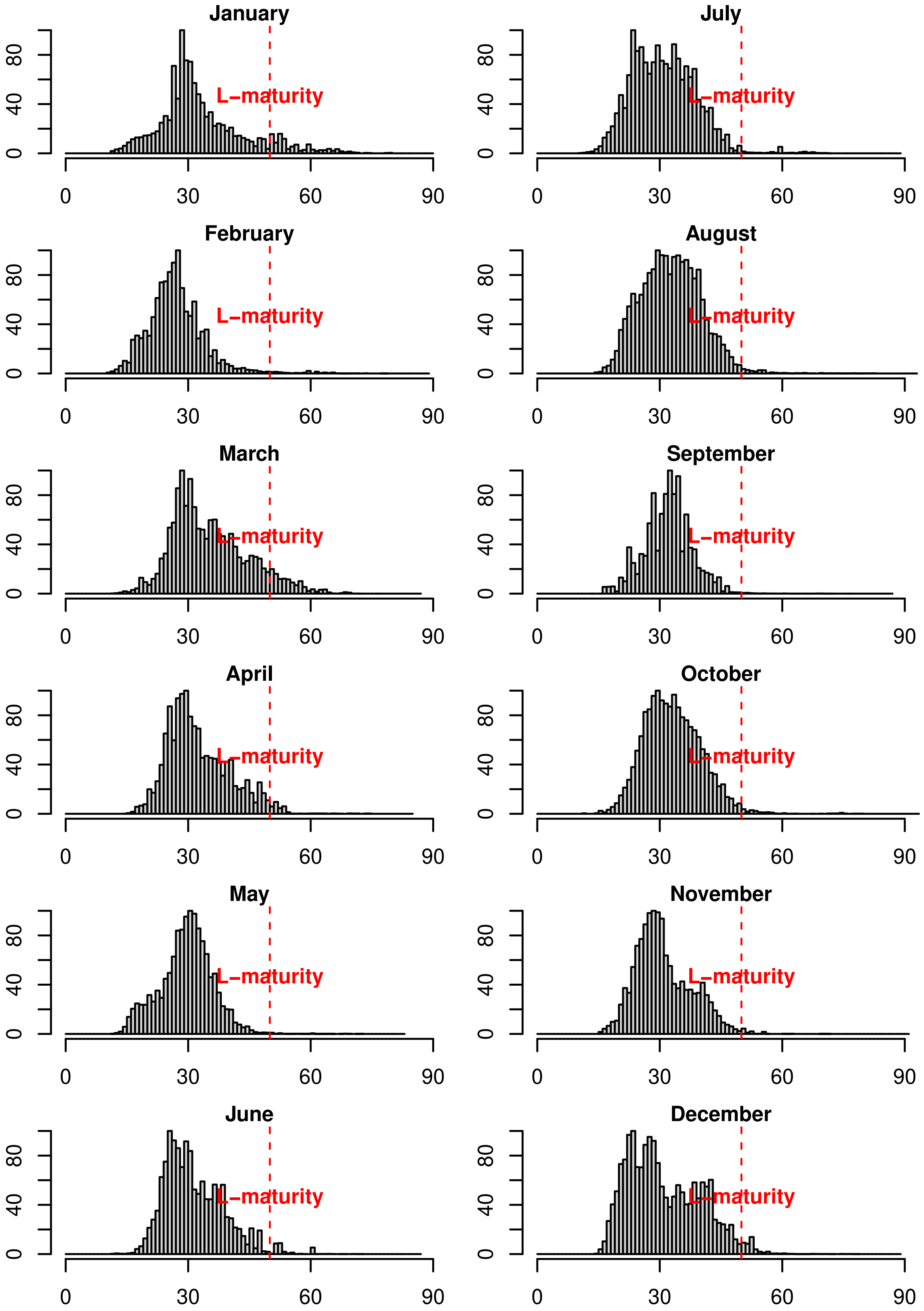


Figure 3.32: Relative catch size frequency distribution of *Katsuwonis pelamis* in the IAW in 2020, all gears combined. Size in centimeter fork length.

4 Simulating Potential Management Interventions

4.1 Model structure

Our basic age- and size-structured cohort simulation model works with numbers of fish by age group, with age expressed in quarters, and using time steps of 1 quarter to calculate numbers of survivors after total mortality. The total mortality at each specific age ($Z_{(q)}$, per quarter), follows from combining natural and fishing mortality ($Z_{(q)} = M_{(q)} + F_{(q)}$) at that age. Deriving values for length dependent natural mortality from published studies, we obtained length based fishing mortality estimates by calibrating observed (CODRS) versus modelled size frequency distributions of the catch. We then calibrated absolute values for recruitment with numbers from regional stock assessments and so that the basic model achieves the annual total catch as recorded from CODRS data for the IAW in 2020. Starting from the fixed number of recruits, the number of survivors at any following age ($N_{(q+1)}$), with time steps of one quarter, was calculated as the number at the previous age ($N_{(q)}$) reduced through the mean total mortality Z (per quarter) during the time step from q to q+1.

$$N_{(q+1)} = N_{(q)} * exp\left[\frac{-\left(Z_{(q)}+Z_{(q+1)}\right)}{2}\right]$$

The difference between the number of surviving fish at age q+1 ($N_{(q+1)}$) and the starting number at the beginning of the time step ($N_{(q)}$) is the total number of fishes which have died as a result of combined natural and fisheries mortality. The number of deceased fish equals $N_{(q+1)} - N_{(q)}$. The number of fish caught by all fisheries combined over the period between the two ages follows as that part of the deceased fish that was caught as a result of the mean overall fishing mortality in the period between age q and age q+1. Therefore, the catch in numbers (between ages q and q+1) was calculated with:

$$C_{(n)} = \left[\frac{\left(\frac{F_{(q)}+F_{(q+1)}}{2}\right)}{\left(\frac{Z_{(q)}+Z_{(q+1)}}{2}\right)}\right] * \left(N_{(q+1)} - N_{(q)}\right)$$

The fork length (FL) of each individual fish in any age group with age t in years, using time steps of 0.25 years (1 quarter) between ages in the model, was calculated with the von Bertalanffy growth equation (Sparre and Venema, 1992) and growth parameter values from published studies as discussed in more detail elsewhere in this report. For YFT we used L_{inf} = 200, K = 0.25, and t_0 = -0.4. For SKJ we used L_{inf} = 99, K = 0.45, and t_0 = -0.35. The individual body weight (in kg) of each fish at any length and age was calculated with the length-weight (L-W) relationship for YFT (Chassot et al., 2016) and SKJ (Kiyofuji et al., 2019):

$$\text{YFT: } W_{(t)} = 0.00002459 * \left(L_{(t)}^{2.9667}\right)$$

$$\text{SKJ: } W_{(t)} = 0.00000976 * \left(L_{(t)}^{3.2}\right)$$

The catch in numbers by age group was converted to a catch weight (in kg) by inserting the mean length in the age interval (L_{mean}) in the L-W relationship and multiplying the resulting mean fish weight (W_{mean}, in kg) with the numbers caught in that interval.

$C_{(kg)} = W_{(mean)} * C_{(N)}$. The total catch realized from the cohort is simply the sum of the catches realized from each age group. The total catch from one cohort was again assumed to be equal to the total annual catch in the equilibrium situation that we assumed for our simple model. We calculated catches now for specific size groups of fish. After calibration for actual catch, we also used our "back of an envelope" predictive model to evaluate the expected outcomes of various harvest scenarios by varying fishing mortality F by species and size class of fish (see for example Sparre and Venema, 1992).

Spawning Stock Biomass (SSB) was estimated by adding up the biomass of each mature age group present in the population within the simulated year. With maturation complete after 2.5 years of age and 103 cm FL in YFT, and 1.25 years of age and 50 cm FL in SKJ (as described in more detail elsewhere in this report) we calculated SSB by species as the average weight of all combined generations older than 2.5 years for YFT and older than 1.25 years in SKJ. The unfished Spawning Stock Biomass ($SSB_{F=0}$) can also be calculated with our simple model using an F=0 input for all size and age groups and therewith simulating an unfished cohort. This allows for calculation of the level of SSB compared to an unfished situation as $SSB/SSB_{F=0}$. This Spawning Potential Ratio (SPR) was taken as reference point for the current exploitation level and to compare outcomes of different harvest strategies (Satria and Sadiyah, 2018).

4.2 Baseline 2020: Recruitment, catch and spawning biomass

For the 2020 baseline we calibrated our model with the total YFT catch from the IAW as recorded from CODRS data. This production was estimated at 172,286 MT in 2020. Using the above-described model parameter values, we reached that YFT catch with an input of 100 million YFT recruits at an age of 1 quarter and a size of 30 cm FL. WCPC estimates YFT recruitment (at age 1 quarter) in the WCPO at about 1.6 billion per year, with around 500 million of those recruits originating from YFT Region 7 (Vincent et al., 2020), which includes East Indonesia and the Philippines. With 100 million recruits estimated by us from the IAW, that means 20% of recruits from WCPFC Region 7 originate from the IAW. This seems plausible with IAW roughly making up some 20% of deep oceanic waters in WCPFC YFT Region 7.

Production of SKJ from the IAW in 2020 was estimated at 105,240 MT, based on CODRS data. We reach that SKJ catch with an input of 350 million SKJ recruits, at an age of 1 quarter and a length of 23 FL. SKJ recruitment in the WCPO is estimated by WCPFC at about 4.5 billion recruits per year. Around 1.25 billion of those recruits are reportedly originating from SKJ Region 5 (Vincent et al., 2019; 8-Region Model), which includes East Indonesia and the Philippines. SKJ Region 5 in the WCPFC 8-Region model for SKJ is overlapping but not exactly the same as YFT Region 7. With 350 million recruits estimated by us from the IAW, this means about 28% of recruits from WCPFC SKJ Region 5 would originate from IAW. This seems plausible with IAW roughly making up some 25% of deep oceanic waters in WCPFC SKJ Region 5 in the 8-Region model.

Split over major size groups (Table 4.1), and based on CODRS data, the total estimated catch of 172,286 MT YFT in 2020 included 24,918 MT of small tuna in the size range of 0.1 to 6 kg, 20,907 MT of medium YFT in the size range of 6 to 25 kg and no less than 126,461 MT of large YFT in the size category above 25 kg (Table 4.2). With 100 million recruits, our model predicts a YFT catch of 170,185 MT annually from the IAW, including 24,567 MT of small tuna, 19,775 MT of medium YFT and 125,843 MT of large YFT, all very close to recorded catches by category (Figure 4.1). Average weights by size category based on 2020 model predictions were around 1.3 kg for small YFT, 18.1 kg for medium YFT and 44.0 kg for large YFT. The predicted YFT catch length frequency distribution for the IAW in the 2020 baseline scenario compares very well with the size frequency recorded from CODRS data in that year (Fig. 3.14). This simulated catch length frequency distribution is also very similar to what has been reported recently for Indonesian and Philippine archipelagic fisheries (e.g. Brouwer et al., 2018), with numbers in the catch dominated by small tuna.

Table 4.1: Size, weight and price categories for Yellowfin and Skipjack Tuna in Indonesia.

Category	Min Size (cm FL)	Max Size (cm FL)	Min Weight (kg)	Max Weight (kg)	Price/kg
YFT Small	15	65	0.1	5.9	1.50
YFT Medium	66	106	6.1	25.1	3.00
YFT Large	107	175	25.8	111.0	6.00
SKJ Small	15	36	0.1	0.9	0.83
SKJ Medium	37	48	1.0	2.3	1.60
SKJ Large	49	90	2.5	17.5	2.00

Table 4.2: Recorded compared with Modelled catch volumes by size category in Thunnus albacares and Katsuwonus Pelamis catches from Indonesian Archipelagic waters in 2020, all gear types combined

	Thunnus albacares		Katsuwonus Pelamis	
	Recorded	Modeled	Recorded	Modeled
small	24918	24567	33533	33765
medium	20907	19775	45912	45495
large	126461	125843	25796	25974
Total	172286	170185	105241	105234

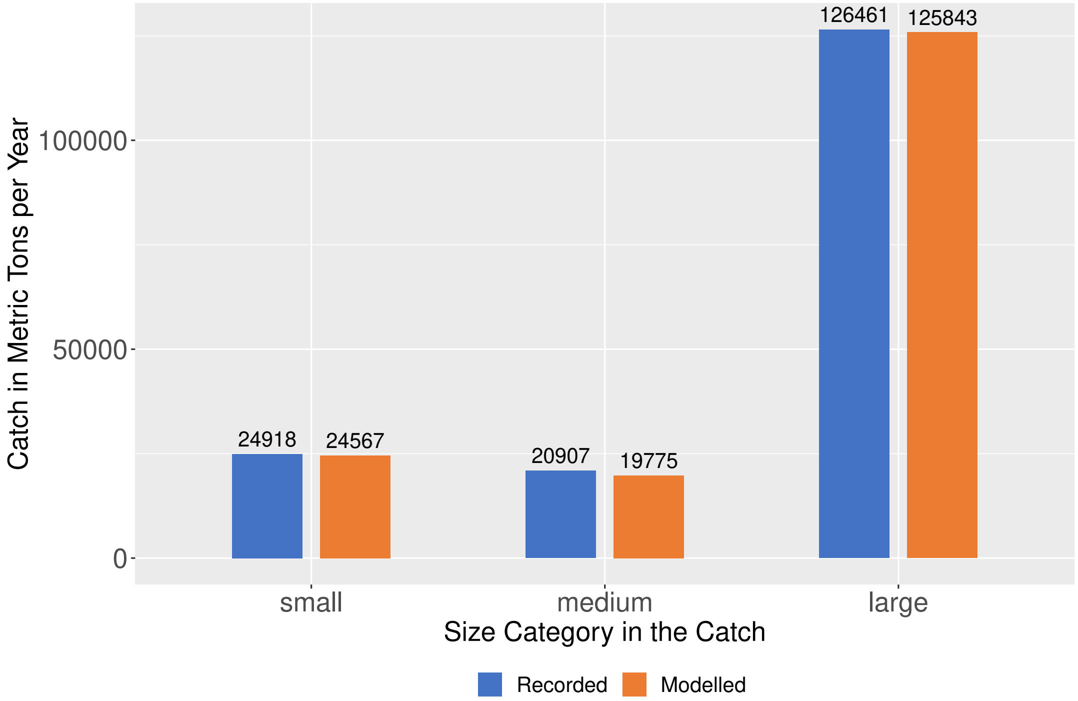


Figure 4.1: Recorded compared with modeled catch volumes by size category in *Thunnus albacares* catches from Indonesian Archipelagic Waters in 2020, all gear types combined

Based on CODRS data, the total catch of SKJ in the IAW amounted to 105,241 MT in 2020, with mainly very small to medium sized fish of 0.1 to 2.5 kg (Tables 4.1 and 4.2), almost all immature. The total catch of SKJ for 2020, estimated from CODRS data, was almost 135,000 MT below the 239,039 MT reported for 2016 in official statistics (MMAF, 2018b). A very large difference indeed, and it is unclear if this reflects a drop in catches or a malfunctioning of either the statistical system or the CODRS data collection program. Either way, with 350 million SKJ recruits, our model predicts an SKJ catch of 105,234 MT from the IAW in 2020, with simulated distribution over size categories very close to recorded catches by category (Fig. 4.2). The predicted SKJ catch length frequency distribution for the IAW in the 2020 baseline scenario compares very well with the size frequency recorded from CODRS data in that year (Fig. 3.26), and this catch length frequency distribution is also similar to what has been reported recently for various SKJ fisheries in Indonesia and the Philippines (Vincent et al., 2019), with numbers in the catch dominated by immature SKJ. The vast majority of SKJ in the IAW are caught by pole-and-line and purse seine gears, which harvested well over 100 million individual fish, almost all immature, in 2020. This represented close to 30% of the estimated SKJ recruitment for that year.

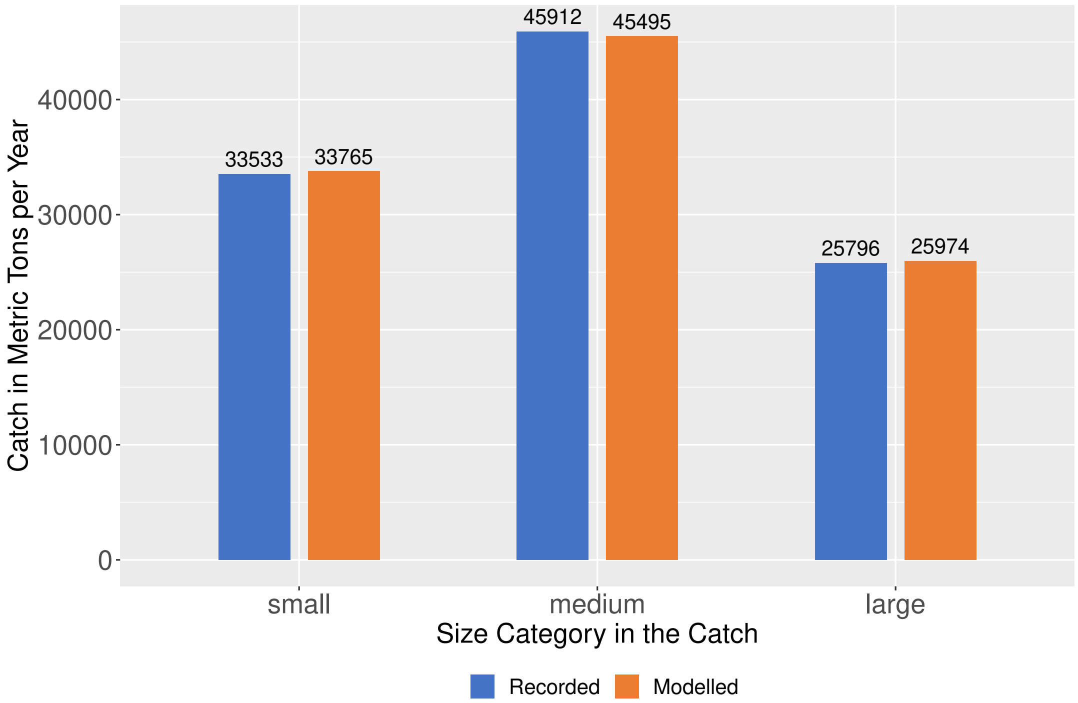


Figure 4.2: Recorded compared with modeled catch volumes by size category of *Katsuwonus pelamis* catches from Indonesian Archipelagic Waters in 2020, all gear types combined

Officially reported landings of YFT in 2016 included 16,791 MT from pole-and-line and 12,782 from purse seines (MMAF, 2018b; Satria et al., 2017). These two gear types combined therefore reportedly landed some 29,573 MT tons of YFT in that year. This would have been almost exclusively small tuna based on gear specific catch size frequencies (Fig. 3.16 and 3.17). This combined amount of 29,573 MT reported in 2016 for small tuna from pole-and-line and purse seine exceeded the total amount of 24,918 MT small tuna recorded by CODRS in 2020, while we know that certain types of Hand Line and Trolling Lines also catch considerable amounts of small tuna (e.g. Figure 3.8). The total recorded landings of 24,918 MT of small tuna in 2020 (based on CODRS data) represented some

19 million individual fish or close to 20% of annual YFT recruitment in the IAW, with the vast majority taken by pole-and-line and purse seine gears plus a significant contribution coming from handline and trolling gears with multiple small hooks and artificial lures, which target small tuna as well as other small tunas. The smallest category in the total YFT catch by volume is medium YFT, which is produced mainly as by-catch in gear types that target either small tuna or large YFT.

By far the largest category by volume from overall YFT landings in our baseline is large YFT with an estimated total catch of 125,843 MT in 2020 according to CODRS data and supported by model predictions. This volume included close to 3 million individual fish with average body weights around 40 to 45 kg. A large volume of fish indeed, but the numbers of large YFT, caught at sizes between 100 and 145 cm FL, are dwarfed in the overall catch length frequency distributions because catch numbers in the smallest size classes are so much higher. The peak for large YFT in the modelled catch size frequency overlaps well with recorded peaks in catch size frequencies for the handline and longline fisheries in IAW, while an average body weight of somewhere between 40 kg and 45 kg is a common rule of thumb in the fisheries for large YFT in recent years.

Spawning Stock Biomass (SSB) of YFT in IAW was estimated with our model for the 2020 baseline at 295,323 MT. This SSB mostly consists of 3, 4, and 5 years old fish. The total estimated SSB is only 75% higher than the total annual catch of 170,185 MT as per model output, and less than 2.5 times higher than the annual catch of mature large YFT. This means that in terms of weight, almost half the SSB is caught by fisheries every year. Simulating a pristine situation without fisheries, the model estimated an $SSB_{F=0}$ of 682,852 MT for the IAW, which means an estimated $SSB/SSB_{F=0}$ ratio of 43%. This is in line with what was estimated for Region 7 (containing eastern Indonesian and Philippines oceanic waters) by the WCPFC (Vincent et al., 2020), well above the limit reference point of 20% $SSB_{F=0}$ (Preece et al., 2011; MMAF-a, 2018) and also just above the interim target reference point of 40% $SSB_{F=0}$, as adopted under the management objectives in the operational mode for YFT in the IAW (Hoshino et al., 2018). With an estimated $SSB/SSB_{F=0}$ ratio of 43% the YFT fisheries in the IAW may be close to the interim management target, based on current SSB and volume of the catch, but substantial economic gains may still be achieved letting the fish grow to larger sizes where prices per kg are significantly higher (Fig. 4.1). We explore this further with our model in Section 4.4.

SSB of SKJ in the IAW was estimated with our model for the baseline at just over 100,000 MT, which compares to an estimated annual catch of about 105,000 MT that included about 25% adult biomass in 2020. Our model estimated an $SSB_{F=0}$ of 312,349 MT for the IAW, which results in an estimated $SSB/SSB_{F=0}$ ratio of 32% for SKJ. This is well above the limit reference point of 20% $SSB_{F=0}$ (Preece et al., 2011), but below our target reference point of 40%. An SPR of 32% for SKJ in the IAW is in the middle of a range of SPR values estimated since 2010 for SKJ Region 5 of the WCPO (which includes the IAW) in stock assessments by WCPFC (Vincent et al., 2019; 8-Region Model), and significantly below what was reported for the complete WCPO. WCPFC uses a target reference point of 50% $SSB/SSB_{F=0}$ for SKJ in the WCPO. It seems therefore that some overfishing of SKJ may be occurring in the IAW and that effort reductions, resulting in reductions in fishing mortality, could be needed to rationalize this fishery. We explored options for effort reduction further with our model in Section 4.4.

4.3 Baseline 2020 monetary value of the fisheries

Global YFT production in 2016 was estimated at about 1.46 million MT (FAO, 2018). This was up from about 1.31 million MT in 2012 and 1.37 million MT in 2014, when dock values of these total global YFT catches were estimated at US$ 3.93 billion and US$ 3.24 billion respectively for those years (Macfadyen et al., 2016; Macfadyen and Defaux, 2016; Macfadyen, 2016; Galland et al., 2016). This indicates that global ex-vessel prices must have ranged between US$ 3.00 per kg and US$ 2.36 per kg from 2012 to 2014 on average, over all the size classes and quality categories that were landed. A multiple year average ex-vessel price of about US$ 2.75 per kg therefore seems a reasonable estimate for YFT based on these figures. Global end values for total YFT production were estimated at US$ 15.4 billion and US$ 14.9 billion for 2012 and 2014 respectively (Galland et al., 2016), indicating end consumer prices of around US$ 11.75 per kg and US$ 10.88 respectively for those 2 years. This suggests that the price per kg for YFT is multiplied 4 times on average, from dock to end consumer.

A global average dock price for reasonable quality YFT of US$ 2.75 was estimated above and this value is doubled (100% price increase) to an average "domestic retail price" of US$ 5.50 as deemed globally valid by experts (Macfadyen and Defaux, 2016). We need to keep in mind though that this price in general relates to relatively good quality fish, especially compared to Indonesian landings. YFT prices vary considerably with the quality of the fish, but a suggested price increase of 100% from dock to domestic market is assumed reasonable for Indonesia and also applicable as price increase for good quality tuna from ex-vessel to export price.

The total reported dock value (ex-vessel value) of landed YFT in Indonesia was close to IDR 5 trillion (for 209,227 MT) in 2016 according to DGCF statistics (MMAF, 2017a). With an average exchange rate of about IDR 13,000 to the US$ for 2016, this results in a total reported dock value of about US$ 380 million for the combined YFT fisheries for that year in Indonesia. This means that a dock price was realized of not more than US$ 1.80 per kg on average, for all size and quality classes combined in Indonesia, which is well below the global average. This may partly be explained by size classes landed, but due to often unsatisfactory treatment of the catch on board (and at the dock) in various segments of the fisheries, losses of at least 10% in value due to quality problems are also highly likely. Quality categories like "spoiled" (*busuk*) and "very spoiled" (*busuk sekali*) are commonly used by buyers at various landing sites in eastern Indonesia. Fishes in those categories are often still used in various processes for local markets, but prices of these raw materials are very low.

True dock value of the landed YFT catch in 2016, with good quality management, would have reached at least US$ 2.00 per kg, if losses of about 10% would have been prevented. Potential domestic retail value for the total Indonesian YFT production from 2016, assuming reasonable quality, can be estimated with a mark-up of 100% from a dock value of about US$ 2.00 per kg, to reach US$ 4.00 per kg on average with a size composition as landed in 2016. This is estimated value for Indonesia is US$ 1.50 below the global average domestic retail value, which seems plausible. With officially reported total YFT landings of 209,227 MT from Indonesia in 2016 (MMAF, 2017a), this would have resulted in a total "domestic retail" value of about US$ 837 million for Indonesian YFT in that year. With 103,291 MT of YFT reportedly produced from IAW (Satria et al., 2017; MMAF, 2018b) this would have included US$ 413 million from the IAW.

Indonesian traders were reported to sell large YFT at just over US$ 6.00 per kg in 2014 (Macfadyen and Defaux, 2016) and based on interviews with traders and buyers this price has not changed much in recent years. Smaller YFT fetch much lower prices and purse seine frozen small tuna sells to the canning industry at only about US$ 1.50 per kg (Macfadyen, 2016). Medium sized YFT often finds its way to local retail markets at an intermediate price of around US$ 3.00 per kg, which is well below the average global retail market price for YFT.

For modelling purposes, we worked with size specific trading prices of US$ 1.50 per kg for small tuna, US$ 3.00 per kg for medium YFT and US$ 6.00 per kg for large YFT, assuming good quality management on board, and further along the supply lines. This value is realized as a result of all trades combined, including local markets, and domestic as well as international markets for cannery grade and all other qualities of frozen and fresh YFT. Our model for YFT fisheries in the IAW predicts a total YFT catch of 170,185 MT annually (Table 4.2). This catch is differentiated over three size groups in the model output, and includes 24,567 MT of small YFT in the size range of 0.1 to 6 kg, 19,775 MT of Medium YFT in the size range of 6 to 25 kg and 125,843 MT of Large YFT in the size category above 25 kg.

With trading prices by size class as above, the model predicts a trading value for YFT from IAW of well over US$ 850 million for 2020 (Table 4.3), or more than twice the "domestic retail" value of combined 2016 YFT landings from the IAW as estimated above from official statistics. The simulated value for the 2020 landings of small tuna is US$ 37 million, while medium YFT adds US$ 59 million to the total and large YFT is by far the biggest earner with US$ 755 million predicted from the baseline scenario. The model predicts an average trade value of US$ 5.00 per kg in the 2020 baseline scenario, some 25% higher than the estimated US$ 4.00 per kg Indonesian domestic retail price based on 100% mark-up from dock value after correction for 10% losses.

For modelling of SKJ fisheries and trade, we worked with size specific trading prices obtained in early 2021 from interviews with buyers and traders. Common price levels were US$ 0.83 per kg for small SKJ from 0.1 to 1.0 kg, US$ 1.60 per kg for medium SKJ from 1.0 up to 2.5 kg and US$ 2.00 per kg for large SKJ of 2.5 kg and above. These prices are assuming good quality management on board, and further along the supply lines, when we predict overall potential value. This value is realized as a result of all trades combined, including local markets, and domestic as well as international markets for cannery grade and all other qualities of frozen and fresh SKJ.

Our model for SKJ fisheries in the IAW predicted a total SKJ catch of 105,234 MT annually (Table 4.2). This catch is differentiated over three size groups in the model output, and includes 33,765 MT of small SKJ in the size range of 0.1 to 1.0 kg, 45,495 MT of medium SKJ in the size range of 1.0 to 2.5 kg and just 25,974 MT of large SKJ in the most valuable size category 2.5 kg and up. With trading prices by size class as above, this resulted in a potential trading value of close to US$ 153 million for the combined 2020 SKJ landings from the IAW (Table 4.4), or just 18% of the value of the YFT landings. From these numbers, the YFT trade seems to be much more valuable than the SKJ trade at this time. The simulated value for the 2020 landings of small SKJ is US$ 28 million, while medium SKJ adds US$ 73 million to the total and large SKJ is a modest earner with just US$ 52 million predicted from the baseline scenario. It seems worth exploring if earnings from large SKJ could potentially be increased by reducing fishing mortality among the smaller and less valuable size classes.

4.4 Simulated outcomes of optional harvest scenarios

4.4.1 Description of optional harvest scenarios

We used our model to evaluate a number of optional harvest scenarios and make some predictions on likely outcomes of a range of possible fisheries management interventions. While much remains to be discussed in terms of management goals for the Indonesian tuna fisheries, we have for now adopted the combined goals of bringing back the stocks of YFT and SKJ towards or even above interim target reference points of 40% $SSB/SSB_{F=0}$ (e.g. Hoshino et al., 2018). We consider goals not only to maximizing total annual catch volume by species, but also to maximizing economic returns from the combined fisheries.

We tested 5 different scenarios, which have recently been discussed to some extent, and compared the predicted outcomes with the simulated results from the 2020 baseline situation. Evaluated harvest scenarios include effort reductions to various levels, assuming that current effort is on the high side based on the current SPR levels for YFT and especially SKJ, combined with catch length frequency distributions which for both species included mainly very small immature fish. Three different levels of overall effort reduction are evaluated in this paper:

1. **Harvest Scenario 1** (HS1) is a 20% overall effort reduction including all gear types and fisheries, resulting in an overall reduction of fishing mortality by 20% for all age and size groups in the YFT and SKJ fisheries.
2. **Harvest Scenario 2** (HS2) is a 40% overall effort reduction including all gear types and fisheries, resulting in an overall reduction of fishing mortality by 40% for all age and size groups in the combined fisheries.
3. **Harvest Scenario 3** (HS3) is a 50% overall effort reduction including all gear types and fisheries, resulting in an overall reduction of fishing mortality by 50% for all age and size groups in the combined fisheries.

Harvest Scenario 4 (HS4) is a restructuring of the fisheries, whereby commercial targeting of small tuna is avoided and growth over-fishing of SKJ is addressed. This includes adjustments in the behavior and operations of various fisheries, as well as significant reductions in fishing effort for specific fishing gears, supported by adjustments in industry approaches and government regulations. A small (10%) reduction in fishing effort targeting large YFT is tied into this restructuring scenario.

Under the Restructuring Scenario (HS4), pole-and-line fisheries would focus on skipjack tuna only, thereby drastically reducing the capture of small tuna. Pole-and-line operations would adjust their behavior at sea under this scenario. Fishing on schools of small tuna would be avoided, halting fishing if the fisher sees that the catch includes many small tuna, after which searching for skipjack tuna would be resumed. A small percentage of small tuna is still expected and acceptable under this scenario. A major reduction of 70% in pole-and-line fishing effort is also included in this scenario to address growth overfishing of SKJ, and to enable the above-mentioned change in fishing behavior, while keeping the economies of individual vessels intact. Such reduction in effort would also reduce the take of small tuna, and have a significant positive effect on the problematic situation related to baitfish fisheries that supply pole-and-line operations (Gillet, 2012; Gillet 2014).

Purse seine operations under HS4 would also avoid small tuna and small SKJ, instead focusing on available and resilient small pelagic species such as *Euthynnus*, *Auxis*, *Decapterus*, *Sardinella*, and *Rastrelliger*. As part of the restructuring, purse seiners would not set around deep-water FADs which are known to hold dense schools of small tuna and small SKJ. Small percentages of small tuna and small SKJ would be acceptable as unintended bycatch from the purse seine fisheries, but would not be marketed for industrial processing, under an industry-led change in trading practices. Supporting government regulations would prohibit commercial processing and trading of small tuna and small SKJ. The production potential and total value of the combined stocks of small pelagic species, without small tuna and small SKJ, is large (MMAF, 2011), and could sustain the purse seine fisheries without it targeting small SKJ and small tuna. Avoidance of small tuna and small SKJ seems feasible for purse seine fisheries, and we simulated a reduction of 70% in fishing mortality among SKJ and small tuna. Reductions in effort in the purse seine fisheries may be needed if behavior change is not working, but effects will need to be studied in detail in relation to production of the combined spectrum of small pelagic species harvested by this fishery.

Under HS4, all hook-and-line fisheries would have to adjust their operations and fully focus on large YFT for commercial purposes. Some fishing of small tuna would be sustainable if restricted to use for consumption, bait, and local barter only. Fishing crews operating at FADs would concentrate on fishing deep only, with large baits, focusing on catching large YFT. Some fishing on the side for small tuna for above listed purposes would be acceptable, but commercial trade of these immature fish would not be accepted. Similar rules would apply to all other pelagic gears. As a result of HS4, the fishing mortality of small tuna and all size classes of SKJ would be reduced by 70% while the fishing effort targeting large YFT would be reduced with around 10% only.

Harvest Scenario 5 (HS5) is a more extreme version of HS4, under which we tested what the hypothetical outcomes would be from a complete ban on fishing for small tuna and small SKJ, in combination with an overall reduction in fishing effort of 30% in fisheries that target large YFT. We simulated this with an 80% reduction in fishing mortality in the SKJ fisheries, combined with a 100% reduction of mortality among small tuna and a 30% reduction in fishing mortality among large YFT. We realize that there would be serious feasibility issues related to implementation of such a scenario, but are including it here in the analysis just to see what (if any) further gains could be expected from this approach versus the more measured approach explained under HS4.

4.4.2 Evaluation of optional harvest scenarios

We compared the predicted volumes and values by size category in the catch for YFT and SKJ fisheries, under a range of optional harvest scenarios, to the simulated baseline scenarios for 2020 (Tables 4.3 and 4.4). For small tuna and medium YFT under HS1 to HS3, there was a reduction in catch volume with reduction in overall fishing effort. The catch of small tuna dropped from 24,567 MT in the baseline scenario to 13,142 MT under HS3, a drop of 46%, after an overall effort reduction of 50%. At the same time the volume of medium YFT dropped with 40% under HS3, while the volume of large YFT also dropped with 16% under this harvest scenario.

All of the simulated "across the board" general fishing effort reductions lead to lower overall catches of YFT, with HS3 leading to a substantial overall catch reduction of 24%.

For SKJ, the overall catch is predicted to drop even sharper with up to 33% reduction in total catch volume when fishing effort is reduced up to 50%, with a substantial shift in relative contributions from small SKJ to large SKJ in the catch. Under HS3, the small SKJ catch is predicted to drop by 46%, while medium SKJ catch shows a more moderate drop of 33% and large SKJ catch drops with just 16% when fishing effort is halved.

Table 4.3: Evaluation of harvest strategies for Yellowfin Tuna in Indonesian Archipelagic Waters. Catch is in Metric Tons (MT) and Value is in US$

R=100 Million	Catch	Value SYFT	Catch	Value MYFT	Catch	Value LYFT	Catch
STRATEGY	Small YFT	US$ 1.50 / kg	Medium YFT	US$ 3.00 / kg	Large YFT	US$ 6.00 / kg	TOTAL
Baseline (F*1)	24,567	36,850,137	19,775	59,325,570	125,843	755,058,621	170,185
HS1 (F@80%)	20,188	30,281,402	16,829	50,486,877	121,780	730,678,187	158,796
HS2 (F@60%)	15,556	23,334,522	13,427	40,280,555	112,709	676,253,514	141,692
HS3 (F@50%)	13,142	19,712,491	11,540	34,621,465	105,339	632,033,105	130,021
HS4 (ReFocus)	8,105	12,157,001	18,275	54,825,177	147,867	887,200,362	174,246
HS5 (SmallBan)	0	0	17,150	51,450,302	143,104	858,625,954	160,254

STRATEGY	SSB/SSBf=0	Catch	C/Cbase	Value	Val/Vbase	D Value	Value/kg
Baseline (F*1)	43%	170,185	100%	851,234,327	100%	0	5.00
HS1 (F@80%)	49%	158,796	93%	811,446,466	95%	-39,787,861	5.11
HS2 (F@60%)	57%	141,692	83%	739,868,590	87%	-111,365,737	5.22
HS3 (F@50%)	62%	130,021	76%	686,367,061	81%	-164,867,266	5.28
HS4 (ReFocus)	55%	174,246	102%	954,182,539	112%	102,948,212	5.48
HS5 (SmallBan)	64%	160,254	94%	910,076,256	107%	58,841,928	5.68

Table 4.4: Evaluation of harvest strategies for Skipjack Tuna in Indonesian Archipelagic Waters. Catch is in Metric Tons (MT) and Value is in US$

R=350 Million	Catch	Value SSKJ	Catch	Value MSKJ	Catch	Value LSKJ	Catch
STRATEGY	Small SKJ	US$ 0.83 / kg	Medium SKJ	US$ 1.60 / kg	Large SKJ	US$ 2.00 / kg	TOTAL
Baseline (F*1)	33,765	28,025,352	45,495	72,791,539	25,974	51,947,680	105,234
HS1 (F@80%)	27,843	23,109,600	40,621	64,992,821	25,577	51,154,360	94,041
HS2 (F@60%)	21,531	17,870,449	34,032	54,451,781	23,630	47,260,480	79,193
HS3 (F@50%)	18,221	15,123,211	29,985	47,975,611	21,862	43,723,799	70,067
HS4 (F@30%)	11,277	9,359,929	20,125	32,199,232	16,177	32,353,473	47,578
HS5 (F@20%)	7,636	6,338,242	14,194	22,711,114	11,980	23,959,687	33,811

STRATEGY	SSB/SSBf=0	Catch	C/Cbase	Value	Val/Vbase	D Value	Value/kg
Baseline (F*1)	32%	105,234	100%	152,764,571	100%	0	1.45
HS1 (F@80%)	40%	94,041	89%	139,256,780	91%	-13,507,790	1.48
HS2 (F@60%)	51%	79,193	75%	119,582,710	78%	-33,181,861	1.51
HS3 (F@50%)	57%	70,067	67%	106,822,621	70%	-45,941,949	1.52
HS4 (F@30%)	71%	47,578	45%	73,912,634	48%	-78,851,936	1.55
HS5 (F@20%)	80%	33,811	32%	53,009,043	35%	-99,755,528	1.57

All of the unstructured effort reduction scenarios (HS1 to HS3), lead to reduced overall revenue from the YFT fisheries in IAW, with up to 19% reduction in revenue from HS3. Obviously, this is gross revenue, not taking into account that a 50% reduction in effort under HS3 would also lead to major reductions in costs of fishing and net financial results of HS3 may well be positive for YFT.

A reduction of 20% in overall fishing effort under HS1 would lead to an increase in $SSB/SSB_{F=0}$ for YFT to a very safe level of 49%, well above the target reference point. The same effort reduction of 20% would also be sufficient to reach the target reference point of 40% $SSB/SSB_{F=0}$ for SKJ. The catch volumes of YFT and SKJ would drop with around 7% and 11% respectively, and gross revenues would drop with 5% and 9%, but fishing costs would likely drop by at least that much when effort would be reduced by 20%.

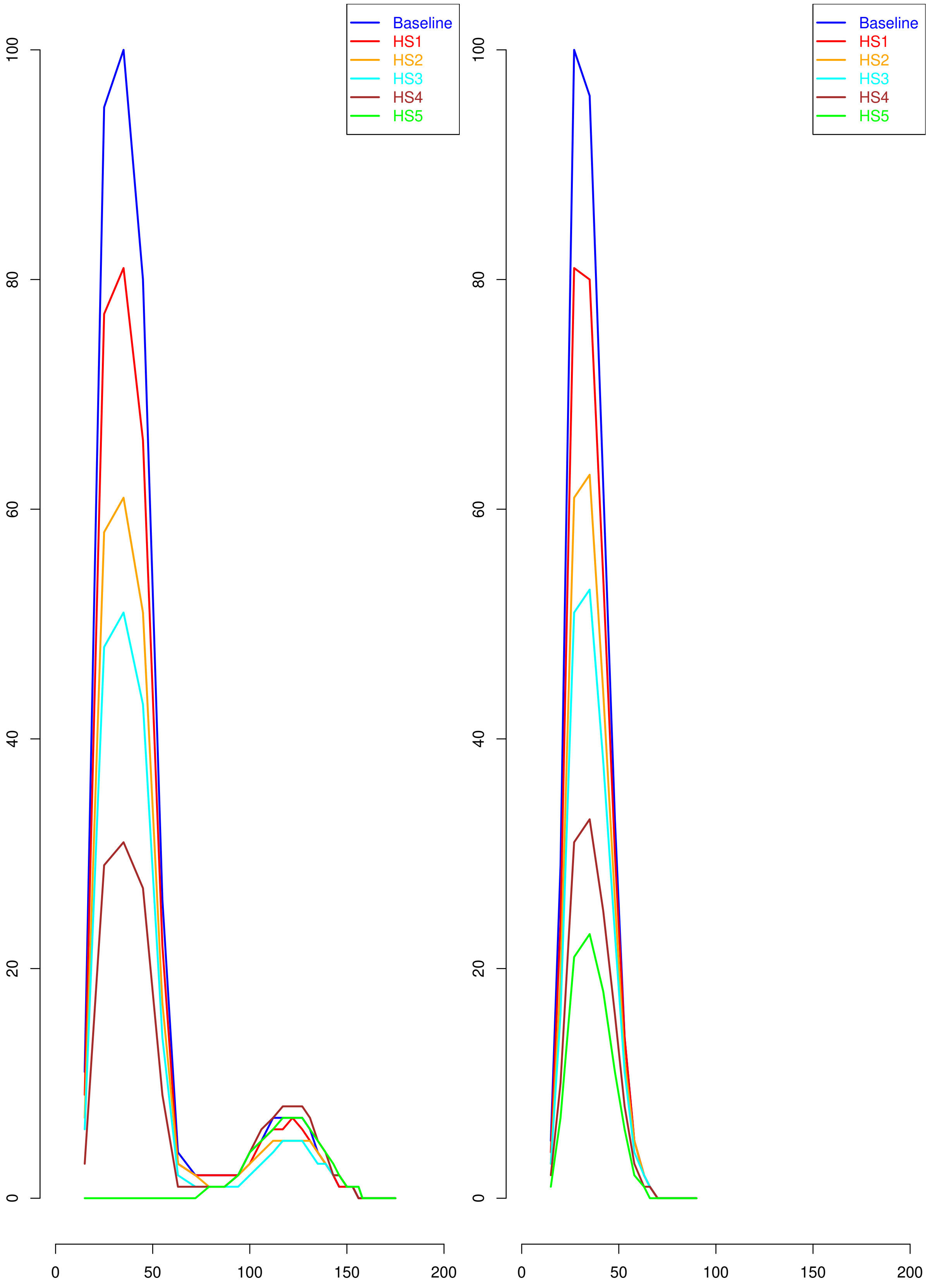


Figure 4.3: Simulated Catch Length Frequencies for Yellowfin Tuna (left) and Skipjack Tuna (right) in 2020 baseline scenario relative to predicted catch curves under various optional Harvest Scenarios (HS1 to HS5) as explained in the text.

We also analysed the predicted outcome of a more structured harvest scenario, explained above as fisheries restructuring strategy HS4 (see Section 4.4.1 for details). A substantial amount of more than 8,000 MT of small tuna would still be harvested under this scenario (Table 4.3 and Fig. 4.3), be it for non-commercial purposes (e.., bait, consumption on board, or barter). We assigned the basic price also to this amount, as this catch did represent such value even though it was not commercially traded. Annual catch of small tuna under HS4 was down some two thirds (67%) compared to the 2020 baseline scenario. The catch of small SKJ dropped with a similar percentage under this scenario. The annual YFT catch from the IAW under HS4 increased slightly with 2% from 170,185 to 174,246 MT, despite a 67% reduction in catch of small tuna and an 8% reduction in catch of medium YFT. The annual catch of large YFT is predicted to increase with 18% from 125,843 MT under the 2020 baseline scenario to 147,867 MT under HS4.

The overall economic value of the YFT fisheries increases with close to US$ 103 million under HS4, which is an increase of 12% in trade value compared to the 2020 baseline scenario. This increase in value is due to the increase in volume of the most valuable category, large YFT, compensating for losses in the smaller size categories and resulting in an increased overall mean price per kg. Moreover, with the HS4 fisheries restructuring possibly being more feasible than unstructured effort reductions, the predicted $SSB/SSB_{F=0}$ of 55% after HS4 also surpassed the interim target reference point to reach a level (above 50%) which may be truly sustainable. $SSB/SSB_{F=0}$ in YFT was expected to rise directly as a result of unstructured effort reductions, but these strategies resulted in losses in total revenue. Such losses in gross revenue may be compensated by cost reductions when effort is reduced, but more detail on costs factors would be needed to quantify the net outcome of each strategy under consideration.

For SKJ, our model predicted that an effort reduction by 70% under HS4 would lead to a loss of gross revenue in the SKJ fisheries of almost US$ 79 million, which is a loss of half the gross revenue compared to the 2020 baseline scenario. These losses however would be more than compensated through increased revenue from the YFT fisheries, while profitability in both fisheries would be greatly improved. With a 70% reduction of fishing effort in the SKJ fisheries, a massive reduction in costs, carbon footprint, baitfish depletion and other undesirable impacts of overfishing would be mitigated. The net economic and fisheries conservation gains from HS4 therefore appear to be worth consideration.

HS4 is socially responsible and also in line with considerations (Brouwer et al., 2018) that fishing mortality be reduced in fisheries that target juvenile YFT, with the goal to maximize fishery yields and reduce any further impacts on the spawning potential for this stock in the tropical regions. FAD management, or rather the management of fisheries around FADs, should be an important component of HS4 (e.g. Kantun et al., 2014). Participation of stakeholders will be vital for any scenario to succeed, especially if it requires changes in behavior from sectors in the fleet and from the processing and trading industries.

HS5 was added here as an example of a more extreme measure which would not result in any better results than what we can expect from HS4. Besides the fact that a complete ban on catching small tuna would be utterly unfeasible and could potentially lead to socio economic issues at the grass roots level, economic benefits were not predicted to be any better while desired fisheries conservation outcomes could be achieved with the more feasible approach in HS4.

5 Impact by Gear Type on IAW Tuna Fishing Sustainability

From our analysis of catch size frequencies across all segments of the fleet that operated in the IAW in 2020, it was clear that pole-and-line and purse seine caught large numbers of small tuna and immature SKJ. Small tuna was also harvested by handline and trolling line operations that use multiple small hooks with artificial lures, while SKJ was almost exclusively caught with pole-and-line and purse seine gears. There has been much discussion about the relative impacts of various gear types on the stocks of both YFT and SKJ, in the framework of harvest scenario development for these species, especially also about the relative impact of purse seine fisheries versus pole and line fisheries in the IAW.

As pole-and-line and purse seine (Figs. 5.1 and 5.2) played such a prominent role in the discussions related to harvesting of both small tuna (juvenile YFT) and small SKJ, we assessed the effect of these two gears in terms of their impact on the spawning biomass of each of the two species. We again used a simple model for this, which was based on 2020 data, where we looked at the total number of harvested fish by species in combination with the median size in the narrow catch curves that characterize both types of gear. We then used the model to evaluate how much biomass these extracted juveniles would have produced, if they would have been allowed to reach adulthood.

Figure 5.1: Pole-and-line vessel catching small tuna and skipjack tuna in the IAW.

For YFT we estimated that about 8.8 million juveniles were caught by pole-and-line in 2020. These juveniles ranged between 20 and 50 cm FL, and with a median size of just 37 cm FL. The model estimated losses to YFT spawning biomass though harvesting small tuna by pole-and-line at around 47,000 MT per year. For the same year, we found that about 3.2 million small tuna per year were caught by purse seine in a narrow size range of very small fish around a median of just 25 cm FL. The extraction of these juveniles caused a loss to the YFT spawning stock of about 9,400 MT per year (Fig. 5.3). With a currently estimated SSB of about 295,000 MT for YFT, this means that SSB could be expanded substantially by addressing the targeting of YFT in pole-and-line and purse seine fisheries. Pole-and-line causes substantially larger losses to YFT SSB than purse seine, as pole and line catches much larger numbers and purse seines catch smaller sizes of fish, which are still experiencing a higher natural mortality than the larger fish caught by pole-and-line.

Figure 5.2: Purse seine vessel catching small pelagics, small tuna, and small skipjack in the IAW.

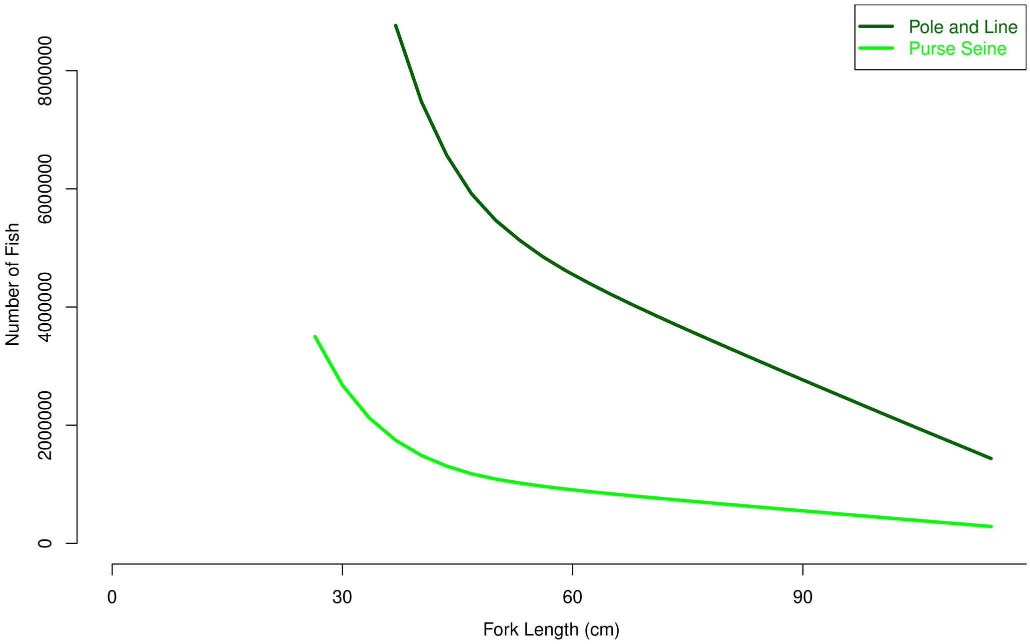


Figure 5.3: Impact by gear type on sustainability of yellowfin tuna (YFT) fishing in the IAW. Graphs show the trajectories in numbers of YFT towards adult populations, if they would not be removed by pole-and-line and purse seine fishing. The pole and line fisheries in the IAW caused much greater losses to SSB then the purse seine fishing in 2020.

For SKJ we found that almost 66 million fish were caught in 2020 by pole-and-line, with over 90% of those being immature, in a size range of 20 to 55 cm FL. With a median size of 36 cm FL the overall catch size frequency for SKJ by pole-and-line was strikingly similar to the one for small tuna in the same type of gear. The model estimated that this extraction of small SKJ caused losses to spawning biomass of around 80,000 MT annually. For the same year, we estimated that purse seines extracted about 37 million small SKJ in a narrow size range around a median of 28 cm FL, with a size range similar to the one for purse seines catches of small tuna in the IAW. Our model estimated that this extraction by purse seine caused a loss to SKJ spawning stock of about 23,000 MT per year (Fig. 5.4). As for juvenile YFT, losses in biomass of SKJ caused by pole-and-line are higher than for purse seine, due to greater numbers of juveniles caught by pole and line as well as the difference in size of fish caught. With a currently estimated SSB of only 100,000 MT for SKJ, the combined impact of the pole-and-line and purse seine fisheries on SKJ spawning stock is substantial and the SKJ SSB could be expanded by addressing growth overfishing in these fisheries.

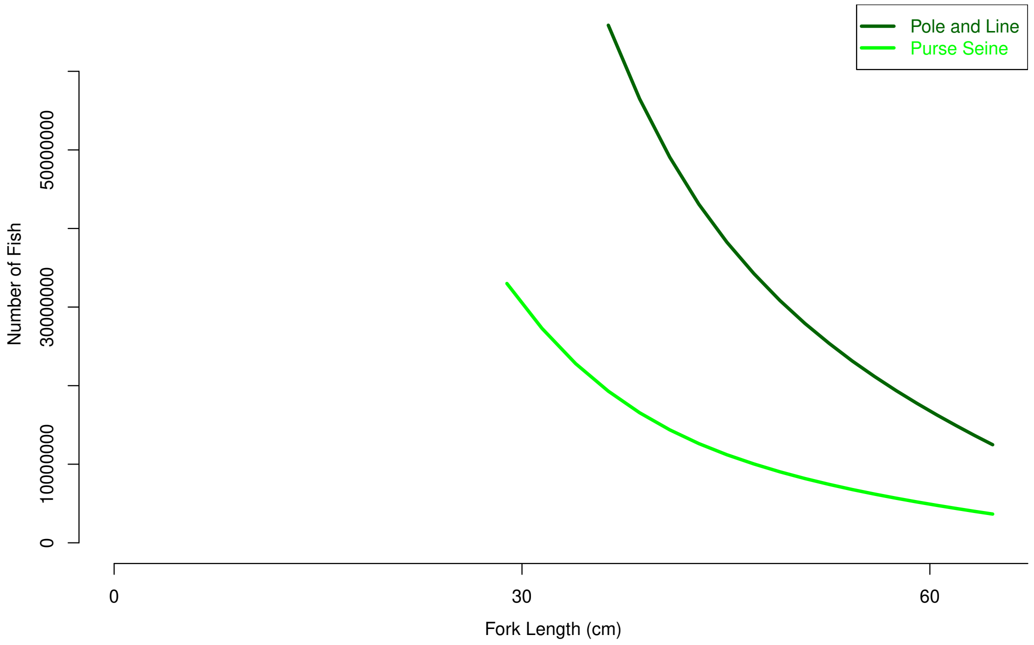


Figure 5.4: Impact by gear type on sustainability of skipjack tuna (SKJ) fishing in the IAW. Graphs show the trajectories in numbers of SKJ towards adult populations, if they would not be removed by pole-and-line and purse seine fishing. The pole and line fisheries in the IAW caused much greater losses to SSB then the purse seine fishing in 2020.

This comparison between gears showed that one cannot draw conclusions about sustainability, at least in respect to growth overfishing, based on gear type alone. Even though pole-and-line is often perceived as a sustainable option (Widodo et al 2016, these links[1&2]), our analysis showed that for Indonesia Archipelagic Waters the impact of pole-and-line on spawning stock biomass is substantially higher compared to purse seine, for both YFT and SKJ. One should keep in mind that the purse seiners of the IAW, measured to international standards, are very small: Even the vessels categorized here as “large” only measure 50 GT on average, whereas a typical ocean-going industrial tuna purse seiner would be around 1,500 GT (SEAFDEC 2004). The small purse seiners operating in IAW target a wide range of small pelagic species and are not comparable to industrial purse seiners that specifically target oceanic tunas in the open Pacific and Indian Oceans. This nuance however is often lost in public discourse.

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[1] www.greenpeace.org.au/blog/6-reasons-to-choose-pole-and-line-tuna/

[2] www.indonesiantuna.com/our-tuna-facts/

6 Conclusions and Discussion

6.1 Catch and Spawning Potential Ratio of yellowfin and skipjack tuna

Yellowfin tuna and skipjack tuna catches from the IAW were reported at 103,291 and 239,039 MT respectively for 2016 (Satria et al., 2017; MMAF, 2018b), and at 137,501 and 273,718 MT respectively for 2017 (Hoshino et al., 2020). These catch volumes amounted to 342,330 MT for both species combined in 2016 and 411,219 MT in 2017. Based on our CODDRS data, we found a significantly lower total of 277,527 MT for the two species combined in 2020, consisting of 172,286 MT of YFT and 105,241 MT of SKJ. And even though we are looking at different years, the relative contribution of YFT and SKJ seemed oddly different, almost reversed, between our estimated volumes on the one hand and the 2016 and 2017 statistics on the other.

Skipjack tuna and juvenile yellowfin tuna are usually the two dominant species in mixed catches by pole and line and purse seine vessels, and are usually landed without being separated on board or at the dock (Figure 6.1). These fisheries typically target mixed schools and the two species remain mixed when stored in the holds on board and are not commonly separated before being landed on the dock. Separation may occur on the dock or later when these fish are entering various supply lines like cannery plants or local fresh markets, but this may take place after enumerators have already recorded landing statistics. These statistics may therefore not be accurate in terms of separating juvenile yellowfin from skipjack tuna.

Yuniarta et al. (2017) described in detail how incorrect reporting and under-reporting of juvenile YFT and BET tuna in Indonesia may have caused underestimation of total catch of YFT and BET around that time. Juvenile YFT and BET was often misreported as SKJ, while under-reporting was rampant in the small scale tuna fisheries. SKJ catches may have been overestimated as a result of the misreporting of juvenile YFT and BET. The official figures for YFT landings from the IAW in 2016 and 2017 may have underestimated the total YFT catch also because government reports may have included mainly (or perhaps only) large YFT or “Madidihang”, as it was called in the statistical yearbooks around that time.

Inconsistencies in current monitoring and enumeration methods, as well as in approaches to data analysis, may be contributing to inconsistencies in landing statistics and issues in official statistical reports (Pet et al., 2019). For example, the results of catch LFD and volume by major gear type and species are significantly different if we ignore the differences by detailed sub-category of gear. In this study with high resolution CODRS data, the background calculations are all done by sub-category of gear and boat size as presented in Yuniarta and Satrioajie, (2021b), taking into account their relative contribution by weighing for effort.

Our estimate of the total YFT catch from the IAW in 2020 is considerably higher than official statistics in reports for 2016 and 2017, whereas our estimated catch of SKJ is much lower. Persisting anecdotal information about juvenile YFT being recorded as SKJ could explain part of this inconsistency. Massive changes in species composition between 2016 and 2020 could be another cause of the differences, but would be hard to explain in the absence of major changes in the fleet. Our analysis resulted in an estimate of 126,461 MT for large YFT from the IAW in 2020, with a large part of that caught with and lines from small-scale boats (Figure 6.2). This very large volume is plausible given information from Hoshino et al. (2020) combined with Yuniarta et al. (2017). Moreover, our total production estimate of 172,286 MT for YFT from the IAW in 2020 was roughly in line with KKP reports on landings by province for that year, after taking into account spatial patterns in effort distribution. The large volume of large YFT harvested in the IAW with unregulated small scale boats does deserve close attention in management discussions at the WCPFC level.

Our length-based stock assessments for YFT and SKJ are based on the overall catch curve by species from the IAW, combining information from all segments of the fleet that operates here. For YFT in the IAW we estimated an SPR of 43%, so just above our target reference point of 40%, and thus achieving management objectives. It seems however that spawning biomass can still be improved somewhat in this area, while a question remains on potentially higher economic benefits from a fishery with more large and valuable fish in the population. The estimated SPR of 43% for YFT in the IAW is in line with the SPR reported for YFT Region 7 of the WCPO, one of the most depleted regions, according to a recent stock assessment by WCPFC (Vincent et al., 2020). This SPR of 43% is well below the average reported for the wider WCPO in the same assessment.

For SKJ in the IAW we estimated an SPR of 32%, well below our target reference point of 40%, and indicating a medium high risk of overfishing in this area. An SPR of 32% for SKJ in the IAW is in the middle of a range of SPR values estimated since 2010 for SKJ Region 5 of the WCPO (which includes the IAW) in stock assessments by WCPFC (Vincent et al., 2019; 8-Region Model), and significantly below what was reported for the complete WCPO. A risk of growth overfishing impacting the skipjack stock in the IAW has recently also been reported by Indonesian scientists (Setiyawan et al., 2021), specifically in relation to the pole-and-line fisheries. Multiple year CODRS studies would be needed to provide further context to our assessment for 2020, taking into account recruitment fluctuations.

6.2 IAW as unit of assessment, and connectivity with neighboring FMAs

The present study focuses on the area covered by FMAs 713, 714, and 715, which comprises the deep seas in between Indonesia's islands. In the context of tuna management, this area has become known as the Indonesia Archipelagic Waters (IAW), a term that sets it aside from FMAs that are part of the open oceans (i.e., 572 and 573 in the Indian Ocean, and 716 and 717 in the Pacific Ocean). In this context, the IAW excludes other FMAs that are in between Indonesia's islands (571, 711, 712, and 718), even though these could be characterized as "archipelagic waters" as well. The reason for this distinction is that the latter FMAs cover mostly shallow seas, which are not important for tuna fisheries (with the exception of deep waters in the eastern part of WPP 718. Our study aims to support the Indonesia Ministry of Marine Affairs and Fisheries in their efforts to develop a Harvest Scenario for tuna fisheries in the IAW (Satria and Sadiyah, 2017; Satria and Sadiyah, 2018). Most recently, Hoshino et al. (2020) also worked with the IAW as a unit for assessment and to develop empirical harvest strategies for oceanic tunas.

Recent studies however suggest that a combination of the IAW with FMAs 716 and 717 might make sense as a "core connectivity zone" for tuna, rather than just the IAW (Lewis and Davies 2021). Some governmental researchers have also called for this extension of the area-of-interest for development of harvest strategies. This begs the question how representative the results of an assessment in the IAW are for a wider area that would include FMAs 716 and 717. One way to shed light on this question is by comparing the importance of tuna fisheries in FMAs 716 and 717 to the tuna fisheries in the IAW. According to official statistics on landings in 2016, oceanic tuna from the IAW amounted to around 60% of the total catch from Indonesian waters. At the same time, tuna from the IAW amounted to more than 75% of the production from the "core connectivity zone". FMA 715 by itself already represented around 50%) of the catch of the "core connectivity zone" (MMAF, 2017a). The importance of the IAW, relative to the wider core connectivity zone, suggests that inclusion of 716 and 717 will not dramatically change the findings and conclusions of this report on the IAW. Nevertheless, it would seem prudent to heed the findings from Lewis and Davis (2021), and expand the scope of a for harvest scenario for archipelagic waters to one for the core connectivity zone including FMA 716 and 717. This means that future data collection programs to underpin implementation of a harvest scenario must also include these two FMAs. A comparison of IAW findings with fisheries characteristics from FMA 716 and 717 could be obtained from available CODRS data from boats that fished both inside the IAW and in those 2 FMAs (Figure 3.6).

6.3 Options for tuna fisheries management in the IAW

We used a simple model to show that if catches of small tuna were significantly reduced, the gains in biomass due to growth, combined with the price increase (per kg) from juvenile to large YFT, would exceed losses due to natural mortality. The total value of YFT catches from the IAW was predicted to increase significantly with around US$ 103 million per year when fisheries mortality among small tuna is reduced by 70% through fisheries restructuring, alongside an overall effort reduction of 10% in the entire fleet. The model showed that the SSB in these waters could be maintained at a target level of at least 40% of $SSB_{F=0}$, and even above 50% of $SSB_{F=0}$, if commercial targeting of small tuna is significantly reduced. Major unstructured effort reductions (i.e., reductions in effort for all gears) in the fisheries for YFT had negative effects on total catch and value, with the notes that overall costs would be reduced after such effort reductions, and that $SSB_{F=0}$ would rise above the target level.

Our assessment of SKJ fisheries in the IAW indicated serious growth overfishing and our model predicted that an effort reduction by 70% under HS4 would lead to a loss of gross revenue in the SKJ fisheries of almost US$ 79 million, which is a loss of half the gross revenue compared to the 2020 baseline scenario. These losses however would be more than compensated through increased revenue from the YFT fisheries, while profitability in both fisheries would be greatly improved. With a 70% reduction of fishing effort in the SKJ fisheries, a massive reduction in costs, carbon footprint, baitfish depletion and other undesirable impacts of overfishing would be mitigated. The net economic and fisheries conservation gains from HS4 therefore appear to be worth consideration.

There are many studies that warn about economic overfishing through targeting of premature age groups (e.g. Diekert, 2013), and tuna fisheries are not excluded from this discussion (e.g. Sun et al., 2010; Maunder et al., 2011; Bailey et al., 2013; Sun et al., 2019). Management of YFT and SKJ fisheries in the IAW is not yet optimal with respect to its economic value, and the same issue has been reported from the wider Pacific region (e.g. Sun, 2010). Our analysis showed that YFT and SKJ in the IAW were caught at sizes too small to take advantage of their individual growth potential and of the higher prices (per kg) that can be obtained for large mature fish. Hampton (2000) noted that domestic tuna fisheries in the Philippines and Indonesia catch significant quantities of very small YFT. Hampton (2000) also noted that estimates of the impact can be derived using yield per recruit or other size- or age-structured models, as we did in this paper, corroborating effects from previous studies (e. g. Bailey et al., 2013).

Large YFT supply markets for sashimi and other fresh and frozen products, whereas SKJ and small tuna supply the canning industry as well as local markets. Hence, interventions to reduce selectivity for, and therefore fishing mortality of, small tuna boil down to a restructuring of the fishery. Whereas such re-structuring of the YFT fishery would have to address social and equity issues, we concluded that overall economic output from the YFT fisheries in the IAW would greatly improve by shifting the fisheries away from targeting small tuna. This could be done simultaneously with rationalizing the SKJ fisheries which could be improved significantly by reductions in effort in the same fleet segments that also target small tuna. We recommend a cooperative management approach to create incentives for pole-and-line, purse seine and handline fishermen to reduce their catches of juvenile YFT, while effort in pole-and-line fisheries would need to be reduced. The details of a more sustainable management system would have to be worked out to address the complexities of the fisheries and the communities that depend on them, but the potential benefits and the possibility of implementing such a system should not be ignored (Sun, 2010; Global Tuna Alliance, 2021).

Adjustment of behavior and sound decision making is essential to reform fisheries that reduce overall economic returns through over-harvesting of juvenile tunas (Sun et al., 2010), and this also applies to YFT fisheries in IAW. Preventing unwanted catch of juvenile tunas is possible by changing fishing practices, possibly assisted by innovative technology. Skipper trainings and development of acoustic technology has already helped industrial purse seiners to make more sustainable decisions during their operations at sea (Restrepo et al., 2017), and similar approaches are also needed in Indonesia to reform medium-scale purse seine, pole-and-line, and handline fisheries in the IAW. The competitive situation between fisheries supplying the canning industry with small- to medium-sized tuna, mostly pole-and-line and purse seine fisheries, and fisheries for large YFT and BET supplying markets for sashimi and other fresh and frozen products (mostly handline and longline fisheries) has been discussed for decades (e.g. Miyake et al., 2010; Sun et al., 2017; Sun et al., 2019). Cooperative management is a key issue in addressing the problems in situations where different sizes or age groups of the same species are vulnerable to multi-gear fisheries (Diekert et al., 2010; Bailey et al., 2013).

The use and management of FADs deserves attention, and improved FAD management should focus on the problem of targeting small tuna and SKJ. In Indonesia, both small scale and industrial fishers use anchored FADs to catch small tuna as well as large YFT, be it using different gears with large baits deployed at greater depth to catch large YFT. Whereas FADs do play a role in the fishery for small tuna in IAW, regulation of FADs will also affect the fishery for large YFT. Therefore, management of FADs should aim to optimize use of this auxiliary fishing gear for capturing large YFT, while ensuring that the gear is not used to catch excessive amounts of small tuna. When evaluating economic gains from simulation models, one must keep in mind though, that predictions are sensitive to input assumptions for size-specific natural mortality, fishing mortality, growth, and migration. In some cases, the uncertainty surrounding input levels can be of such magnitude that model predictions cannot be used to recommend specific management interventions (e.g. Lehuta et al., 2010). The sensitivity analysis that we performed on the predecessor of our model, however, suggested that uncertainties about input parameter values would not affect our overall recommendations for management.

6.4 Sensitivity of Model Conclusions to Input Parameter Values

Input parameters and other assumptions in this model, like in any model, are subject to discussion. Such uncertainties are usually quantified through a sensitivity analysis. We performed a sensitivity analysis for a predecessor of this model, which had the same structure and where we assessed the same management scenarios. The conclusion from that sensitivity analysis was that the relative outcomes of the management scenarios were not affected by variation in input parameters for growth and mortality (sections 6.3 through 6.7 in Pet et al. 2019). We felt that a sensitivity analysis for the model presented in this report would result in the same conclusion, and therefore we did not perform a new sensitivity analysis for the model presented in this report. We acknowledge, however, that a sensitivity analysis should be performed if researchers plan to use this model for decision-making going forward.

Growth and mortality parameter values affect predictions on the effects of simulated harvest strategies. Over-estimation of natural mortality (M) leads to under- estimation of fishing mortality (F) if estimation starts from a total mortality (Z) from catch curve analysis or tag returns. Under-estimation of potential growth leads to under-estimation of the benefits from simulated harvest scenarios. Under-estimation of growth could occur if Linf is under-estimated due to lack of large fish in samples (from heavily fished populations) used for estimation of potential growth. This effect is causing concern also in assessments of other heavily fished species. These issues should be subject of further detailed studies, but sensitivity analysis for alternative levels of natural and fishing mortality, as well as for alternative values in growth parameters, showed that our overall conclusion on the results from a proposed fisheries restructuring are not changed substantially, but that the predicted levels of potential gains can vary significantly. The sensitivity analysis of the predecessor of the model presented here is available as a spreadsheet together with the downloadable version of the relevant report (Pet et al., 2019).

6.5 CODRS compared to other data collection methods

As costs for CODRS depend on the size of the vessel, the costs of a CODRS program depends on the average size of boats in the fleet and on the number of fleet segments. Table 6.1 below provides an overview of costs for implementation per vessel size category, assuming that the number of participating CODRS vessels is large enough (at least 500 vessels) to fully occupy technicians, senior technicians, and a database developer, and that the program continues long enough for all hardware to fully depreciate (five years). These costs represent the effort needed for the fishers to obtain the images, to get them analyzed and quality-checked by technicians and senior technicians, and to make the data available in an on-line database, which means that costs for a database developer are included. Note that these costs cover all landings of one vessel in a full calendar year. The costs presented in Table 6.1 do not include administrative costs, costs for supervision, costs for a fisheries expert, and occupancy.

This is more expensive than logbooks, but cheaper than using observers ($2,700 per observer-trip). One full year of cooperation by 110 boats resulted in 3,286 landings in a stratified sampling program covering all segments of the fleet and measurements on well over 400,000 fish. For the size of the fishery and the specific geography this represented very good and high-quality coverage, which would be hard to achieve with a port sampling program in an area which such dispersed landings. One important advantage of CODRS compared to other methods is that the images allow for verification of species and size data. Especially for the biodiverse fisheries of Indonesia, species identification is a major challenge and mis-identifications are common. The CODRS images allow for consultation with experts and for correction if mis-identification occurred. Another aspect of the CODRS method that is particularly useful is the detailed geographic data it provides for each fishing trip. Researchers can match GPS coordinates and dates from the tracking device with the date-timestamps on CODRS images, thereby obtaining time and location of capture of each fish. Researchers can map fishing grounds in detail, determine spatial distribution and habitat preference, analyze vessel dynamics, and determine management implications related to fleet movement patterns. CODRS, logbooks, and even on-board observers all depend on some level of collaboration with fishers, so this dependency is not exclusive to any one method.

Table 6.1: Annual costs per vessel (in US$) for implementation of CODRS, assuming a CODRS fleet of at least 500 vessels, and a monitoring program lasting at least five years (after which all hardware has fully depreciated).

		Boat size category			
Item	Included costs	< 5 GT	5-10 GT	10-30 GT	> 30 GT
Fishers	Fees for participating fishers, fees for local coordinators / SD card collectors	$987	$987	$1619	$2266
Personnel	Technicians, senior technicians, database developer	$294	$553	$553	$1006
Hardware	Spot Trace units, batteries, Spot Trace subscription, measuring boards, compact cameras, SD cards, cloud server subscription, laptops and external hard disks for personnel.	$332	$360	$360	$388
Travel	Domestic travel for technicians and senior technicians	$86	$173	$173	$324
Misc	Costs for training, stationary, etc.	$100	$100	$100	$100
Total		$1800	$2172	$2804	$4083

6.6 Review of Bigeye Tuna in Pole and Line and Purse Seine catches

The initial analysis of images from catches by pole-and-line and purse seine vessels in Indonesian Archipelagic Waters resulted in extremely low presence of bigeye tune, relative to the other two large oceanic tuna species in the catch, yellowfin and skipjack tuna. We have therefore reviewed a large number of images from these catches and went over those no less than three times, in great detail, to be absolutely sure about our results. This was deemed necessary as these catches, perhaps especially purse seine catches, were expected by some to contain considerable percentages of juvenile bigeye tuna. We have therefore reviewed a large sample of ImageJ photos from IAW pole-and-line and purse seine catches, and we have specifically scanned those, meticulously, for the presence of any bigeye tuna among the oceanic tunas in the catches. The main challenge here was to separate bigeye tuna from yellowfin tuna in among the large quantities of "small tuna" in the catch.

While looking at the results of our detailed catch analysis review (Table 6.2), we need to keep in mind that these are very specific to the small scale ("mini") versions of purse seines operating in the Archipelagic Waters of Indonesia, protected fishing grounds in between the islands. This fishery is very different for example from the much larger ocean-going operations, especially industrial purse seine vessels, fishing in the open Pacific and Indian Oceans. For those type of large-scale oceanic operations, catch characteristics are separately shown for example in WCPFC reports under "Purse Seine" and "Pole and Line". But combined catches characteristics from all gear types comprising the small-scale fleet in the IAW, including our small-scale purse seine and pole-and-line, are all shown together under “Indonesian and Philippines Archipelagic Fisheries”. This may cause confusion as people may look at “Purse Seine” catch characteristics from such reports, and wonder why those look different from what we find for purse seine and pole-and-line in the IAW.

Table 6.2: Review of oceanic tuna species distribution in IAW pole-and-line and purse seine catches, based on a large sample of images from the Crew Operated Data Recording System

Fishing Gear	N-Image	Species	Specimen	% Oceanic Tuna	Measured	Length-Min	Length-Max	Length-Avg.
PoleAndLine	210	BET	12	0.1	6	38	49	44
PoleAndLine	210	YFT	1520	12.1	554	22	74	39
PoleAndLine	210	SKJ	10991	87.8	4763	20	80	34
PurseSeine	257	BET	14	0.1	8	32	53	41
PurseSeine	257	YFT	2368	24.2	1472	11	63	26
PurseSeine	257	SKJ	7388	75.6	3937	12	62	28

Our team reviewed 210 ImageJ photos from pole-and-line catches, as well as 257 ImageJ photos from purse seine catches, all from the IAW. ImageJ photos by nature contain a large number of fish in each image. For this review we focused on the 3 main species of oceanic tunas caught in the IAW, skipjack tuna, yellowfin tuna, and bigeye tuna. After species identification was completed for all oceanic tuna in the images, it was concluded that the 210 images of pole-and-line catches included a total of 10,991 skipjack tuna (SKJ), 1,520 yellowfin tuna (YFT) and 12 bigeye Tuna (BET). This means overall in terms of numbers of oceanic tuna (SKJ+YFT+BET) we found 88% skipjack, 12% yellowfin and just 0.1% bigeye tuna in pole-and-line catches. All the YFT and BET in these catches were juveniles, or small tuna, well below the size of maturity.

If we just look at the small tuna in pole-and-line, with small tuna here being a combination of YFT and BET, we can conclude that 0.8% of the small tuna from pole-and-line in the IAW, are in fact BET. Pole-and-line catches almost exclusively consist of SKJ and small tuna, with only very small numbers of other species. The 257 images with purse seine catches included a total of 7,388 skipjack (SKJ), 2,368 yellowfin (YFT) and 14 bigeye tuna (BET). This means overall in terms of numbers of oceanic tuna (SKJ+YFT+BET) we found 76% skipjack, 24% yellowfin and just 0.1% bigeye tuna in purse seine catches. Looking at the small tuna in purse seine catches, with small tuna a combination of YFT and BET, we can conclude that 0.6% of the small tuna from purse seine in the IAW, are in fact BET. Similar but somewhat less than in pole-and-line catches. It is important to note here that purse seine catches include very large amounts of other small pelagic species besides the three oceanic tunas mentioned above. Keeping that in mind, the percentage of BET in terms of numbers in the catch of purse seines is close to zero.

Not all fish in ImageJ photos can be measured accurately, even though the species can be identified, because sometimes too much of the body is covered by other fish. Out of the 12 BET in 210 pole-and-line catch images, only 6 specimen could be measured accurately. And out of the 14 BET in 257 purse seine catch images, just 8 could be measured accurately. The extreme low numbers of BET in pole-and-line and purse seine catches, thus resulted in even lower number numbers of BET that could be accurately measured to contribute to the reconstruction of catch LFD and CpUE. And we need to keep in mind here that these few specimens were then further separated by different boat size categories, for CpUE calculations. As a result, the number of BET were so extremely low for each segment in the fleet, that they did not add up to conditions for minimum sample sizes that would allow accurate estimation of CpUE and catches. Due to this extremely low occurrence of BET in pole-and-line and purse seine catches in the IAW, we could only conclude that those were “near zero” when it comes to volume, on the basis of the procedures that we have in place to calculate catches from size frequencies by species for each segment in the fleet. In this specific sample of images for detailed review, we found 0.1% of BET in terms of numbers of “large oceanic tunas” both in pole-and-line and in purse seine catches. Both in pole-and-line and in purse seine catches we found less than 1% of all small tuna (YFT+BET) to be BET. Moreover, purse seine catches in the IAW contain huge amounts of other small pelagic species, bringing the total percentage very close to zero.

6.7 Measuring length with ImageJ and reference versus measuring boards

We used two length measurement methods in the CODRS program. For fish that were photographed with a measuring board in the background (on hand line, trolling line, and longline boats), technicians simply used the image of the fish on the board to read the length at the fork of the tail, to the nearest centimeter (Figures 1.8 and 1.9). For fish that were photographed in bulk in the holds of purse seine and pole-and-line vessels, with a reference measuring stick on top of the fish, technicians used the image analysis software ImageJ to draw a measuring line length from the tip of the snout to the fork of the tail, using the measuring stick as a size reference (Figure 2.1). For the latter procedure, technicians only used those fish for which both the snout and the tail were visible.

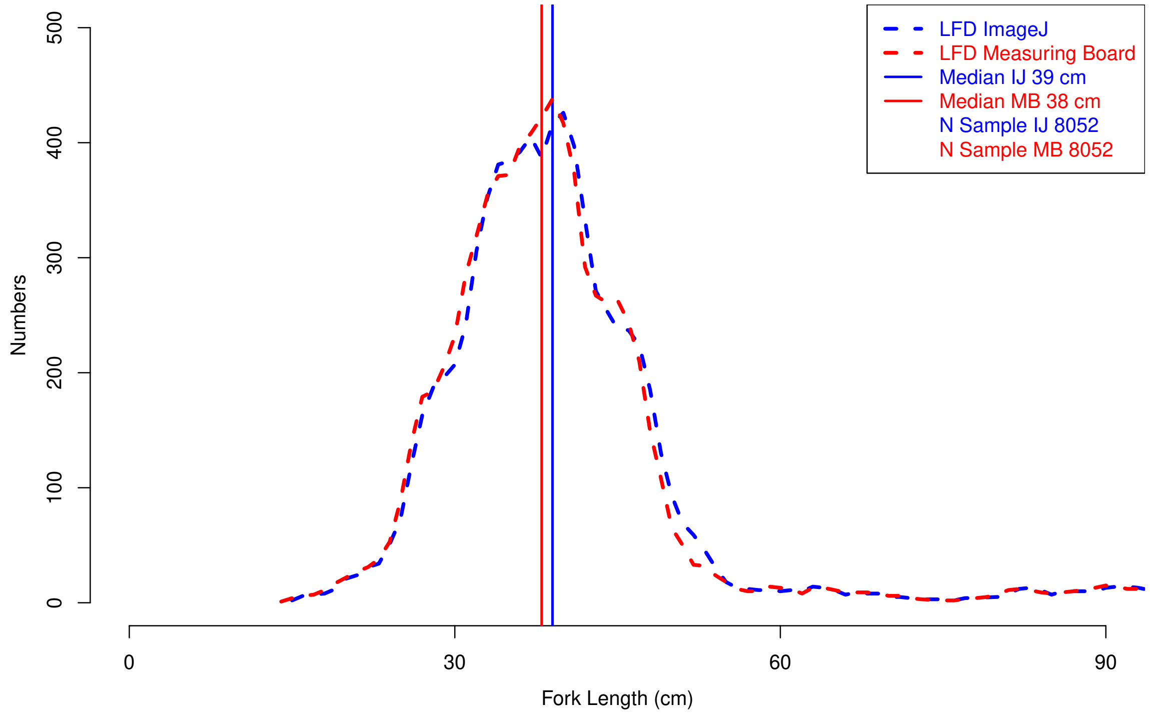

Figure 6.1: Comparison of size frequencies of YFT in catches measured with ImageJ and Measuring Board.

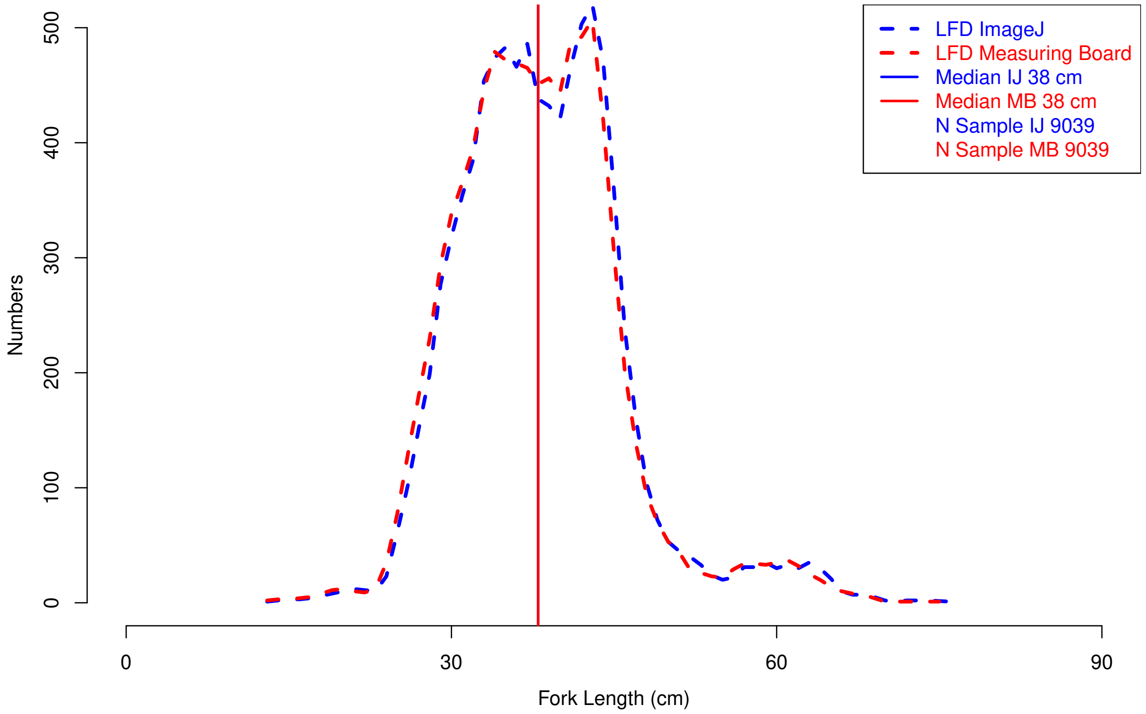

Figure 6.2: Comparison of size frequencies of SKJ in catches measured with ImageJ and Measuring Board.

To verify whether the two length measurement methods lead to comparable results, we randomly selected images with measuring boards in the background for which the length measurement was already done, and we then measured them again using ImageJ. We re-measured 8052 yellowfin tuna, and 9039 skipjack tuna with both methods and then compared the results. The resulting length frequency distributions (Figure 6.1 for yellowfin tuna and Figure 6.2 for skipjack tuna) were very similar, and median sizes differed not more than 1 cm between the two methods. It is highly unlikely that such small differences would affect conclusions about stock health indicators.

Table 6.3: Results from the comparison between measurements for yellowfin tuna (YFT) and skipjack tuna (SKJ) on a measuring board and ImageJ, with results of three statistical tests: Two-tailed paired t-test, Mood's median test (for testing a difference between medians), and the Kolmogorov-Smirnov (KS) test for testing a difference in the shape of the distributions.

Species	N	Average length measuring board	Average length ImageJ	Median length measuring board	Median length ImageJ	P value Two-tailed paired t-test	P value median test	P-value K-S test
YFT	8052	41.5479	41.9996	38	39	<0.0001	0.0089	0.00223
SKJ	9039	38.077	38.4944	38	38	<0.0001	0.0562	0.00234

We did find a small difference of 0.5 cm in mean length between the two measuring methods which was difficult to explain. The difference is consistent between species and over length classes, and the differences are significant (Table 6.3). A 0.5 cm difference suggests inconsistent application of rounding procedures between measuring board readings and ImageJ readings, and we scrutinized for various measurement irregularities (rounding to the nearest cm below instead to the nearest cm, errors with drawing the scale reference line in ImageJ), but we could not find the source of this bias. As this bias is likely a small oversight specific to this experiment, and not to the routine measurements, and because the difference between methods was very small, we decided to ignore it.

While designing and trialing this experiment, we did come across a much more substantial bias which would have been introduced in our data set if we had in fact tried to photograph fish directly on measuring boards on purse seine and pole-and-line vessels in the routine CODRS program. This issue is related to the way observers "randomly" pick fish from the catch for measurement. Initially, we asked observers to first take an images of a batch of fish as in Figure 2.1, with the reference sticks put on top, following our prescribed sampling procedure. We then asked observers to randomly pick five fish, for photographing on a measuring board. This was repeated many times during one trip of a pole-and-liner operating from Bitung, until reaching about 1,500 measurements with both the measuring board and the ImageJ method. Our hypothesis was that, due to the large number of measurements, the length-frequency distributions for each of the methods should be similar, or at most there should be small consistent difference.

The results, however, showed much more substantial differences (Figure 6.3). Firstly, it appeared that the second mode, representing the larger fish, was much more pronounced in the length-frequency distribution for the measuring board observations than for the ImageJ observations, Secondly, the measuring board observations were shifted 3-5 cm to the right compared to the ImageJ observations. Since the difference between the methods should be 0.5 cm at most, we concluded that the difference was caused by the tendency of observers to pick larger fish for measurement. We therefore concluded that photographing fish in bulk in the hold, followed by processing of the photos with ImageJ is the preferred method, because it is not sensitive to the bias introduced by observer preference.

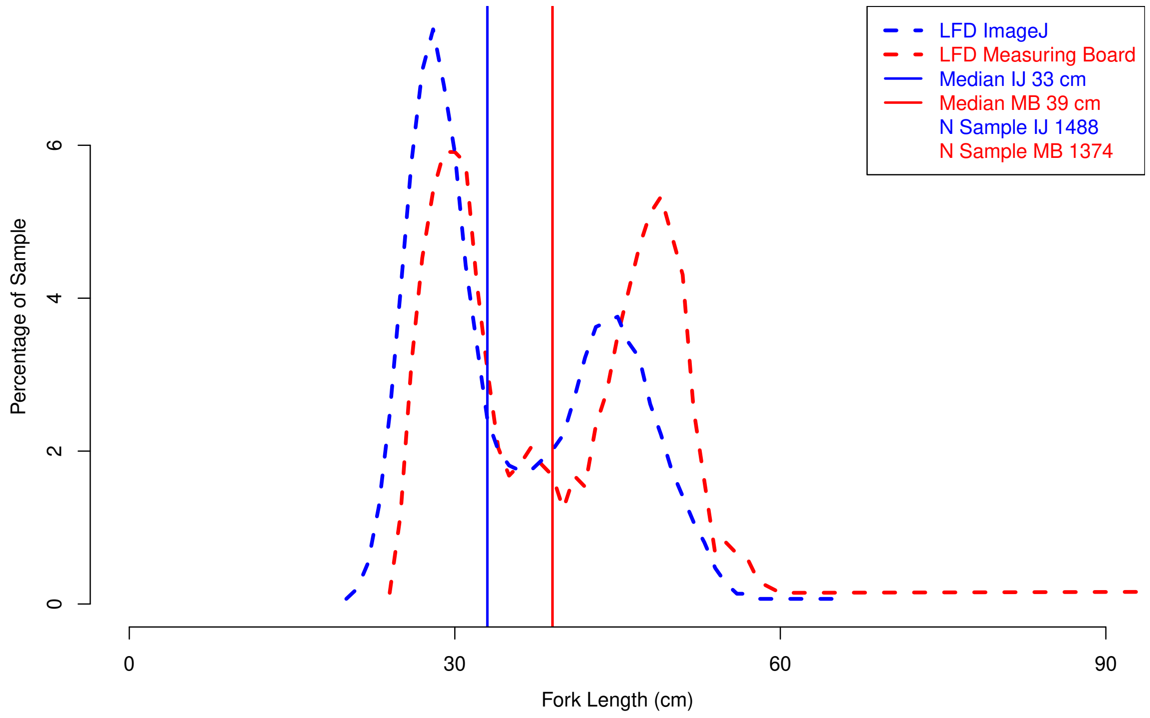

Figure 6.3: Comparison of size frequencies of SKJ in catches by Pole and Line vessels measured with ImageJ and Measuring Board.

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8 Links to Detailed Background Reports

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