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

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Executive Summary

This paper reports on the most recent length and age data on SBT caught by the Indonesian longline fishery operating out of the port of Benoa, Bali. Lengths of SBT were sampled up to the end of April 2003 by the expanded IOTC monitoring program and through supplementary sampling of most landings by the fishery that contained SBT. This effectively covers the entire 2003 spawning season (July 2002 – June 2003).

The lengths of 1369 SBT from the 2003 spawning season ranged from 142 to 210 cm. The recruitment of small (especially <165 cm) fish into the spawning stock that first became apparent in the 2001 spawning season appears to have continued through the 2002 and 2003 spawning seasons.

The decline in the relative proportion of large SBT appears to have continued. The proportion of SBT<165 cm appears to have increased dramatically in the 2000-2002 spawning seasons at all levels of the BE index (a proxy for the depth of fishing), although there appears to be a slowing in the increase in 2003 and a decreased proportion at BE index 0.8-1.0. There has been a slight increase in the catch rate of SBT <165 cm from 1999 to 2001, whereas there has been a steady decline in the catch rate of SBT >165 cm. The catch rate of both size groups increased in the 2002 spawning season, although the increase was more marked in the smaller fish. As the mean weight of SBT <165 cm has dropped over this period this would contribute to the decline.

The ages of 489 SBT from the 2002 season ranged from seven to 33 years. As found in previous seasons, large variations were detected in length-at-age for both males and females, but mean length-at-age was not significantly different between sexes up to age 14. Thereafter, males were larger than females at the same age. The preliminary catch-at-age shows an increase in the relative abundance of young fish in the 2002 spawning season, reflecting the increase in the relative abundance of small fish. This increase of small/young fish continues to support theories that cohorts spawned since quotas were introduced in 1984 have survived to spawning age.

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 modelling 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 et al. (2002) by including the most recent length and age frequency data for the Indonesian fishery. Age frequency data is presented up to the 2002 spawning season, while length frequency data includes the 2003 season.

Methods

Length measurement and otolith sampling

SBT are sampled at export processing sites at the port of Benoa, Bali as part of the large-scale catch monitoring program (Davis and Nurhakim, 2001). SBT graded as not suitable for export are available for length measurement and otolith sampling. The lengths of these SBT were measured, and otoliths sampled from a random selection of approximately 500 to 700 fish each year. SBT are graded on flesh quality which is dependent on handling and/or condition. There is no selection based on length (Davis and Farley, 2001). However, fish of poor condition will be lighter for a given length.

The IOTC catch monitoring was implemented in 2002 and was fully operational in Benoa by July 2002. At this point in time the CSIRO/RIMF monitoring scheme was abandoned and the six new enumerators followed the IOTC protocols (see IOTC, 2003). A seventh enumerator was employed to measure and collect otoliths of SBT. This is the same enumerator whose SBT length measurements have been used since monitoring began. He ensured that as many SBT were measured as possible (only one in ten fish are measured under the protocol of the IOTC system), and also collected >1000 otoliths in the 2003 spawning season (collection of otoliths from export SBT was usually restricted). The seventh enumerator also monitored landings that had SBT that were not selected for sampling under the IOTC protocols. This was done in order to boost the number of length measurements and opportunities to collect otoliths. Two of the IOTC program enumerators have also been measuring a small proportion of SBT since June 2002 after appropriate training. 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 and the targeted sampling were added to the CSIRO/RIMF database for biological studies. All otoliths are archived at CSIRO.

Direct age estimates on the spawning ground

Gunn et al. (1998) and Farley et al. (2001, 2002) described the methods used to estimate the age distribution of SBT caught in the Indonesian-based longline fishery for the spawning seasons 1995 to 2001. These methods were used for otoliths sampled in the 2002 spawning season. Briefly, otoliths were sampled from 715 SBT between September 2001 and June 2002. The depth and exact location fished 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). Of the 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. All 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 78 (16%) 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) and Farley et al. (2001, 2002) for the previous six 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 2002 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.

Prior to the 2002 spawning season, we restricted the length frequency data to only those obtained by one sampler at the processing plants at Benoa and applied the age-length keys generated from the previous spawning seasons (Farley et al. 2001) to the restricted length frequency data. However, in the 2002 analysis we included length frequency data from two IOTC enumerators.

Results and Discussion

Length Distributions

Lengths of SBT were available up to the end of April 2003, which effectively covers the entire 2003 spawning season (July 2002 – June 2003). The length frequency distributions of all SBT measured at the processing sites are plotted by spawning season (Figure 1). The lengths of 1369 SBT from the 2003 spawning season ranged from 142 to 210 cm. The recruitment of small (especially <165 cm) fish into the spawning stock that first became apparent in the 2001 spawning season appears to have continued through the 2002 and 2003 spawning seasons. The decline in the relative proportion of large SBT appears to have continued.

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). In order to determine whether the apparent increase in frequency of SBT<165 cm might be due to changes in fishing methods, we investigated the possible effects that the BE index might have on the observed length frequency distributions. In Figure 2, the proportion of SBT<165 cm at five levels of the BE index were plotted against spawning season. The increased proportion of SBT <165 cm with an increase in the bigeye index (deeper fishing) over most spawning seasons supports the previous findings of Davis and Farley (2001). The proportion of SBT<165 cm appears to have increased dramatically in the 2000-2002 spawning seasons at all levels of the BE index, although there appears to be a slowing in the increase in 2003 and a decreased proportion at BE index 0.8-1.0. This would suggest that most of the observed increase in the proportion of SBT<165 cm in Figure 1 has occurred independent of any changes in fishing practices. There was little change in the overall BE index from 1999 – 2001, being 0.42, 0.45 and 0.46, respectively. However, the change is slightly more marked in 2002 at 0.51 (the 2003 catch data is not yet available to estimate the index in the 2003 spawning season).

Changes in relative abundance by size

It is not clear how much of the increase in proportion of small fish is due to a reduction in the abundance of larger fish or to the increase in abundance of smaller fish. In order to clarify this, catch rates for each size group were determined using vessel year as the unit of effort as reported in Davis and Andamari (2002). The weights of SBT corresponding to each length group were totaled by month and raised to the estimated weight of SBT caught in the month. The estimated weight of SBT caught each spawning season by length group was divided by effort and plotted (Fig. 3). It can be seen that in recent years there has been a slight increase in the catch rate of SBT <165 cm from 1999 to 2001, whereas there has been a steady decline in the catch rate of SBT >165 cm. In the 2002 spawning season the catch rate of both size groups increases, although the increase is more marked in the smaller fish. The dotted lines indicate the trend between 2001 and 2002 when a more conservative estimated catch of 1,741 tonnes rather than 2,126 tonnes is used for the 2002 spawning season (Davis and Andamari, 2003). In this case there is hardly any increase in the catch rate of the larger

SBT but still a marked increase in the catch rate of small SBT. The mean individual weight of SBT in these two size groups have been plotted by spawning season (Fig. 4). There has been little change in mean weight of fish in the small size group, but there has been a decline in the mean weight of fish in the larger size group over the last three spawning seasons. This would partly account for the decline in catch rate (expressed as weight/effort).

Direct age estimates

Age was estimated for a total of 489 SBT in the 2002 spawning season from fish ranging in size from 147 - 223 cm LCF. The range of ages for the 2002 season (7-33) was similar to the previous seasons. The precision of readings was considered good. The second age estimate of the primary reader agreed with the original estimate in 34% of cases and 89% were within two years of the original. The APE between replicate readings by the primary reader was 3.11 (n=489), between replicate readings by the secondary reader was 2.90 (n = 78) and between the two readers it was 4.68 (n = 78). These very low levels of error, especially between the two readers suggest consistent interpretation of age in blind tests. However, when the primary and secondary readers age estimations were compared, a bias was present in SBT <18 years. The primary reader was underestimating by one year. This bias is currently being examined and further training may be required. For our analysis of the 2002 data, one year was added to all age estimates <18 years. These results should be considered as preliminary.

Comparison of growth between sex

Age has been estimated for a total of 3,378 SBT caught in the Indonesian-based longline fishery over seven spawning seasons (Table 1). Of these fish, 1534 were of known sex; the majority being sampled in the three most recent spawning seasons. As indicated in Farley et al. (2002), a bias towards females exists in fish with age estimated. The ratio was 2.0 to 1 in 2000, 1.6 to 1 in both 2001 and 2002.

The maximum estimated age was 40 years for a 185 cm LCF female. The largest fish aged was a 223 cm male estimated to be 30 years old. 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 (Fig. 5, Table 2). 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. Unfortunately, otoliths were not sampled from the very small fish measured by IOTC enumerators (n=18; length classes 135 and 140 cm LCF) or for some larger fish (n=3; length class 210 cm). Therefore, the age-length key could not assign ages to these fish. As these are the smallest SBT recorded in the Indonesian fishery to date, age-length keys from previous spawning seasons could not be applied. Using age-length keys developed for SBT caught off the spawning ground (Farley et al., 2001), we estimated these small fish to be between five and nine years old, with the majority being 7 years old (43%). However, Farley et al. (2001) concluded that it is the older fish in the smaller length classes that are most likely to be caught on the spawning ground. Using an age-length key developed for fish caught off the spawning ground will, therefore, bias the age estimates towards younger fish. It is likely that fish <145 cm LCF caught on the spawning ground are older than the 5-9 years age range suggested. It is impossible to assign an age to the three larger SBT (210 cm LCF) due to the large growth variability with age. However they are likely to be ≥ 20 years old.

Despite the problem of assigning age to small fish, the age distributions derived from the catch-at-length data show that younger fish have continued to increase in relative abundance (Fig. 6). In the first spawning season examined (1995), very few fish ≤12 years old were caught (2.2%). Between 1999 and 2002 the proportion fish ≤12 years old in the catch increased dramatically from 10% to 38%. Conversely, the relative proportion of older fish (>20 years old) decreased from 49% to 14% between 1995 and 2002. When the age distributions were viewed for the two extreme seasons (Fig. 7) or as cumulative percent frequencies (Fig. 8), the dramatic shift towards a dominance of young fish can be seen very clearly.

Given the dimorphism in growth between sexes, and the bias towards females aged, the age-length keys developed for the 2000 - 2002 spawning seasons will be biased towards female length-at-age. Since females are smaller for a given age (older for a given length) than males, the bias towards females would not be the cause of the recent shift towards smaller fish in the estimate catch-at-age. If anything, a bias towards females will actually cause the reverse to occur. Unfortunately, due to the low number of fish aged per spawning season, separate age-length-keys could not be developed for male and female SBT.

Conclusions

- The proportion of SBT<165 cm appears to have increased dramatically in the 2000-2002 spawning seasons at all levels of the BE index, although there appears to be a slowing in the increase in 2003 and a decreased proportion at BE index 0.8-1.0. These changes have occurred irrespective of changes in fishing practices (depth fished as indicated by the BE index).

- There has been a slight increase in the catch rate of SBT <165 cm from 1999 to 2001, whereas there has been a steady decline in the catch rate of SBT >165 cm. In the 2002 spawning season the catch rate of both size groups increases, although the increase is more marked in the smaller fish. As the mean weight of SBT <165 cm has dropped over this period this would contribute to the decline.

- The minimum age of SBT caught in the Indonesian fishery remains at age 7 years. However it is possible that several small fish (135-144 cm) that did not have otoliths sampled and could not be directly aged, were less than 7 years old.

- The preliminary catch-at-age shows a dramatic increase in the relative abundance of young fish in the 2002 spawning season, reflecting the increase in the relative abundance of small fish. This increase of small/young fish continues to support theories that cohorts spawned since quotas were introduced in 1984 have survived to spawning age.

References

Beamish, R.J. and D.A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38(8): 982-983.

Clear, N.P., Gunn, J.S., Rees, A.J. 2000. Direct validation of annual increments in the otoliths of juvenile southern bluefin tuna, *Thunnus maccoyii*, through a large-scale mark-and-recapture experiment using strontium chloride. Fish. Bull. 98, 25-40.

Davis, T.L.O. and R. Andamari. 2002. Catch monitoring of the fresh tuna caught by the Bali-based longline fishery in 2001. CCSBT Scientific Meeting.

Davis, T.L.O. and R. Andamari. 2003. The catch of SBT by the Indonesian longline fishery operating out of Benoa, Bali in 2002. CCSBT Scientific Meeting.

Davis, T.L.O. and J.H. Farley. 2001. Size partitioning by depth of southern bluefin tuna (*Thunnus maccoyii*) on the spawning ground. Fish. Bull. 99: 381-386.

Davis, T.L.O. and Nurhakim, S. 2001. Catch Monitoring Of The Fresh Tuna Caught By The Bali-Based Longline Fishery. CCSBT Scientific Meeting; 23-31 July 1998, Far Seas Fisheries Res. Lab, Shimizu, Japan. CCSBT/SC/0108/11.

Farley, J.H., Davis, T.L.O., Eveson, J.P. 2001. Length and age distribution of SBT in the Indonesian longline catch on the spawning ground. CCSBT Scientific Meeting; 23-31 July 1998, Far Seas Fisheries Res. Lab, Shimizu, Japan. CCSBT/SC/0108/12.

Farley, J.H., and Davis, T.L.O. 1998. Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. Fish. Bull. 96: 223-236.

Gunn, J.S., Clear, N.P., Carter, T.I., Rees, A.J., Stanley, C.A., Farley, J.H., Kalish, J.M., In Press. The direct estimation of age and growth in southern bluefin tuna, *Thunnus maccoyii* (Castelnau), using otoliths, scales and vertebrae. Fish. Bull.

Gunn, J., Farley, J. and N. Clear. 1998. The age distribution and relative strength of cohorts of SBT on the spawning ground. CCSBT Scientific Meeting; 23-31 July 1998, Far Seas Fisheries Res. Lab, Shimizu, Japan. CCSBT/SC/9808/39.

IOTC (2003). Notes on IOTC data collection activities in Indonesia. CCSBT Indonesian Catch Monitoring Review, 10-11 April 2003, Queenstown, New Zealand. CCSBT-ICM/0304/17.

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
Total	4299	2082	3378	1534

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	150.0	-	1	149.5	13.4	2	
8	156.8	5.7	15	159.2	9.4	5	0.496
9	157.7	3.9	34	158.8	7.5	21	0.474
10	159.0	5.9	50	160.1	8.7	32	0.505
11	163.3	8.1	85	161.0	7.1	28	0.189
12	166.3	7.5	98	166.6	7.9	43	0.800
13	168.9	7.2	72	167.5	8.4	43	0.372
14	169.6	8.0	65	170.1	10.5	23	0.791
15	168.9	8.4	51	173.5	9.8	31	0.026
16	172.1	6.9	47	179.7	11.9	27	0.001
17	175.2	8.3	38	178.5	10.2	24	0.165
18	174.0	7.3	40	182.7	11.1	28	<0.001
19	178.4	7.0	37	184.0	7.4	25	0.004
20	179.8	9.1	46	186.4	7.5	28	0.002
21	180.0	6.8	40	186.9	7.0	29	<0.001
22	179.0	6.2	41	188.0	9.3	26	<0.001
23	180.5	6.2	28	189.2	7.3	31	<0.001
24	179.0	6.3	32	190.9	8.5	24	<0.001
25	179.6	8.1	40	189.0	4.4	20	<0.001
26	180.3	11.0	28	188.9	9.4	24	0.043
27	182.1	4.8	18	187.8	5.3	8	0.013
28	180.3	5.9	15	189.2	7.9	9	0.005
29	185.2	8.8	14	194.8	5.9	10	0.007
30	185.1	8.8	10	199.3	12.4	6	0.018
31	184.6	9.9	5	195.0	10.7	6	0.132
32	186.3	13.9	7	197.7	7.6	3	0.228
33	187.4	8.3	5	191.4	6.5	7	0.367
34	184.0	5.3	3				
35	190.5	0.7	2	187.3	2.1	3	0.141
36							
37							
38	180.0	-	1				
Total			968			566	

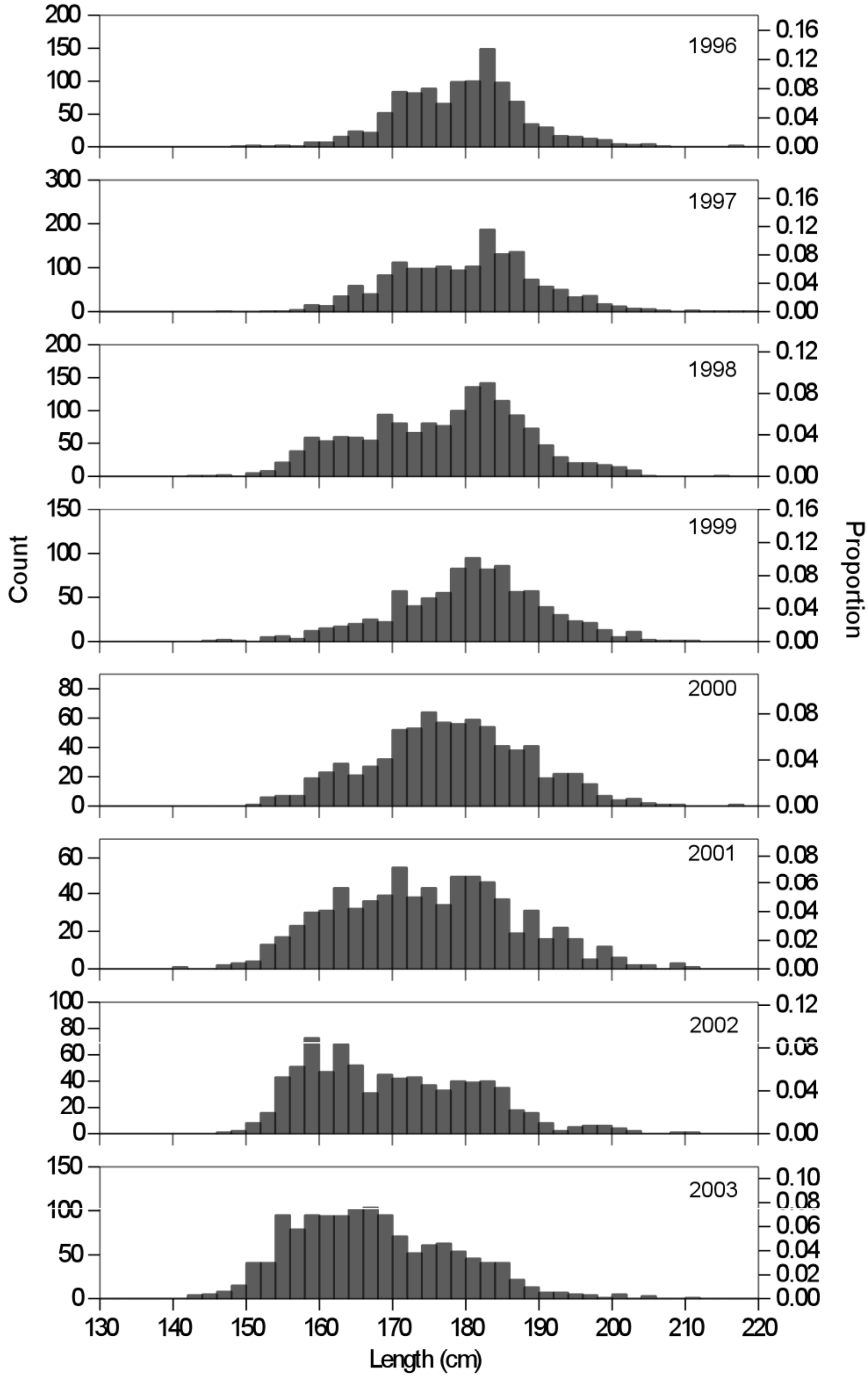

Figure 1. Length frequency (2 cm intervals) of SBT by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

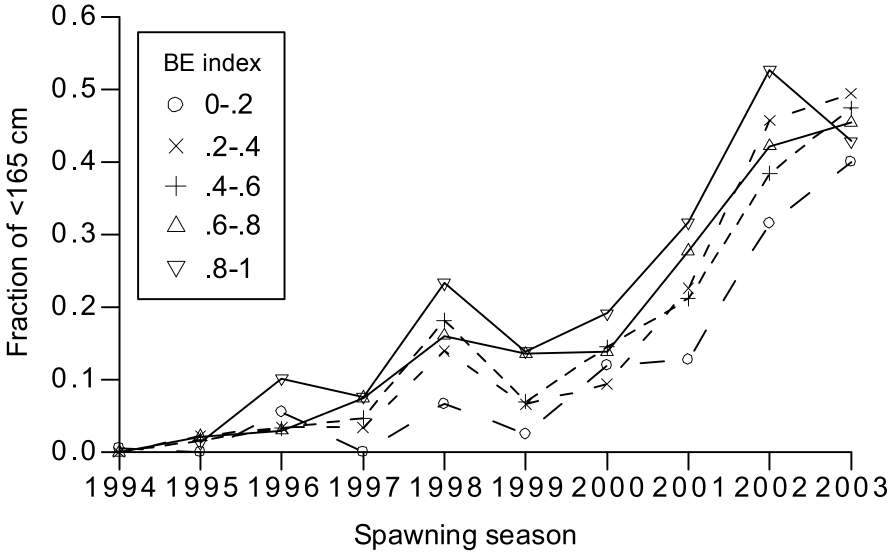

Figure 2. The proportion of SBT < 165 cm in length (of all SBT with a length measurement) in each spawning year. A spawning season is defined as July 1 of the previous year to June 30 of the given year.

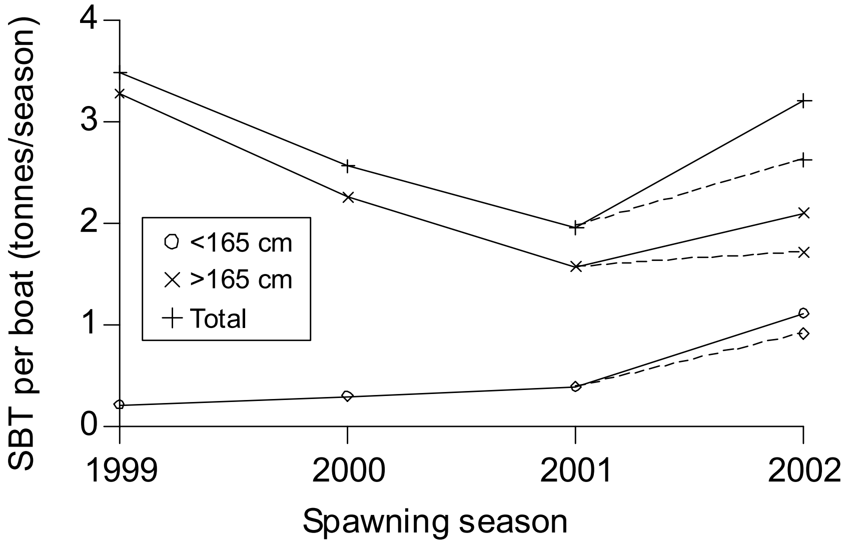

Figure 3. Catch rate of SBT (tonnes/boat) by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year. Dotted line depicts catch rate if using the alternate conservative estimate of SBT catch in the 2001/2002 spawning season of 1,741 tonnes rather than 2,126 tonnes from Davis and Andamari (2003).

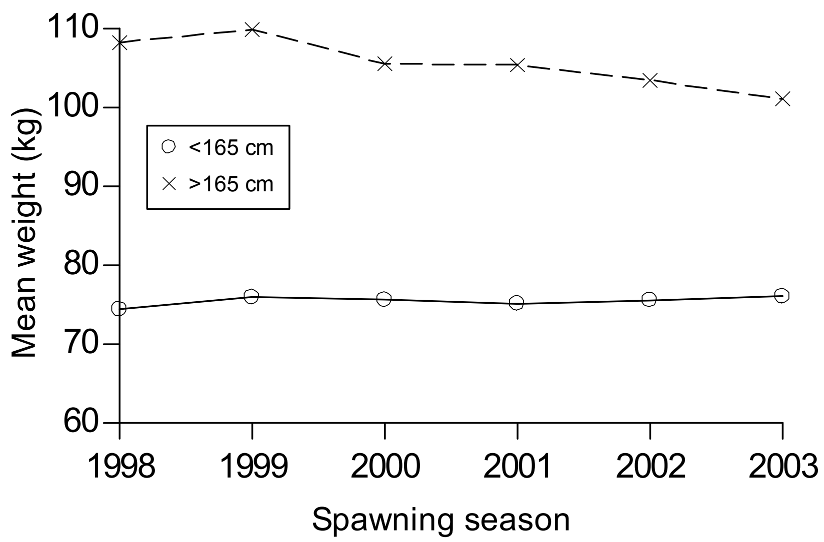

Figure 4. Mean individual weight of SBT in <165 cm and >165 cm length groups by spawning season.

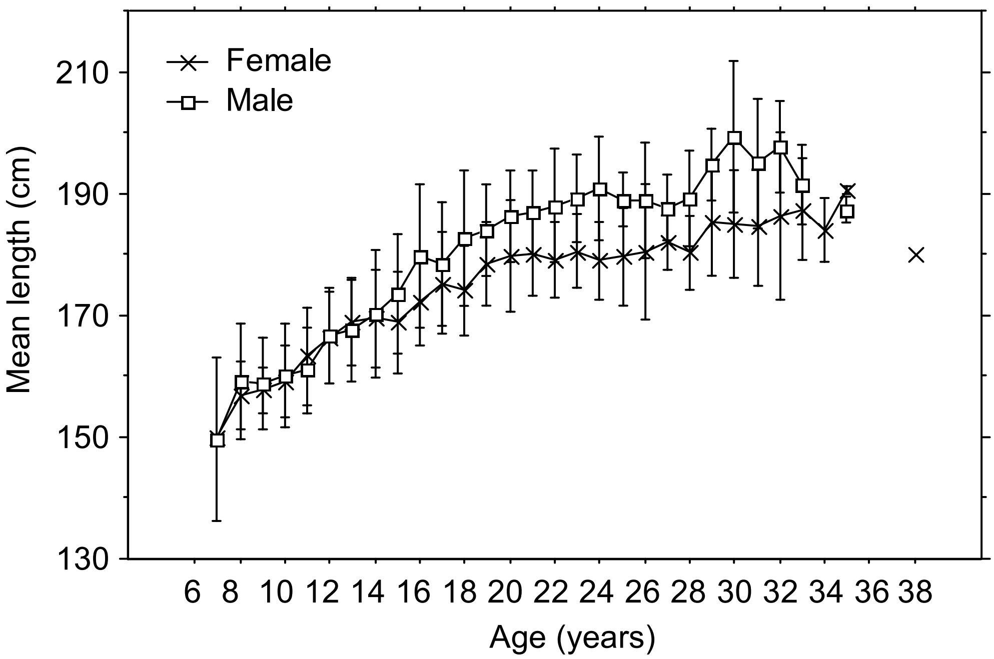

Figure 5. Mean length-at-age (+/- 1 standard deviation) of male and female SBT caught in the Indonesian longline fishery.

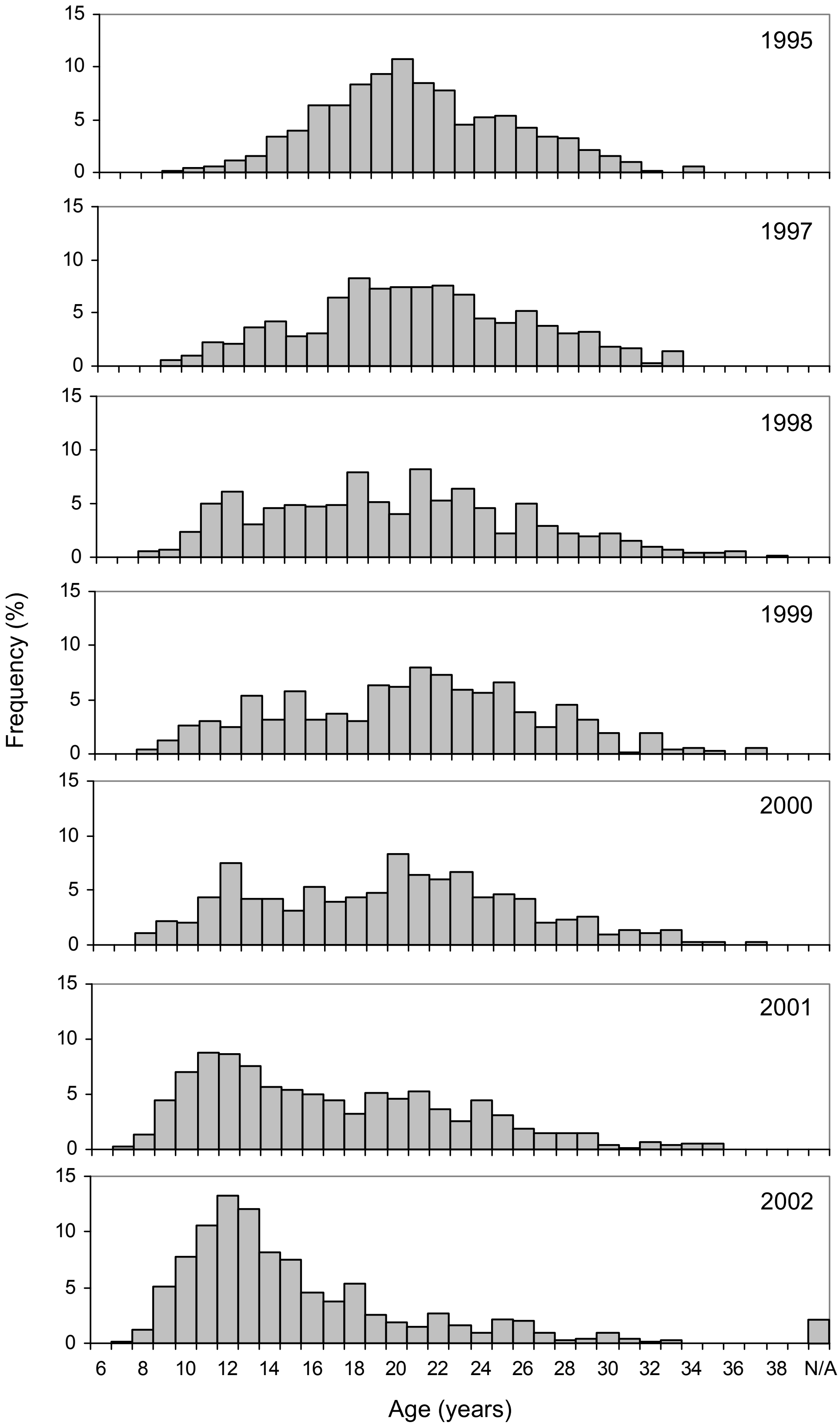

Figure 6. Age distribution of SBT by spawning season. A spawning season is defined as July 1 of the previous year to June 30 of the given year. Age could not be assigned to 22 (2%) fish with length measured in the 2002 season (N/A). By using age-length keys developed for SBT caught off the spawning ground (Farley et al., 2001), we estimated the majority to be between five and nine years old.

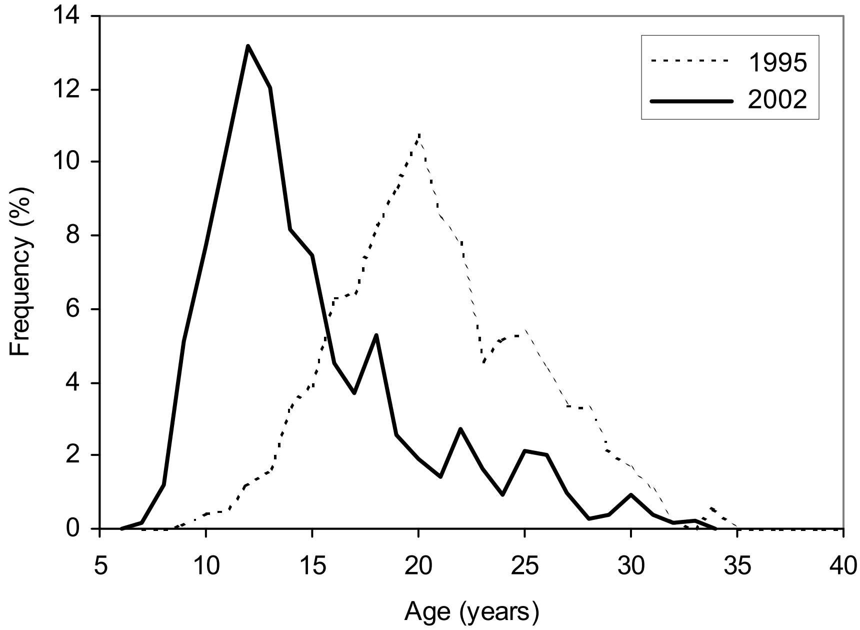

Figure 7. Age distribution of SBT for the first (1995) and current (2002) spawning seasons. A spawning season is defined as July 1 of the previous year to June 30 of the given year. The 22 SBT not assigned aged in the 2002 season have not been included.

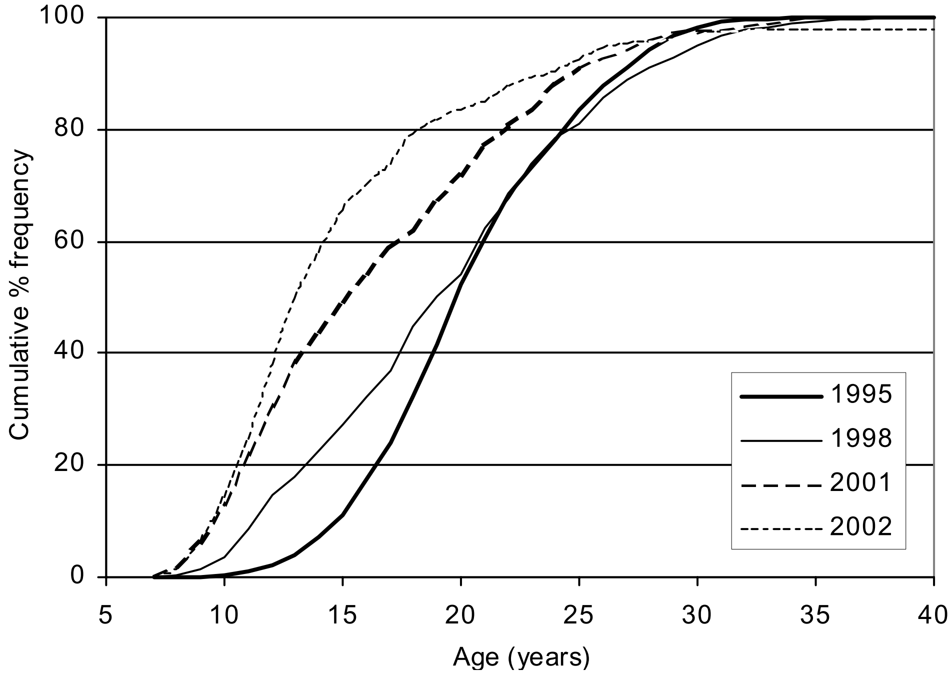

Figure 8. Cumulative percent frequency distribution of SBT age by spawning season. Four spawning seasons were selected from the seven analysed to highlight the dramatic change over time.