The Value of Growth: a "Back of an Envelope" Model to Assess Economic Gains from Size Specific Harvesting of Yellowfin Tuna in Indonesian Archipelagic Waters

With 2016 YFT Baseline Scenario and Evaluation of Alternative Harvest Strategies

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ALB	Albacore Tuna
BET	Big Eye Tuna
DGCF	Directorate General Capture Fisheries
DNA	Deoxyribonucleic acid
EEZ	Exclusive Economic Zone
EPO	Eastern Pacific Ocean
F	Fishing mortality
FAD	Fish Aggregating Device
FL	Fork Length
FAO	Food and Agriculture Organization of the United Nations
FMA	Fisheries Management Area
HL	Hand Line
HS	Harvest Strategy
IAW	Indonesia Archipelagic Waters
IOTC	Indian Ocean Tuna Commission
K	Growth rate
L	Length
LFD	Length Frequency Distribution
L_{inf}	Length infinity, meaning asymptotic length at which growth is zero
LL	Long Line
M	Natural mortality
MT	Metric tons
MMAF	Ministry of Marine Affairs and Fisheries
NGO	Non-Government Organization
PL	Pole-and-Line
PS	Purse Seine
RFMO	Regional Fisheries Management Organization
SBT	Southern Bluefin Tuna

SCAA	Statistical-Catch-At-Age
SKJ	Skipjack Tuna
SPC	The Secretariat of the Pacific Community
SSB	Spawning Stock Biomass
$SSB_{F=0}$	Spawning Stock Biomass at zero fishing mortality
TNC	The Nature Conservancy
W	Weight
WCPF	Western and Central Pacific Fisheries Commission
WCPO	Western Central Pacific Ocean
WPP	*Wilayah Pengelolaan Perikanan*
YFT	Yellowfin Tuna
Z	Total mortality

EXECUTIVE SUMMARY

To guide how The Nature Conservancy (TNC) may support the Government of Indonesia and private sector partners in their quest for sustainability of Indonesia's tuna fisheries in Indonesian Archipelagic Waters (IAW, Fishery Management Areas 713, 714, and 715), we constructed a simple "back of an envelope" model for Yellow Fin Tuna (YFT) fisheries in these waters. The model provides a preliminary indication of the effects of effort reduction in fisheries targeting mainly Baby YFT and Large YFT. The current level of $SSB/SSB_{F=0}$ is only 25% and thus not far above the Limit Reference Point (LRP) of 20% as adopted for IAW. The model indicates that minor reductions across all tuna sectors do not achieve the interim Target Reference Point (TRP) for the IAW of 40% $SSB/SSB_{F=0}$. Major effort reductions across all sectors with 40% or more could achieve the interim TRP, but only at the cost of at least 10% decrease in total catch and slight decrease in monetary value of that catch. A far more efficient way to achieve the interim TRP is addressing the fisheries that target Baby YFT.

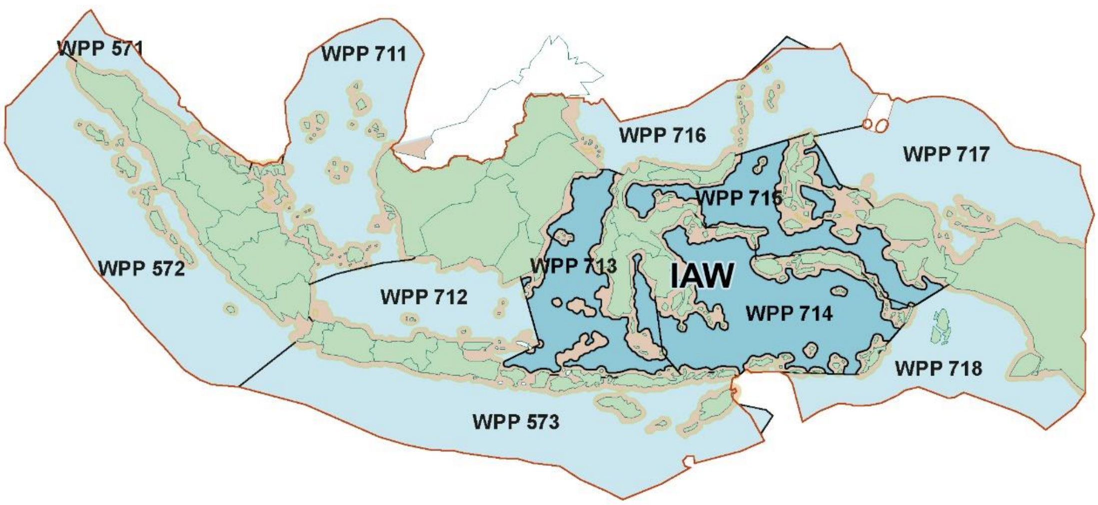
A reduction of fishing effort with 90% in specific fisheries targeting Baby YFT, combined with a minor (10%) reduction in fishing effort across all sectors, will surpass the interim TRP while at the same time increasing the total trade value of the catch with US$ 225 million. This is an increase of no less than 53% compared to current levels. The total catch volume is also predicted to increase with 14% from this strategy. Restructuring of the fisheries under this scenario would essentially mean a transition from a fishery for low-value, Baby YFT used for canning as well as for local markets, to a fishery for high-value, large YFT for loins and sashimi-grade tuna. We conclude that a collaborative approach towards restructuring of the YFT fishery, combined with control of the overall level of fishing effort, forms an obvious path for improvement of the YFT fishery in the IAW. Management of Fish Aggregating Devices (FADs) should be addressed as an important aspect of the restructuring, as it is relevant for Baby YFT as well as for Large YFT fisheries.

Most fisheries models are sensitive to the estimated level of size dependent natural mortality, and our model is no exception to this. We used natural mortality estimates that are based on research findings from the Western and Central Pacific and from the Indian Ocean regions, but published estimates vary widely. The scientific community agrees that tagging studies are the best way to measure natural mortality, and therefore we recommend to review existing results from tagging studies previously implemented in the IAW, and assess whether additional tagging studies could reduce uncertainty. Such reduction of uncertainty will help to increase the precision in harvest strategy evaluations, but it is not expected to change the overall conclusion that significant economic gains can be expected from restructuring the YFT fishery to one that mainly targets large mature fish.

1.0 INTRODUCTION

Fisheries for tropical tuna in Indonesia are among the most diverse and complex in the world. Indonesian catch statistics include five major species of oceanic tunas, as well as several coastal tuna species. The valuable oceanic tuna species include albacore (ALB), bigeye (BET), southern bluefin (SBT), yellowfin (YFT) and skipjack tuna (SKJ). Large numbers of fishing boats, ranging in size from small canoes to industrial scale vessels, caught a reported 712,668 Metric Tons (MT) of oceanic tuna in 2016 (MMAF-a, 2017). The most common fishing gears used in Indonesian tuna fisheries include pole-and-line, purse seine, longline and various types of handlines and trolling lines. Information on the status of tuna stocks in Indonesia is fragmented, but available data indicate that Indonesia's Archipelagic Waters (IAW)[1], comprising Fisheries Management Areas (FMAs) 713, 714 and 715 are of major importance, especially for the production of yellowfin and skipjack tuna (MMAF-a, 2017). The Indonesian term for FMA is *Wilayah Pengelolaan Perikanan* or WPP (**Figure 1.1**). The relatively high production from the IAW, combined with indications for a strong residential behavior for skipjack and yellowfin tuna in this area (Natsir et al., 2012), has encouraged Indonesia to prioritize the development of a harvest strategy for these species here (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.

Figure 1.1 Indonesian Fisheries Management Areas (FMAs or WPPs) and details of Indonesia's Archipelagic Waters (IAW).



Led by the Ministry of Fisheries and Marine Affairs (MMAF), the development of a Harvest Strategy (HS) for tropical tuna in the IAW (MMAF-a, 2018) was started as a science-based and participatory process, which included data collection and analysis, expert consultations, and modeling in support of decision- making processes (Satria and Sadiyah, 2018). A series of technical and consultative stakeholder workshops have ensured a collaborative process, while an operating model for evaluation of harvest strategies has been developed (Anon., 2018; Hoshino et al., 2018). MMAF has committed to continue collaboration with stakeholders including government, experts, fishers, fishing associations, industry and NGOs, and to adopt a participatory approach to the implementation of their framework for harvest strategies (Satria and Sadiyah, 2018).

[1] This paper uses term Indonesia's Archipelagic Waters as described in Satria and Sadiyah 2018 and in WCPFC 2018.

Involvement of Indonesian and international experts through consultation and technical workshops is an ongoing part of harvest strategy development. New data collection and -processing technologies are being developed, with new roles for NGOs and the private sector, feeding information into government databases (Satria and Sadiyah, 2018). The Nature Conservancy (TNC) is one of the NGOs actively working with government within this process of collaborative fisheries management, with contributions to information systems on demersal fisheries delivered in 2018 (Satria et al., 2018). TNC is exploring an expanding role in the development and implementation of the harvest strategy for tropical tunas in the IAW (Mous, 2018). In this paper, TNC attempts to reconcile currently available information on production levels through an analysis of production statistics and by relating these statistics to figures reported to Regional Fisheries Management Organizations (RFMOs). These production figures (e.g. MMAF-a, 2017; Satria et al., 2017) play an important role in prioritization and decision making in fisheries management and form essential input in decision support models that predict absolute levels of outcomes from alternative harvest strategies.

TNC Indonesia in recent years has been supporting government and industry with the development of cost-effective and scientifically sound approaches to management-informing data collection that can be taken to scale. Starting with the present paper, TNC has also embarked on a process of engagement in the science-based development of harvest control rules for tropical tuna in the IAW, as part of the existing empirical harvest strategy for this area. This empirical harvest strategy is expected to be transparent and easily explained to non-technical audiences, while hopefully being straightforward to implement (Satria and Sadiyah, 2018). For effective engagement in the process of harvest strategy development for the YFT fisheries in the IAW, it is important to understand the processes and underlying assumptions that together form the input in the operating model that is used for the evaluation of alternative harvest strategies (Anon., 2018; Hoshino et al., 2018). Therefore, this paper introduces a "back of an envelope" model as a simple tool to generate meaningful discussion and comprehensible ideas, in support of the collaborative approach.

The model focus is on YFT, as indicator species for the fisheries targeting large oceanic tunas in the focus area of the IAW. There is ample information on YFT fisheries in Indonesia. In 2016 the reported landings of YFT in Indonesia totaled 209,227 tons (MMAF-a, 2017). Global yellowfin production in that same year was estimated at 1,462,540 MT (FAO, 2018). This means that Indonesia produced 14% of the global yellowfin catches in 2016. Total YFT production in Indonesia in 2016 was about 4 times the volume recorded for BET and the ratio was even higher for YFT versus BET in the IAW. The IAW currently contain by far the most productive fishing grounds for YFT in Indonesia (Satria et al., 2017). Improvements in the management of YFT in the IAW may also benefit the BET stocks and fisheries there. Also, we will assume the SKJ stocks to be more resilient to fishing than YFT, as SKJ is a smaller and fast-growing species that matures at much smaller size than YFT. Many of the problems in SKJ fisheries in our target area, as well as globally, have to do with YFT by catch issues (Baily et al. 2013, Itano 2005). By taking a deeper dive into the YFT fisheries, we will therefore have to deal with overlap issues in the SKJ fisheries as well.

The basic model introduced in this paper is not meant to replace more sophisticated approaches to modeling for the purpose of harvest strategy evaluations (e.g. Hoshino et al., 2018). Our simple model is merely a tool to bring together basic information and assumptions, or values for input parameters, to assess how the input affects conclusions related to management, and to learn more about the sensitivities of model predictions to the values of specific input parameters. Uncertainty about values of input parameters is a common issue when using decision support models. In this paper, we highlight some of the most important uncertainties, we discuss ways forward for optimized management of the IAW tuna fisheries, and we recommend specific additional work to reduce uncertainty.

2.0 MATERIALS AND METHODS

The model we used in this paper is a straightforward population dynamics model that assumes equilibrium of the stock and the fishery. Under the equilibrium assumption, with constant annual recruitment, constant 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 simulated 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 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 (Langley et al., 2009). We have therefore not included any stock-recruitment relationship in our model, and we assumed constant recruitment.

For our model, we assumed a “closed system” in the IAW, with all recruits originating from and remaining inside the region, without any inflow of YFT into this region from elsewhere. 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 of YFT 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 (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 YFT movements between the Indian Ocean and IAW is scarce, but potential corridors are relatively narrow between the Southern Banda and the Savu Seas.

To obtain model input parameter values, we reviewed literature on growth and natural mortality in YFT, and we developed a size dependent fisheries mortality curve for all major gear types combined. 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. This approach is explained in more detail below.

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 the government-reported actual YFT catch for 2016 from IAW. Because governmental statistics on tuna production are important not only to calibrate the model, but also in their own right, we discuss these statistics in detail below. The resulting model with estimated input parameter values represents our baseline scenario for the 2016 YFT fisheries in 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 below also in operational terms.

Input parameters and other assumption in this model, like in any model, will be subject to discussion. Growth and mortality parameter values are potentially affecting predictions on the effects of alternative harvest strategies. Over-estimation of natural mortality (M) could for example lead to under-estimation of fishing mortality (F) when we start with calculating a total mortality (Z) from catch curve analysis or tag returns. Under-estimation of potential growth could lead to under-estimation of the benefits from alternative harvest strategies. Under-estimation of growth would occur if L_{inf} 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 (Wibisono et al., In Prep.). These issues should be subjected to discussions while working with any stock assessment models, including those currently used by WCPFC and IOTC. Considering different estimates by different sources for estimated growth, natural mortality and fisheries mortality parameter values, we conducted a sensitivity analysis for the relevant input parameters and discussed the results and related recommendations below.

3.0 TUNA PRODUCTION

3.1 PRODUCTION FROM MAJOR TUNA FISHING AREAS

The MMAF conducted a series of workshops over recent years to estimate tuna production by species over major tuna fishing areas, falling under two RFMOs, the WCPFC and the Indian Ocean Tuna Commission (IOTC) (Satria et al., 2017; MMAF-b, 2018). These workshops produced tables with tuna production by species, by fishing gear, and by fishing area up to the year 2016. Data from 2017 were still considered preliminary during the writing of this report. The regions of interest comprised 3 combinations of Indonesian FMAs or *Wilayah Pengelolaan Perikanan* (WPPs):

- The Indonesian EEZ part of the Indian Ocean (IOTC, part of FAO Area 57) incl. WPPs 571+572+573,
- The Indonesian Archipelagic Waters (WCPFC, part of FAO Area 71) incl. WPPs 713+714+715, and
- The Indonesian EEZ part of the Pacific Ocean (WCPFC, part of FAO Area 71), and incl. WPPs 715+716.

The table for Area 57 (WPP 571+572+573) included tuna production from "*payang*" (encircling net) and "*bagan*" (lift net), gears that were not specified separately in tables for other areas. To avoid losing these production figures for Area 57, while aligning with estimates for the other WPPs, we have combined production for these categories into production under the "others" category. It appears that not all workers have always included those production figures from "*payang*" and "*bagan*" in Area 57. The information from the workshop tuna production tables, has been reported by MMAF as official landings to WCPFC, IOTC and other RFMOs[2].

Statistics for all major fishing areas are presented in **Table 3.1** and **Table 3.2** and from these tables we find the following 2016 production figures, as also reported in Satria et al. (2017):

- YFT: WPP 571+572+573= 36,485 MT, WPP 713+714+715= 103,291 MT, WPP 716-717= 56,801 MT.

[2] WPPs 711, 712 and 718, all part of Area 71, are not included in these tables. It is generally assumed that these areas with shallow seas are not producing much oceanic tuna but it is not clear from these tables if any or no tuna had been reported there at all. This will be investigated further below.

- BET: WPP 571+572+573= 22,135 MT, WPP 713+714+715= 23,514 MT, WPP 716-717= 4,830 MT.
- SKJ: WPP 571+572+573= 72,359 MT, WPP 713+714+715= 239,039 MT, WPP 716-717= 97,416 MT.
- ALB: WPP 571+572+573= 7,179 MT, WPP 713+714+715= 0 MT, WPP 716-717= 0 MT.
- SBT: WPP 571+572+573= 601 MT, WPP 713+714+715= 0 MT, WPP 716-717= 0 MT.

These production numbers add up to a total of 160,092 MT for YFT from Area 71 (WPP 713+714+715+716+717) in 2016, which closely resembles the number of 160,418 MT reported for YFT in that year for the same area in the WCPFC Tuna Fisheries Yearbook 2017 (WCPFC, 2018). Production estimated by species, by gear type and by major fishing ground for both IOTC and WCPFC management areas (**Table 3.1** and **Table 3.2**), are based on the summary tables produced for this purpose by Indonesian Government (Satria et al., 2017; MMAF-b, 2018).

When cross referencing these numbers with the overall totals that are reported in the "*Buku Statistik 2016*" (MMAF-a, 2017) we found some differences. The workshop tables by major fishing area show that the production by species over the three major areas in 2016 included 7,179 MT of albacore, 50,479 MT of bigeye, 601 MT of southern bluefin, 196,578 MT of yellowfin and 408,815 MT of skipjack tuna. This is below the numbers from the "*Buku Statistik 2016*" which, for example, reported the total production of YFT at 209,227 MT and production of SKJ at 440,812 MT in 2016.

To reconcile production numbers and get a better idea about production by WPP, we studied "*Statistics of Marine Capture Fisheries by Fisheries Management Area (FMA) 2005-2016*" (MMAF-b, 2017). Tables 1-12 from this MMAF report attribute reported landings by Province to specific WPPs. A summary of the data by WPP is presented in **Table 3.3** and **Table 3.4**, using the most recent data available, from 2012 to 2016 for comparisons. Total production for all major species combined, from **Table 3.1** and **Table 3.2** adds up to just 663,651 MT for 2016, whereas the total reported in the "*Buku Statistic*" (MMAF-a, 2017) is 712,668 MT over the same range of species**. Table 3.1** and **Table 3.2** clearly do not show the total domestic landings, and the difference is at least partly explained by the fact that landings attributed to WWPs 711, 712 and 718 in MMAF-b (2017) were not included in the tables by major fishing area (MMAF-b, 2018; Satria et al., 2017). This means that some under reporting of production from Area 71 may have occurred to the WCPFC.

3.2 YFT PRODUCTION FROM ARCHIPELAGIC WATERS

As explained above our focus is on YFT in IAW, a priority area for tuna management in Indonesia (Satria & Sadiyah, 2018), including FMAs 713, 714 & 715. In 2012, a reported 191,047 MT of the total Indonesian oceanic tuna production was YFT (MMAF-b, 2017). This was up to 219,816 MT in 2013 and 217,848 MT in 2014. Landings dropped to 189,931 MT in 2015, the same level as had been reported for 2012. It seems that peak production may have been reached during these years, with 2016 YFT total landings reported at 209,227 MT. MMAF statistics show 2016 YFT production from the Indonesian IOTC Area 57 (WPP 571, 572 and 573) totaling 36,799 MT (**Table 3.3 and Table 3.4**), or about 18% of the total domestic production for that year. Fisheries management areas under WCPFC, Area 71 produced a total of 172,428 metric tons or 82% of Indonesian YFT production in 2016.

Table 3.1 YFT, BET & SKJ production 2012-2016 by major fishing area and by gear type according to MMAF-b (2018) and Satria et al. (2017).

AREA	GEAR	YELLOWFIN TUNA PRODUCTION BY FISHING AREA					BIGEYE TUNA PRODUCTION BY FISHING AREA					SKIPJACK TUNA PRODUCTION BY FISHING AREA				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
	Gillnet	1,353	617	445	1,241	2,912	2,493	430	341	938	729	10,183	4,394	3,434	7,652	12,892
	Handline	3,634	9,524	6,865	5,145	5,655	218	745	590	1,064	1,440	5,002	8,167	6,382	5,087	10,577
	Longline	11,222	16,325	12,645	10,549	10,404	11,150	15,037	16,197	7,919	7,642	8,943	9,517	5,729	4,763	2,281
571+572+573	Pole & line	394	3,860	2,782	1,288	600	0	0	0	0	0	8,328	12,256	9,577	7,364	1,044
	Purse Seine	11,776	20,229	14,582	8,363	10,786	9,537	12,012	9,516	5,779	9,199	31,190	33,871	26,468	18,597	28,828
	Trolling Line	7,150	5,297	3,818	3,212	3,021	6,392	5,788	4,585	844	1,432	9,597	11,738	9,172	7,023	5,343
	Other	**3,003**	**5,528**	**3,985**	**10,773**	**3,107**	**2,751**	**1,493**	**1,183**	**2,121**	**1,692**	**14,090**	**14,494**	**11,326**	**30,452**	**11,394**
571+572+573	**TOTAL**	**38,533**	**61,380**	**45,122**	**40,571**	**36,485**	**32,540**	**35,505**	**32,412**	**18,665**	**22,135**	**87,333**	**94,437**	**72,088**	**80,938**	**72,359**
	Gillnet	0	1,697	5,482	942	1,306	0	1,599	1,868	246	572	0	14,918	15,318	4,346	7,604
	Handline	10,910	13,649	23,423	25,516	33,194	941	569	3,004	5,368	4,634	0	0	0	43,720	36,889
	Longline	7,207	10,937	15,363	900	9,027	1,690	1,653	3,521	61	4,946	0	0	0	0	3,998
713+714+715	Pole & line	29,354	14,039	16,975	30,155	16,719	285	2,209	1,996	4,179	2,608	65,358	68,971	72,393	69,978	77,497
	Purse Seine	17,558	39,063	15,041	3,987	12,782	1,705	4,507	1,765	1,110	2,669	43,894	106,672	84,775	16,660	50,196
	Trolling Line	0	23,184	9,796	19,988	26,171	0	2,775	3,474	3,762	6,703	0	40,518	55,064	23,545	55,383
	Other	49,635	19,623	8,621	2,784	4,092	7,719	3,051	2,435	1,813	1,383	67,075	26,517	20,611	22,660	7,472
713+714+715	**TOTAL**	**114,664**	**122,191**	**94,700**	**84,271**	**103,291**	**12,340**	**16,363**	**18,065**	**16,540**	**23,514**	**176,327**	**257,597**	**248,162**	**180,908**	**239,039**
	Gillnet	0	460	584	297	136	0	2	6	2	2	0	2,312	3,351	1,046	1,522
	Handline	3,359	3,801	15,173	26,817	11,039	290	158	461	476	396	0	0	0	6,118	14,994
	Longline	11,656	8,271	13,060	18,509	5,632	3,681	2,860	3,673	3,701	8	0	0	0	0	0
716-717	Pole & line	1,277	4,284	3,316	2,280	3,165	1,532	377	57	727	311	35,500	16,825	7,356	8,860	8,027
	Purse Seine	8,198	2,614	7,000	8,247	20,546	235	0	289	1,153	509	25,164	62,726	36,085	25,205	40,262
	Trolling Line	0	2,447	915	1,788	13,929		400	435	299	3,533		5,290	19,877	36,076	28,160
	Other	12,635	2,577	1,462	3,988	2,354	1,398	285	881	55	71	35,061	7,151	8,010	4,714	4,451
716-717	**TOTAL**	**37,125**	**24,454**	**41,510**	**61,925**	**56,801**	**7,136**	**4,083**	**5,803**	**6,413**	**4,830**	**95,725**	**94,304**	**74,678**	**82,018**	**97,416**
	Gillnet	0	2,157	6,066	1,239	1,442	0	1,602	1,875	248	574	0	17,230	18,669	5,392	9,126
	Handline	14,269	17,450	38,596	52,333	44,234	1,231	727	3,466	5,844	5,030	0	0	0	49,837	51,883
	Longline	18,863	19,207	28,423	19,408	14,659	5,371	4,513	7,194	3,763	4,954	0	0	0	0	3,998
AREA 71	Pole & line	30,631	18,323	20,291	32,435	19,884	1,817	2,586	2,054	4,906	2,918	100,857	85,796	79,748	78,838	85,524
	Purse Seine	25,755	41,676	22,040	12,233	33,327	1,940	4,507	2,054	2,263	3,178	69,058	169,398	120,860	41,865	90,459
	Trolling Line	0	25,631	10,711	21,776	40,100	0	3,175	3,910	4,061	10,236	0	45,808	74,942	59,621	83,543
	Other	62,271	22,200	10,083	6,772	6,446	9,116	3,337	3,316	1,868	1,454	102,136	33,668	28,621	27,374	11,923
AREA 71	**TOTAL**	**151,789**	**146,646**	**136,210**	**146,196**	**160,092**	**19,476**	**20,446**	**23,868**	**22,953**	**28,344**	**272,052**	**351,901**	**322,840**	**262,927**	**336,456**
	Gillnet	1,353	2,774	6,511	2,480	4,354	2,493	2,032	2,216	1,186	1,303	10,183	21,624	22,103	13,044	22,018
"TOTAL" AREAS	Handline	17,903	26,974	45,461	57,478	49,889	1,448	1,472	4,056	6,908	6,470	5,002	8,167	6,382	54,924	62,460
57+71	Longline	30,085	35,532	41,068	29,957	25,063	16,522	19,550	23,391	11,682	12,596	8,943	9,517	5,729	4,763	6,279
EXCL:	Pole & line	31,025	22,183	23,073	33,723	20,484	1,817	2,586	2,054	4,906	2,918	109,186	98,052	89,325	86,202	86,568
711+712	Purse Seine	37,531	61,906	36,622	20,596	44,114	11,477	16,519	11,570	8,042	12,376	100,248	203,269	147,328	60,462	119,287
718	Trolling Line	7,150	30,928	14,529	24,988	43,121	6,392	8,963	8,495	4,905	11,668	9,597	57,546	84,114	66,644	88,886
	Other	65,274	27,728	14,068	17,545	9,553	11,867	4,830	4,499	3,989	3,146	116,226	48,162	39,947	57,826	23,317
	TOTAL	**190,322**	**208,026**	**181,332**	**186,767**	**196,578**	**52,016**	**55,951**	**56,280**	**41,618**	**50,479**	**359,385**	**446,338**	**394,928**	**343,865**	**408,815**

Table 3.2 ALB & SBT production 2012-2016 by major fishing area and by gear type according to MMAF-b (2018) and Satria et al. (2017).

AREA	GEAR	ALBACORE TUNA PRODUCTION BY FISHING AREA					SOUTHERN BLUEFIN TUNA PRODUCTION BY FISHING AREA				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
571+572+573	Gillnet	95	0	0	965	20	0	0	0	0	0
	Handline	423	3	9	755	602	0	0	0	0	0
	Longline	7,631	6,021	8,539	4,488	6,278	910	1,382	1,063	593	601
	Pole & line	0	0	0	0	0	0	0	0	0	0
	Purse Seine	98	70	199	7	18	0	0	0	0	0
	Trolling Line	2,552	0	0	424	258	0	0	0	0	0
	Other	**229**	**1**	**3**	**662**	**3**	**0**	**0**	**0**	**0**	**0**
571+572+573	**TOTAL**	**11,028**	**6,095**	**8,750**	**7,301**	**7,179**	**910**	**1,382**	**1,063**	**593**	**601**
713+714+715	Gillnet	0	0	0	0	0	0	0	0	0	0
	Handline	0	0	0	0	0	0	0	0	0	0
	Longline	0	0	0	0	0	0	0	0	0	0
	Pole & line	0	0	0	0	0	0	0	0	0	0
	Purse Seine	0	0	0	0	0	0	0	0	0	0
	Trolling Line	0	0	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0
713+714+715	**TOTAL**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
716-717	Gillnet	0	0	0	0	0	0	0	0	0	0
	Handline	0	0	0	0	0	0	0	0	0	0
	Longline	0	0	0	0	0	0	0	0	0	0
	Pole & line	0	0	0	0	0	0	0	0	0	0
	Purse Seine	0	0	0	0	0	0	0	0	0	0
	Trolling Line	0	0	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0
716-717	**TOTAL**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
AREA 71	Gillnet	0	0	0	0	0	0	0	0	0	0
	Handline	0	0	0	0	0	0	0	0	0	0
	Longline	0	0	0	0	0	0	0	0	0	0
	Pole & line	0	0	0	0	0	0	0	0	0	0
	Purse Seine	0	0	0	0	0	0	0	0	0	0
	Trolling Line	0	0	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0
AREA 71	**TOTAL**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
"TOTAL" AREAS 57+71 EXCL: 711+712 718	Gillnet	95	0	0	965	20	0	0	0	0	0
	Handline	423	3	9	755	602	0	0	0	0	0
	Longline	7,631	6,021	8,539	4,488	6,278	910	1,382	1,063	593	601
	Pole & line	0	0	0	0	0	0	0	0	0	0
	Purse Seine	98	70	199	7	18	0	0	0	0	0
	Trolling Line	2,552	0	0	424	258	0	0	0	0	0
	Other	229	1	3	662	3	0	0	0	0	0
	TOTAL	**11,028**	**6,095**	**8,750**	**7,301**	**7,179**	**910**	**1,382**	**1,063**	**593**	**601**

Table 3.3 Tuna production by WPP for 2012-2016, according to MMAF-b (2017) Tables 1-12.

SPECIES	YEAR	WPP											TOTAL
		571	572	573	711	712	713	714	715	716	717	718	
ALB	2012	0	136	10,892	0	0	0	0	0	0	0	0	11,028
	2013	0	459	5,636	0	0	0	0	0	0	0	0	6,095
	2014	0	352	6,621	0	0	0	0	0	0	0	0	6,973
	2015	0	686	6,615	0	0	0	0	0	0	0	3	7,304
	2016	0	297	6,880	0	3	0	0	0	0	0	0	7,180
BET	2012	2,054	7,240	23,246	1,173	44	5,054	6,603	19,212	8,045	0	932	73,603
	2013	1,246	11,547	22,712	1,322	82	3,205	8,016	18,345	9,619	926	1,122	78,142
	2014	1,374	18,503	12,535	136	15,343	4,984	7,405	12,967	12,795	973	1,022	88,037
	2015	1,611	11,401	5,653	1,421	488	8,481	7,205	8,522	5,188	1,572	1,117	52,659
	2016	3,408	7,072	11,655	214	1,964	8,308	7,873	6,950	1,321	4,873	1,210	54,848
SBT	2012	0	0	910	0	0	0	0	0	0	0	0	910
	2013	0	0	1,382	0	0	0	0	0	0	0	0	1,382
	2014	0	0	1,015	0	0	0	0	0	0	0	0	1,015
	2015	0	0	593	0	0	0	0	0	0	0	0	593
	2016	0	0	601	0	0	0	0	0	0	0	0	601
YFT	2012	1,389	9,623	27,521	680	129	13,791	35,780	57,538	28,108	11,471	5,017	191,047
	2013	0	25,629	35,751	0	436	17,174	34,748	59,700	28,626	11,616	6,136	219,816
	2014	2,386	19,901	22,835	140	17,026	18,198	19,325	49,595	38,421	13,223	16,798	217,848
	2015	5,863	19,450	15,258	2,483	1,603	12,441	14,169	64,622	42,720	8,252	3,070	189,931
	2016	**2,299**	**12,163**	**22,337**	**0**	**3,404**	**16,600**	**18,087**	**95,497**	**23,062**	**10,669**	**5,109**	**209,227**
SKJ	2012	2,644	25,140	59,549	1,612	2,163	44,893	66,107	145,342	54,518	16,119	10,937	429,024
	2013	4,334	48,658	41,445	217	1,893	52,325	64,293	148,571	92,399	15,971	10,908	481,014
	2014	3,554	30,389	38,145	147	37,793	56,299	68,929	73,890	108,547	17,216	61,773	496,682
	2015	8,040	50,636	22,262	5,392	9,429	37,994	69,089	113,243	79,300	10,976	8,691	415,052
	2016	3,592	30,822	37,792	1,456	12,957	40,184	57,403	169,189	54,169	20,709	12,539	440,812
GRAND TOTAL	2012	6,087	42,139	122,118	3,465	2,336	63,738	108,490	222,092	90,671	27,590	16,886	705,612
	2013	5,580	86,293	106,926	1,539	2,411	72,704	107,057	226,616	130,644	28,513	18,166	786,449
	2014	7,314	69,145	81,151	423	70,162	79,481	95,659	136,452	159,763	31,412	79,593	810,555
	2015	15,514	82,173	50,381	9,296	11,520	58,916	90,463	186,387	127,208	20,800	12,881	665,539
	2016	9,299	50,354	79,265	1,670	18,328	65,092	83,363	271,636	78,552	36,251	18,858	712,668

Table 3.4 Tuna production by major fishing area based on landings by province, and attributed to WPP, according to MMAF-b (2017) Tables 1-12.

SPECIES	YEAR	WPP						TOTAL
		571+572+573	711-712	713+714+715	716-717	718	AREA 71	
ALB	2012	11,028	0	0	0	0	0	11,028
	2013	6,095	0	0	0	0	0	6,095
	2014	6,973	0	0	0	0	0	6,973
	2015	7,301	0	0	0	3	3	7,304
	2016	7,177	3	0	0	0	3	7,180
BET	2012	32,540	1,217	30,869	8,045	932	41,063	73,603
	2013	35,505	1,404	29,566	10,545	1,122	42,637	78,142
	2014	32,412	15,479	25,356	13,768	1,022	55,625	88,037
	2015	18,665	1,909	24,208	6,760	1,117	33,994	52,659
	2016	22,135	2,178	23,131	6,194	1,210	32,713	54,848
SBT	2012	910	0	0	0	0	0	910
	2013	1,382	0	0	0	0	0	1,382
	2014	1,015	0	0	0	0	0	1,015
	2015	593	0	0	0	0	0	593
	2016	601	0	0	0	0	0	601
YFT	2012	38,533	809	107,109	39,579	5,017	152,514	191,047
	2013	61,380	436	111,622	40,242	6,136	158,436	219,816
	2014	45,122	17,166	87,118	51,644	16,798	172,726	217,848
	2015	40,571	4,086	91,232	50,972	3,070	149,360	189,931
	2016	**36,799**	**3,404**	**130,184**	**33,731**	**5,109**	**172,428**	**209,227**
SKJ	2012	87,333	3,775	256,342	70,637	10,937	341,691	429,024
	2013	94,437	2,110	265,189	108,370	10,908	386,577	481,014
	2014	72,088	37,940	199,118	125,763	61,773	424,594	496,682
	2015	80,938	14,821	220,326	90,276	8,691	334,114	415,052
	2016	72,206	14,413	266,776	74,878	12,539	368,606	440,812
GRAND TOTAL	2012	170,344	5,801	394,320	118,261	16,886	535,268	705,612
	2013	198,799	3,950	406,377	159,157	18,166	587,650	786,449
	2014	157,610	70,585	311,592	191,175	79,593	652,945	810,555
	2015	148,068	20,816	335,766	148,008	12,881	517,471	665,539
	2016	138,918	19,998	420,091	114,803	18,858	573,750	712,668

For 2016, the MMAF-b (2017) statistics show YFT production in WCPFC areas WPP 713, 714 and 715 (IAW) at 130,184 MT or 62% of Indonesian YFT landings. An extremely high production in WPP 715 of no less than 95,497 MT from WPP 715, almost half the Indonesian production of YFT that year, contributed to that very high estimate of YFT production from IAW in 2016, and this was flagged by us for further analysis. YFT production in WCPFC fisheries management areas WPP 716 and 717 -the Pacific Ocean waters- was reported at just 33,731 MT for 2016, making up only 16% of the total. This relatively low contribution from Pacific waters was also flagged by us for further analysis. The shallow seas of WPP 711 and 712 were reported to have produced 3,404 MT or about 1.6% of YFT in 2016, whereas the Arafura Sea or WPP 718 would have contributed 5,109 MT or about 2.4%.

From MMAF-b (2017), it is clear that in the process of attributing landings by province to specific FMAs, some YFT production has been attributed also to WPP 711, 712 and 718. This attribution totaled 8,513 MT (3,404 MT + 5,109 MT) in 2016 according to Tables 1-12 in MMAF-b, 2017. This amount has not been included in the reporting to the RFMOs. Total YFT production from Area 71 (WCPFC) is estimated at 172,428 MT. Total production of YFT from WPP 713+714+715, as well as YFT production from WPP 716+717, show major differences between statistics by WPP (MMAF-b, 2017) and estimates by major fishing area (MMAF-b, 2018; Satria et al., 2017). YFT production from MMAF-b (2017) is reported at 130,184 MT for WPP 713+714+715 and 33,731 MT for WPP 716+718 respectively, in 2016. This should compare to estimates of 103,291 MT and 56,801 MT respectively for YFT from the same areas in the same year from MMAF-b (2018). The production numbers by WPP for YFT do appear to align for IOTC Area 57 with 36,799 MT reported in the statistics (MMAF-b, 2017) and 36,485 MT reported in workshop estimates.

To understand some of the differences in numbers, we need to know more about how landings that have always been recorded at the province level, have been attributed to the recently introduced WPPs. Table 46 from the “Statistics of Marine Capture Fisheries by Fisheries Management Area (FMA) 2005-2016” (MMAF-b, 2017) shows attribution of YFT landings by province to the actual WPP from where the catches originated (**Table 3.5**). In this table we find a very high attribution of YFT landings reported from the province of North Sulawesi into the production for WPP 715. This was 44,613 MT for 2016, whereas a much lower volume (3,467 MT) was allocated to this WPP in 2015. For WPP 716, 2016 shows 20,071 MT only, while 42,017 MT was reported from that WPP in 2015 (MMAF- b, 2017).

WPP 716+717 includes the Sulu Sea and Pacific waters which are known to be productive YFT fishing grounds utilized intensively by Indonesian fishers (Satria et al. 2017). Some changes may have occurred between 2015 and 2016, resulting in increased production from WPP 715, but it is not clear that any changes were as dramatic as reflected in the figures discussed above. We are assuming that this was also noted by those tasked to summarize production by major fishing area in MMAF-b (2018) and Satria et al. (2017) and that corrections were made - using the best available information. This may have led to re-attribution of some of the YFT production from WPP 715 to WPP 716 and WPP 717.

The difference between MMAF-b (2018) and MMAF-b (2017) in YFT production estimates for WPP 713+714+715 (103,291 MT and 130,184 MT respectively) is close to 27,000 MT. And it seems that such an amount was indeed re-attributed from WPP 715 to WPP 716 and 717 for North Sulawesi in 2016. The authors feel that this does indeed make sense considering where the fish most likely came from. We have adjusted the numbers from Table 46 (MMAF-b, 2017) accordingly, re-attributing 22,000 MT from WPP 715 to WPP 716 and aligning with 2015 estimates for that WPP as well as re-attributing the remaining 5,000 MT from WPP 715 to WPP 717 (**Table 3.6**).

In Table 4.6 of MMAF-b (2017) we also noted an attribution of 6,428 MT of YFT from the Province of Papua to WPP 718 (**Table 3.5**), leading to total landings of 11,537 MT of YFT for WPP 718 in 2016, which is very different from the 5,109 MT recorded in Tables 1-12 of the same report (**Table 3.3 and Table 3.4**). Moreover, in those tables the total in 2016 for WPP 717 is 10,669 MT of YFT, whereas only 4,241 MT is reported for the same WPP 717 in Table 46 in the same report (**Table 3.5**). With an exact difference of 6,428 MT, we must conclude that this amount has been swapped between WPP 717 and WPP 718 in the different tables in MMAF-b (2017). A very high production of YFT would not be expected from the shallow Arafura Sea (WPP 718), and this was probably also noted by those tasked to summarize production by fishing area.

We assume that a correction was made by attributing equal halves of the 6,428 MT of the YFT landings reported for the Papua province to WPP 717 and 718. Combining this with the adjustments discussed for North Sulawesi, we end up with adjusted YFT production estimates of 36,799 MT for WPP 571>573, 103,184 MT for WPP 713+714+715 and 57,517 MT for WPP 716-717 in 2016 (**Table 3.6**). These values align closely with estimates of 36,585 from WPP 571+572+573, and 103,291 MT from WPP 713+714+715 and 56,801 MT from WPP 716-717 for that year in Satria et al., (2017) and MMAF-b (2018). The latter numbers have been reported to the various RFMOs, and these numbers were also reconciled by us with the statistical yearbook figures (MMAF-a & MMAF-b, 2017). A total of close to 12,000 MT of YFT, allocated to WPP 711+712 and WPP 718 in the statistics (MMAF-b, 2017) may not have been included in Satria et al. (2017), as these had been attributed to WPP outside major tuna fishing areas.

After this reconciliation exercise, while still acknowledging remaining uncertainty about accuracy and possible under-reporting (Yuniarta et al., 2017), we accept the estimates from MMAF-b (2018) for YFT production from major fishing areas as reported to the various RFMOs for our purpose of further modeling and development of a 2016 baseline scenario. Specifically, for our target area we assume a YFT production of 103,291 MT from WPP 713+714+715 is the best available estimate for the year 2016.

When considering *other* major tuna fishing areas, outside IAW, including the IOTC area comprising WPP 571, 572 and 573 and the WCPFC area comprising WPP 716 and 717, we need to keep in mind that production estimates for Indian Ocean and Pacific Ocean waters include catches that were made outside Indonesian EEZ waters. However, for 2016, Indonesian vessels would not have operated very far outside EEZ waters and following changes in the fleet from large oceanic to smaller coastal vessels, the fishing effort is increasingly concentrated in Archipelagic and EEZ waters, as well as waters not far outside the EEZ.

Table 3.5 YFT production by WPP in 2016, according to Table 46 in *DGCF Statistics of Marine Capture Fisheries by FMA, 2005-2016,* MMAF-b, 2017.

AREA	WPP											
	TOTAL	571	572	573	711	712	713	714	715	716	717	718
WEST SUMATRA												
Aceh + Malaka Strait	**7,980**	2,236	5,744	0	0	0	0	0	0	0	0	0
Sumatera Utara	**1,548**	63	1,485	0	0	0	0	0	0	0	0	0
Sumatera Barat	**2,827**	0	2,827	0	0	0	0	0	0	0	0	0
Bengkulu	**1,754**	0	1,754	0	0	0	0	0	0	0	0	0
Lampung	**8**	0	8	0	0	0	0	0	0	0	0	0
JAVA N+W+S												
Banten	**831**	0	0	831	0	0	0	0	0	0	0	0
DKI Jakarta	**10,717**	0	345	6,968	0	3,404	0	0	0	0	0	0
Jawa Barat	**868**	0	0	868	0	0	0	0	0	0	0	0
Jawa Tengah	**899**	0	0	899	0	0	0	0	0	0	0	0
DI Yogyakarta	**335**	0	0	335	0	0	0	0	0	0	0	0
Jawa Timur	**982**	0	0	982	0	0	0	0	0	0	0	0
BALI-NTB-NTT												
Bali	**8,404**	0	0	6,918	0	0	1,486	0	0	0	0	0
Nusa Tenggara Barat	**4,450**	0	0	2,198	0	0	2,252	0	0	0	0	0
Nusa Tenggara Timur	**3,137**	0	0	2,338	0	0	294	505	0	0	0	0
EAST KALIMANTAN												
Kalimantan Selatan	**37**	0	0	0	0	0	37	0	0	0	0	0
Kalimantan Timur	**890**	0	0	0	0	0	890	0	0	0	0	0
Kalimantan Utara	**92**	0	0	0	0	0	0	0	0	92	0	0
SULAWESI S+W+E												
Sulawesi Selatan	**7,635**	0	0	0	0	0	6,290	1,345	0	0	0	0
Sulawesi Barat	**3,471**	0	0	0	0	0	3,471	0	0	0	0	0
Sulawesi Tenggara	**10,014**	0	0	0	0	0	1,880	7,775	359	0	0	0
SULAWESI N+CENTRAL												
Sulawesi Utara	***64,684***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***44,613***	***20,071***	***0***	***0***
Gorontalo	**19,692**	0	0	0	0	0	0	0	19,325	367	0	0
Sulawesi Tengah	**1,404**	0	0	0	0	0	0	222	650	532	0	0
MALUKU and PAPUA												
Maluku	**9,438**	0	0	0	0	0	0	4,696	4,207	0	0	535
Maluku Utara	**31,814**	0	0	0	0	0	0	3,544	24,029	2,000	2,241	0
Papua	***6,428***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***6,428***
Papua Barat	**8,888**	0	0	0	0	0	0	0	2,314	0	2,000	4,574
TOTAL	***209,227***	**Total 571+572+573**			**Total 711+712**		**Total 713+714+715**			**Total 716+717**		**718**
		36,799			*3,404*		***130,184***			***27,303***		***11,537***
		2,299	***12,163***	***22,337***	***0***	***3,404***	***16,600***	***18,087***	***95,497***	***23,062***	***4,241***	***11,537***

Note: Underlined italic numbers will be adjusted as explained in the text.

Table 3.6 YFT production 2016 after adjustment of Table 46 in *DGCF Statistics of Marine Capture Fisheries by FMA, 2005-2016,* MMAF-b, 2017.

AREA	WPP											
	TOTAL	571	572	573	711	712	713	714	715	716	717	718
WEST SUMATRA												
Aceh + Malaka Strait	**7,980**	2,236	5,744	0	0	0	0	0	0	0	0	0
Sumatera Utara	**1,548**	63	1,485	0	0	0	0	0	0	0	0	0
Sumatera Barat	**2,827**	0	2,827	0	0	0	0	0	0	0	0	0
Bengkulu	**1,754**	0	1,754	0	0	0	0	0	0	0	0	0
Lampung	**8**	0	8	0	0	0	0	0	0	0	0	0
JAVA N+W+S												
Banten	**831**	0	0	831	0	0	0	0	0	0	0	0
DKI Jakarta	**10,717**	0	345	6,968	0	3,404	0	0	0	0	0	0
Jawa Barat	**868**	0	0	868	0	0	0	0	0	0	0	0
Jawa Tengah	**899**	0	0	899	0	0	0	0	0	0	0	0
DI Yogyakarta	**335**	0	0	335	0	0	0	0	0	0	0	0
Jawa Timur	**982**	0	0	982	0	0	0	0	0	0	0	0
BALI-NTB-NTT												
Bali	**8,404**	0	0	6,918	0	0	1,486	0	0	0	0	0
Nusa Tenggara Barat	**4,450**	0	0	2,198	0	0	2,252	0	0	0	0	0
Nusa Tenggara Timur	**3,137**	0	0	2,338	0	0	294	505	0	0	0	0
EAST KALIMANTAN												
Kalimantan Selatan	**37**	0	0	0	0	0	37	0	0	0	0	0
Kalimantan Timur	**890**	0	0	0	0	0	890	0	0	0	0	0
Kalimantan Utara	**92**	0	0	0	0	0	0	0	0	92	0	0
SULAWESI S+W+E												
Sulawesi Selatan	**7,635**	0	0	0	0	0	6,290	1,345	0	0	0	0
Sulawesi Barat	**3,471**	0	0	0	0	0	3,471	0	0	0	0	0
Sulawesi Tenggara	**10,014**	0	0	0	0	0	1,880	7,775	359	0	0	0
SULAWESI N+CENTRAL												
Sulawesi Utara	***64,684***	*0*	0	0	0	0	0	0	***17,613***	***42,071***	***5,000***	***0***
Gorontalo	**19,692**	0	0	0	0	0	0	0	19,325	367	0	0
Sulawesi Tengah	**1,404**	0	0	0	0	0	0	222	650	532	0	0
MALUKU and PAPUA												
Maluku	**9,438**	0	0	0	0	0	0	4,696	4,207	0	0	535
Maluku Utara	**31,814**	0	0	0	0	0	0	3,544	24,029	2,000	2,241	0
Papua	***6,428***	*0*	0	0	0	0	0	0	0	0	***3,214***	***3,214***
Papua Barat	**8,888**	0	0	0	0	0	0	0	2,314	0	2,000	4,574
TOTAL	***209,227***	**Total 571+572+573**			**Total 711+712**		**Total 713+714+715**			**Total 716+717**		**718**
		36,799			*3,404*		***103,184***			***57,517***		***8,323***
		2,299	***12,163***	***22,337***	***0***	***3,404***	**16,600**	***18,087***	***68,497***	***45,062***	***12,455***	***8,323***

Note: underlines italic numbers are adjusted as explained in the text.

4.0 A BASIC MODEL FOR YFT FISHERIES IN THE IAW

4.1 MODEL STRUCTURE

Deriving input parameter values for growth and mortality from published studies, we calibrated absolute values for recruitment so that the basic model achieves the annual total production as reported for IAW. With calibration for current production, we used a basic age- and size-structured cohort simulation as a “back of an envelope” predictive model to evaluate the expected outcomes of various harvest strategies (see for example Sparre and Venema, 1992).

Our 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. Starting from the calibrated number of recruits, the number of survivors at any following age (N_{q+1}), with time steps of one quarter, is 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.

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

The difference between the number of surviving YFT 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 YFT 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) is calculated with:

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

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, is calculated with the von Bertalanffy growth equation[3] (Sparre and Venema, 1992) and parameter values as described and discussed further below (L_{inf} = 200, K = 0.25, t_0 = -0.4). The individual body weight (in kg) of each fish at any length and age is calculated with the Length – Weight (L-W) relationship for YFT (Chassot et al., 2016):

$$\mathbf{W_{(t)} = 0.00002459 * (L_{(t)}^{2.9667})}$$

The catch in numbers by age group is 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 is again assumed to be equal to the total annual catch in the equilibrium situation that we are assuming for our simple model. We can also calculate catches now for specific YFT size groups.

3 The most widely used growth curve in fisheries studies. One needs values for three parameters for this equation: l is length, K is the growth rate and L_∞, termed 'L infinity' in fisheries science, is the asymptotic length at which growth is zero.

Spawning Stock Biomass (SSB) is 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 as described from our literature review (see Section 3.2) we calculated SSB as the average weight of all combined generations older than 2.5 years. 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 is taken as reference point for the current exploitation level and to compare outcomes of different harvest strategies (Satria and Sadiyah, 2018).

4.2 MODEL INPUT: GROWTH AND MATURITY

Age and growth of YFT from the Western and Central Pacific Ocean have been studied in detail on the basis of daily growth increments and tagging data (Lehodey and Leroy, 1999). For the development of a simulated growth curve for YFT for the WCPO, the 2017 WCPFC stock assessment for YFT (Tremblay-Boyer et al., 2017) refers to these 1999 study results. 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). WCPFC technical documents have repeatedly recommended further studies on the growth of YFT in the WCPO and this need for further studies was also highlighted in the most recent stock assessment report for this species in the WCPFC region (Tremblay-Boyer et al., 2017). Uncertainty about growth assumptions for YFT was however not specifically mentioned in the most recent Pacific Community (SPC) overview and status of tuna stocks (Brouwer et al., 2018).

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). 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.

Lehodey and Leroy (1999) presented and analyzed plots of otolith readings as well as tag and recapture data to determine growth in YFT in the WCPO. 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, very much 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). The growth curve used in modeling of YFT growth for the purpose of stock assessment in the western and central Pacific Ocean (Tremblay-Boyer et al., 2017) reaches about 148 cm after 5 years, after which this curve flattens out. Zhu et al. (2011) reported YFT in the Pacific Ocean to reach about 160 cm fork length at 6 years of age.

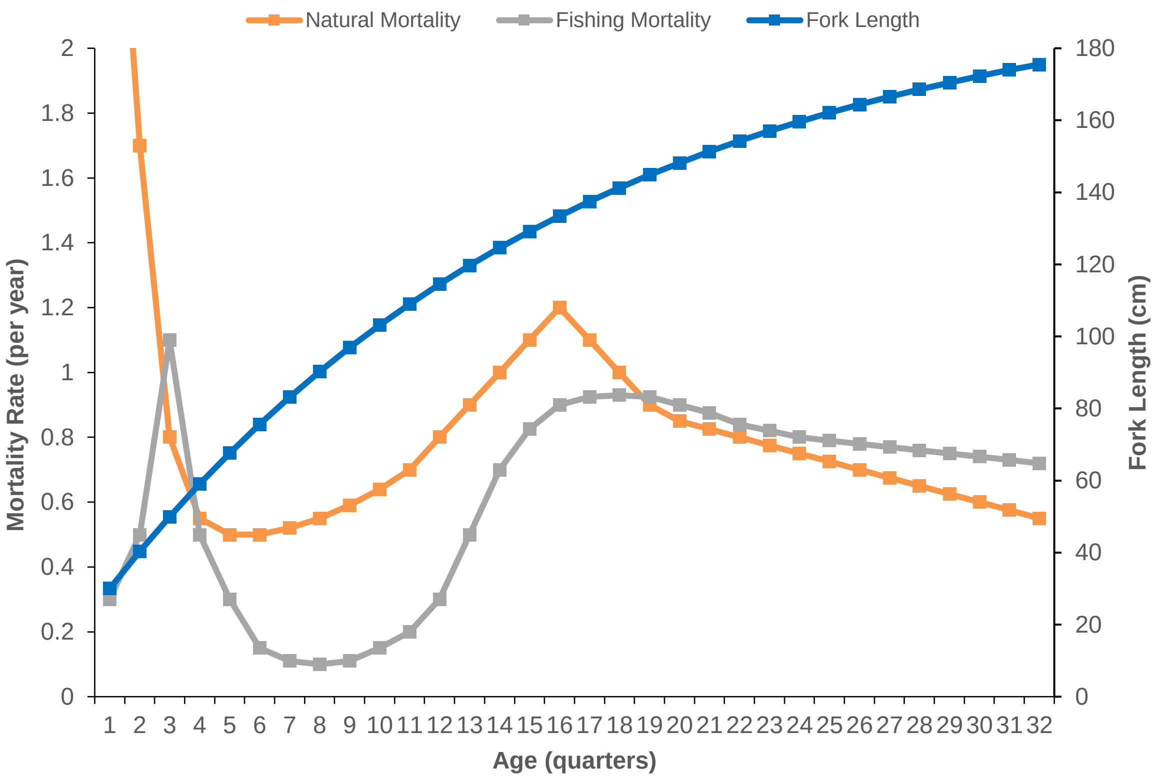
Historical catch length frequency distributions from YFT fisheries show that fish up to 175 cm were common in the past, while fish up to 185 cm fork length and larger have regularly been recorded in the Indo Pacific Oceans (Rohit et al., 2012; Damora and Baihaqi, 2013). A recent study on hand line fisheries 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; Schaefer, 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[4].

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 “back of an envelope” modeling exercise, we have fitted a von Bertalanffy growth curve through the above estimated “size at age” points with growth parameters L_{inf} = 200 cm fork length, K = 0.25 per year and t_0 = -0.4 years (**Figure 4.1**). In comparison, Hampton (2000) also worked with a K = 0.25 but used a much smaller L_{inf} of 166 cm to fit his curve to a relatively small sample, which was lacking larger fish. Rohit et al. (2012) estimated L_{inf} 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 ($L_{mat50\%}$) 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.

[4] http://www.fish.gov.au/report/81-Yellowfin-Tuna-2016

Figure 4.1 Estimated natural and fishing mortality (per year) and body length (cm fork length) at age (in quarters) for YFT in Indonesian Archipelagic Waters.



4.3 MODEL INPUT: NATURAL MORTALITY

Natural mortality in YFT is largely depending on body size (Hampton, 2000; Hampton and Fournier, 2001). Like in most 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 start reaching 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 which do not differentiate between sexes, the overall natural mortality by size group is assumed to be the average over the remaining males and females.

WCPFC reports (e.g. Tremblay-Boyer et al., 2017) refer to Hampton (2000) for the lowest natural mortality rate in pre-adult YFT to be around 0.6 to 0.8 per year for fish in the size range of 50-80 cm fork length. This is not very precise however, as the lowest M reported by Hampton (2000) is below 0.5 per year for YFT in the size class 61 to 70 cm. A value for M of 0.5 per year in YFT also follows from Pauly's empirical formula (Pauly, 1983) using growth parameters as estimated above. The plot for natural mortality at age in the WCPFC assessment reports shows a minimum not lower than 0.8 per year. 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. This study however did not provide a specific estimate for M in the size class of 61 to 70 cm where the lowest M is expected (Hampton, 2000). 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).

For YFT stock assessment in the Indian Ocean, the IOTC uses a value of ca. 0.55 per year (Fu et al., 2018; Nishida, et al., 2018) as the minimum level of M in pre-mature fish. This is consistent with levels reported for pre-mature fish of 61 to 70 cm fork length from the Western and Central Pacific Ocean (Hampton, 2000; Hampton and Fournier, 2001). Previously much 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, to the levels currently used (Fu et al., 2018), after sensitivity analysis and after comparison with levels estimated for the Pacific Ocean (Langley, 2012; 2015 and 2016). The relative levels of natural mortality by age group were maintained by the IOTC when overall levels were adjusted upwards. IOTC overall levels however remained at 0.25 per year below WCPFC estimates.

By not including the dip in M to 0.5 for 61 to 70 cm YFT, as described by Hampton (2000), the WCPFC graph for estimated M by age group (Tremblay-Boyer et al., 2017) is flattened out, possibly above actual levels, for pre-mature fish in the YFT stock assessment for the WCPO. Itano (pers. comm.) however 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. A flat level of natural mortality for pre-mature fish from 6 to 10 quarters is also used in IOTC stock assessments, but at a lower (compared to WCPFC) level of 0.55 per year (Fu et al., 2018). In a recent IOTC stock assessment by SCAA (Statistical-Catch-At-Age) of YFT in the Indian Ocean (Nishida et al., 2018), natural mortality was estimated at 0.55 per year both for 1 year and 2 years old fish, based on tagging data. These levels fit very well around Hampton's (2000) minimum level of about 0.5 per year between 1 year and 2 years of age at a fork length of about 61 to 70 cm, assuming a smooth (organic) shape of the curve for M.

The minimum 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. Fort the development of a YFT population model, Hampton and Fournier (2001) used a much lower estimate for natural mortality among 30 to 50 cm fish, but this was not generally accepted (Itano, pers. comm.). 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 allowing 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 our model we will adopt the peak in natural mortality at around 16 quarters or 4 years of age, coinciding with 135 cm fork length (Schaefer, 1998). Beyond this size the sex ratio (female / male) starts dropping due to female mortality causing males with lower natural mortality to start dominating among the survivors.

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 4.1**) 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 4.1**) 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 quarters to 1-year 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 1 year to 2.5 years pre-mature fish (59 to 103 cm FL),
- $M_{(avg)}$ = 0.7 per year for YFT of 2 years to 3 years old maturing fish (90 to 115 cm FL), and
- $M_{(avg)}$ = 0.8 per year for YFT from 2.5 to 8 years old mature fish (103 to 176 cm FL).

4.4 MODEL INPUT: SELECTIVITY AND FISHING MORTALITY

To understand selectivity and fishing mortality in YFT in IAW we have to recognize two distinct types of fisheries operating in these waters. The first type includes the various fisheries for Baby YFT (Nurani et al., 2014), specifically targeting 1 quarter to 1-year old juveniles with individual body weights of about 0.5 to 5 kg and a targeted length range of about 30 to 60 cm fork length. The term Baby YFT is used here because this is the trade name for the commodity and it is referred to as such also in Indonesian fisheries law (MMAF, 2015). The most important gear types in these fisheries include pole-and-line, mini and small purse seines, surface handlines, drop lines, and trolling lines. Most if not all of these gear types are used around FADs as well as around free surface schools.

The main gear types in use for targeting Baby YFT have similar narrow selection curves, peaking around 40 cm (hand line) to 45 cm (pole & line and purse seine) fork length, before fish reach 1 year of age, and dropping off sharply after that (Ernawati et al., 2018; Bailey et al., 2013). As a result, the combined selectivity curve over these gear types targeting Baby YFT is similar to the individual curves, but somewhat wider due to gear differences, dropping to very low levels by the age of 5 quarters (Davies et al., 2014).

Pole-and-line fisheries are targeting both SKJ and Baby YFT, often in an opportunistic approach, simply going for the schools of small tuna and/or SKJ they run into first. The purse seiners as combined fisheries are targeting a wider array of small pelagic species, including SKJ and Baby YFT, but also *Sardinella, Decapterus, Rastrelliger, Auxis, Euthynnus* and other small pelagics. Some purse seiners are specialized in specific species but many are flexible to adjust if needed or deemed opportune. The types of nets can be somewhat different for the smallest pelagics (*Sardinella, Decapterus, Rastrelliger and Auxis*) than what is used for Baby YFT, SKJ and eastern little tuna (*Euthynnus*). Hook-and-line gear for Baby YFT (incl. trolling) is specific for the small size classes and is sometimes used as part of a specialized fishery but often also used “on the side”. This can be by fishers targeting large YFT with hand lines with larger hooks and baits aiming for YFT upwards from 25 kg, but also by pole-and- line crews, depending on the size of the fish they encounter and the amount of bait they have on board.

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 100 kg, with sizes ranging from 110 cm to 170 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 include deep droplines with large hook and large (often live) baits used around FADs, trolling lines with large baits and surface handlines with live baits or dead baits under kites, used around dolphin pods. Some longlines are also operated in IAW, according to statistics on YFT landings.

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). Hand lines and long lines are catching most of the Large YFT and overall selectivity continues to rise for larger fish due to deep fishing with large live baits at FADs, and surface hand line fishing and trolling for large dolphin- associated YFT. Selectivity peaks between 15 and 24 quarters for 130 cm to 160 cm fork length YFT in these fisheries.

A third category of fisheries can be described as harvesting Medium YFT (Haruna et al., 2018), mainly juveniles, 1 year old to 2.5 years old, weighing between 5 and 25 kg and measuring somewhere between 60 and 105 cm fork length. These fish are mainly bycatch in the various hook-and-line fisheries, as well as to some extent in purse seine, and in pole-and-line fisheries. Medium sized YFT are sometimes targeted specifically, if they are encountered by fishers in much greater numbers than "Baby YFT" or large YFT. Due to differences in price per kg though, the "one by one fisheries" 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 "Baby YFT" or SKJ if and when these schools are present. This is more an issue of shifting fishing effort than a selectivity effect, although gear is sometimes also temporarily adjusted to specifically target medium sized tuna when those are locally abundant. But this is not assumed to lead to any additional peak in selectivity. It is also assumed by some (Lewis, pers. comm.) that catchability (availability to the gear) is reduced for Medium YFT compared to Baby YFT 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 Baby YFT 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 seem to be missing to some extent from models used by WCPFC. 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, 2007).

Fishing Mortality is a combination of selectivity, catchability (availability to the gear) and fishing effort and it is the assumed curve and level of the fishing mortality (F) by age group which we will be using as input for our model, using available information from the literature. 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 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.

Hampton (2000) reported an F close to 0.8 per year for Baby YFT (31 to 40 cm), but he does not include a high F for fisheries targeting large tuna in his overview. Hampton and Fournier (2001) noted that fishing mortality for all ages of YFT had increased significantly, almost 2 decades ago, with the highest levels being estimated for YFT aged approximately 0−1 year. They are showing a selectivity curve for the Philippines which would also apply to Indonesia today, taking into account the high fishing effort with hook-and-line for large tuna.

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 Region 7, which includes the IAW (Tremblay-Boyer et al., 2017). The estimated F for adults in 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 small juveniles and for adults is starting to show 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).

Based on a combination of all the above information on selectivity, catchability, fleet activity and fishing mortality, we have inferred a curve for F by age group which is shown in **Figure 4.1**. It should be noted that estimated Eastern Pacific Ocean (EPO) levels for F (Minte-Vera et al., 2018) are higher by about 0.1 per year above the levels we are currently assuming for IAW and there is some concern among the authors about possible under-estimation of F in our region. For further comparison purposes, the resulting average fishing mortality by age and size group from the curve we have adopted is as follows:

- $F_{(avg)}$ = 0.6 per year for Baby YFT of 1 quarter to 1 year old (30 to 59 cm FL),
- $F_{(avg)}$ = 0.3 per year for "Juvenile YFT" of 1 quarter to 2.5 years old (30 to 103 cm FL),
- $F_{(avg)}$ = 0.2 per year for Medium YFT of 5 quarter to 2.5 years old (68 to 103 cm FL), and
- $F_{(avg)}$ = 0.7 per year for Large YFT of 2.5 years to 8 years old (103 to 176 cm FL).

5.0 BASELINE SCENARIO 2016

5.1 RECRUITMENT, CATCH & SPAWNING BIOMASS

For our 2016 baseline scenario we are calibrating our model with the estimated total YFT production of 103,291 MT from IAW comprising WPP 713, 714 and 715 (MMAF-b, 2018; Satria et al., 2017). Using the above described model parameter values, we reach that estimated YFT catch with an input of 61 million recruits at an age of 1 quarter of one year of. SPC estimates YFT recruitment (at age 1 quarter) in the WCPO at about 750 million (Brouwer et al., 2018) and an estimated 225 million of those recruits are assumed to be originating from WCPFC Region 7 (Tremblay-Boyer et al., 2017), which includes East Indonesia and the Philippines. With 61 million recruits estimated by us from IAW (WPP 713+714+715) that would mean 27% of recruits from WCPFC Region 7 to originate from IAW. This seems plausible with WPP 713+714+715 roughly making up some 20% to 25% of deep oceanic waters in WCPFC Region 7.

With 61 million YFT recruits, our model predicts a YFT catch of 103,198 MT annually from Indonesian pelagic waters, and this catch is differentiated over size and age groups in the model output. Split over major size groups the total annual catch in baseline scenario includes 31,140 MT of Baby YFT in the size range of 0.25 to 6 kg, 19,179 MT of Medium YFT in the size range of 6 to 25 kg and 52,878 MT of Large YFT in the size category larger than 25 kg. Average weights by size category based on model predictions are 2.1 kg for Baby YFT, 13.6 kg for Medium YFT and 41.9 kg for Large YFT from IAW in 2016. The predicted catch length frequency distribution for the 2016 baseline scenario is shown in **Figure 5.1**. This simulated catch length frequency distribution is clearly very similar to what has been reported recently for Indonesian and Philippine archipelagic fisheries (Brouwer et al., 2018), with numbers in the catch overwhelmingly dominated by Baby YFT.

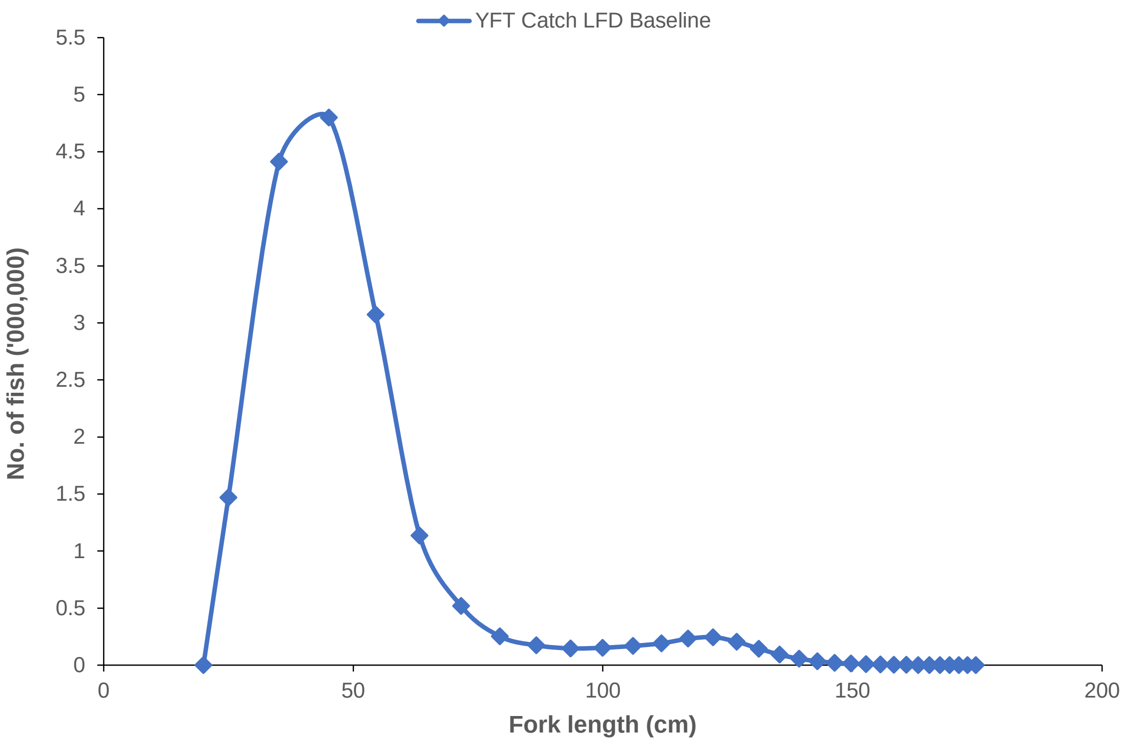
Model output in terms of annual catch by size category for the 2016 baseline scenario can be compared with statistics on landings by gear type from WPPs 713+714+715 (MMAF-b, 2018; Satria et al., 2017). Model output includes a predicted 31,140 MT of Baby YFT in the size range of 0.25 to 6 kg from this area. With pole- and-line and purse seine gears in these waters catching YFT mainly in that size category, we can compare that volume with the recorded landings for 2016 of 16,791 MT from pole-and-line and 12,782 from purse seines (**Table 3.1**). These two gear types combined reportedly landed some 29,573 MT tons of YFT, of which a large part most likely was Baby YFT and the rest most likely Medium YFT. It should be noted here that both pole-and-line and purse seines catch much larger volumes of SKJ than YFT, with 77,497 MT of SKJ reported for pole-and-line and 50,196 MT of SKJ for purse seines in WPPs 713+714+715 in 2016 (MMAF-b, 2018; Satria et al., 2017). Medium sized YFT would have totaled an estimated 19,179 MT over all gear types combined in 2016 according to model output.

Pole-and-line and purse seines combined caught almost 30% of all YFT landings from IAW in 2016 (MMAF-b, 2018; Satria et al., 2017), and we assume that these 2 gear types combined also landed about 30% of the Medium YFT. This then leads to an estimate of about 5,754 MT of Medium YFT landed by pole-and-line and purse seines combined in 2016. If we deduct that estimated amount of Medium YFT from total YFT catch by these 2 gear types (29,573 MT in 2016), we have an estimate of 23,819 MT of Baby YFT caught by pole-and-line and purse seines in 2016 in IAW. The remaining 7,321 MT of Baby YFT would have been caught mainly by various hook-and-line methods, including trolling lines with multiple small hooks that specifically target small fish. The total landings of 31,140 MT of Baby YFT in 2016 represented 14.9 million individual fish or 24% of annual recruitment in IAW, with 11.5 million

(77%) of the Baby YFT taken by pole-and- line and purse seine gears combined and 3.4 million (23%) of the Baby YFT taken by other gears.

The largest category by volume from overall YFT landings in our baseline scenario is Large YFT with an estimated total catch of 52,878 MT in 2016 according to model predictions. This included close to 1.3 million individual fish with an average body weight of close to 42 kg. A large volume of fish indeed, but the peak numbers of Large YFT, caught at around 122 cm, hardly show in the overall simulated catch length frequency distributions (**Figure 5.1)** due to the fact that catch numbers in the smallest size classes are so much higher. The peak for Large YFT does coincide though with the recorded peak in sizes caught in the handline and longline fisheries in IAW (Ernawati et al., 2018), 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 most recent years.

Figure 5.1 Simulated annual catch length frequency distribution from model baseline scenario (2016) for YFT fisheries in Indonesian Archipelagic waters.



The simulated catch length frequency distribution for Baby YFT from mixed fisheries in our 2016 baseline scenario (**Figure 5.2**) predicts peak numbers in a size range between 30 and 55 cm. The simulated catch length frequency is a combination of length frequencies caught in the major gear types (**Figure 5.3**) as we can see from comparing with recorded catches (Ernawati et al., 2018). The overall catch LFD is somewhat wider than just the combination of the 3 main gear types shown here, due to various other gear types used for harvesting Baby YFT (MMAF-a&b, 2017; MMAF-b, 2018; Satria et al., 2017). These other gear types include trolling lines, drifting gillnets, small encircling nets (*payang*), lift nets and other miscellaneous gear.

Figure 5.2 Simulated 2016 annual catch length frequency distribution for Baby YFT from mixed fisheries.

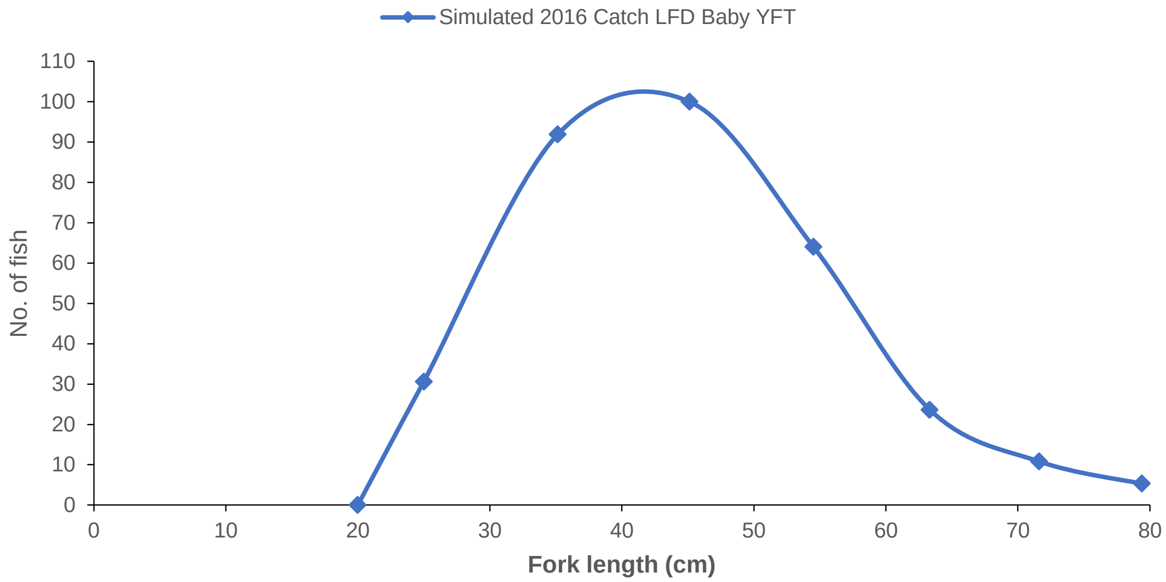
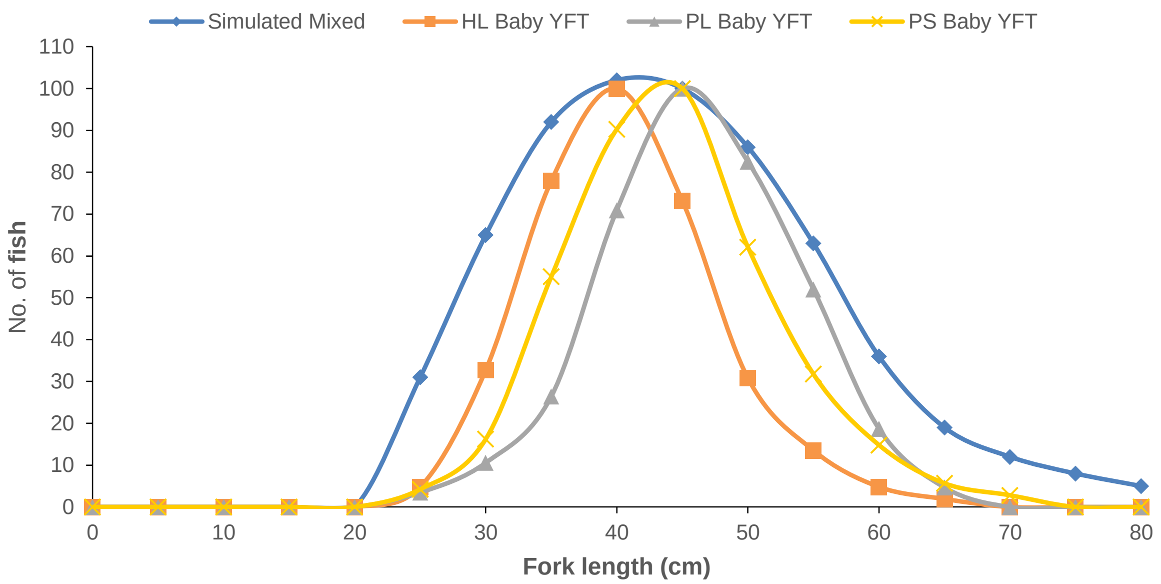


Figure 5.3 Simulated catch length frequency distribution for Baby YFT, compared with recorded catch length frequencies from Hand Line (HL), Pole-and-Line (PL) and Purse Seine (PS) fisheries.



The simulated catch length frequency distribution for Large YFT from mixed fisheries in our 2016 baseline scenario (**Figure 5.4**) peaks at 122 cm and then gradually drops to include Large YFT (caught by various handline methods and with longlines) over a size range from 110 to 170 cm. Fish below 110 cm are abundant in the simulated catch, originating from mixed fisheries harvesting Medium YFT. The simulated catch length frequency for Large YFT closely follows recorded length frequencies caught in the major gear types (**Figure 5.5**). Our simulated 2016 catch length frequency distribution falls slightly to the left of recorded 2010 to 2015 length frequencies from hand lines and long lines targeting Large YFT (Ernawati et al., 2018), and is shifted somewhat into the direction of 2016 catches from mixed hand line fisheries recorded from the Banda Sea (Haruna et al., 2018).

Figure 5.4 Simulated 2016 annual catch length frequency distribution for Large YFT from mixed fisheries.

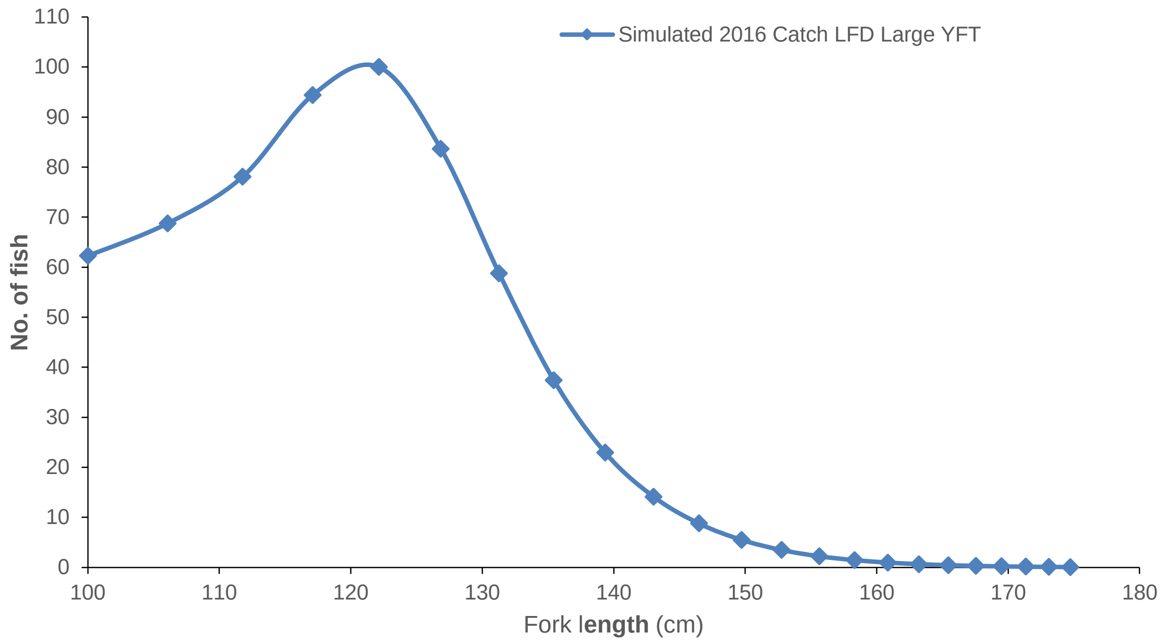
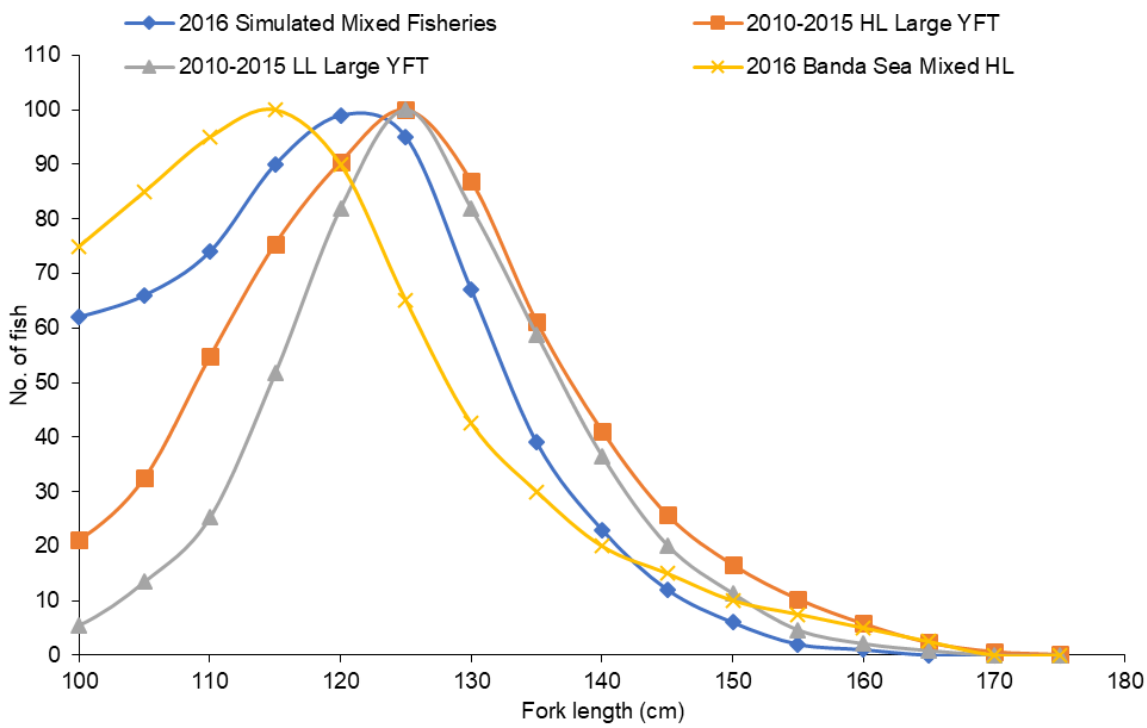


Figure 5.5 Simulated catch length frequency distribution for Large YFT from mixed fisheries, compared with recorded catch length frequencies from Hand Lines targeting Large YFT (HL), Long Line (LL) and Banda Sea Mixed Hand Line fisheries.



Spawning Stock Biomass (SSB) of YFT in IAW was estimated with our model for the baseline 2016 scenario at 105,234 MT. This SSB mostly consists of three, four, and five years old fish. The total estimated SSB is comparable to the total annual catch of 103,198 MT as per model output, and it is about twice as much as 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 416,540 MT for the IAW, which means an estimated $SSB/SSB_{F=0}$ ratio of 25%. This is below the 30% that was estimated for 2015 in Region 7 (containing eastern Indonesian and Philippines oceanic waters) by the WCPFC (Tremblay-Boyer et al., 2017). For evaluation of the level of $SSB/SSB_{F=0}$ we will adopt a limit reference point of 20% $SSB_{F=0}$ (Preece et al., 2011; MMAF-a, 2018) and an 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 25% the YFT fisheries in the IAW is closing in on the limit reference point and is far away from the interim management target.

5.2 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 based on these figures. Global end values for total yellowfin 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 (209,227 MT) was close to IDR 5 trillion in 2016 according to DGCF statistics (MMAF, 2017-a). 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 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 the reported total YFT landings of 209,227 MT from Indonesia in 2016, this would have resulted in a total “domestic retail” value of about US$ 837 million for Indonesian YFT in that year. And with the 103,291 MT of YFT produced from WPP 713+714+715 this would have included US$ 413 million from IAW.

Indonesian traders were reported to sell Large YFT at just over US$ 6.00 per kg in 2014 (Macfadyen and Defaux, 2016). Smaller YFT fetch much lower prices and purse seine frozen Baby YFT 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 modeling purposes, we will work with size specific trading prices by size class of US$ 1.50 per kg for Baby YFT, US$ 3.00 per kg for Medium YFT and US$ 6.00 per kg for Large YFT, assuming good quality management on board, and along 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 YFT.

Our “back of an envelope” model for YFT fisheries in IAW predicts a total YFT catch of 103,198 MT annually. This catch is differentiated over size and age groups in the model output and includes 31,140 MT of Baby YFT in the size range of 0.25 to 6 kg, 19,179 MT of Medium YFT in the size range of 6 to 25 kg and 52,878 MT of Large YFT in the size category larger than 25 kg. With trading prices by size class of US$ 1.50 per kg for Baby YFT, US$ 3.00 per kg for Medium YFT and US$ 6.00 per kg for Large YFT, this results in a potential trading value of about US$ 422 million, just above the estimated US$ 413 million “domestic retail” value.

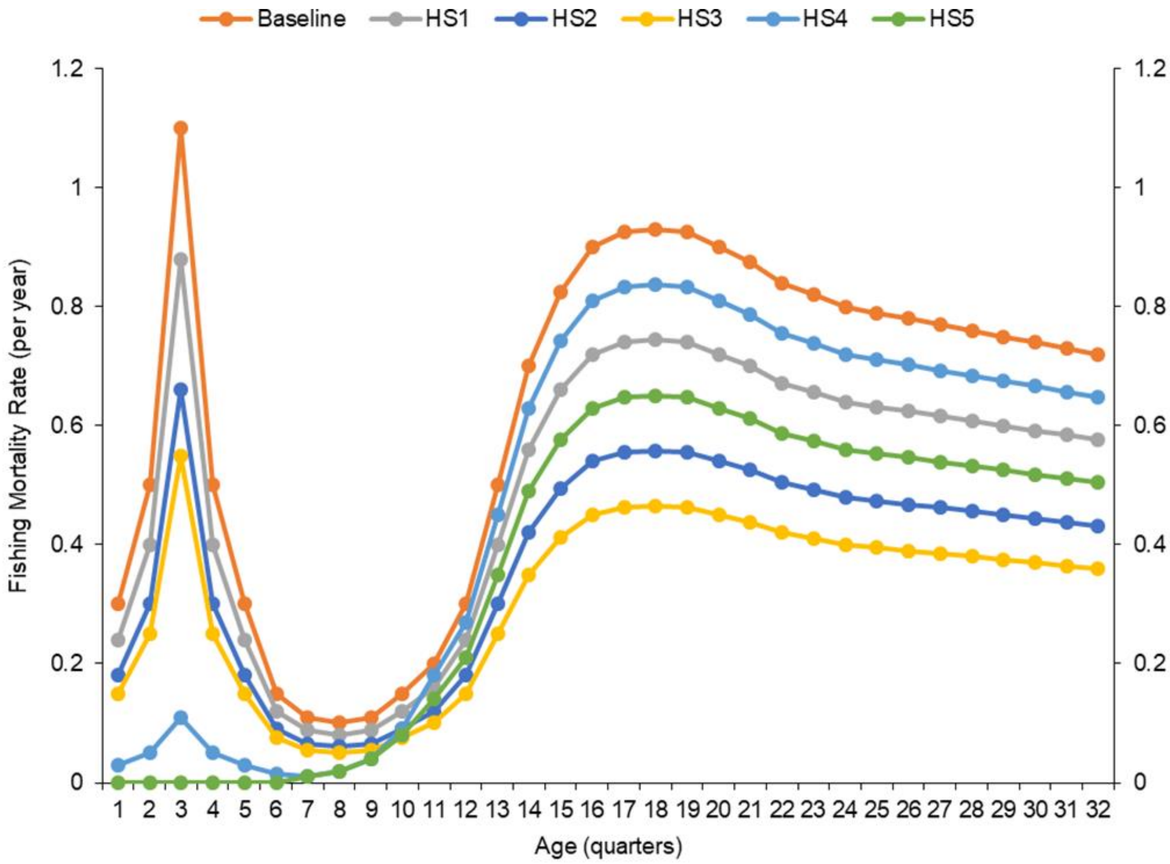
The simulated value for the 2016 landings of Baby YFT is US$ 47 million, while Medium YFT adds US$ 58 million to the total and Large YFT is by far the biggest earner with US$ 317 million predicted from the baseline scenario. The model predicts an average trade value of US$ 4.08 per kg in the 2016 baseline scenario, similar to the estimated US$ 4.00 per kg Indonesian domestic retail price based on 100% mark-up from dock value after correction for 10% losses.

6.0 EVALUATION OF HARVEST STRATEGIES

6.1 DESCRIPTION OF HARVEST STRATEGIES

In order to predict the outcomes of fisheries management interventions, we have used our model to evaluate a number of harvest strategies. While much remains to be discussed in terms of management goals for the Indonesian YFT fisheries, we have for now adopted the combined goals of bringing back the stock towards the interim target reference point of 40% $SSB/SSB_{F=0}$ (Hoshino et al., 2018), maximizing annual total catch volume, and also maximizing economic returns from the fisheries. Multiple potential harvest strategies could be tested with our model, but with the above in mind we have tested 5 different strategies which have recently been discussed to some extent, and compared the predicted outcomes with the simulated results from the 2016 baseline situation (**Figure 6.1**).

Figure 6.1 Levels of fishing mortality by age group for YFT in IAW, in baseline scenario (2016) and as resulting from 5 optional harvest strategies (HS).



HS1 to HS3 are fishing effort reductions of 20%, 40% and 50% respectively. **HS4** is a restructuring leading to 90% reduction in fishing mortality for Baby YFT combined with only 10% overall reduction in fishing effort. **HS5** is a "Ban on Baby YFT" combined with a 30% overall reduction in fishing effort.

Evaluated harvest strategies first of all include effort reductions to various levels, assuming that current effort is on the high side based on the current $SSB/SSB_{F=0}$ ratio of 25%, combined with a catch Length Frequency Distribution (LFD) including mainly very small juvenile fish.

Three different levels of overall effort reduction are evaluated in this paper:

1. **Harvest Strategy 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 fisheries.

2. **Harvest Strategy 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 fisheries.

3. **Harvest Strategy 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 fisheries.

In addition, strategies 4 and 5 are described below.

Harvest Strategy 4 (HS4) is a restructuring of the fisheries, whereby commercial targeting of Baby YFT is avoided. This includes adjustments in the behavior of a number of major fishing gears and their operations, as well as adjustments in industry approaches and government regulations. A small (10%) reduction in fishing effort targeting Medium YFT and Large YFT is tied into this restructuring strategy, based on a cap on new or renewed licenses, leading to a natural 10% drop in effort.

Under the Restructuring Strategy (HS4), pole-and-line fisheries would focus solely on skipjack tuna and avoid the capture of Baby YFT. Pole-and-line operations would adjust their behavior at sea to a strategy where schools of Baby YFT are avoided and where fishing is halted, and search patterns for skipjack tuna or other target species are resumed, in situations where very high percentages of Baby YFT are coming on board. Pole-and-line gear accounted for 16,719 MT of YFT from IAW in 2016, whereas 77,497 MT of skipjack were reportedly landed in that same year (MMAF-a, 2017) for WPP 713+714+715. A reduction of about 10% in pole-and-line fishing effort may therefore be needed to enable this change in fishing behavior while keeping the economies of individual vessels intact. Such reduction in effort may have a positive effect on the problematic situation related to baitfish production and use for pole-and-line fisheries (Gillet, 2012; Gillet 2014) versus use for direct consumption.

Similarly, purse seine operations under HS4 would endeavor to avoid Baby YFT, instead focusing not only on skipjack tuna but also on other available and resilient species such as *Euthynnus, Auxis, Decapterus, Sardinella, Rastrelliger* and other small pelagics. As part of this restructuring, purse seiners will not set around those deepwater FADs which are known to hold dense schools of Baby YFT. Small percentages of Baby YFT would be acceptable as unintended bycatch but would not be marketed for industrial processing, under an industry-led change in trading practices supported by government regulations that would prohibit commercial processing and trading of Baby YFT.

Purse seines caught a recorded 12,782 MT of Baby YFT in IAW in 2016, versus 50,196 MT of skipjack in that same area and year. Production numbers for purse seine from other small pelagics are not included here at this time and may need to be studied in more detail to determine the exact details of the restructuring related to purse seine gear. However, the production potential of and total value of the combined stocks of resilient small pelagics is known to exceed that of skipjack tuna (MMAF, 2011). Avoidance of Baby YFT and shift of focus to the combined skipjack and other small pelagics would seem feasible with not more than a cap on further licensing combined with some (10%) natural drop in effort after that.

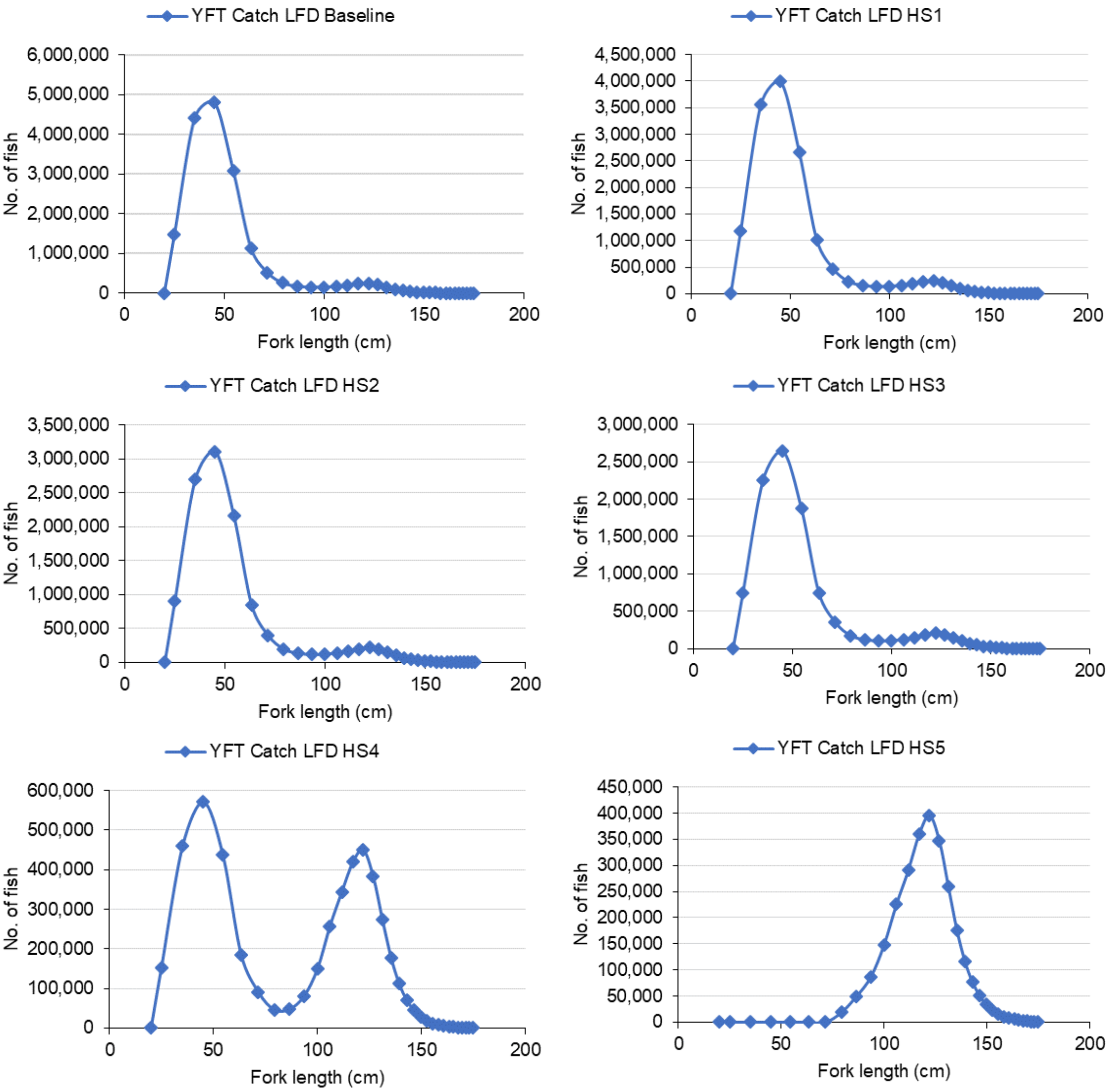
Under HS4, hook-and-line fisheries will also have to adjust their behavior and fully focus on Large YFT for commercial purposes. Some fishing of Baby YFT will be sustainable, if restricted to use for consumption, bait and local barter only. Fishing crews operating at FADs would concentrate on working deep only, with large baits, focusing on catching Large YFT. A little fishing on the side for Baby YFT for above listed purposes would be acceptable, but commercial trade of these fish would not be accepted. Similar rules would apply to all other pelagic gears in use. As a result of HS4, the fishing mortality of Baby YFT would be reduced by 90% while the fishing effort targeting Large YFT, as well as effort in pole-and-line and purse seine fisheries, would be reduced with not more than 10% only.

Harvest Strategy 5 (HS5) is a more aggressive version of HS4, under which we are testing what the hypothetical outcomes would be from a complete Ban on fishing for Baby YFT, in combination with an overall reduction in fishing effort of 30%. We realize the feasibility issues related to such a strategy, and are not necessarily promoting this, 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. The results of evaluation of the above strategies are presented below.

6.2 OUTCOMES OF HARVEST STRATEGIES

The first results from our simulations that we will look at are the predicted shapes of the catch length frequency distributions under various harvest strategies (**Figure 6.2**), compared to the baseline simulated catch length frequency distribution for 2016. We see a drop in the peak Baby YFT with increasing levels of fishing effort reduction from **HS1** to **HS 3**. The peak for Large YFT becomes slightly more prominent when fishing effort is reduced but the catch in numbers remains overwhelmingly dominated by Baby YFT even at overall effort reductions up to 50%.

Figure 6.2 Simulated catch length frequency distributions for 2016 baseline and alternative harvest strategies (HS).



HS1 to HS3 are fishing effort reductions of 20%, 40% and 50% respectively. **HS4** is a restructuring leading to 90% reduction in fishing mortality for Baby YFT combined with only 10% overall reduction in fishing effort. **HS5** is a “Ban on Baby YFT” combined with a 30% overall reduction in fishing effort

Table 6.1 Predicted outcomes from potential harvest strategies YFT WPP 713+714+715.

R=61 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	31,140	46,710,512	19,179	57,536,951	52,878	317,269,305	103,198
HS1 (F@80%)	26,520	39,780,487	17,704	53,111,253	56,070	336,419,751	100,294
HS2 (F@60%)	21,200	31,800,496	15,323	45,968,776	56,620	339,722,167	93,144
HS3 (F@50%)	18,248	27,371,870	13,718	41,154,161	55,139	330,833,745	87,105
HS4 (ReFocus)	4,167	6,249,833	12,899	38,697,504	100,209	601,252,116	117,274
HS5 (BabyBan)	0	0	11,175	33,524,422	95,284	571,701,525	106,458
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	25%	103,198	100%	421,516,768	100%	0	4.08
HS1 (F@80%)	32%	100,294	97%	429,311,490	102%	7,794,722	4.28
HS2 (F@60%)	41%	93,144	90%	417,491,440	99%	-4,025,328	4.48
HS3 (F@50%)	47%	87,105	84%	399,359,777	95%	-22,156,991	4.58
HS4 (ReFocus)	52%	117,274	114%	646,199,452	153%	224,682,684	5.51
HS5 (BabyBan)	61%	106,458	103%	605,225,947	144%	183,709,179	5.69

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

Only when fishing mortality among Baby YFT is reduced by 90%, in combination with a 10% overall reduction in fishing effort (**HS4**), do we see a truly bimodal catch length frequency distribution emerge, with numbers of Large YFT in the catch somewhat similar to numbers of Baby YFT. We do note that under this harvest strategy (**HS4**), there are still many (millions) of Baby YFT being harvested, for non-commercial purposes, but at the same time the number of Large YFT is greatly increased in the annual catch. Under **HS5**, with the total “Ban on Baby YFT” (assumed here to be fully implemented), combined with a 30% in effort reduction, we see no more Baby YFT in the catch. We also note that numbers of Large YFT in the catch under **HS5** are somewhat below the numbers of Large YFT predicted to be caught under **HS4**.

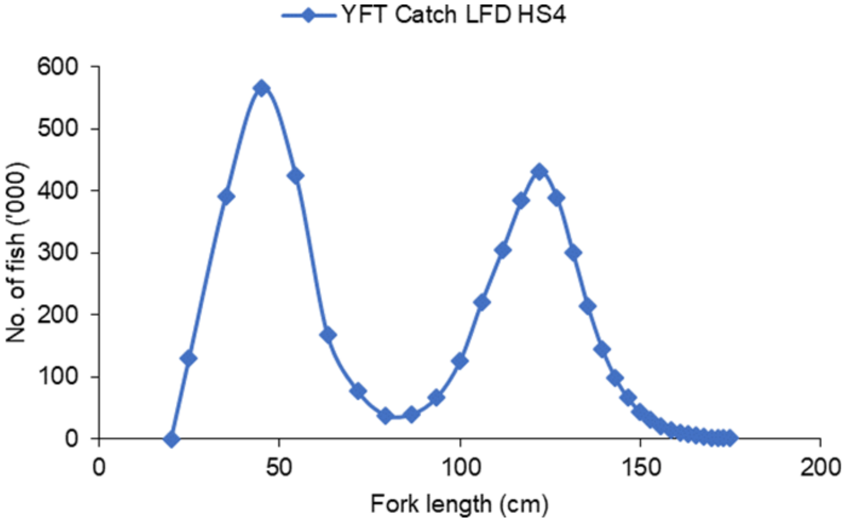
The second outcome to investigate is the predicted volume by size category in the catch, under the different harvest strategies, compared to the simulated baseline scenario for 2016 (**Table 6.1**). For Baby YFT and Medium YFT under **HS1 to HS3**, we see a reduction in catch volume with reduction in overall fishing effort. Predicted Baby YFT drops from 31,140 MT in the baseline scenario to a predicted 18,248 MT of Baby YFT under **HS3**, after an overall effort reduction of 50%. The model predicts that the volume of Baby YFT drops with 41% when the effort is reduced with 50%. At the same time the volume of Medium YFT drops with 28% under **HS3**, while the volume of Large YFT slightly increases with 4% under this harvest strategy. All of the simulated “across the board” general fishing effort reductions are predicted to lead to somewhat lower overall catches, with **HS3** leading to a substantial overall catch volume reduction of 16%.

Out of the unstructured effort reduction strategies (**HS1 to HS3**), only **HS1**, with 20% reduction in fishing effort, is predicted to lead to some increase in the overall economic value of the YFT fisheries in IAW, at a slight drop in predicted catch volume. This increase in value is due to the increase in volume of the most valuable category, the Large YFT, compensating for losses in the smaller size categories and resulting in an increased overall mean price per kg. The economic gain is minor though at just 2%, and with a 20% in overall effort reduction we have reached a peak in potential economic value from unstructured effort regulations. The predicted increase in economic value of just 2% from a 20% overall reduction in fishing effort does not look like much of an incentive for what is potentially a difficult management intervention. Cost savings from a 20% effort reduction are also not expected to be massive.

The expected increase of $SSB/SSB_{F=0}$ from **HS1** is only minor, reaching just 32%, compared to the 25% calculated from the baseline scenario. Only with a major 40% reduction in overall fishing effort would we be able to reach the interim target reference point, with $SSB/SSB_{F=0}$ predicted at 41% for **HS2**. The model predicts a 10% drop in catch, as well as a minor economic loss (1% or US$ 4 million reduction in value) from this 40% unstructured effort reduction “across the board”. It seems that there may be few incentives for fishery managers to implement a major unstructured effort reduction. Profitability for individual fishing vessels, on the other hand, might improve due to reduced operational expenses.

We are also analyzing the predicted outcome of a more structured harvest strategy, explained above as fisheries restructuring strategy **HS4** (see Section 6.1 for details). We see that a substantial amount of Baby YFT is still harvested under this strategy (**Figure 6.3**), be it for non-commercial purposes. We will assign the basic price also to this amount, as this catch does represent such value even though it is not commercially traded. The 4,167 MT annual catch under **HS4** represents some 2 million Baby YFT which are caught mainly as bycatch and used as bait, for consumption and for local barter by fishing crews who are otherwise focusing on catching Large YFT or other species. Annual catch of Baby YFT under **HS4** is down 87% compared to the 2016 baseline scenario.

Figure 6.3 Predicted annual catch length frequency distribution for YFT fisheries in IAW after HS4 restructuring leading to 90% reduction in fishing mortality for Baby YFT combined with a 10% overall reduction in fishing effort.



The annual YFT catch from IAW under **HS4** is predicted to increase with 14% to 117,274 MT, despite an 87% reduction in catch of Baby YFT and a 33% reduction in catch of Medium YFT (**Table 6.1**). The annual catch of Large YFT is predicted to increase with no less than 90% from 52,878 MT under the 2016 baseline scenario to 100,209 MT under **HS4**. More importantly perhaps, the overall economic value of the fisheries is predicted to increase with close to US$ 225 million, which is an increase of 53% in trade value compared to the 2016 baseline scenario. Last but not least, with the **HS4** fisheries restructuring being perhaps more feasible than massive unstructured effort reductions, the predicted $SSB/SSB_{F=0}$ of 52% after **HS4** also surpasses the interim target reference point.

HS4 is socially responsible and also in line with WCPFC and SPC recommendations (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 will be an important component of HS4, or rather the management of fisheries around FADs will have to be (e.g. Kantun et al., 2014). Participation of stakeholders will be vital for any strategy to succeed, especially if it requires changes in behavior from sectors in the fleet and from the processing and trading industries. With a potential value increase of US$ 225 million (53%) predicted for YFT fisheries in IAW alone, a total amount of US$ 0.5 billion could be at stake for the country as a whole.

HS5 has been added here as an example of a draconian 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 Baby YFT would be utterly unfeasible and could potentially lead to socio economic issues at the grass roots level, an overall effort reduction of 30% in the tuna fisheries would also seem to be very hard to achieve at this time in Indonesia. $SSB/SSB_{F=0}$ would reach very safe territory in this (impossible) scenario (**HS5**), but neither economic results nor total catch would be as good as what could be achieved from **HS4** (**Table 6.1**).

We realize that input parameters and other assumption in this model, like in any model, will be a subject of discussion. Growth and mortality parameter values are potentially affecting predictions on the effects of simulated harvest strategies. Over-estimation of natural mortality (M) could lead to under- estimation of fishing mortality (F) when we start with calculating a total mortality (Z) from catch curve analysis or tag returns. Under-estimation of potential growth could lead to under-estimation of the benefits from simulated harvest strategies. Under-estimation of growth could occur if L_{inf} 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 (Wibisono et al., In Prep.). These issues should be subject of further detailed studies while working with any stock assessment models, including those currently used by WCPFC and IOTC. To investigate the effect of our baseline assumptions on growth parameter values and size dependent natural mortality and fisheries mortality levels, we have performed a sensitivity analysis below, for the relevant input parameters.

6.3 SENSITIVITY ANALYSIS FOR ALTERNATIVE GROWTH PARAMETER VALUES

We can use different combinations of parameter values to fit growth curves to size at age information. In the baseline scenario we used an estimate for L_{inf} of 200 cm, with K=0.25 and t_0=-0.4 to fit our curve. WCPFC assessments (Tremblay-Boyer et al., 2017) are using a lower estimate for L_{inf}. To test model sensitivity for the shape of the growth curve, we looked at model outcomes resulting from an alternative set of parameters with L_{inf}=180 cm fork length, with K=0.3 and t_0=-0.35, keeping the size at age for the youngest fish in line with above discussed size at age information (**Figure 6.4**).

Figure 6.4 Growth curve fitted with L_{inf}=180, K=0.3 and t_0=-0.35.

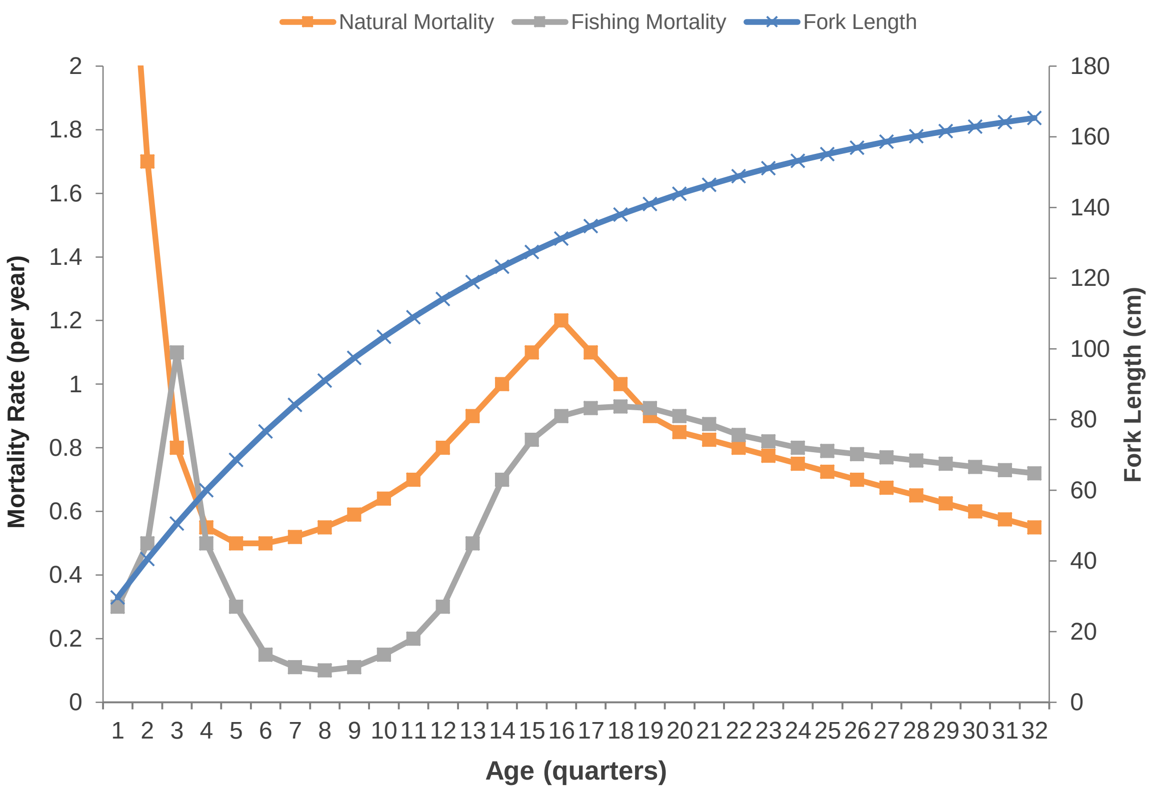


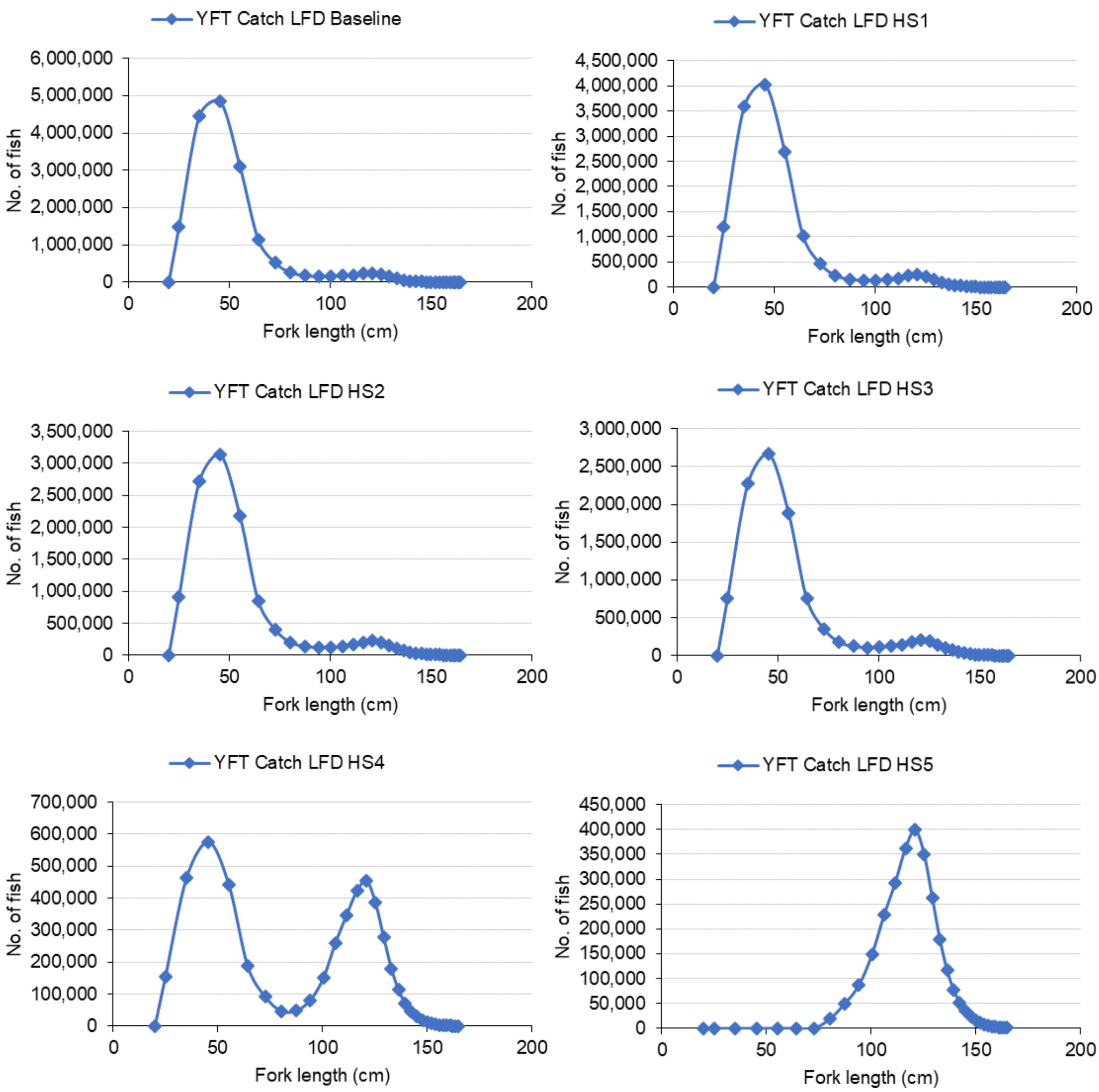
Table 6.2 Sensitivity of model outcomes; alternative growth parameter values: L_{inf}=180, K=0.3 and t_0=-0.35.

R=61.5 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	32,370	48,555,147	19,813	59,437,525	51,270	307,621,046	103,453
HS1 (F@80%)	27,581	41,371,463	18,285	54,856,169	54,193	325,159,028	100,060
HS2 (F@60%)	22,059	33,088,041	15,824	47,470,847	54,514	327,085,120	92,396
HS3 (F@50%)	18,991	28,486,778	14,165	42,495,248	52,968	317,810,760	86,125
HS4 (ReFocus)	4,340	6,510,335	13,178	39,533,241	97,015	582,091,316	114,533
HS5 (BabyBan)	0	0	11,396	34,188,213	91,926	551,553,711	103,322
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	26%	103,453	100%	415,613,718	100%	0	4.02
HS1 (F@80%)	33%	100,060	97%	421,386,660	101%	5,772,943	4.21
HS2 (F@60%)	42%	92,396	89%	407,644,008	98%	-7,969,710	4.41
HS3 (F@50%)	48%	86,125	83%	388,792,785	94%	-26,820,932	4.51
HS4 (ReFocus)	53%	114,533	111%	628,134,893	151%	212,521,175	5.48
HS5 (BabyBan)	62%	103,322	100%	585,741,923	141%	170,128,206	5.67

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

Resulting size at age, using adjusted growth parameter values, was 30 cm at 1 quarter, and 60, 91, 114, 131, 144 and 153 cm at 1, 2, 3, 4, 5 and 6 years of age respectively, differing with more than 3 cm from the baseline model only for fish older than 5.5 years. Estimated recruitment was adjusted only slightly to 61.5 million to reach the calibration level of total catch. Estimated SSB was almost the same with 115,633 MT versus 117,463 MT in the baseline scenario. Catch curves remained almost identical with adjusted growth versus baseline scenario (**Figure 6.5**) and conclusions on harvest strategies also remained largely the same (**Table 6.2**).

Figure 6.5 Simulated catch length frequency distributions assuming alternative growth parameter values L_{inf}=180, K=0.3 and t_0=-0.35.



6.4 SENSITIVITY ANALYSIS FOR IOTC ASSUMPTIONS ON NATURAL MORTALITY

A very important sensitivity analysis is the one for assumed levels of natural mortality. IOTC uses a flattened "curve" bottoming out at M=0.55 per year for juvenile YFT (**Figure 6.6**), and we have used this curve to test sensitivity of model outcomes and major conclusions about potential harvest strategies for this alternative assumption of natural mortality by age group. The main difference with the baseline scenario is that we had to reduce our estimate of recruitment by 24%, to 46.1 million recruits, to reach the calibration level of total catch. This number of recruits compares to 20% of the total number of recruits estimated by WCPFC for all of Area 7, which seems plausible with WPP 713+714+715 roughly making up some 20% to 25% of all deep oceanic water in WCPFC Region 7.

The estimated SSB in this test dropped very slightly only to 116,888 MT versus the estimate of 117,463 MT in our baseline scenario. Catch curves remained almost identical versus our 2016 baseline scenario after natural mortality was modelled according to IOTC (**Figure 6.7**), with slightly less Baby YFT and Medium YFT and some more Large YFT being caught under the IOTC natural mortality assumptions. Absolute total values increase slightly (4%), from a total value of US$ 422 million in 2016 baseline scenario compared to US$ 438 million from the scenario with IOTC assumptions on natural mortality (**Table 6.3**). Most important though is that our overall conclusions on harvest strategies remain the same. **HS4** (fisheries restructuring as explained above) is by far the best possible option. The interim target reference point is reached (43% $SSB/SSB_{F=0}$) and economic value raised by 60% for a significant 21% increase in total catch.

Figure 6.6 Alternative input parameter values with natural mortality according to IOTC.

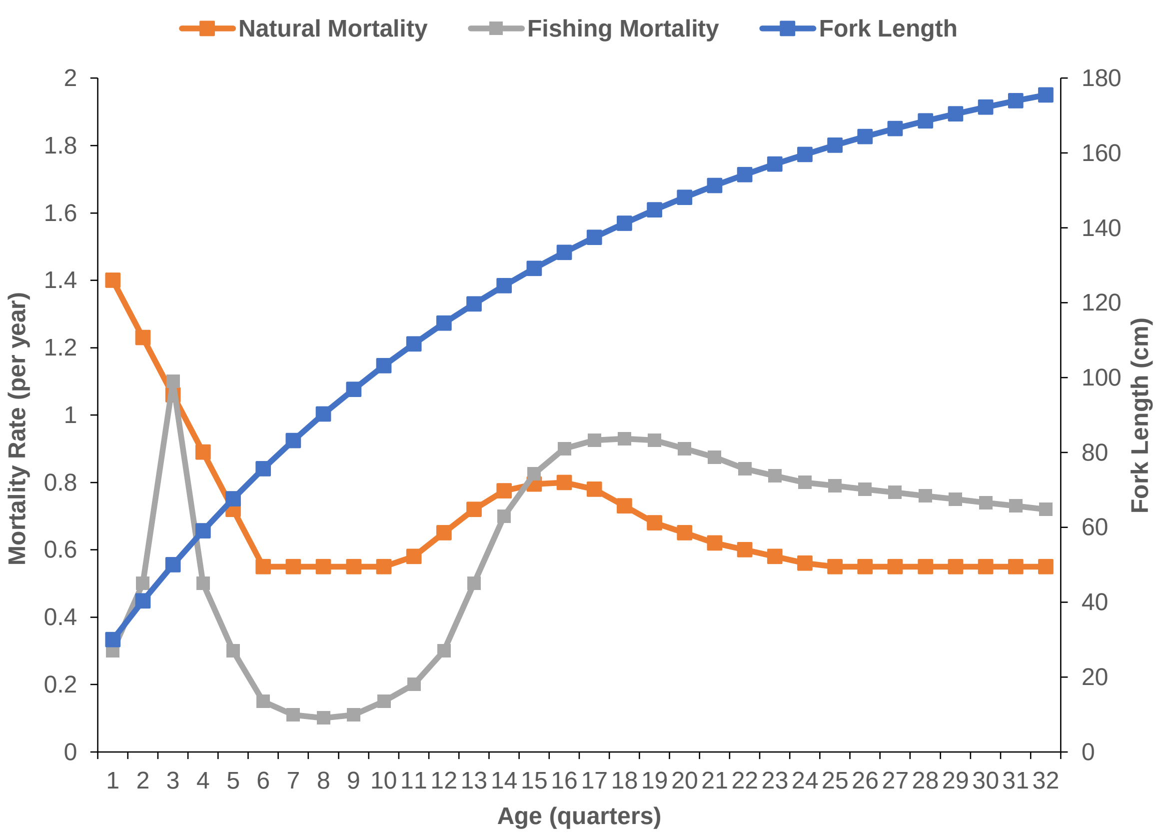
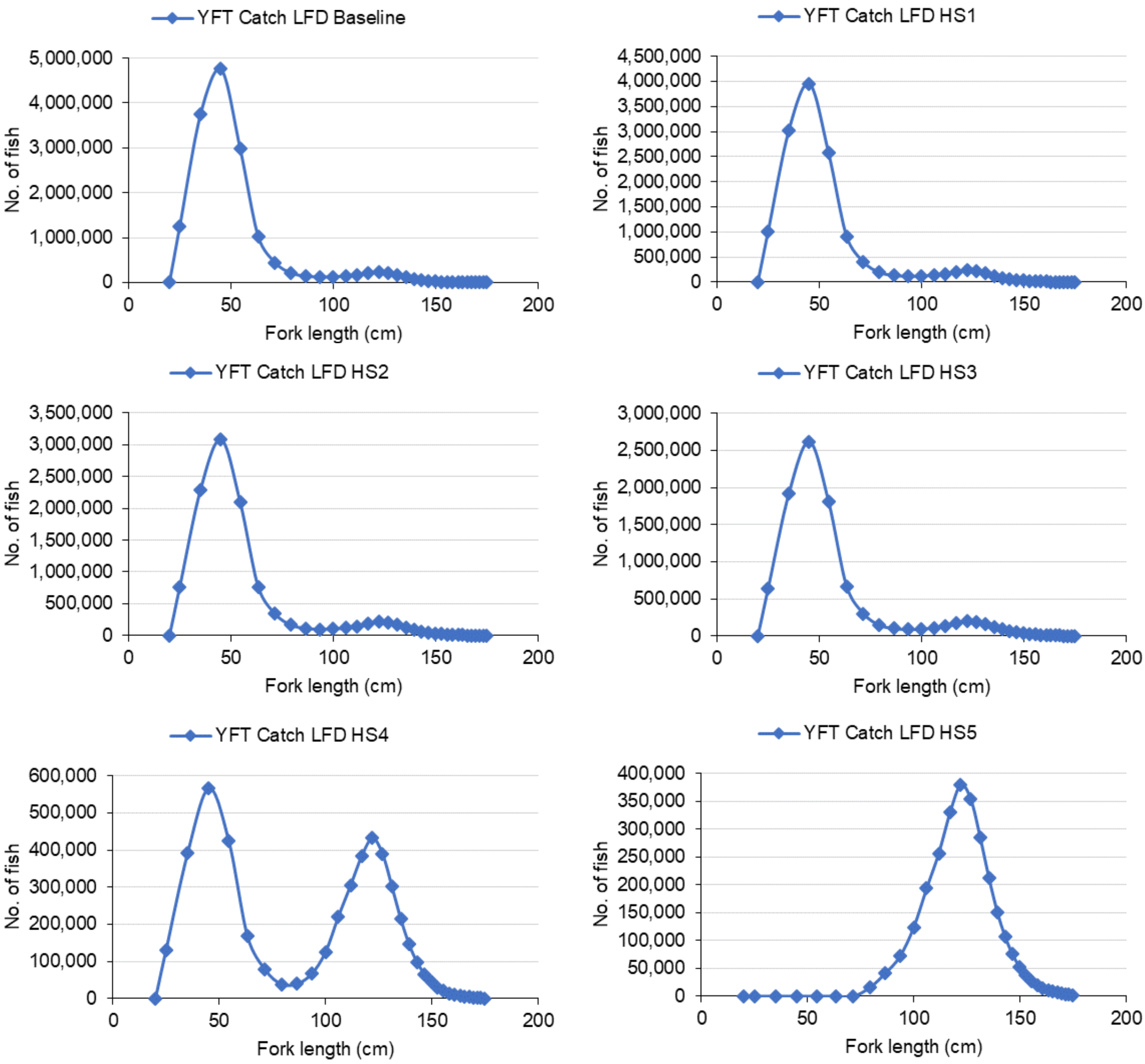


Table 6.3 Sensitivity of model outcomes: assuming M according to IOTC.

R=46.1 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	29,424	44,135,987	16,191	48,572,079	57,578	345,468,341	103,193
HS1 (F@80%)	25,062	37,592,449	14,945	44,836,427	62,611	375,667,161	102,618
HS2 (F@60%)	20,035	30,053,154	12,936	38,807,251	65,182	391,094,407	98,154
HS3 (F@50%)	17,245	25,868,046	11,581	34,742,955	64,601	387,607,264	93,428
HS4 (ReFocus)	3,937	5,905,757	10,939	32,816,123	110,433	662,596,951	125,309
HS5 (BabyBan)	0	0	9,465	28,395,866	107,955	647,728,682	117,420
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	21%	103,193	100%	438,176,407	100%	0	4.25
HS1 (F@80%)	27%	102,618	99%	458,096,037	105%	19,919,630	4.46
HS2 (F@60%)	36%	98,154	95%	459,954,813	105%	21,778,406	4.69
HS3 (F@50%)	42%	93,428	91%	448,218,264	102%	10,041,857	4.80
HS4 (ReFocus)	43%	125,309	121%	701,318,831	160%	263,142,424	5.60
HS5 (BabyBan)	52%	117,420	114%	676,124,548	154%	237,948,141	5.76

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

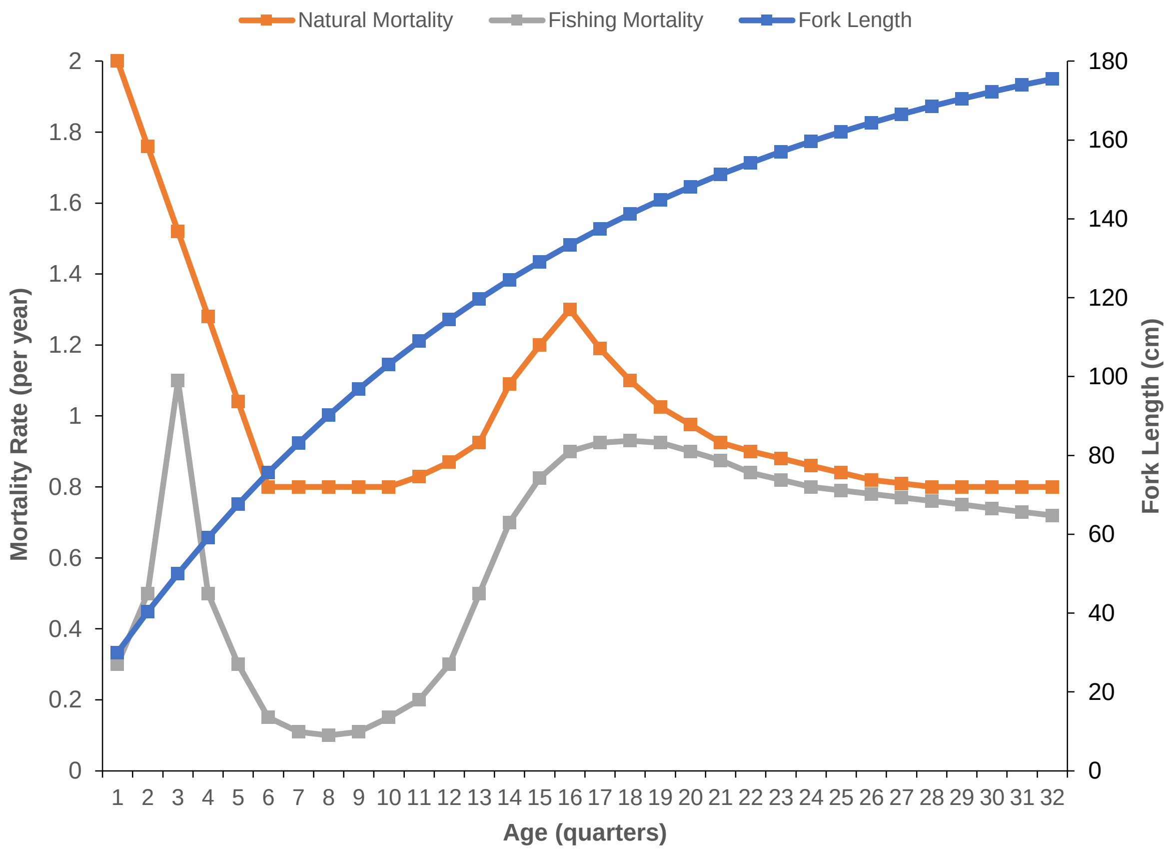
Figure 6.7 Simulated catch length frequency distributions with natural mortality according to IOTC.



6.5 SENSITIVITY ANALYSIS FOR WCPFC ASSUMPTIONS ON NATURAL MORTALITY

We also investigated the effect of adopting the exact plot for natural mortality at age as used in WCPFC stock assessments, without trying to relate this back to available literature on the subject. This results in a linear drop (straight line) from M = 2 per year for 1 quarter old recruits down to M = 0.8 for the 6 quarter old fish (Tremblay-Boyer et al., 2017), after which a flattened section starts for juvenile fish, keeping natural mortality fixed at 0.8 until 10 quarters of age (**Figure 6.8**). From there the curve rises again to 1.3 for fish at 16 quarters of age, to then drop off again slowly to the minimum level of 0.8. This WCPFC curve for assumed natural mortality levels bottoms out at 0.8 per year, which is 0.25 per year above IOTC assumed levels of 0.55 per year. Peak levels for M among the smallest fish (2.0 versus 1.4) and for spawning fish (1.3 versus 0.8) are also estimated much higher in the WCPFC model than what is assumed by IOTC.

Figure 6.8 Alternative set of input parameter values with natural mortality according to WCPFC.



Closely following the WCPFC assumptions for growth and natural mortality, we had to increase our estimate of recruitment to 96.2 million recruits, to reach the calibration level of total catch in IAW. This number of recruits compares to 43% of the total number of recruits estimated by WCPFC for all of Area 7, which seems to be rather high judging from the relative size of the area. The estimated SSB in this test dropped to 86,983 MT versus the estimate of 117,463 MT in our 2016 baseline scenario, which is a substantial difference. Catch curves remained similar versus our original baseline scenario (**Figure 6.9**), but with significantly more Baby YFT compared to decreased numbers of Large YFT being caught under the WCPFC natural mortality assumptions.

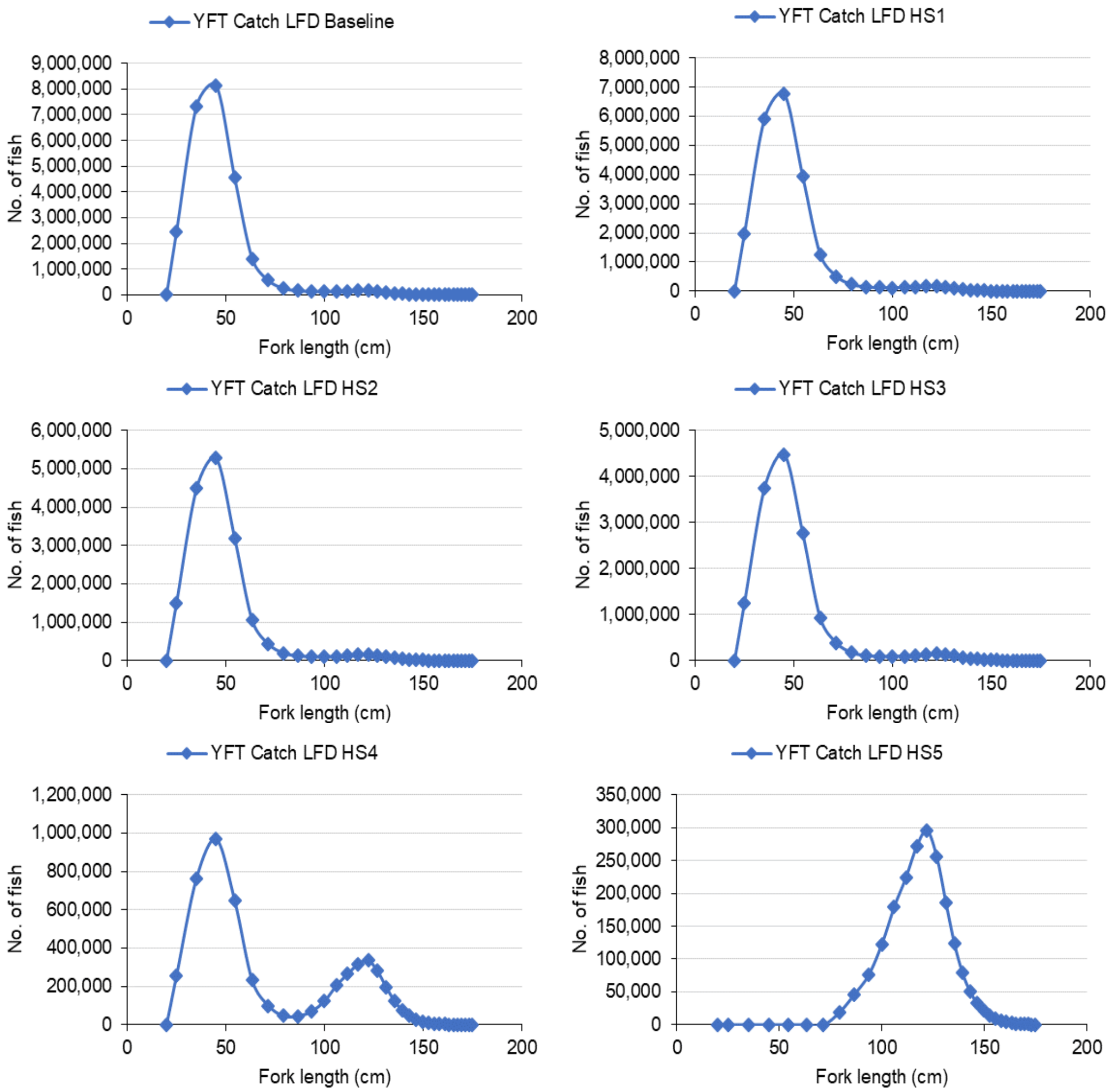
Large quantities of Baby YFT are caught in the baseline scenario under the WCPFC assumptions for natural mortality, with the volume exceeding that of Large YFT by 20%. Total value drops from US$ 422 million in our baseline scenario to US$ 353 million under WCPFC assumptions of natural mortality (**Table 6.4**), due to the high ratio of small fish appearing in the catch. Most important though is that conclusions on harvest strategies remain the same, with **HS4** (fisheries restructuring), coming out again as the best possible option. The interim target reference point is surpassed (55% $SSB/SSB_{F=0}$) and total economic value raised with 34% at a small reduction (14%) in total catch. No other strategy can promise similar economic results.

Table 6.4 Sensitivity of model outcomes: assuming M according to WCPFC.

R=96.2 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	47,562	71,343,695	17,609	52,825,608	38,155	228,927,316	103,326
HS1 (F@80%)	40,353	60,529,551	16,230	48,690,697	40,139	240,836,898	96,723
HS2 (F@60%)	32,135	48,202,334	14,027	42,080,961	40,134	240,801,221	86,295
HS3 (F@50%)	27,606	41,409,554	12,549	37,645,986	38,853	233,118,742	79,008
HS4 (ReFocus)	6,254	9,381,594	10,867	32,600,001	72,037	432,222,218	89,158
HS5 (BabyBan)	0	0	9,238	27,712,672	67,894	407,364,584	77,132
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	27%	103,326	100%	353,096,619	100%	0	3.42
HS1 (F@80%)	34%	96,723	94%	350,057,146	99%	-3,039,473	3.62
HS2 (F@60%)	43%	86,295	84%	331,084,516	94%	-22,012,103	3.84
HS3 (F@50%)	49%	79,008	76%	312,174,281	88%	-40,922,338	3.95
HS4 (ReFocus)	55%	89,158	86%	474,203,814	134%	121,107,194	5.32
HS5 (BabyBan)	64%	77,132	75%	435,077,256	123%	81,980,636	5.64

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

Figure 6.9 Simulated catch length frequency distributions with natural mortality according to WCPFC.



6.6 SENSITIVITY ANALYSIS FOR A SCENARIO WITH INTERMEDIATE (IOTC-WCPFC) LEVEL OF NATURAL MORTALITY COMBINED WITH LIMITED GROWTH

Indonesia is situated on the border of IOTC and WCPFC regions of interest, with tuna fisheries in both these regions. With some concerns about the large differences in estimated natural mortality levels between the 2 levels, we have therefore also tested a scenario with a hypothetical natural mortality curve including the intermediate values of M by age class from the 2 models. In this test, besides introducing the intermediate values from the IOTC and WCPFC plots for natural mortality, we are also using the “alternative” limited growth curve described above.

The limited growth curve closely follows the growth curves used by the RFMOs and starts flattening out at an age of 5 years and 144 cm, falling somewhat below our 2016 baseline growth curve from there onwards due to the lower estimate of L_{inf} by the RFMOs.

In this combination test we compared our 2016 baseline output with output resulting from the use of intermediate (IOTC-WCPFC) levels of natural mortality by age group, combined with the limited growth curve resembling the growth potential assumed in WCPFC and IOTC models. The resulting curve for M bottoms out at M = 0.675 per year for juvenile YFT (**Figure 6.10**), coming down from 1.7 per year for 30 cm recruits and peaking at 1.05 per year for 4-year old spawning fish.

Compared to our 2016 baseline scenario we had to increase the estimate for recruitment with just 12%, to 68.5 million recruits, to calibrate the total catch. This number of recruits compares to 30% of the total number of recruits estimated by WCPFC for all of Area 7, which is plausible with WPP 713+714+715 making up some 20% to 25% of all deep oceanic water in this region. The estimated SSB in this test dropped somewhat to 100,470 MT, from the estimated 117,463 MT in our 2016 baseline scenario. Catch curves remained similar versus our 2016 baseline scenario (**Figure 6.11**), with some more "Baby YFT and some less Large YFT being caught in this test.

Absolute total values dropped somewhat, from a total value of US$ 422 million in 2016 baseline scenario down to US$ 388 million in the scenario with intermediate (IOTC-WCPFC) levels of natural mortality combined with reduced potential growth (**Table 6.1**). Differences with 2016 baseline outputs were small though and overall conclusions on harvest strategies remained the same. Under **HS4**, the interim target reference point was surpassed (51% $SSB/SSB_{F=0}$) and economic value raised with 46% while the estimate for total catch remained unchanged.

Figure 6.10 Model input with intermediate (IOTC-WCPFC) natural mortality and limited growth.

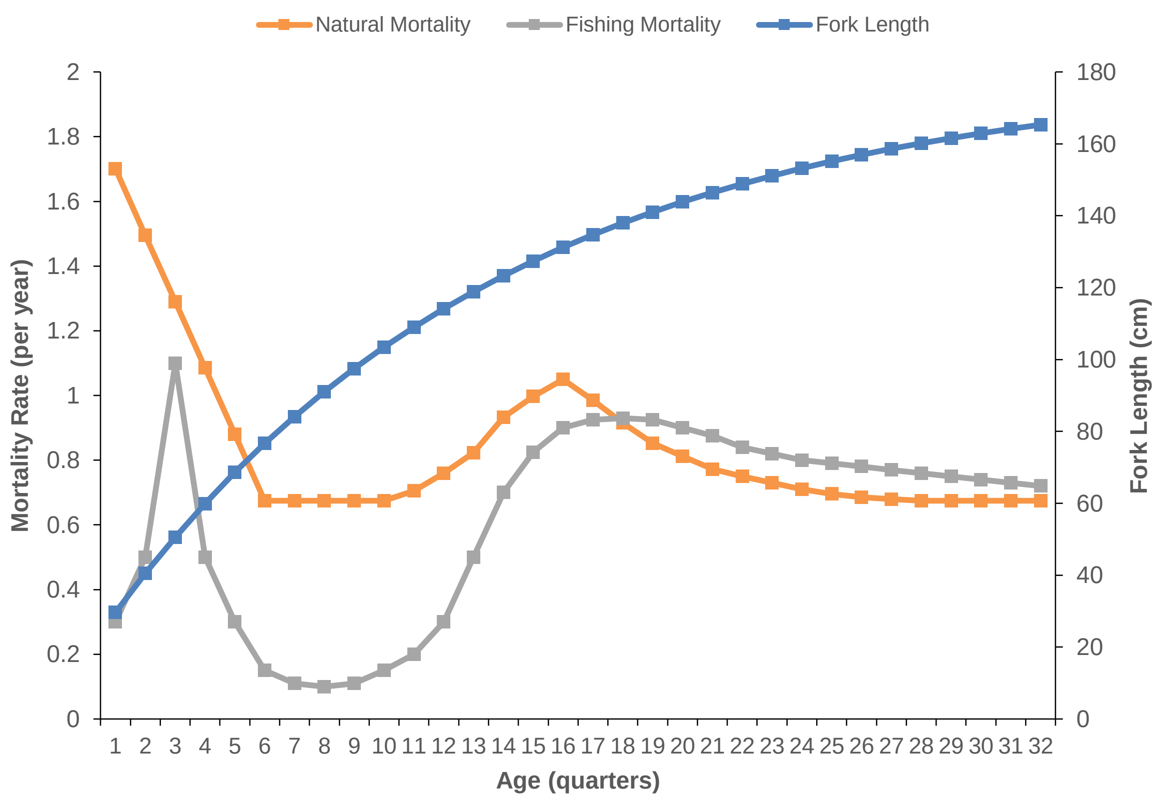
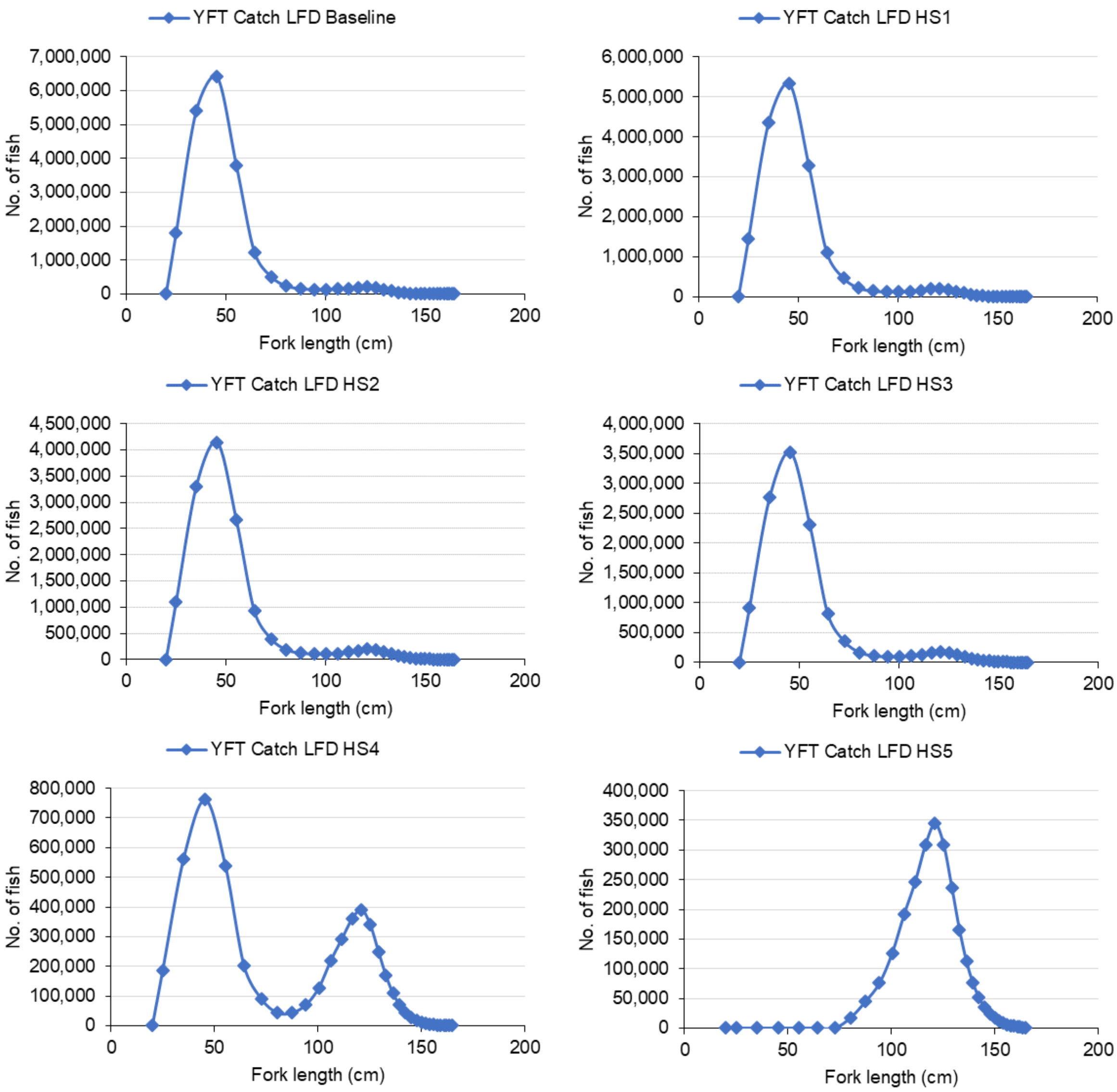


Table 6.5 Sensitivity of model outcomes: assuming intermediate natural mortality and limited growth.

R=68.5 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	39,595	59,393,171	17,778	53,334,928	45,917	275,503,575	103,291
HS1 (F@80%)	33,675	50,512,981	16,396	49,188,016	48,866	293,195,732	98,937
HS2 (F@60%)	26,882	40,322,960	14,178	42,534,848	49,551	297,304,956	90,611
HS3 (F@50%)	23,121	34,682,203	12,688	38,062,805	48,364	290,185,742	84,173
HS4 (ReFocus)	5,263	7,894,938	11,356	34,068,039	87,170	523,018,622	103,789
HS5 (BabyBan)	0	0	9,725	29,176,088	83,208	499,249,485	92,934
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	25%	103,291	100%	388,231,675	100%	0	3.76
HS1 (F@80%)	31%	98,937	96%	392,896,729	101%	4,665,054	3.97
HS2 (F@60%)	41%	90,611	88%	380,162,765	98%	-8,068,910	4.20
HS3 (F@50%)	46%	84,173	81%	362,930,750	93%	-25,300,925	4.31
HS4 (ReFocus)	51%	103,789	100%	564,981,598	146%	176,749,924	5.44
HS5 (BabyBan)	60%	92,934	90%	528,425,573	136%	140,193,898	5.69

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

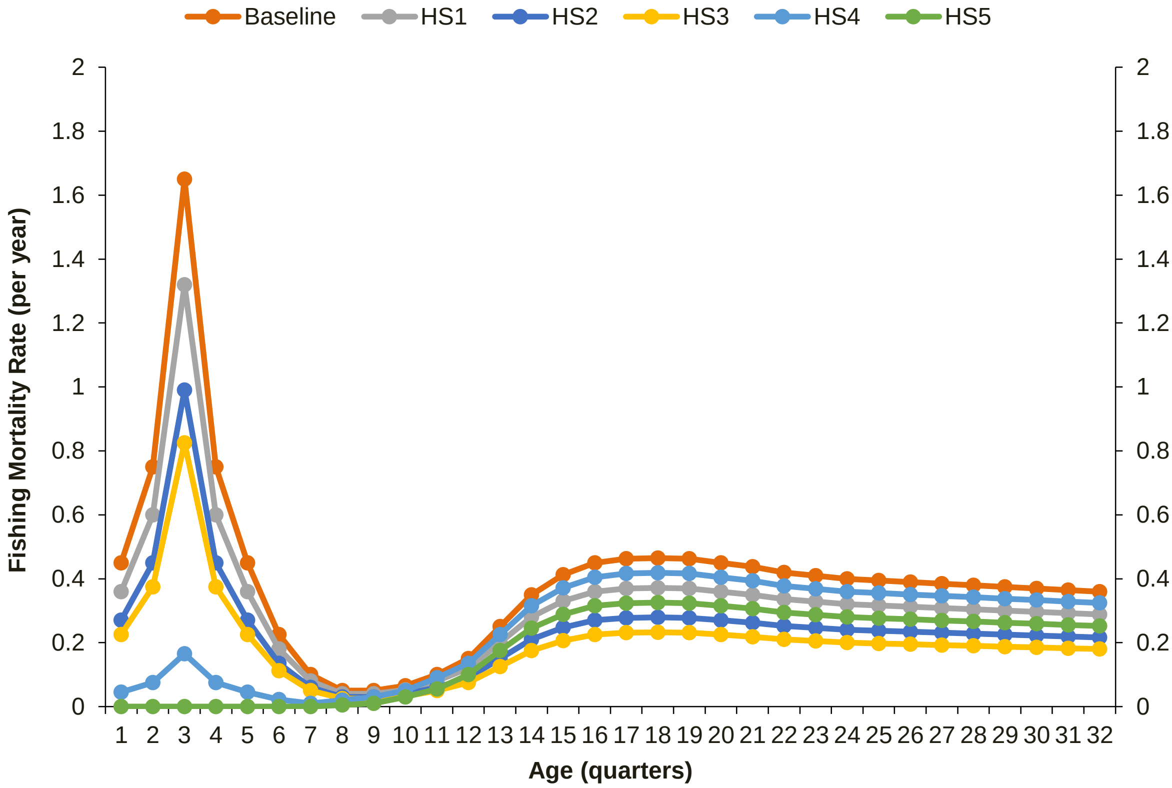
Figure 6.11 Simulated catch length frequencies with intermediate natural mortality and limited growth.



6.7 SENSITIVITY ANALYSIS FOR ALTERNATIVE ASSUMPTIONS ON FISHING MORTALITY LEVELS

Another important sensitivity analysis is the one for assumed levels of fishing mortality. In our 2016 baseline scenario we have used an average level of fishing mortality for juvenile YFT comparable to the level which WCPFC estimates for the WCPO (see also section 4.4). Juvenile YFT in Region 7 (which includes Indonesia) and Region 8 are assumed to experience the highest fishing mortality in the entire WCPO (Tremblay Boyer et al., 2017). Juvenile YFT in IAW are most likely experiencing levels of fishing mortality that are among the highest again in Regions 7 and 8. It is quite plausible that fishing mortality among the juvenile YFT is even higher than what was assumed in our 2016 model and we will therefore include a 50% upwards adjusted F for juveniles in our sensitivity analysis for alternative levels of fishing mortality by age group.

Figure 6.12 Alternative assumptions on fishing mortality, including a 50% higher F for juveniles combined with 50% lower F for adult YFT.



We have in our 2016 baseline scenario assumed a high level of fishing mortality for adults, based on trends from the literature combined with observations on recent developments. Some might argue that we may have over-estimated F for adults, compared to estimated levels from the WCPO (Davies et al., 2014; Tremblay-Boyer, 2017). We have therefore also included a 50% downwards adjusted F for adults in our sensitivity analysis for alternative levels of fishing mortality by age group. Age dependent fishing mortality rates for baseline scenario and various harvest strategies were adjusted accordingly in our model input (**Figure 6.12**), to test the sensitivity of model outcomes and conclusions for alternative assumptions on fishing mortality levels by age group.

Using the alternative assumptions for fishing mortality by age group, we had to increase to 79 million recruits, to reach the calibration level of total YFT catch in IAW. This number of recruits compares to 35% of the total number of recruits estimated by WCPFC for all of Region 7, which seems to be rather high judging from the relative size of the IAW. The estimated SSB in this test increased somewhat to 124,018 MT versus the estimate of 117,463 MT in our 2016 baseline scenario. Catch curves remained similar versus our original baseline scenario (**Figure 6.13**), but with significantly more Baby YFT compared to decreased numbers of Large YFT being caught under our alternative assumptions on fishing mortality levels by age group.

Large quantities of Baby YFT are caught in the baseline scenario under the assumptions with a 50% higher fishing mortality for juveniles combined with a 50% lower fishing mortality for adults. The volume of Baby YFT exceeds that of Large YFT by 56% under these assumptions. The total value of the catch drops from US$ 422 million in our baseline scenario to US$ 333 million under the alternative assumptions of fishing mortality (**Table 6.6**), due to the high ratio of small fish appearing in the catch.

Most important though is that conclusions on harvest strategies remain the same, with **HS4** (fisheries restructuring), coming out again as the best possible option. The interim target reference point is surpassed (64% $SSB/SSB_{F=0}$) and total economic value raised with more than US$ 212 million at just a very small reduction (1%) in total catch.

In two more final tests we have looked at the sensitivity of our conclusions for the unlikely scenarios that (a) fishing mortality was 50% higher across all age groups or (b) fishing mortality was 50% lower across all age groups (**Table 6.7 and Table 6.8**). Recruitment remained similar to that in the 2016 baseline scenario under the "F 50% UP" assumption, while recruitment was raised considerably under the "F 50% DOWN" assumption. Perhaps most notable is that $SSB/SSB_{F=0}$ dropped to just 15% for the baseline situation, indicating that serious over-fishing is already occurring if F is in fact 50% higher overall than what we assumed in our 2016 baseline scenario. Perhaps just as notable though is that $SSB/SSB_{F=0}$ would currently be as high as 48%, or well above the interim target reference point if F would be 50% lower overall than what we have assumed. Neither seem very likely and would be far off from the more generally accepted current estimates for $SSB/SSB_{F=0}$ of around 25%. Most important though is that conclusions on **HS4** again remained the same as before.

Table 6.6 Sensitivity of model outcomes: assuming a 50% higher F for juveniles combined with 50% lower F for adult YFT.

R=79 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	53,567	80,349,920	15,404	46,212,189	34,385	206,307,297	103,355
HS1 (F@80%)	46,907	70,360,419	15,056	45,166,970	36,957	221,743,410	98,920
HS2 (F@60%)	38,615	57,922,960	13,797	41,391,497	37,459	224,755,083	89,872
HS3 (F@50%)	33,749	50,623,419	12,710	38,129,819	36,377	218,262,087	82,836
HS4 (ReFocus)	8,222	12,333,630	11,291	33,873,427	83,207	499,240,057	102,720
HS5 (BabyBan)	0	0	4,967	14,900,517	78,612	471,672,699	83,579
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	24%	103,355	100%	332,869,405	100%	0	3.22
HS1 (F@80%)	32%	98,920	96%	337,270,798	101%	4,401,393	3.41
HS2 (F@60%)	42%	89,872	87%	324,069,539	97%	-8,799,866	3.61
HS3 (F@50%)	48%	82,836	80%	307,015,325	92%	-25,854,080	3.71
HS4 (ReFocus)	64%	102,720	99%	545,447,114	164%	212,577,709	5.31
HS5 (BabyBan)	77%	83,579	81%	486,573,217	146%	153,703,812	5.82

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

Figure 6.13 Simulated catch length frequency distributions assuming a 50% higher F for juveniles combined with 50% lower F for adult YFT.

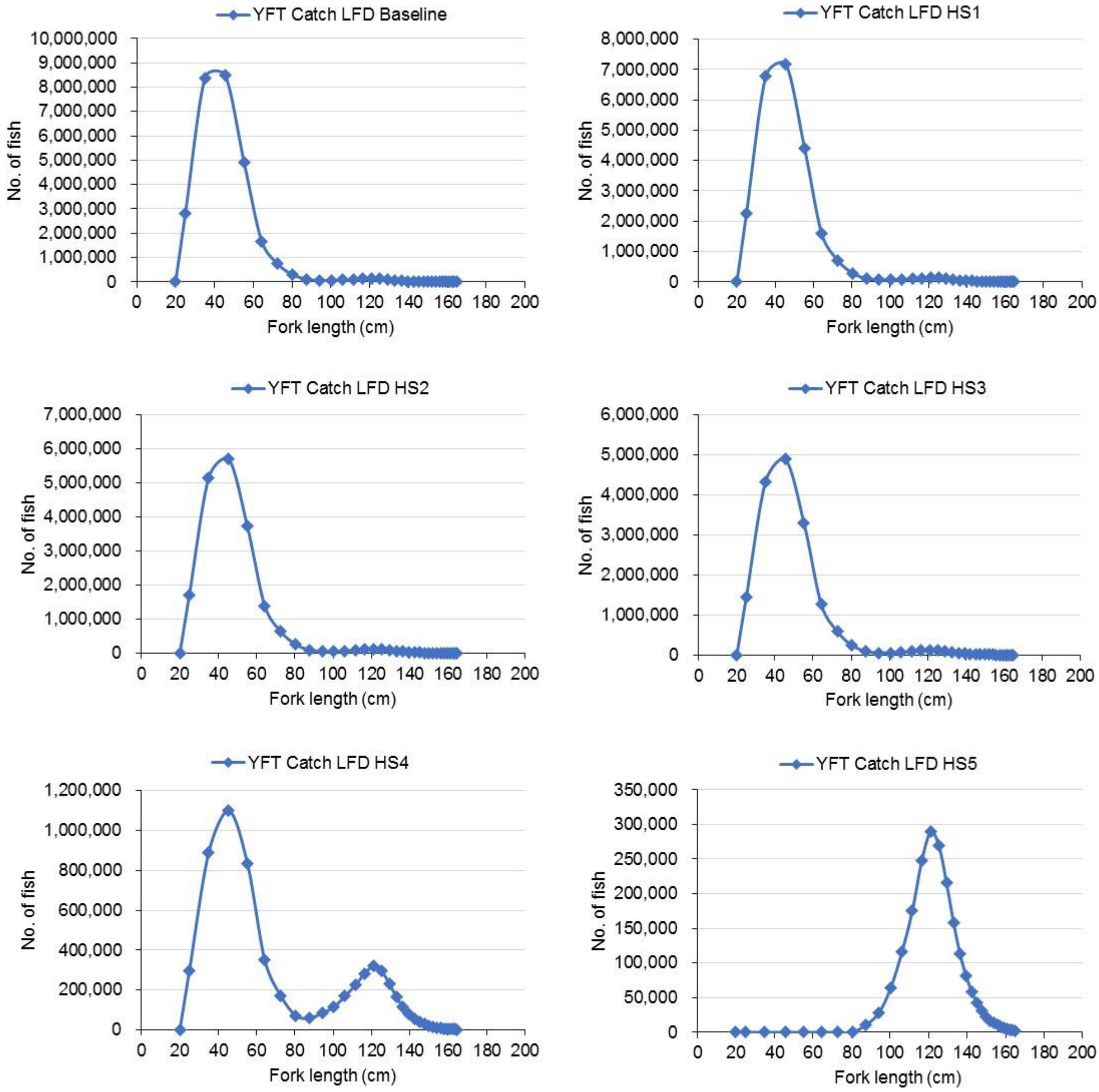


Table 6.7 Sensitivity of model outcomes: assuming a 50% higher F for all age groups.

R=62 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	42,040	63,059,431	20,972	62,917,113	40,545	243,269,286	103,557
HS1 (F@80%)	36,813	55,219,569	20,779	62,337,496	47,515	285,087,305	105,107
HS2 (F@60%)	30,306	45,458,525	19,308	57,922,727	53,382	320,289,267	102,995
HS3 (F@50%)	26,487	39,729,772	17,911	53,733,144	55,035	330,211,395	99,433
HS4 (ReFocus)	6,453	9,679,558	18,995	56,984,427	109,266	655,593,748	134,713
HS5 (BabyBan)	0	0	16,999	50,995,906	110,191	661,143,520	127,189
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	15%	103,557	100%	369,245,830	100%	0	3.57
HS1 (F@80%)	21%	105,107	101%	402,644,370	109%	33,398,540	3.83
HS2 (F@60%)	29%	102,995	99%	423,670,519	115%	54,424,689	4.11
HS3 (F@50%)	35%	99,433	96%	423,674,311	115%	54,428,481	4.26
HS4 (ReFocus)	43%	134,713	130%	722,257,732	196%	353,011,902	5.36
HS5 (BabyBan)	53%	127,189	123%	712,139,426	193%	342,893,596	5.60

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

Table 6.8 Sensitivity of model outcomes: assuming a 50% lower F for all age groups.

R=74 Million STRATEGY	Catch (MT) Baby YFT	Value (US$) US$ 1.50 / kg	Catch (MT) Medium YFT	Value (US$) US$ 3.00 / kg	Catch (MT) Large YFT	Value (US$) US$ 6.00 / kg	Catch (MT) TOTAL
Baseline (F*1)	22,851	34,276,773	17,044	51,132,493	63,734	382,406,443	103,630
HS1 (F@80%)	18,892	28,338,415	14,648	43,943,830	59,763	358,575,107	93,303
HS2 (F@60%)	14,647	21,971,215	11,802	35,406,778	52,845	317,071,890	79,295
HS3 (F@50%)	12,412	18,617,898	10,194	30,582,635	47,933	287,598,042	70,539
HS4 (ReFocus)	2,656	3,983,989	6,090	18,268,990	84,321	505,925,876	93,067
HS5 (BabyBan)	0	0	4,869	14,608,442	73,732	442,392,231	78,602
STRATEGY	**$SSB/SSB_{F=0}$***	**Catch (MT)**	**C/Cbase (%)**	**Value (US$)**	**Val/Vbase (%)**	**D Value (US$)**	**Value/kg (US$)**
Baseline (F*1)	48%	103,630	100%	467,815,709	100%	0	4.51
HS1 (F@80%)	55%	93,303	90%	430,857,352	92%	-36,958,358	4.62
HS2 (F@60%)	63%	79,295	77%	374,449,883	80%	-93,365,826	4.72
HS3 (F@50%)	68%	70,539	68%	336,798,574	72%	-131,017,135	4.77
HS4 (ReFocus)	70%	93,067	90%	528,178,855	113%	60,363,146	5.68
HS5 (BabyBan)	77%	78,602	76%	457,000,674	98%	-10,815,036	5.81

* Interim Target Reference Point for $SSB/SSB_{F=0}$ is 40%; Limited Reference Point is 20%.

7.0 CONCLUSIONS AND DISCUSSION

We used a simple "back of an envelope model" model to show that if catches of Baby YFT were significantly reduced in the IAW, the gains in biomass due to growth, combined with the price increase (per kg) from juvenile to large YFT, would exceed the losses due to natural mortality (**Table 6.1**). The total value of YFT catches from the IAW is predicted to increase significantly with more than 50% when fisheries mortality among baby YFT is reduced by 90% alongside an overall effort reduction of not more than 10%. The model shows that the SSB in these waters can be maintained at a target level of at least 40% of $SSB_{F=0}$, and probably even higher at 50% of $SSB_{F=0}$, if commercial targeting of Baby YFT is stopped. We note that even significant effort reductions in the fisheries for medium and large YFT will have only moderate effect on total catch and value of the catch, although overall costs will be reduced after such effort reductions. **Table 7.1** provides a summary of all modeling results.

Table 7.1 Summary of modeling results.

STRATEGY	$SSB/SSB_{F=0}$ (Target: 50%)	Catch (MT)	Catch as a percentage of the baseline	Value (US$)	Value as a percentage of the baseline
Baseline (representative for the situation in 2016)	25%	103,198	100%	421,516,768	100%
HS1: Reduction in overall fishing mortality with 20%	32%	100,294	97%	429,311,490	102%
HS2: Reduction in overall fishing mortality with 40%	41%	93,144	90%	417,491,440	99%
HS3: Reduction in overall fishing mortality with 50%	47%	87,105	84%	399,359,777	95%
HS4: Reduction of baby YFT fishing mortality with 90%, combined with a reduction of fishing mortality of medium and large YFT with 10%	52%	117,274	114%	646,199,452	153%
HS5: Ban on fishing for baby YFT, combined with a reduction in fishing mortality for all other YFT with 30%	61%	106,458	103%	605,225,947	144%

There are many studies around the globe that warn about economic over-fishing through targeting of pre-mature 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). YFT in IAW is currently not managed optimally with respect to its total economic value, and the same issue has been reported since decades from the wider Pacific region (e.g. Sun, 2010). YFT in IAW are 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, and that the question of the impact of these catches on the overall YFT fisheries is frequently raised. Hampton (2000) also noted that estimates of the impact can be derived using yield per recruit or other size- and/or age-structured models, which is what we have done in this paper, and what others have done before us with similar results (e. g. Bailey et al., 2013).

We modeled the selectivity of the tuna fishery with a bimodal curve, including the combined effects of different, but partly overlapping fisheries. Large YFT in the IAW are caught with drop lines using large live baits, often deep at FADs, or associated with dolphin pods, as well as with trolling lines and long lines. Baby YFT are caught with pole-and-line, in the purse-seine fisheries and with drop lines and trolling lines with multiple small hooks, often also around FADs. Large YFT supply markets for sashimi and other fresh and frozen products, whereas small sized tunas supply the canning industry as well as local markets. Hence, interventions to reduce selectivity for, and therefore fishing mortality of, Baby YFT boil down to a restructuring of the fishery. Whereas such re-structuring of the YFT fishery will have to address social and equity issues, we must conclude that overall economic output from the YFT fisheries in the IAW can be greatly improved by shifting the fisheries away from targeting Baby YFT. 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. The details of such a 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 must not be ignored (Sun, 2010).

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 hook-and-line fisheries in the IAW.

The competitive situation between fisheries supplying the canning industry with small- to medium-sized tuna, mostly purse seine and pole-and-line fisheries, and fisheries for large tuna supplying markets for sashimi and other fresh and frozen products (mostly hook-and-line fisheries) has been discussed for decades, and specific management action has been recommended (e.g. Miyake et al., 2010; Sun et al., 2017). Cooperative management, or the lack thereof, has been pointed at as 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 Baby YFT. In Indonesia, both small-scale and industrial fishers use anchored FADs to catch baby YFT 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 baby YFT in IAW, regulation of FADs will also affect the fishery for large YFT. Therefore, we recommend that management of FADs should aim to optimize use of this auxiliary fishing gear for capturing large tuna, while ensuring that this gear is not used to catch excessive amounts of Baby YFT.

While evaluating predicted levels of economic gains from simulation models, we need to keep in mind that predictions can be highly sensitive to input assumptions related to 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 confidently recommend specific management interventions (e.g. Lehuta et al., 2010). We have not found uncertainty surrounding input parameter values for our simple model of the IAW YFT fisheries to be of such magnitude that they would raise any doubt in relation to recommendations to improve economic output from these fisheries through drastically reducing fishing mortality among immature fish.

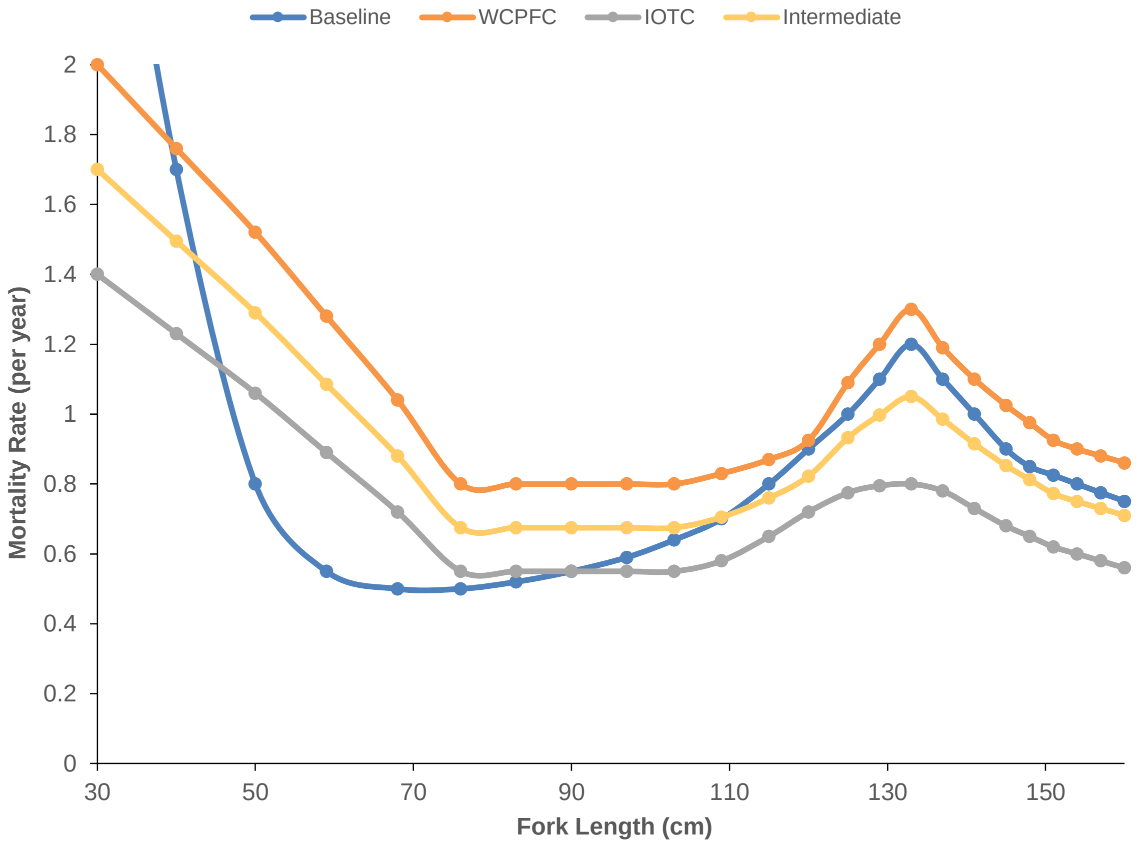
8.0 RECOMMENDATIONS FOR RESEARCH

Natural mortality (M) is one of the most influential quantities in fisheries stock assessment and the calculation of management advice. Indeed, model output was highly sensitive to assumptions on the levels of size- and age-specific natural mortality. Unfortunately, M is notoriously difficult to estimate from standard fisheries data (Maunder and Aires-da-Silva, 2012). However, tagging studies have been applied to tuna (e.g. Hampton, 2000) and they represent the most promising approach to estimate M for YFT (Maunder and Aires-da-Silva, 2012). Sensitivity analysis for different levels of natural mortality in the present study has shown that our overall conclusion on the results from a proposed fisheries restructuring are not changed, but that the predicted levels of potential gains can vary significantly. It is therefore of the greatest importance that any modeling exercise for the purpose of evaluating potential harvest strategies takes into account the uncertainty surrounding levels of natural mortality.

The size dependent natural mortality levels that we inferred for our baseline from the literature (e.g. Hampton, 2000; Adam et al., 2003; Nishida et al., 2018) results in an estimated M curve which falls mostly within the range between the levels used by IOTC and WCPFC. The initial M inferred at 3 per year for recruits aged 1 quarter is higher than what is currently used by WCPFC and IOTC but close to what was estimated by Hampton (2000). For 2 quarter old fish the inferred level is 1.7 per year, just below the level used by WCPFC and within the range of levels used between the two RFMOs. At 2 to 3 quarters of age the fish measure between 41 and 50 cm fork length and our inferred level of 1.3 per year for M closely follows Hampton (2000) and is within the range between IOTC and WCPFC adopted levels.

The only section where our inferred levels of M fall outside and significantly below the range of levels used by the two RFMOs is for the 3 quarters, 1 year, and 5 quarters old fish (**Figure 8.1**). These juvenile YFT measure about 50, 59 and 68 cm fork length with estimated levels of M at 0.8, 0.55 and 0.5 respectively, all confirmed in the literature which is most commonly cited in RFMO stock assessment reports. For older and larger YFT our inferred size dependent level of natural mortality falls within the range of levels use by the two RFMOs which each partly cover Indonesian waters.

Figure 8.1 Alternative levels of size dependent natural mortality, for modeling of YFT fisheries in Indonesia.



Hampton (2000) reported the lowest levels of M for YFT to occur in the size ranges 51–60 and 61–70 cm fork length. These estimates, of 0.68 and 0.44 per year respectively, are well below the value of 0.8 per year, which is used in the WCPFC YFT assessments (Tremblay-Boyer et al., 2018), even though estimates as low as 0.4 to 0.6 per year have also been reported (Schaefer, 1967; Francis, 1977). Below is another summary of the most relevant ranges discussed here:

- 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 (Adam et al., 2003).
- ***50 - 59 cm FL (3 to 4 quarters): $M_{(avg)}$ = 0.7 per year (Hampton, 2000).***
- ***55 - 65 cm FL (ca. 4 quarters): $M_{(avg)}$ = 0.6 per year (Hampton 2000, Nishida et al., 2018).***
- ***59 - 68 cm FL (4 to 5 quarters): $M_{(avg)}$ = 0.5 per year (Hampton, 2000).***
- ***50 - 83 cm FL (3 to 7 quarters), pre-mature fish: $M_{(avg)}$ = 0.6 per year (Hampton, 2000).***
- 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.

For pre-mature YFT ranging from 51 to 80 cm fork length, Hampton (2000) reports an average natural mortality level of 0.6 only. In a recent and extensive review of natural mortality in YFT, Maunder and Aires-da-Silva (2012) advise that "*specifying M for pre-mature YFT at an average M of 0.1625 per quarter (or 0.65 per year) might be prudent*", while they also refer to Hampton (2000) for that advice. Our inferred average level of 0.6 for M in pre-mature YFT of 4 to 10 quarters is very close to all of this and we have not found any literature evidence for much higher levels in these immature fish.

Supporting literature for the rather high levels of M adopted by WCPFC, for pre-mature fish from 1 to 2 years old, does not seem to be available at this time. Levels adopted by IOTC seem to be closer to those indicated in the literature as cited above. The bottom level of 0.65 per year recommended by Maunder and Aires-da-Silva (2012) is just below the flat "intermediate" value of 0.675 for pre-mature YFT of 6 to 10 quarters, in between IOTC and WCPFC levels. It is notably well below the flat level of 0.8 used by the WCPFC for pre-mature YFT. IOTC levels used for M in large YFT are also closest to what is used by ICCAT in the Atlantic Ocean (Walter and Sharma, 2017; Anon., 2016).

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 Baby YFT. And over-estimating M would under-estimate the potential gains for fisheries targeting Large YFT from harvest strategies that reduce fisheries mortality among premature YFT. Levels of M should be chosen and investigated carefully in any modeling exercise.

Based on the above literature review related to various levels of size based natural mortality used by WCPFC and IOTC, combined with the fact that Indonesia covers tuna fishing grounds that are part of both RFMOs, we suggest that using "intermediate" levels for M, in between values used by WCPFC and IOTC, is perhaps the most suitable and possibly also an acceptable way to approach baseline model runs for YFT assessment in Indonesia. Sensitivity analysis for levels of M should always be conducted and presented though, together with baseline results. We suggest that our literature inferred curve for M at age, as presented in this paper, may also serve its purpose in such sensitivity analysis.

Any presentation of modeling outputs should include at least a range of potential outcomes resulting from the use of different levels of M. For Indonesia, which includes tuna fishing grounds falling under IOTC in the south of the country and under WCPFC in the north, we suggest that working with the intermediate level of M, used between the two RFMOs, might be an elegant way to form a country-wide baseline approach. This would be further justified by the fact that boundaries between the Pacific Ocean and the Indian Ocean are not clearly defined and part of the IAW could even be argued to belong to the Indian Ocean and therewith fall under IOTC responsibility (Hampton, pers. comm.). Sensitivity analysis around an intermediate level of assumed natural mortality should always include model runs using the actual levels used by both RFMOs and we suggest that an additional run using the levels inferred in this paper may also further support decision making in tuna fisheries management in Indonesian waters.

We strongly recommend to further address uncertainty, especially related to natural and fishing mortality, and well-designed tagging studies seem to be best available methods to go about this (Hampton, 2000; Adam et al., 2003; Pine et al., 2003; Leigh et al., 2006; McGarvey 2009; Maunder and Aires-da-Silva, 2012). Many tuna tagging studies have been done in the general region, although it is not clear what has been done and what has been concluded to date specifically in relation to the IAW. We therefore recommend to implement an inventory and analysis of all relevant tagging studies done in the area to date. Some reports on tagging studies that have been delivered to Indonesian government may not yet have been specifically analyzed for the purpose of mortality estimations.

We recommend a review of all analyses performed to date on existing data sets from previous tagging studies in and around the IAW, resulting in a summary report on all conclusions drawn to date, additional analysis of existing data if deemed necessary, and assessment of the need for further tagging studies to address knowledge gaps. We propose to assess how information from previous tagging experiments can help to reduce uncertainties surrounding model inputs, with a focus on natural and fisheries mortality, but including also growth and migration. We need to identify data gaps and if those exist, consider costs versus potential benefits from additional tagging studies to answer questions on size specific mortality components, growth and site fidelity of YFT and skipjack in the IAW.

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