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Update on the length and age distribution of SBT in the Indonesian longline catch on the spawning ground

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Abstract

This paper updates previous analyses of SBT length and age data from the Indonesian longline fishery operating out of the port of Benoa, Bali. Length data have been collected for SBT caught in the 1994 - 2004 spawning seasons, and otoliths from SBT caught in the 1995 - 2003 spawning seasons. In summary:

- The recruitment of small (especially <165 cm) fish into the spawning stock that first became apparent in the 2001 spawning season continued through to the 2003 season. In 2004, there was a slight decrease in the proportion of SBT <165 cm compared to the previous season.
- The changes in the proportion of small SBT in the catch have occurred irrespective of changes in fishing practices (depth fished as indicated by the BE index).
- The decline in the relative proportion of large SBT (>190 cm) appears to have continued through to the 2004 season.
- The minimum age of SBT caught in the Indonesian fishery remains at 7 years.
- The catch-at-age shows a steady increase in the relative abundance of young fish since the 1999 spawning season. This increase of small/young fish continues to support theories that cohorts spawned since quotas were introduced in 1984 have survived to spawning age.
- Sexual dimorphism in growth continues to be apparent after age 14 years.
- The sex ratio of SBT sampled is significantly different from 1:1. Females dominate all length classes up to 185 cm, after which males tend to dominate. Although the mechanism behind this skewed sex ratio is unknown, genetic sex determination or assaying tissue for sex specific proteins would confirm the determination of sex by the enumerators, removing a potential source of error.

Introduction

Southern bluefin tuna (SBT) spawn in an area between Indonesia and the north-west coast of Australia, in the north-east Indian Ocean. An Indonesian-based longline fishery operates on the northern part of this spawning ground, catching SBT predominantly from September to April (Farley and Davis, 1998). Since 1992, CSIRO Marine Research and the Research Institute of Marine Fisheries (RIMF) in Indonesia have monitored the catch and size composition of SBT landed by the Indonesian longline fishery in Bali. In 1993, this monitoring was extended to include collecting otoliths from a representative sample of the catch for direct ageing purposes.

Obtaining an accurate estimate of the size and age distribution of SBT caught in the Indonesian longline fishery is vital for population modeling and stock assessments. Traditionally, catch-at-age has been estimated using the 'cohort slicing' method, which ignores individual growth variability with age. This can introduce biases in the estimation of age distributions from lengths as there is substantial variability in growth rates in SBT. The development of validated methods to directly age SBT using otoliths, and the collection of sufficient otoliths from the Indonesian fishery, has allowed us to accurately estimate the age composition of the Indonesian catch over the past six spawning seasons.

Monitoring of Indonesian landings has shown that the parental stock of SBT has undergone dramatic changes in size/age structure since monitoring began. Indications are that an increase in the relative proportion of small/young fish has occurred recently irrespective of changes in fishing practices (depth fished) by the Indonesian fishery. Although the first indications of this shift were identified in the 1998 spawning season, it was not until the 2001 season that the increase became clearly identifiable. It has been suggested that this could be an indication that cohorts spawned since quotas were introduced in 1984 have survived to spawning age.

In this paper we update the information given in Farley and Davis (2003) by including the most recent length and age frequency data for the Indonesian fishery. Age frequency data are presented up to the 2003 spawning season, while length frequency data includes the 2004 season.

Methods

Length measurement and otolith sampling

From 1993 to 2001, SBT were sampled at export processing sites at the port of Benoa, Bali as part of the CSIRO/RIMF large-scale catch-monitoring program (Davis and Nurhakim, 2001). SBT graded as not suitable for export were available for length measurement and otolith sampling (500-700 per spawning season).

In 2002, an IOTC coordinated catch monitoring system was implemented (IOTC, 2003). As part of this monitoring, an enumerator was employed to measure and collect otoliths of SBT in Benoa. This is the same enumerator whose SBT length measurements have been used since monitoring began. Under this new monitoring program, greater numbers of otoliths (>1000) were collected each spawning season. Again, the collection of otoliths from export SBT is usually restricted. Data on the sex of fish with otoliths sampled have been collected since early 1999. All length data collected on SBT from the IOTC monitoring were added to the CSIRO/RIMF database for biological studies. All otoliths are archived at CSIRO.

The depth and exact location fished sampled is not known. However, data on the ratio of bigeye to yellowfin tuna caught is used as a proxy for the depth of fishing (Davis and Farley, 2001).

Direct age estimates on the spawning ground

Gunn et al. (1998), Farley et al. (2001) and Farley and Davis (2002; 2003) described the methods used to estimate the age distribution of SBT caught in the Indonesian-based longline fishery for the spawning seasons 1995 to 2002. These methods were used for otoliths sampled in the 2003 spawning season. Briefly, of the 1503 otoliths sampled, 500 were selected for age estimation. A fixed number of otoliths were chosen from each 5 cm length class (stratified sampling rather than random sampling) to obtain as many age estimates from length classes where sample sizes were small. Otoliths were prepared, sectioned and read (age of fish estimated) by a technician at the Central Ageing Facility (CAF) in Victoria using the techniques described by Clear et al. (2000) and Gunn et al. (In press). Extensive training was provided to the CAF technician in 2000 and again in 2002.

Each otolith was read twice by the primary otolith reader (CAF). A subsample of 10% of the sister otoliths were read twice by a secondary otolith reader (CSIRO). To examine the consistency of readings, the Average Percentage Error (APE) method of Beamish and Fournier (1981) was used to measure the intra-reader consistency in otolith readings (replicate readings by the primary reader) as well as inter-reader consistency (final age estimate of the primary reader and the mean of replicate readings by the secondary reader). All readings were conducted without reference to the size of the fish, date of capture, or to previous readings.

Age estimates from the current work were combined with those of Gunn et al. (1998), Farley et al. (2001), and Farley and Davis (2002; 2003; 2003) for the previous seven spawning seasons.

Sexual dimorphism in growth

Mean length-at-age was calculated for male and female SBT, and compared statistically by unpaired t-tests.

Indonesian catch-at-age

To estimate and compare the age distributions of fish caught by spawning season, we developed an age-length key for the 2003 season derived from our sample of aged fish. The age-length key gives the proportion of fish at age in each 5-cm length class, which enabled us to convert catch-at-length data to catch-at-age. The SBT catch-at-length for the Indonesian longline fishery was estimated using length measurements obtained as part of the tuna monitoring program in Bali.

Farley and Davis (2003) reported using length data from an additional two samplers in the 2002 season, but these were removed from the analysis after determining that they were not IOTC enumerators (n=137 measurements). This had no significant effect on the size distribution of SBT used in the analysis (Kolmogorov-Smirnov test $p = 0.3646$).

Results and Discussion

Length Distributions

Lengths of SBT were available up to the end of April 2004, which effectively covers the entire 2004 spawning season (July 2003 – June 2004). This includes an additional 140 length measurements for March and April that were not included in the CCSBT data exchange process as the data was obtained after the exchange date.

The length frequency distributions of all SBT measured at the processing sites are plotted by spawning season (Fig. 1). The recruitment of small (especially <165 cm) fish into the spawning stock that first became apparent in the 2001 spawning season continued to the 2003 spawning season. In 2004, there was a slight decrease in the proportion of SBT<165 cm compared to the previous season (Fig. 2). The decline in the relative proportion of large SBT appears to have continued through the 2004 season.

The effect of BE index on length distributions

The depth of longline fishing on the spawning ground, as measured by the BE index, has been shown to affect the size distribution of SBT that are caught (Davis and Farley, 2001). To determine whether the apparent increase in frequency of SBT <165 cm might be due to changes in fishing methods, Farley and Davis (2003) investigated the possible effects that the BE index might have on the observed length frequency distributions. They found that the proportion of SBT <165 cm increased dramatically in the 2000-2002 spawning seasons at all levels of the BE index, suggesting that the increase proportion of small SBT occurred independently of any changes in fishing practices. They also found that in 2003, the increase in the proportion of SBT<165 cm slowed slightly.

In 2004, the proportion of SBT<165 cm decreased at all levels of the BE index, except at BE index 0.8-1.0 (Figure 3). However, the latter had dropped exceptionately lower the previous season, and all indices showed the same rate of decline between the 2002 and 2004 seasons.

Direct age estimates

Age was estimated for a total of 488 SBT in the 2003 spawning season from fish ranging in size from 142 - 229 cm LCF. The precision of readings was considered good. The second age estimate of the primary reader agreed with the original estimate in 49% of cases and 96% were within two years of the original. The APE between replicate readings by the primary reader was 2.46 (n=484), between replicate readings by the secondary reader was 3.55 (n = 54) and between the final age of the two readers was 2.09 (n = 54). These very low levels of error, especially between the two readers suggest consistent interpretation of age in blind tests.

Growth

Age has been estimated for a total of 3,875 SBT caught in the Benoa-based longline fishery over eight spawning seasons (Table 1). Of these fish, 2022 were of known sex; the majority being sampled in the four most recent spawning seasons. Large variations in age were detected within length classes for both male and female SBT. Mean length-at-age was not significantly between the sexes up to age 14 (Table 1; Fig. 4). Thereafter, males were larger than females at the same age.

Indonesian catch-at-age

The minimum estimated age for SBT caught in the Indonesian fishery remains at 7 years. The age distributions derived from the catch-at-length data show that young fish have continued to increase in relative abundance (Fig. 5 and 6). The proportion of SBT <13 years estimated in the catch is the highest recorded since 1994 (39%), and the proportion of SBT >20 years is the lowest (11%).

Sex ratio

As indicated in Farley et al. (2002; 2003), there is a significant difference from 1:1 in the sex ratio of SBT sampled in the Indonesian fishery (overall skewed towards females). When examined by size class, females dominate all length classes up to 185 cm, after which males tend to dominate (Fig. 7).

Gunn and Farley (2004) determined from data collected by scientific observers aboard Japanese longliners that the sex ratio of SBT in the southern oceans is about 1:1 for length classes ≤170 cm, but males outnumber females in larger length classes because males reach larger sizes than females. The female-skewed in length classes ≤180 cm in the Indonesian catch is difficult to explain but may be due to:

1. Incorrect determination of sex. The enumerator determines sex using a small sample of remnant gonad tissue taken from the dressed fish at the processor. It seems unlikely that this identification is incorrect as a consistent difference in mean length-at-age is found between males and females after age 14 – approximately 170 cm. In addition, identification of sex is usually only problematic in immature fish. However, if some males are being recorded as female, the sexual dimorphism in growth may be larger than that shown in Fig 4. Tissue sample assay techniques are currently being investigated to confirm the sex of SBT determined by the enumerators.
2. Depth preferences may be sex dependent. Examination of sex ratio by BE index (proxy for depth with 0 being shallow and 4 deep) does not indicate a difference in the depth preference of females or males. Females dominated at all depths: BE index 0 = 73%, 1 = 72%, 2 = 75%, 3 = 71%, and 4 = 70%.
3. Distribution and migration patterns may be sex dependent. It is difficult to examine the distribution patterns for males and females, as data on the catch locations are not available. Examination of sex ratio by month did not indicate different arrival/departure times to or from the spawning ground by sex (Figure 8).
4. Capture may be sex dependent. Female-skewed sex ratio may result if feeding activity was higher in females than males, thus making them more vulnerable to capture. Data on sex-based feeding activities during spawning is not available.

Because the sex ratio in our samples has remained consistently female-skewed since sex data have been collected (2000-2004 seasons), the mechanism behind this bias must have been operating since that time. Further work is required to determine this mechanism.

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Table 1. SBT sampled from the Indonesian-based longline fishery with age estimated by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

Spawning season	Otoliths sampled		Age estimated	
	n	Known sex (n)	n	Known sex (n)
1995	549	0	486	0
1997	602	0	475	0
1998	519	0	489	0
1999	660	121	470	75
2000	533	530	497	494
2001	720	717	481	478
2002	715	713	489	487
2003	1503	1503	488	488
Total	5800	3583	3875	2022

Table 2. Mean length-at-age and standard deviations (SD) of SBT caught in the Indonesian-based longline fishery by sex. Results (*p*-value) of an unpaired t-test to compare the lengths at each age are given.

Age	Females			Males			t-test
	Mean LCF	SD	*n*	Mean LCF	SD	*n*	*p*
7	144.6	3.2	5	149.7	9.5	3	0.298
8	154.0	6.8	25	155.3	9.0	8	0.679
9	157.3	5.0	47	158.6	7.2	25	0.379
10	158.2	5.7	72	159.8	9.0	38	0.262
11	161.2	8.5	128	161.1	7.3	34	0.962
12	164.7	8.1	134	166.8	8.3	65	0.084
13	166.7	8.4	107	167.5	9.0	56	0.576
14	169.2	8.3	99	170.3	9.9	37	0.541
15	168.5	8.4	74	175.1	12.4	51	0.001
16	171.8	7.7	64	178.5	11.2	36	0.001
17	174.2	9.1	46	178.4	9.1	32	0.049
18	174.5	8.0	52	180.4	11.0	37	0.004
19	179.2	7.2	43	183.1	7.7	29	0.031
20	179.8	9.0	47	185.6	7.3	34	0.003
21	180.0	6.7	45	186.4	6.9	32	<0.001
22	178.5	7.3	44	187.6	9.2	31	<0.001
23	181.2	6.0	33	188.5	7.5	36	<0.001
24	181.1	8.6	40	190.0	8.4	30	<0.001
25	180.3	8.7	43	188.9	4.1	23	<0.001
26	182.7	11.3	36	188.9	8.8	29	0.018
27	181.9	5.4	25	189.1	5.0	11	0.001
28	182.6	6.9	21	188.5	7.2	13	0.023
29	186.3	8.4	19	193.4	6.3	13	0.016
30	185.8	7.9	13	198.3	11.6	9	0.007
31	186.9	10.2	7	193.6	10.5	7	0.248
32	187.5	13.3	8	197.7	7.6	3	0.252
33	187.4	8.3	5	191.1	6.1	8	0.369
34	184.0	5.3	3	188.0		1	
35	190.5	0.7	2	187.3	2.1	3	0.141
36							
37							
38	180.0	-	1				
Total			1288			734	

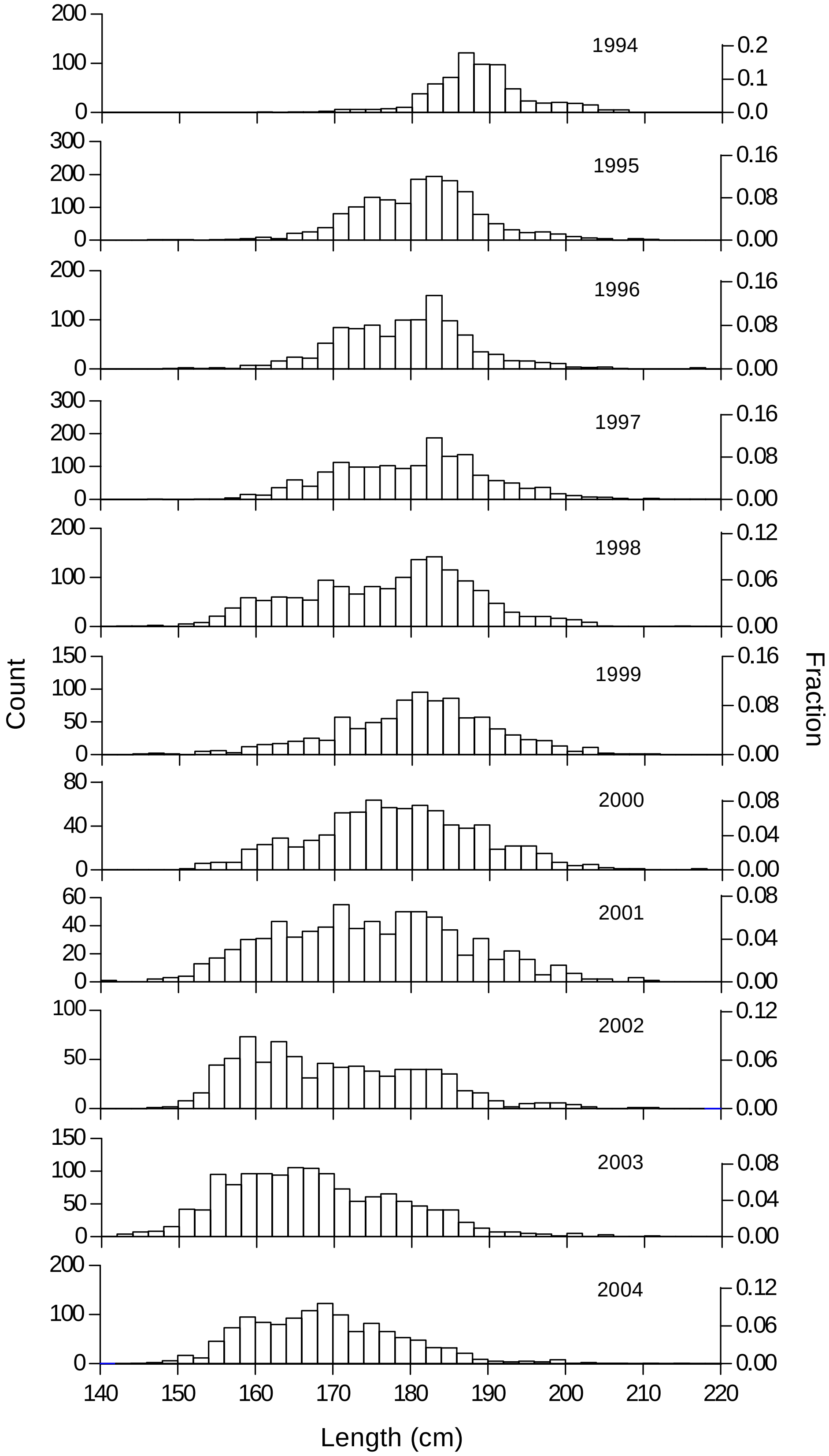

Figure 1. Length frequency (2 cm intervals) of SBT by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

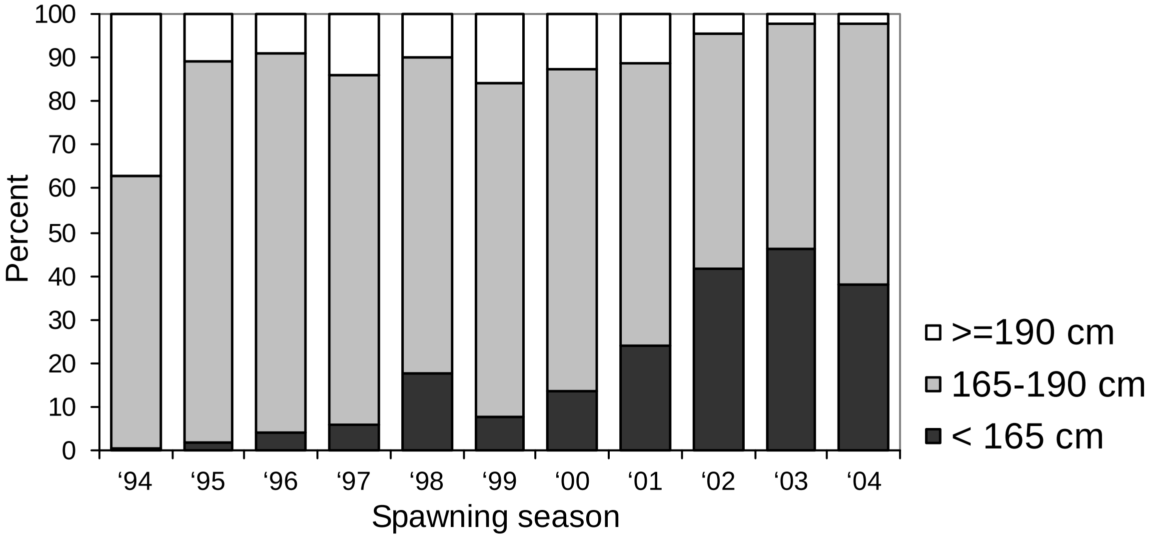

Figure 2. The proportion of SBT by size classes in each spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

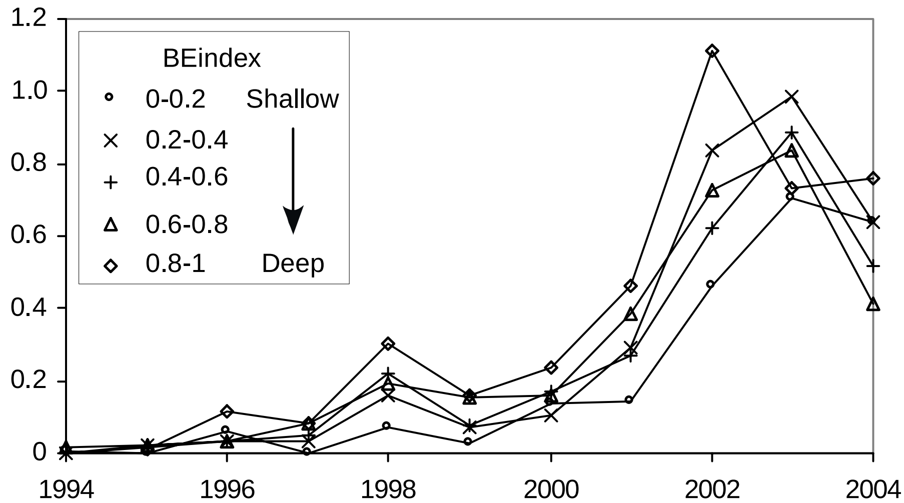

Figure 3. The proportion of SBT <165 cm in length (of all SBT with a length measurement) in each spawning year. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

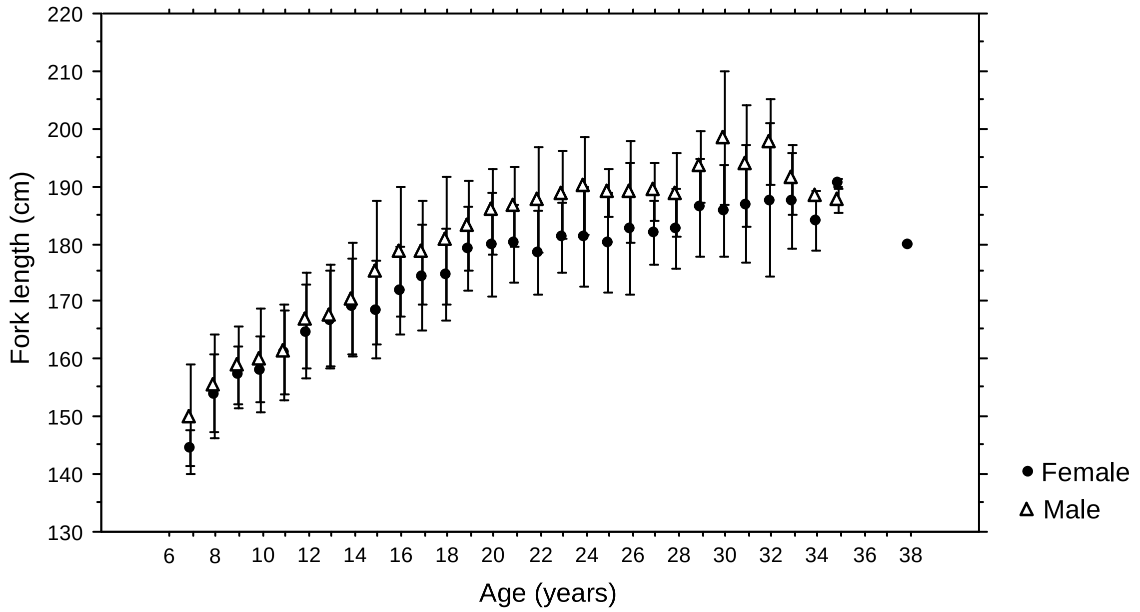

Figure 4. Mean length-at-age (+/- 1 standard deviation) of male and female SBT caught in the Indonesian longline fishery (all seasons combined).

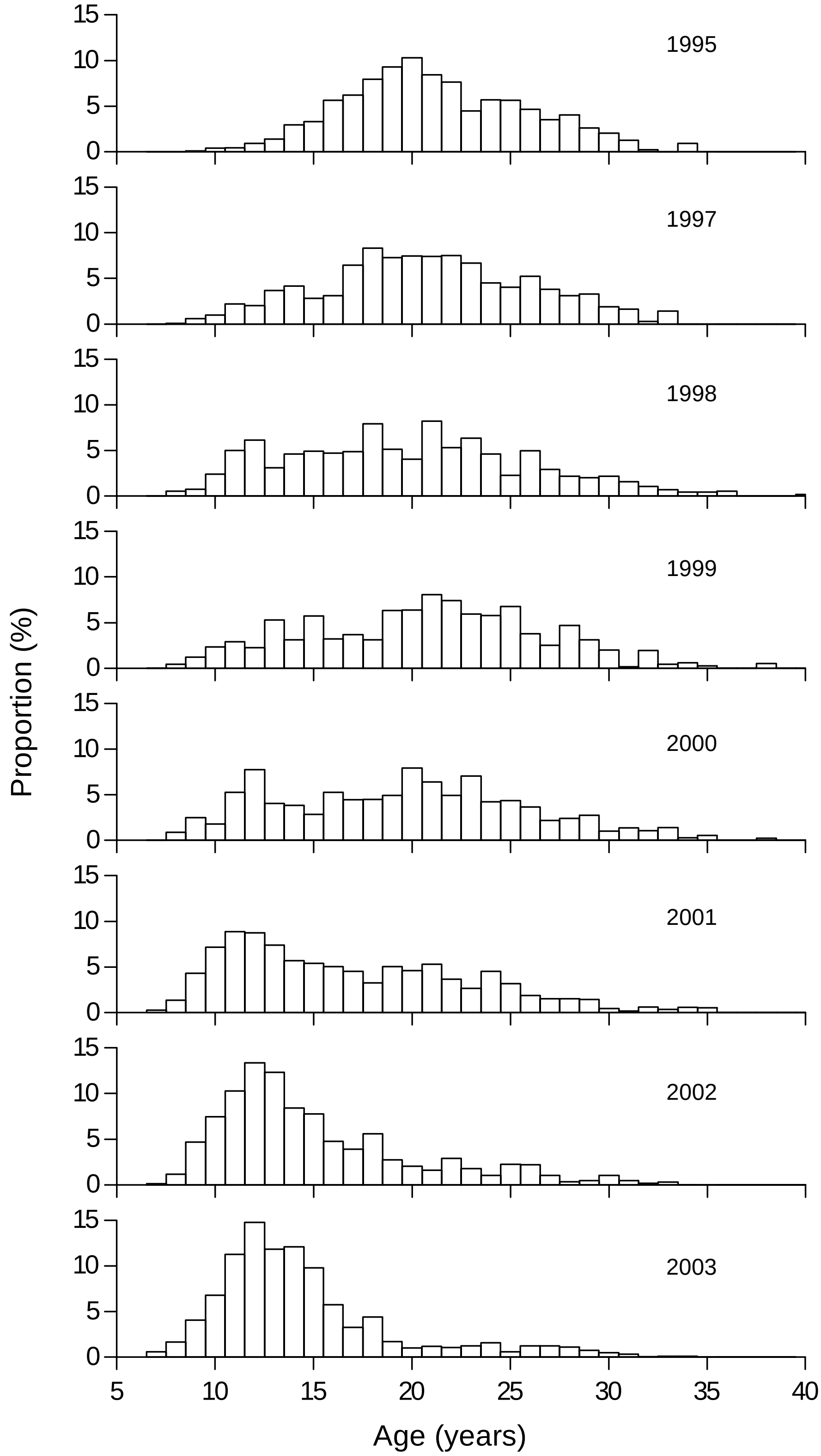

Figure 5. Age distribution of SBT by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year. Age could not be assigned to 22 (2%) fish with length measured in the 2002 season (N/A). By using age-length keys developed for SBT caught off the spawning ground (Farley et al., 2001), we estimated the majority to be between five and nine years old.

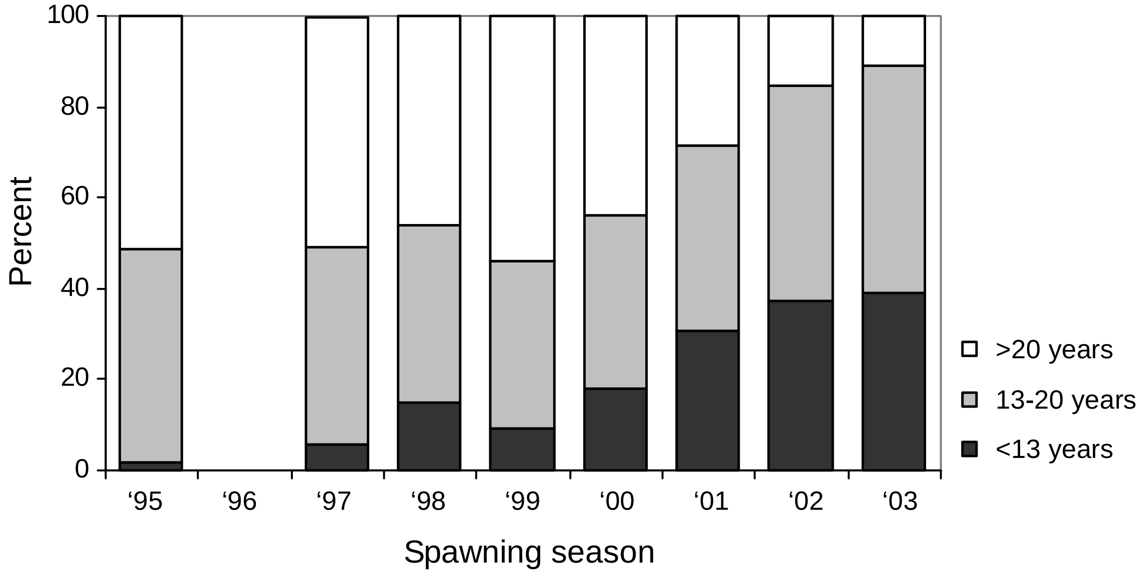

Figure 6. The proportion of SBT by age classes in each spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year. No data is available for the 1996 spawning season.

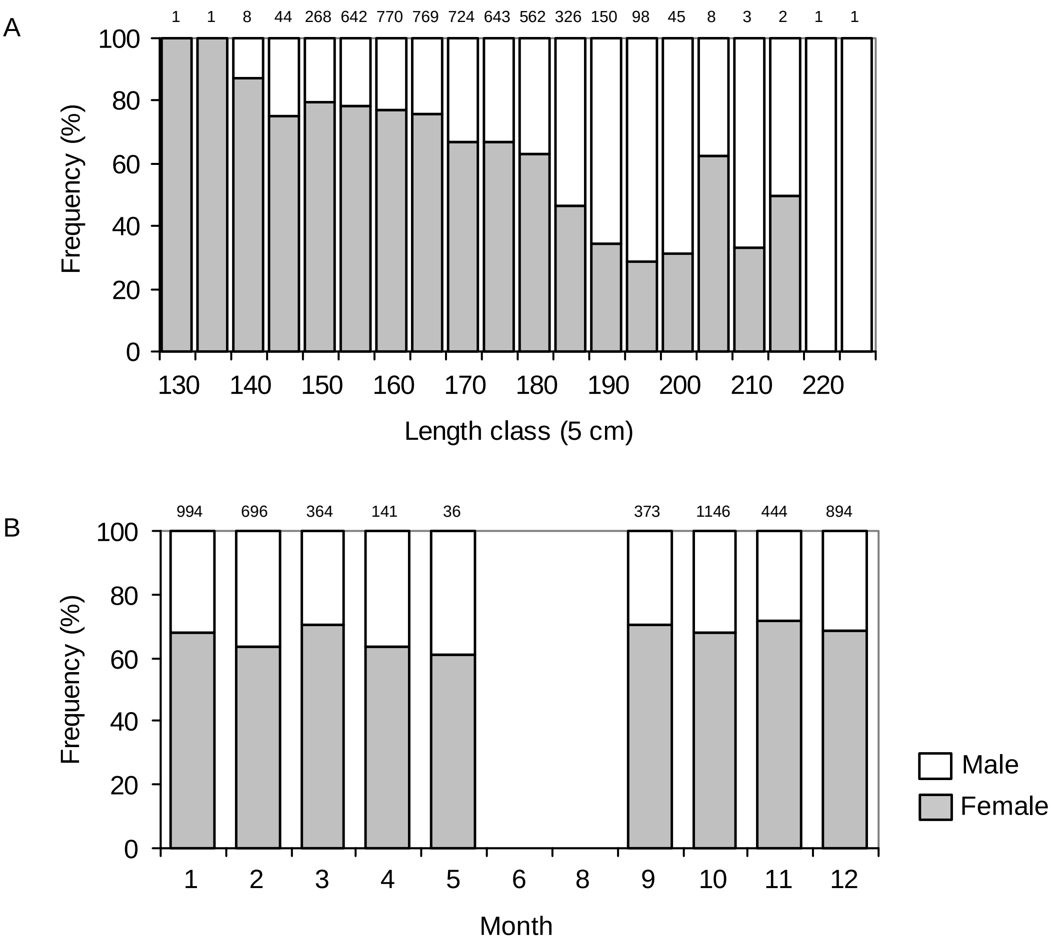

Figure 7. Proportion of males and females caught in the Indonesian longline fishery on the spawning ground by (A) 5-cm length class (n=5066), and (B) month of capture (if sample size was >5) (n=5088).