Update on the length and age distribution of southern bluefin tuna (SBT) in the Indonesian longline catch

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Abstract

This paper updates previous analyses of southern bluefin tuna (SBT) length and age data from the Indonesian longline fishery operating out of the port of Benoa, Bali. Age frequency data are presented up to the 2018/19 season based on length frequency data up to the 2019/20 season. The collection of SBT otoliths was conducted using the existing RITF-CSIRO monitoring program for the longline fishery and otoliths were collected from a total 1,500 SBT ranging from 134-199 cm fork length (FL) in 2018/19. Last year, the Directorate General of Capture Fisheries (DGCF) provided new SBT length and weight data from the Catch Documentation Scheme (CDS) for 2015/16 to 2018/19. The DGCF identified vessels operating in CCSBT statistical areas 1 and 2 using vessel monitoring system (VMS) tracking information. Only SBT caught by vessels operating in area 1 (spawning ground) was included in our analysis. Preliminary examination of the data showed that a proportion of fish were measured to the nearest 10-cm length class, rather than 1 cm, which has the potential to bias estimates of the size distribution of the catch. Individual weight data are considered to be more likely to be accurate, since the data are used for export purposes, these data were used in the analysis, rather than the 10 cm binned data. Weight was converted to length using a weight-length relationship derived from SBT in the Benoa monitoring program over the same time period. As reported last year, the new size data for fish from area 1 showed a clear a shift towards larger fish in the catch in the two most recent spawning seasons. The pulse of SBT that was first observed in the spawning ground catches in 2012/13 appears to have moved through the fishery on an annual time step. New data for the 2019 calendar year were provided by the DGCF after the 2020 CCSBT data exchange. The new data included additional length/weigh measurements collected between January and December 2019, which changes the data for the 2018/19 spawning season. We re-ran the analysis using this new data and provide the results in Appendix A. The updated results are similar to the those provided here, although apart from a slight increase in the proportion of small/young SBT in the catch.

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Introduction

The southern bluefin tuna (SBT) spawning ground is located in an area between Indonesia and the northwest coast of Australia, where spawning occurs during September to April each year (Farley and Davis 1998). SBT in the Indonesian fishery is categorized as a by-product of the longline vessels, which mainly target bigeye and yellowfin tuna. Obtaining an accurate estimate of the size and age composition of SBT landed by the Indonesian longline fishery is central to population modelling and stock assessments and close-kin mark recapture (CKMR), which are used by CCSBT to monitor changes in the spawning population over time.

The 28 year program of monitoring the size and age structure of the SBT spawning population was first established in 1993 through a series of collaborative projects between Indonesia's marine fisheries research institutes[3] within the Ministry of Marine Affairs and Fisheries (MMAF) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Farley *et al.* 2017). The main location monitored for SBT was the Benoa Fishing Port in Bali. In 2002, the scope of research collaboration expanded to include all tuna species (yellowfin and bigeye tuna, and albacore) and related species (billfish and other bycatch species) landed by the longline fleet. This occurred with the addition of new partners to the collaboration, the Indian Ocean Tuna Commission (IOTC) and Japan's Overseas Fishery Cooperation Foundation (OFCF) (Farley *et al.* 2014). The monitoring locations expanded to three fishing ports, including Muara Baru (Jakarta) and Cilacap (south cost Central Java), in addition to Benoa (Farley *et al.* 2007). The majority of targeted SBT sampling, however, still occurs at Benoa, as this is the port where the majority of Indonesian caught SBT are landed. The monitoring program samples otoliths from the 'reject' quality SBT (graded as non-export quality) (Farley *et al.* 2007).

The Extended Scientific Committee (ESC) developed a new Scientific Research Plan (SRP) for SBT in 2013. Specific priorities and projects to be included in the new SRP were reviewed in 2014 and again in 2015. Several items were identified as high priority in the 2016 work plan including the ageing of Indonesian SBT otoliths and continued collection and archiving of

[3] Indonesian collaborating institutions, in chronological order: Central Research Institute for Fisheries Indonesia (CRIFI), Research Institute for Marine Fisheries (RIMF), Research Centre for Capture Fisheries (RCCF), Research Centre for Fisheries Management and Conservation (RCFMC), and currently Centre for Fisheries Research (CFR) in Jakarta, and Research Institute for Tuna Fisheries (RITF) in Bali.

tissue samples for close-kin genetics (see paper CCSBT-ESC/1708/09). This paper provides update on the length and age distribution given by (Sulistyaningsih *et al.* 2019) of SBT in the Indonesian longline catch as a deliverable for one of these SRP projects (Attachment 12, Anon 2019).

Methods

Otolith collection 2019/20

The SBT otolith sample collection in Indonesia was based at the Benoa Fishing port in the 2018/19 spawning season, maintaining the existing Indonesia-CSIRO monitoring program for the longline fishery (Proctor *et al.* 2006). A total 1,500 SBT ranging from 134-199 cm fork length (FL) (Table 1) were sampled. The data collected including the fish lengths and otoliths for ageing purposes. SBT are landed in Benoa fresh, so we are confident that the fish were caught in CCSBT statistical area 1. The otolith sets from each fish were stored in individually labelled vials following cleaning and drying. All samples will be transported to CSIRO in Hobart.

SBT ageing 2018/19

The process of selecting 500 otoliths for ageing from a total of 1,500 otoliths samples obtained during the spawning season 2018/19 season (Table 1) was performed at CSIRO. The selection of otoliths is based on stratification by the length of the fish to obtain a sufficient number of age estimates for all length classes, including those with small sample sizes (Farley *et al.* 2007).

The SBT otolith ageing process (sectioning and reading) involved a private research company in Australia, Fish Ageing Services Pty Ltd (FAS). The selected otoliths are sent to FAS for the process of sectioning and reading, using the techniques described in Anonymous (2002). The otolith reader at FAS has more than 15 years' experience in reading SBT otoliths and has been the primary reader of the SBT otoliths. This year, a new otolith reader at FAS was trained to reading SBT otoliths. All otoliths were subsequently read by both readers and a final age was obtained for 474 fish. During the process of reading the age from otoliths, FAS does not refer to the fish size information, the date of capture, or the previous reading. The precision of the readings between readers (inter-reader consistency) was assessed using the index of average percent error (Beamish & Fournier, 1981). Age-bias and age difference plots were used to detect systematic disagreement between age estimates from the two readers (Campana et al., 1995).

To determine the age structure of the Indonesian catch of SBT in the 2018/19 season, an age-length key (ALK) was developed using the sample of aged fish. The age-length-key (ALK) gives the proportion of fish at age in each 5-cm length class, which is then used to estimate the age-frequency distribution of the catch from the length-frequency distribution of the catch from the port monitoring data. This method has been used to estimate the age distribution of the Indonesian catch since the mid-1990s, apart from 2011/12 when no direct age estimates were available. For that season, an ALK was developed using direct age data for the two preceding spawning seasons (i.e. 2009/10 and 2010/11) and applied to the 2011/12 length frequency data. Previous study found that annual ALKs are more appropriate for tracking cohorts (Rodriguez-Marin et al., 2009).

SBT length data

We had assumed there was no length-based selection bias of SBT for sampling since Davis et al. (2001) found no difference in the length distributions of export and low grade (reject) SBT in the late-1990s. However, it has recently become apparent that a higher proportion of small fish may be classed as “reject” (and available for sampling), skewing the size frequency data used in the ALK analyses to estimate the age distribution of the SBT catch on the spawning ground. Note that skewed sampling for otoliths will not affect the ALK itself, as long as there is enough age data obtained for each length class. The otolith sampling in Benoa is complicated by factors such as different processing practices and rules for accessing fish at the different processors, and the enumerator must consider this when deciding where to sample at to reach the targeted number per month.

In order to improve the SBT length frequency data analysed, last year DGCF provided length data collected through the CCSBT Catch Documentation Scheme (CDS) in the port of Benoa for the four most recent spawning seasons (2015/16 to 2018/19). The DGCF identified vessels operating in CCSBT statistical areas 1 and 2 using vessel monitoring system (VMS) information. Vessels that had >70% of all tracks in area 1 were classes as operating on the spawning ground, and only SBT landed by these vessels/trips were included in our analysis. Preliminary examination of the length data showed that: i) there were a reasonable proportion of outliers, which were removed from the data set analysed, and; ii) a proportion of fish were measured to the nearest 10-cm length class, rather than 1 cm, which has the potential to bias estimates of the size distribution of the catch. Since individual weight data are considered more likely to be accurate, as they are required for export documentation, these data were used in the analysis. The individual weight data was converted to length using a weight-length relationship derived from SBT measured in the Benoa monitoring program over the same time period. Parameters were estimated using least-square linear regression of log transformed length and weight data.

Table 1. Number of length measurements and age estimates for SBT by spawning season.

SPAWNING SEASON	FORK LENGTH (CM)			OTOLITHS	AGE (YEARS)	
	N	MEAN	RANGE	*N*	*N*[1]	MEAN
1993/94	676	188.1	161-207	0	0	NA
1994/95	1610	180.7	147-221	549	486	21.2
1995/96	1107	178.9	149-216	225	50	NA
1996/97	1615	179.6	146-218	602	475	20.8
1997/98	1577	176.4	143-214	519	485	19.8
1998/99	936	179.9	145-210	660	474	20.7
1999/00	786	177.4	150-216	533	498	19.5
2000/01	762	174.2	140-210	720	481	16.9
2001/02	821	169.5	147-223	715	489	14.8
2002/03	1385	166.8	134-229	1502	488	14.5
2003/04	1279	168.5	145-215	1283	494	15.2
2004/05	1580	170.1	89-205	1523	493	15.3
2005/06	1182	169.2	122-201	1180	486	14.4
2006/07	1586	168.3	134-202	1586	491	15.1
2007/08	1693	169.5	145-203	1709	485	16.7
2008/09	1704	171.0	143-219	1697	479	15.6
2009/10	1583	168.5	141-204	1538	488	15.3
2010/11	1015	170.4	142-198	1009	481	16.8
2011/12	864	170.5	136-212	543	*NA*	16.3
2012/13	2051	164.1	131-211	1373	474	14.2
2013/14	1905	161.7	100-210	1637	473	13.8
2014/15	2774	159.9	95-225	1346	482	13.8
2015/16	4273	156.3	93-189	2000	477	11.8
2016/17	4352	154.7	91-189	1499	472	12.9
2017/18	6762	161.9	100-188	1500	486	13.4
2018/19*	2506	161.1	108-185	1500	474	13.2
Total	48384			28948	10687	

* A random sub-sample of 500 are selected for ageing, apart from the 2011/12 season where an ALK based on data from the previous two seasons was used.

Results and Discussion

SBT ageing 2018/19

A final age was obtained for 474 of the 500 otoliths selected from the 2018/19 spawning season. Fish ranged in size from 134-205 cm FL and age estimates ranged from 6 to 38 years. An age bias was not evident (Figure 1; Figure 2) and the average percent error between the two otolith readers was 3.55%. When successive readings of otoliths differed, 92.0% were by ±2 years, indicating a good level of precision.

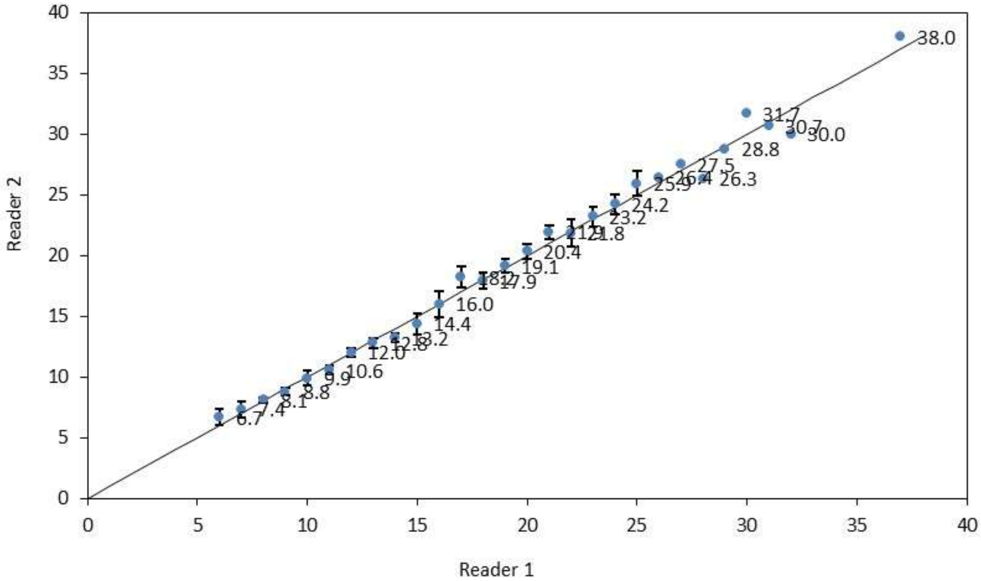

Figure 1. Age-bias (mean±s.e.) for comparisons of counts by otolith reader 1 and otolith reader 2.

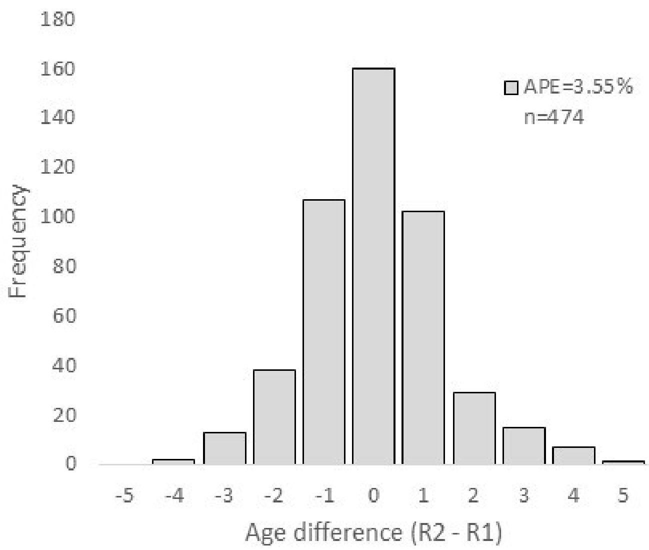

Figure 2. Age difference (right) plots for comparisons of counts by otolith reader 1 (R1) and otolith reader 2 (R2).

Length distribution

The length frequency distribution of SBT captured by the Indonesian tuna longline fleet by spawning season is presented in Figure 3. The data for SBT caught south of the spawning ground in 2003/04 to 2006/07 is shown separately because these fish are not considered part of the spawning population, and were identified at the time (Farley *et al.* 2007). Farley *et al.* (2017) reported that since monitoring began, there has been a major change in the size distribution of SBT caught in the spawning area. The SBT captured in the mid and late 1990s was dominated by a size between 165 and 190 cm FL with an average length of ~ 180 cm (Figure 3). The average size of SBT then decreased in the early 2000s as fish 155-165 cm FL increased in relative abundance (Figure 4). The average size of captured SBT decreased from 188.1 to 166.8 cm between 1993/94 and 2002/03 and remained between 168.3 and 171.0 cm through 2011/12 (Table 1; Figure 5).

In the 2012/13 spawning season, the length frequency indicates a new mode of unusually small fish (relative to the historical distribution) between 140 and 155 cm FL in the catch, in addition to the "usual" mode around 160-180 cm FL (Figure 3). The mode of small fish seems to progress through the fishery moving from ~146 cm in 2012/13 to ~150 cm in 2014/15 season. The revised length frequency data from the CDS data for the 2015/16 to 2018/19 seasons shows a gradual 'disappearance' of the small mode, possibly as it combines with the larger mode 160-180 cm FL. The proportion of SBT <155 cm FL in the catch has decreased, and the mean length of SBT has increased in the last two seasons (Figure 4; Figure 5) reflecting the change in the size frequency of fish landed towards larger fish.

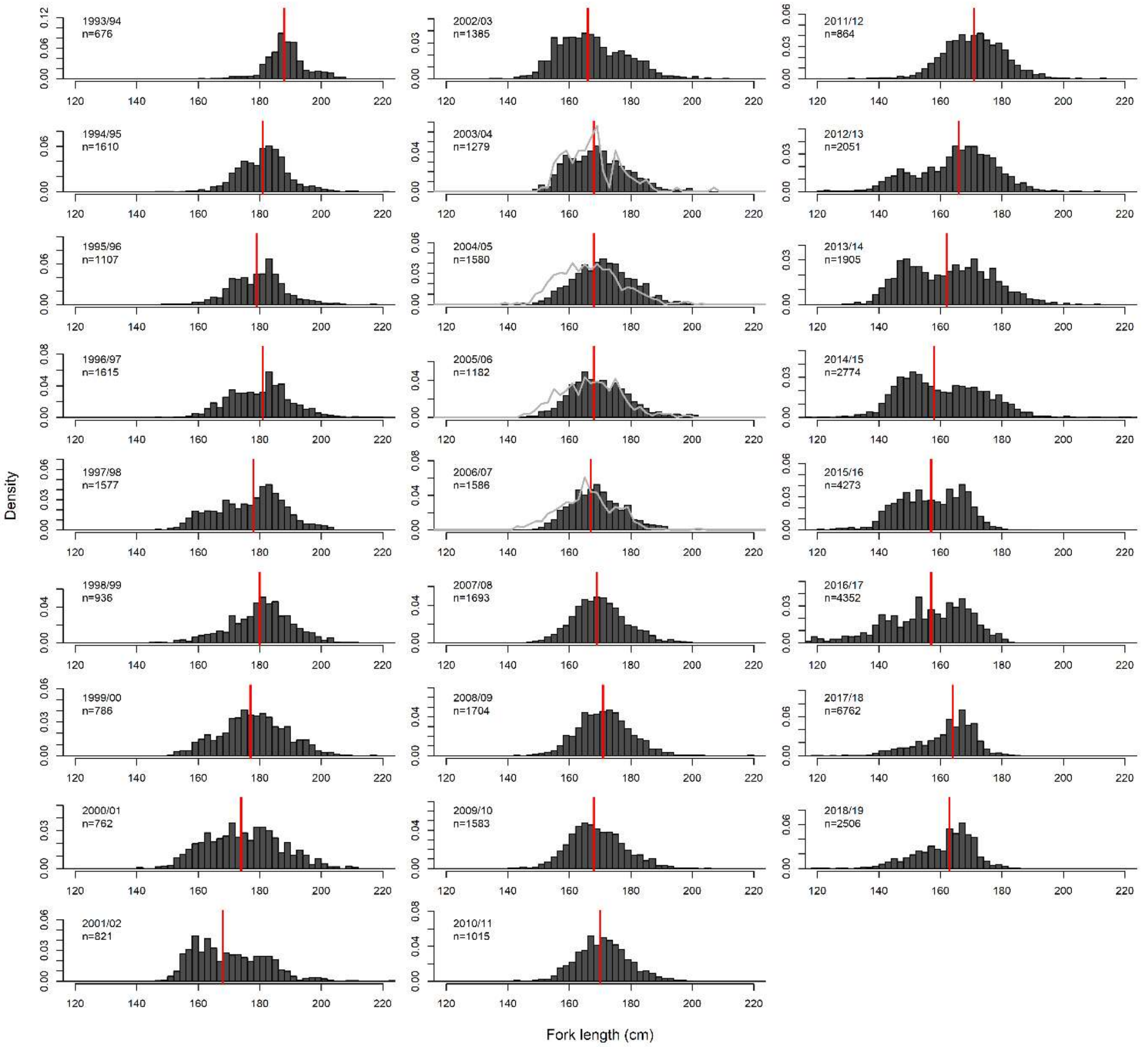

Figure 3. Length frequency (2 cm intervals) of SBT caught by the Indonesian longline fishery (bars) by spawning season. The grey bar shows the median size class. For comparison, the length distribution of SBT thought to be caught south of the spawning ground (Processor A) is shown for the 2003/04 (n=121), 2004/05 (n=685), 2005/06 (n=311) and 2006/07 (n=452) seasons (grey line) (Farley *et al.* 2007).

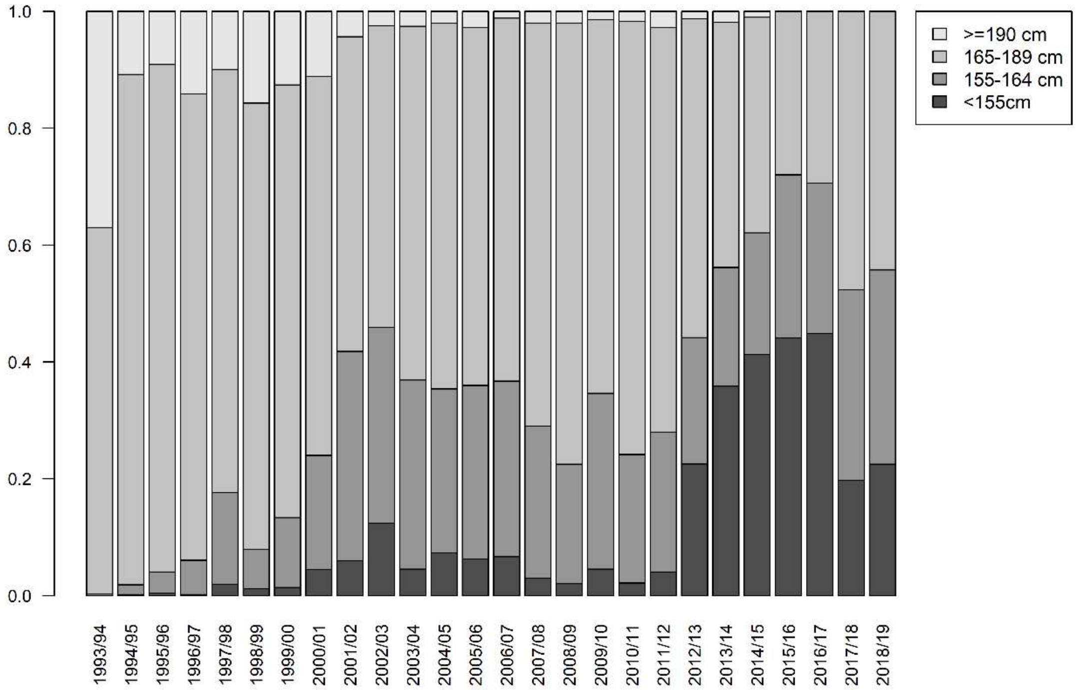

Figure 4. Proportion of SBT caught by the Indonesian longline fishery by size class. Data from Processor A in 2003/04 to 2006/07 are excluded.

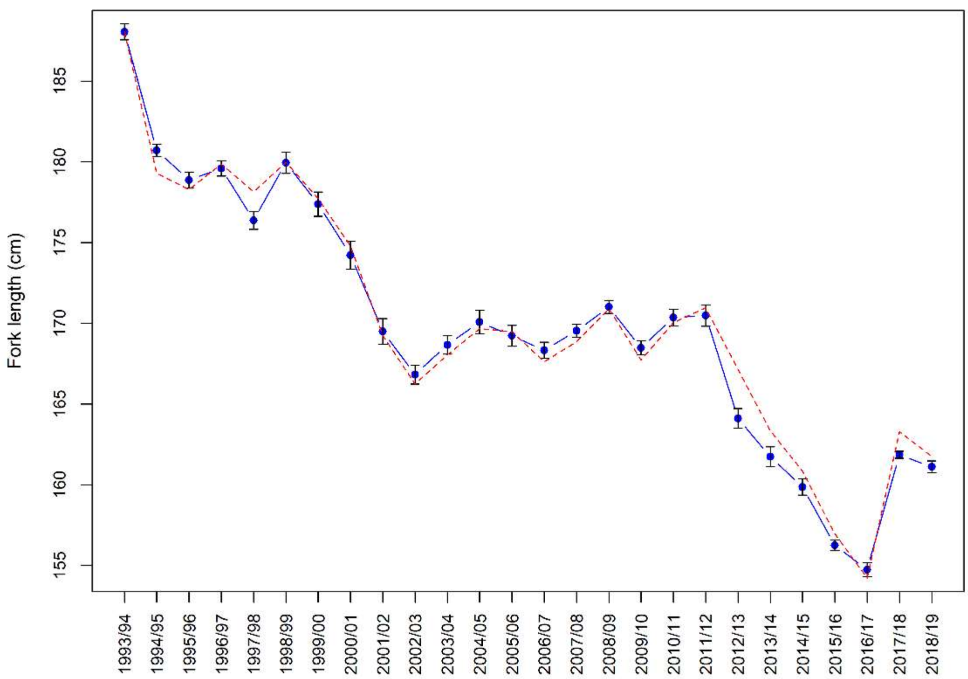

Figure 5. Mean length (+/- 95% CI) of SBT landed by the Indonesian longline fishery by season. Data from Processor A in 2003/04 to 2006/07 are excluded. Dashed line is the mean length of SBT caught in December to May only.

Age distribution

Figure 6 shows the estimated age structure of the Indonesian catch by spawning season. As expected, given the change in the length distribution of the catch, the proportion of young fish aged 10-15 years increased markedly in the early 2000s (Figure 6). These young fish can be tracked through the age distribution of subsequent years suggesting a pulse of recruitment to the spawning population. A second recruitment pulse of young fish occurred in the mid-2000s (Farley *et al.* 2014). The mean age of SBT >20 years has decreased since the mid-2000s (Figure 8).

In 2012/13 there was a substantial increase in the catch of young SBT (<10 years) and the mean age of SBT sampled decreased (Figures 6-8). The mode of young fish in the catch has persisted each year since that time, and there is some indication that the mode has moved through the fishery on an annual time step. Earlier investigations suggested that the small/young SBT appearing in the Indonesian catch since 2012/13 were likely to have been caught south of the SBT spawning ground (Farley *et al.* 2017). However, last year the length data analysed for the three most recent spawning seasons (2015/16 to 2017/18) was revised to only include catches of SBT by vessels predominantly operating in area 1 (spawning ground), so the pulse of young fish appears to be from the spawning ground. This pulse is also present in the 2018/19 season. Given the importance of these size and age data to the monitoring and assessment of the SBT spawning stock, further work to examine the historical uncertainties identified and to refine and improve the quality control of the monitoring program is a high priority. There are several factors that might influence variability in catches such as migration, different environment condition, sex, and sampling effects (Rooker et al., 2007).

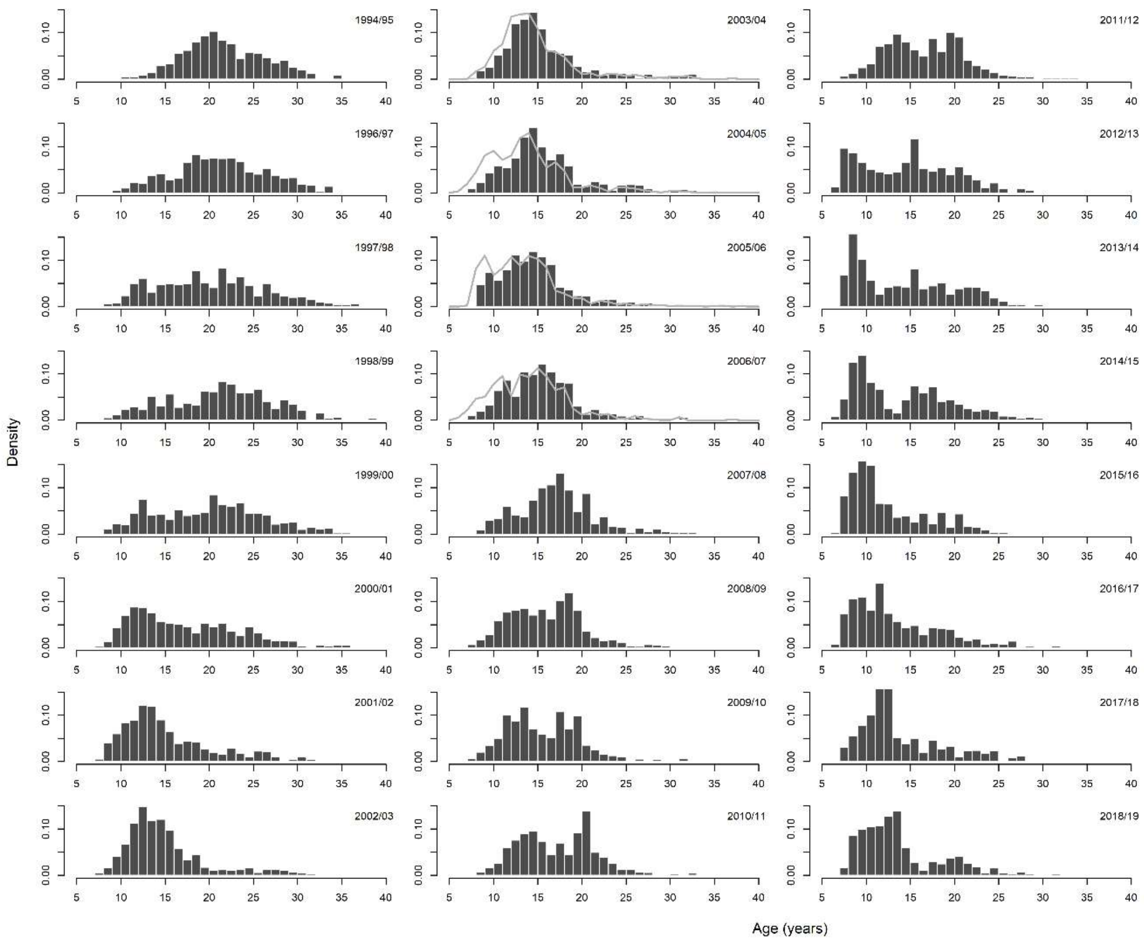

Figure 6. Age frequency distribution of SBT in the Indonesian catch on the spawning ground by spawning season estimated using age-length keys from our sub-samples of aged fish and length frequency data obtained through the Indonesian monitoring program. There was no direct ageing of the 2011–12 otoliths; age frequency is based on the age-length key from the previous two seasons and the 2011–12 length frequency data.

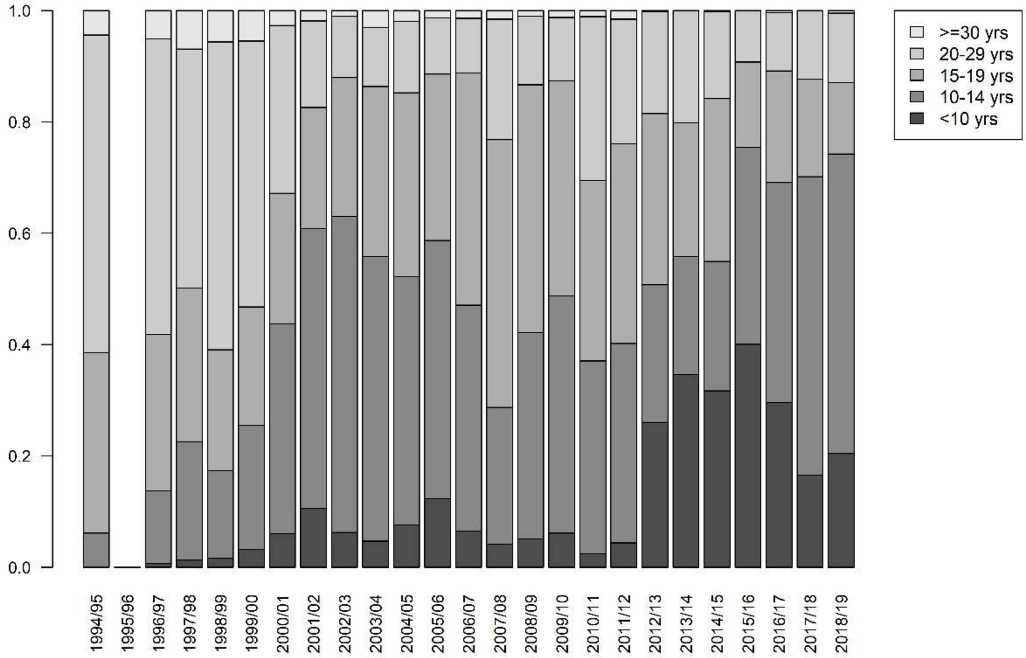

Figure 7. Estimated proportion of SBT by age category in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season. There was no direct ageing of the 2011–12 otoliths; age frequency is based on the age-length key from the previous two seasons and the 2011–12 length frequency data.

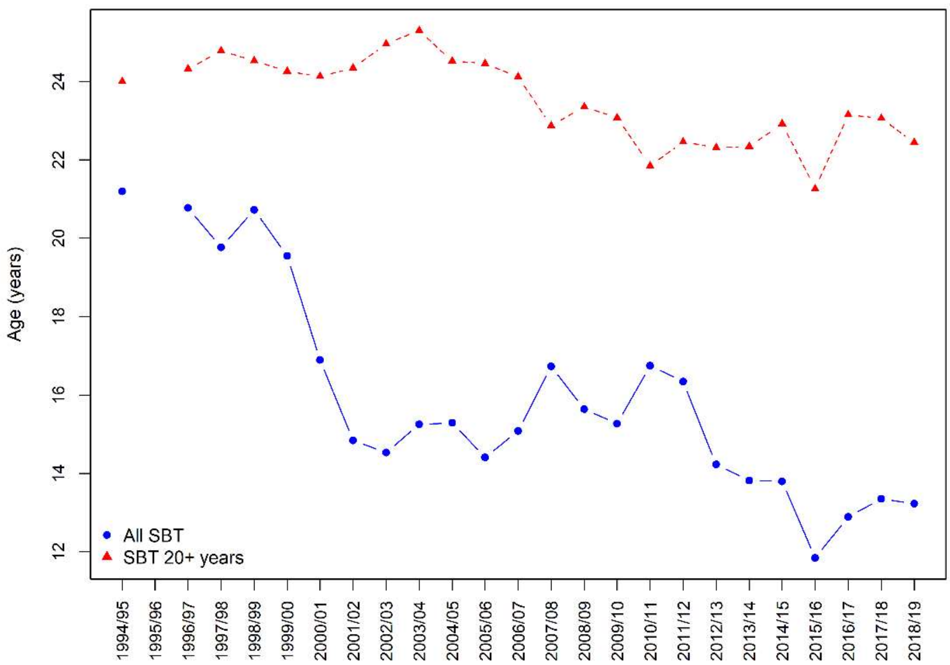

Figure 8. Estimated mean age of SBT in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season.

Updated analysis and results

The length and weight data provided by the DGCF last year for 2018/19 was used in the analysis presented above, and the results were provided to CCSBT during the data exchange.

New data for the 2019 calendar year were provided by the DGCF after the 2020 CCSBT data exchange. The new data included additional length/weigh measurements collected between January and December 2019, which changes the data for the 2018/19 spawning season. We re-ran the analysis using this new data and provide the results in Appendix A. The results are similar to the those provided above. However, the new data indicates a higher proportion of small SBT in the catch in the 2018/19 data, resulting in a slightly lower mean length SBT caught (see Appendix Table 1 and Figures 1-3). The proportion of fish <155 cm increased from 22.5% to 29.4%, and the proportion of fish ≥165 cm decreased from to 44.3% to 35.6%. As a result, the analysis indicates a slightly higher proportion of young SBT in the catch compared to the results presented above (see Appendix Figures 3-6). The proportion of fish age <10 years increased slightly from 20.4% to 22.9%, and the proportion of fish age >20 years decreased from 12.9% to 10.9%.

Acknowledgement

The success of the SBT monitoring program in Indonesia has only been possible due to the dedicated efforts of all participating scientists at Research Institute for Tuna Fisheries (Bali), and in particular that of Mr Kiroan Siregar and Mr Rusjas Mashar and other staff involved in measuring SBT and collecting otoliths and tissue samples in Indonesia. We also thank Mr Zulkarnaen Fahmi for providing the RITF size data for SBT, Mr Enjah Rahmat (RIMF) for earlier years of data entry into the SBT biological database and to Mr Budi Iskandar Prisantoso (RCFMC) and Ms Retno Andamari (Gondol Mariculture Research Institute) in their former roles as database manager and monitoring program manager respectively. We also acknowledge Ms Paige Eveson for providing the R script in this report and Mr I Gede Bayu Sedana for his assistance in fixing the R bugs. The cooperation of the longline tuna industry (coordinated through Asosiasi Tuna Longline Indonesia), and the individual processing companies in providing access and facilities to carry out the sampling is much appreciated. We also acknowledge the support of all other agencies within Ministry of Marine Affairs and Fisheries (Indonesia) for the research activities.

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Appendix A.
Analysis results using revised length and weight data provided by the from the Directorate General of Capture Fisheries (DGCF) for 2019. Data was received after the 2020 CCSBT data exchange.

Table 2. Updated number of length measurements and age estimates for SBT by spawning season. Only data for 2018/19 has changed.

SPAWNING SEASON	FORK LENGTH (CM)			OTOLITHS	AGE (YEARS)	
	N	MEAN	RANGE	*N*	*N*[1]	MEAN
1993/94	676	188.1	161-207	0	0	NA
1994/95	1610	180.7	147-221	549	486	21.2
1995/96	1107	178.9	149-216	225	50	NA
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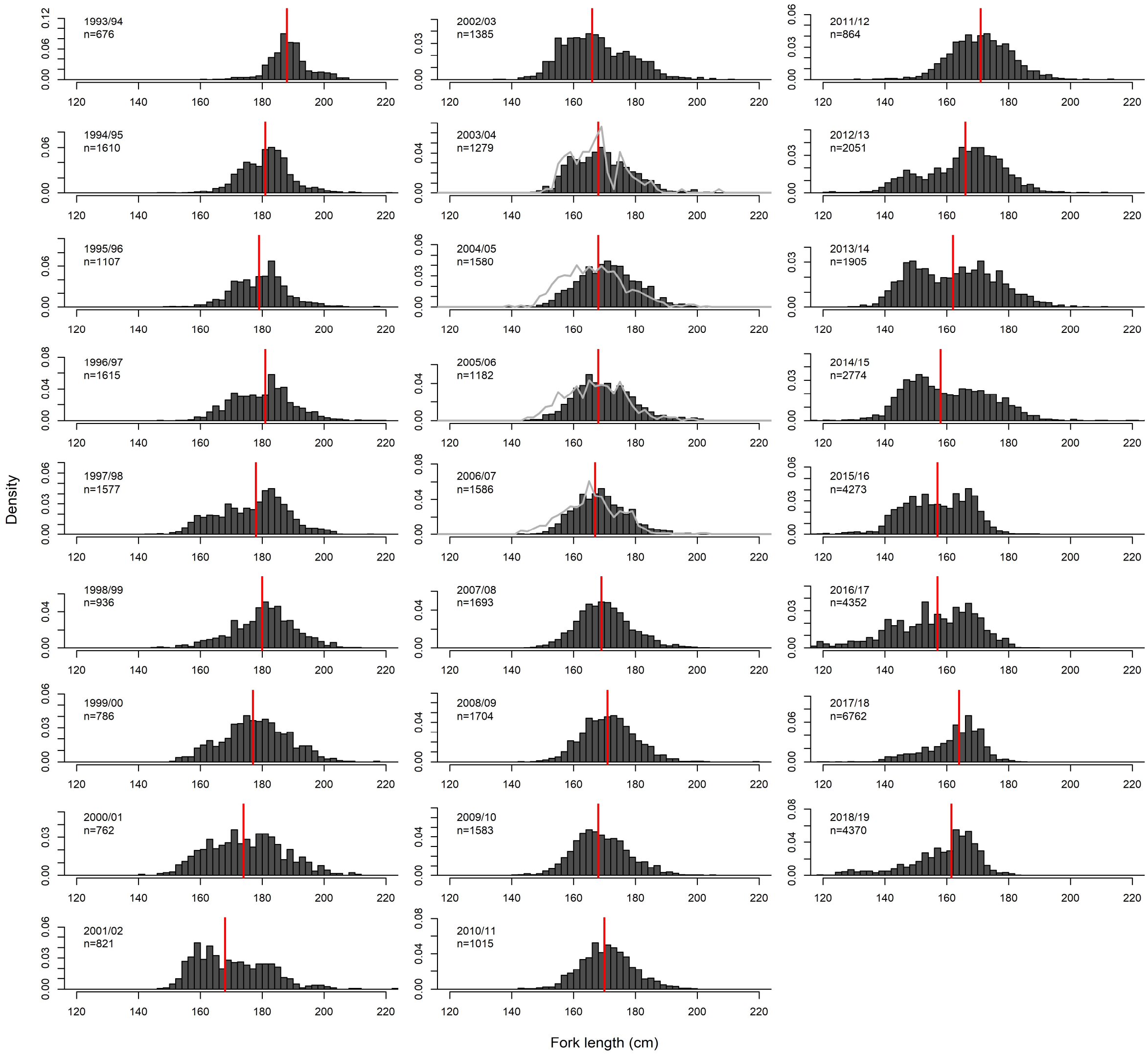
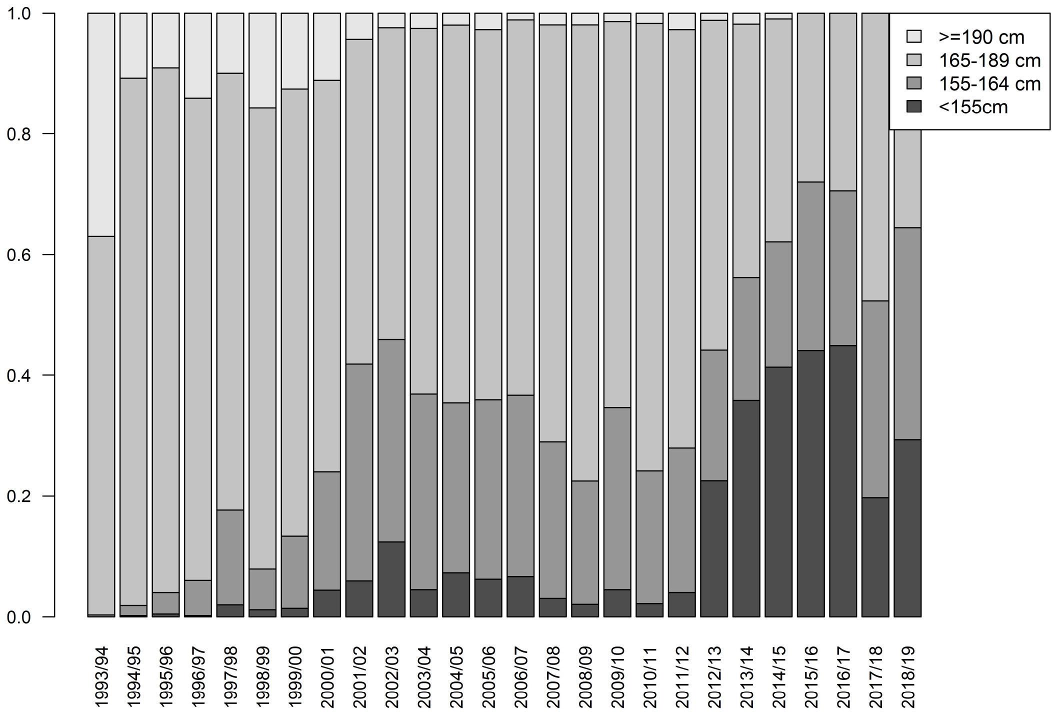
2010/11	1015	170.4	142-198	1009	481	16.8
2011/12	864	170.5	136-212	543	*NA*	16.3
2012/13	2051	164.1	131-211	1373	474	14.2
2013/14	1905	161.7	100-210	1637	473	13.8
2014/15	2774	159.9	95-225	1346	482	13.8
2015/16	4273	156.3	93-189	2000	477	11.8
2016/17	4352	154.7	91-189	1499	472	12.9
2017/18	6762	161.9	100-188	1500	486	13.4
2018/19*	4370	157.8	93-183	1500	474	12.8
Total	50248			28948	12130	

*A random sub-sample of 500 are selected for ageing, apart from the 2011/12 season where an ALK based on data from the previous two seasons was used.

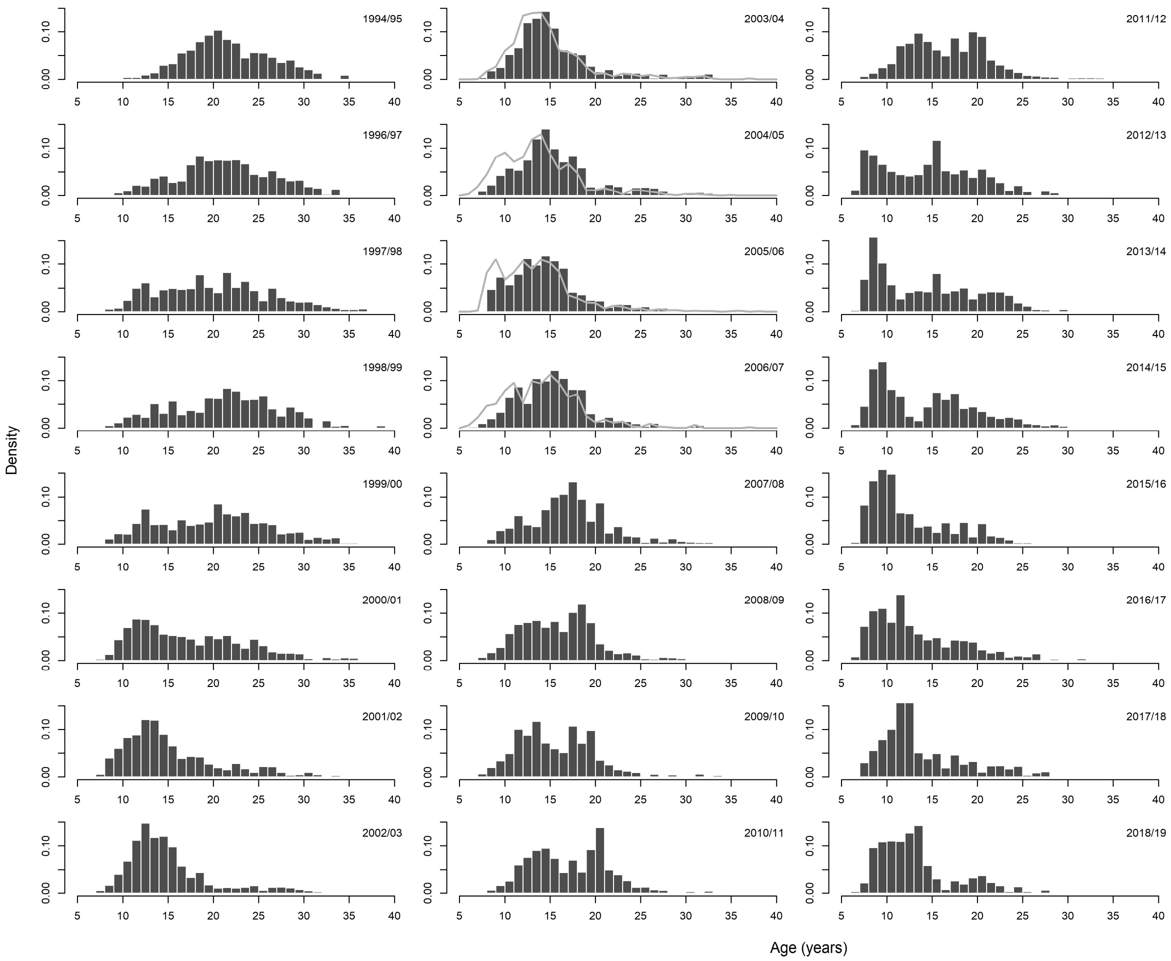


Appendix Figure 1. Revised length frequency (2 cm intervals) of SBT caught by the Indonesian longline fishery (bars) by spawning season. The grey bar shows the median size class. For comparison, the length distribution of SBT thought to be caught south of the spawning ground (Processor A) is shown for the 2003/04 (n=121), 2004/05 (n=685), 2005/06 (n=311) and 2006/07 (n=452) seasons (grey line) (Farley *et al.* 2007). Only data for 2018/19 has changed.

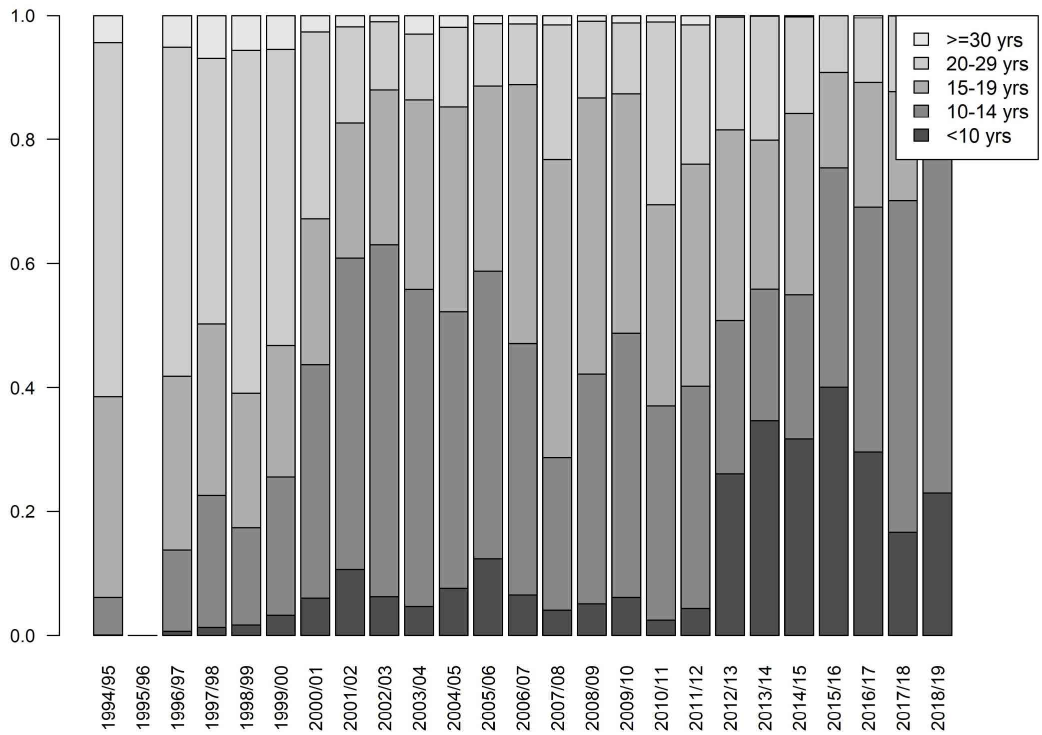


Appendix Figure 2. Proportion of SBT caught by the Indonesian longline fishery by size class. Data from Processor A in 2003/04 to 2006/07 are excluded. Only data for 2018/19 has changed.

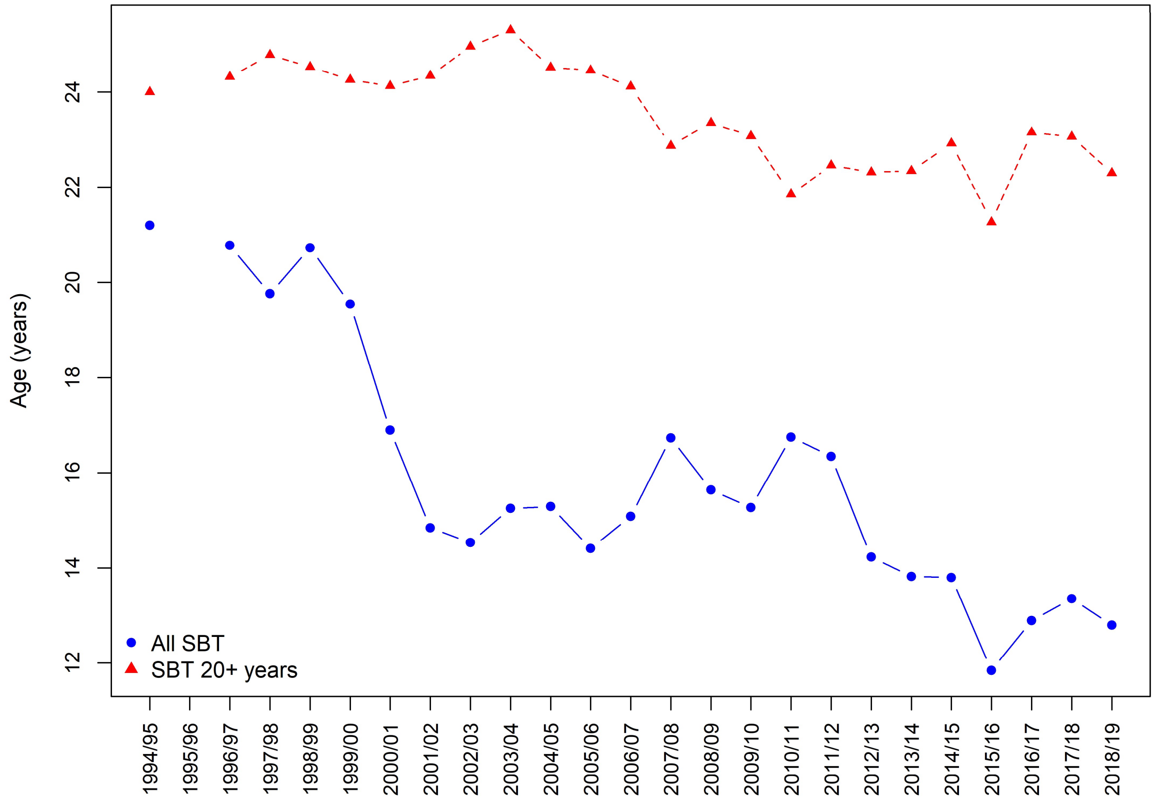
Appendix Figure 3. Revised mean length (+/- 95% CI) of SBT landed by the Indonesian longline fishery by season. Data from Processor A in 2003/04 to 2006/07 are excluded. Dashed line is the mean length of SBT caught in December to May only. Only data for 2018/19 has changed.



Appendix Figure 4. Revised age frequency distribution of SBT in the Indonesian catch on the spawning ground by spawning season estimated using age-length keys from our sub-samples of aged fish and length frequency data obtained through the Indonesian monitoring program. There was no direct ageing of the 2011–12 otoliths; age frequency is based on the age-length key from the previous two seasons and the 2011–12 length frequency data. Only data for 2018/19 has changed. Only data for 2018/19 has changed.



Appendix Figure 5. Estimated proportion of SBT by age category in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season. There was no direct ageing of the 2011–12 otoliths; age frequency is based on the age-length key from the previous two seasons and the 2011–12 length frequency data. Only data for 2018/19 has changed.



Appendix Figure 6. Revised estimated mean age of SBT in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season. Only data for 2018/19 has changed.