Distribution of southern bluefin tuna in Western Australia
西オーストラリア州におけるミナミマグロの分布

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Summary

The existent size data of young southern bluefin tuna in Western Australia (WA) were collected from various research sources. Fishery catch-at-size data, as well as relevant biological information, were also considered. Age-1 SBT appear to be distributed only in WA coastal areas in summer. There were two size groups for young SBT in WA, one is less than 40 cmFL (Oct-SC fish) and the other is 40 - 60 cmFL (Feb-SC fish), and their spawning years are different to each other. More Feb-SC fish appear to be distributed in southern WA than western WA. It was hypothesized that age-1 SBT come from elsewhere in December and expand their distribution toward east part of southern WA in January. The trolling monitoring survey, which do in southern WA in January, is appropriate in terms of survey area and survey season.

要約

西オーストラリア州（WA）のミナミマグロ若齢魚について、各種調査からサイズデータを収集した。体長別漁獲データおよび関連する生物学的情報も考慮した。ミナミマグロ 1 歳魚は夏季にWA 沿岸のみに分布するようであった。WA の若齢魚は、40cm 未満（10 月亜年級魚）と 40-60cm（2 月亜年級魚）の 2 つの体長群に別れ、両者の産卵年度は異なった。2 月亜年級魚は、WA の西岸よりも南岸に多いようであった。1 歳魚は、12 月に WA に来遊し、1 月に WA 南岸の東へ分布を拡大すると考えられた。WA 南岸で 1 月に調査している曳縄調査は、調査海域および時期の観点で適切である。

Introduction

Southern bluefin tuna (*Thunnus maccoyii*; SBT) is born in the tropical waters of eastern Indian Ocean and move to the coastal waters of Western Australia (WA), followed by move away to other places including Great Australian Bight and higher latitude offshore area in Pacific or Indian Oceans. It is known that age-2 fish has already wide spread including Great Australian Bight and southern Indian Ocean, but age 0-1 fish have been found only in WA. SBT at age 0-1 and WA , which and where they have still relatively aggregated, are promising subject to obtain reliable stock abundance index of SBT.

Recruitment surveys for age-1 SBT in WA have been carried out since 1988/89 to present. Because survey range have been small in time and space in recent years, it is now an especially important issue how age-1 SBT found in the survey reflecting whole of age-1 SBT stock. Comprehensive and detail knowledge of age-1 SBT distribution is required to solve the issue.

In old years, Serventy (1956) described young SBT in WA. Hynd (1965) described size of young SBT in southern WA. In the 1980s, a number of age-1 SBT were caught by commercial pole-and-line fishery in southern WA.

Since the late 1980s, through the 1990s and 2000s, several research activities were carried out for SBT in WA. NRIFSF conducted SBT distribution surveys in western WA several times, and succeeded in catching many small SBT less than 40 cmFL which had not ever recognized. In southern and western WA, recruitment monitoring survey using trolling and pole-and-line carried out for five years, conjunction with a large number of conventional tagging in the cooperative frame work of Australia and Japan (Nishida et al. 1993, Anon. 1993). From mid-1990s to mid-2000s, recruitment surveys using acoustic devises such as sonar and echo sounder were conducted (Itoh and Tsuji 2004). In the 2000s, a large number of SBT were tagged in tagging program of CCSBT Scientific Research Program (Anon. 2008). Since 2006 after cease of acoustic survey, the recruitment survey using trolling has been carried out for several years (Itoh and Sakai 2009).

Information and data collected from these research surveys and fishery are enormous, though they are discontinued in time and space.

In addition, examination of otolith daily increments allow new interpretation of age and cohort structure of SBT (Itoh and Tsuji 1996). In recent years, acoustic tagging provides new insight for distribution dynamics and its relation to oceanographic structure in young SBT in WA (Hobday et al. 2008a, Fujioka et al. 2008).

We collected existent data and information, examined it especially for size and interpret the result with conjunction of relevant biological knowledge, and then evaluated the current recruitment survey.

1. Structure of cohort and sub-cohort

In the past until in the 1980s, SBT around 50 cmFL have been assumed to be age-2. Itoh and Tsuji (1996) estimated SBT reached 50.8 cmFL at age-1 and 78.6 cmFL at age-2based on the number of otolith daily increments from 122 individuals ranged from 25 cmFL to 82 cmFL caught in WA. These otolith daily age estimation data were utilized and summarized in terms of age, growth and birth periods for SBT in WA which have several length groups.

The date of fertilization of egg (referred here as being born) was calculated from date of SBT individual sampled by subtracting the number of otolith increment, with assuming the first otolith increment was formed on the 5th day after fertilization by the information of Pacific bluefin tuna otolith (Itoh et al. 2000). Fish of 25 - 35 cmFL between December and February was born between August and October (Fig. 1, Fig. 2). Fish of 40 - 60 cmFL was born between December and April. Then, among SBT in WA in January of year *i*, for example, fish less than 40 cmFL was born between August and October of year *i-1* (age of 3 - 5 months), and fish of 40 - 60 cmFL was born between December of year *i-2* and March of year *i-1*. They are born in different spawning year, which ranges from around September to April, to each other. Because we describe SBT in WA less than 60 cmFL between December and February in the present paper, we refer SBT less than 40 cmFL to Oct-sub-cohort (Oct-SC fish) and SBT 40 - 60 cmFL to Feb-sub-cohort (Feb-SC fish).

Oct-SC fish would reach around 60 cmFL at age-1, but it did not occur in their samples. SBT born in November did not occur either, probably due to too small in size to be sampled with trolling in December.

2. SBT age 0-1 distribution in literature and its interpretation

Serventy (1956) described distribution of young SBT mainly for eastern and southern Australia, but also for young SBT in WA. He stated that there were two size groups of SBT in WA, one reached 34 - 50 cmFL with mean of 41 cmFL and the other did 52 - 66 cmFL with mean of 61 cmFL in May after summer growth. From present point of view, these are interpreted as Oct-SC fish and Feb-SC fish, respectively.

Serventy (1956) also recorded small SBT less than 40 cmFL, which must be Oct-SC fish. One record was for the smallest fish of 31.8 cmFL sampled on March 25, 1951 by R/V Warreen at south of Albany. The other record was for the earliest on February 29, 1944 off Bunbury for SBT of 33.7 cmFL.

He also described SBT distribution in South Australia and southeastern Australia. He stated that in commercial trolling catch in New South Wales, though there were no age 0+ fish (less than 40 cmFL), SBT of age-1+ with mean of 53 cmFL was caught with SBT of age 2+ and 3+. Although detail information was not described, it raises a possibility that a part of

SBT age-1 distributed other than WA.

Hynd (1965) summarized size data collected by governmental fishing research surveys conducted between July, 1961 and July, 1962 in southwestern Australia. Around 6000 individuals were caught with trolling and pole-and-line.

Figure 3 was made from Figure 5 of Hynd (1965) by measuring monthly length modes on the graph. He was interested in two length modes at 70cmFL and 65 cmFL between May and July and estimated they came from different spawning season. At the same time, in his data, there was a series of modal length for small fish from 35 cmFL in March 1962 to 45 cmFL in July 1962, and 45 cmFL in August 1961 to 48 cmFL in October 1961 off Albany in southern WA (colored in green on Fig. 3). This is interpreted as Oct-SC fish. It provides that Oct-SC fish existed also in the 1960s and distributed southern WA between March and October.

3. Size data in WA and general distribution pattern

SBT size data in WA were collected from various available sources as follows (Table 1).

- Data of the trolling recruitment monitoring survey in the 1990s in 1988/89 - 1992/93 in western and southern WA. SBT were caught by trolling or pole-and-line.
- Data of R/V Shoyo-maru research cruises on SBT distribution in western WA. Data were available for five cruises in 1988/89, 1990/91, 1991/92, 1992/93 and 1996/97. SBT were caught by trolling.
- Data in CCSBT conventional tagging database (TAG_CAPTURE_DETAILS in TAG_RECAP_2009_04_09.mdb) in WA. It includes data of tags released provided by CSIRO between 1990 and 1995 and tags released in CCSBT Scientific Research Program (SRP) since 2001. SBT were caught in pole-and-line.
- Data in the acoustic recruitment monitoring survey between 1996 and 2006 in WA. SBT were caught by trolling.
- Data in the trolling recruitment monitoring survey between 2006 and 2009 in southern and western WA. SBT were caught by trolling.

Some identical data records were seemed to be included in different sources. If two records were found in two sources in same date and same location (in resolution of 0.01 degree), one of them with smaller number of fish for the record was deleted. Then, a dataset including 80,861 individuals in total between 1988 and 2009 was established. A large proportion of it were from CSIRO/SRP tagging.

Data were from November to March and frequent in January and February (Table3-2).

Figure 4 shows locations of data obtained. From 24S to 124E, through off the southwest corner of Australia at 35S/115E, it covers wide area of WA. Although north of 24S was also surveyed in R/V Shoyo-maru cruise, the most northern location of SBT sampled was 23 degree 59 minute S. Most of SBT sampled locations were on continental shelf or shelf edge. Although offshore area from shelf edge were surveyed in several researches, including the acoustic survey (southern WA), trolling survey (southern WA) and Shoyo-maru survey (western WA), few SBT were caught there.

Off the WA coast was divided into areas by one degree of latitude or longitude from 23S. Area 1 to 13 was on western WA between 23S and 35S. The area 13 was 35.00S-35.99S and west of 115.99E. Area 14 to 23 was on southern WA between 116E and 125E.

Length frequency was calculated by month and area from November to March (Fig. 5).

Oct-SC fish sampled in western WA between 23S and 34S from November to March. Most of samples came from Shoyo-maru cruises that targeted also on such a small SBT. In December, they were sampled between 23S and 33S without large difference in the number of samples by latitude. In January, they were sampled in 26S -28S though survey effort was small in this month. The reason of absence of Oct-SC fish in 32S-34S in January, in spite of presence of Feb-SC fish, would be later came from SRP tagging that used pole-and-line and ignored small fish. In February, Oct-SC fish were sampled in 29S-34S. Feb-SC fish were also sampled there in the same cruise of Shoyo-maru which suggest overlap of distributions of Oct-SC fish and Feb-SC fish. In southern WA, few Oct-SC fish were sampled.

In summary, Oct-SC fish distributed whole the area south of 24 S of western WA in December and distributed at least south of 29S in western WA in February. Although few Oct-SC fish occurred in southern WA, it is not clear whether they did not distributed or mismatch of gears for such a small size fish.

Feb-SC fish sampled in wide area of WA, from 24S of western WA through to 124E of southern WA. In November, they were sampled western part of southern WA in 117 - 119E. In December, they were sampled from 24S of western WA to 119E in western part of southern WA. In January and February, they were sampled in continuous area from southern part of western WA to the whole of southern WA in 116 - 124E. In March, they were sampled in southern WA in 118 - 124E.

In summary, Feb-SC fish distributed whole the area of WA in many months. They were not sampled in northern part of western WA (24S - 30S) after January and eastern part of southern WA (120E - 124E) in November and December. Assuming no sample means no distribution, distribution of Feb-SC fish changed from December to January, as shifted south in western WA and extend whole the southern WA including eastern part.

We should be careful for quantitative determination, because the dataset includes different sampling methods, e.g. pole-and-line which can sample many fish from a school, and the research efforts were not equally distributed in time and space. Even considering such potential biases, it seems that more Feb-SC fish distributed in southern WA than in western WA.

4. Dynamics of distribution in WA

In order to understand distribution dynamics in southern WA in detail and individual scale, acoustic tagging monitoring survey has been conducted every year since 2002/03 (Hobday et al. 2008a, 2008b). In the survey, SBT implemented asonic transmitter in their body cavity was released in December or January, detected its acoustic signal including identification code with hydrophones that set elsewhere and logged the record in data logger, and then retrieved the data logger after 4-6 months. A total of 547 SBT individuals were released in six years. Listening stations, consists of hydrophone, data logger, etc., 70 in total at the maximum, were set on three arrays and several lumps (small sea mounts) (Fig. 6).

This acoustic tagging survey provided many results on SBT distribution dynamics. Some of the results are that SBT in southern WA retained more than one month and some of them stay there up to May while the number of fish decreased gradually, and that they did not only move to a specific direction (expected to east) but moved to various directions. Their habitat utilization in three years were clearly divided into two patterns; kept aggregation around lumps (2004/05,2006/07) or scattered on continental shelf (2005/06). It was suggested that this different distribution pattern of SBT was relating to oceanographic structure dynamics including sub-Antarctic water (Fujioka et al. 2008). In addition, the data showed that there was inter-annual variations on these characteristics of SBT distribution.

In 2006/07 and 2007/08, a total of 27 SBT with acoustic tags were released in the west coast of WA. Only one of them was detected in listening stations, which set in southern WA. This is too low than that of SBT released in southern WA (38-84% of fish detected in five years) even considering the distance difference. SBT in western WA in December do not appear to move to southern WA between January and April and SBT in WA seems to have arrived earlier in the season (Hobday et al 2008a).

Catch of age-1 SBT in WA is also found in the CCSBT catch statistics for pole-and-line catch reported from Australia. Because the data have already extended to all the catch, detail of it, such as the number of fish measured, is not available. In addition, because it is a fishery data, careful attentions for size selectivity and response to SBT distribution (when SBT distributed in southern WA, did fishermen went fishing always?) are required. Here, we simply assume the catch reflect SBT distribution. On monthly length frequency between 1982 and 1984 when catch in there were large, small SBT around 50 cmFL were newly recruited to the fishery catch in December in both of two years (Fig. 7). In December, fishing area expanded between Albany and Esperance, though it was only off Albany in November (Fig. 8). In January, catch and proportion of catch off Albany (118E) reduced. Higher catch proportion in 119E-124E lasted from January to April. Therefore, SBT of around 50 cmFL presumably Feb-SC fish appear to arrive southern WA in December. They appear to arrive the area between Albany and Esperance at once or expand their distribution toward east rapidly within a month, and remained there from January to April.

5. Discussion

From various information described above, it can be said that age-1 SBT distributed only in WA coastal areas in summer. While Serventy (1956) recorded catch of age-1 SBT in New South Wales, absence of other positive evidence strongly suggest this.

There are two size groups for young SBT in WA, one is less than 40 cmFL (Oct-SC fish) and the other is 40 - 60 cmFL (Feb-SC fish), and their spawning years are different to each other, they should be distinguished in recruitment monitoring surveys.

More Feb-SC fish appear to be distributed in southern WA than western WA. They come from elsewhere in December and expand their distribution toward east part of southern WA in January.

If these hypothesis for SBT age-1 distribution is correct, the trolling monitoring survey, which do in southern WA in January, is appropriate in terms of survey area and survey season.

In the recruitment monitoring surveys in southern WA since 1988, it assumed SBT distribution dynamics as that SBT schools came down south along western WA and then went east along southern WA constantly. It leads an idea that it could monitor many SBT schools that arrive in sequence by surveying one place repeatedly. However, the data we analyzed showed SBT resided between January and March, while moving toward east in southern WA in December to January was suggested. The acoustic tagging data on individual fish moving support the residence. In addition, the acoustic tagging on western WA provide negative evidence for constant moving from western to southern WA in the season. There is a possibility that the recruitment monitoring surveys have subjected only for a small part of SBT populations reside there.

Even if it was the case, it does not mean the recruitment survey index useless at all. In general, strength of recruitment abundance of whole stock must be reflected in abundance in a part of area. We should care for the risk of the recruitment index being affected by various factors, such as oceanographic structures, prey distributions, SBT stock abundance itself, etc, and their inter-annual variations. If our subject to be monitored were tiny part of whole SBT recruitment population, the risk may increase. It is required to know SBT distribution and its dynamics in WA in more detail. For this purpose, we should further collect data from existing information with deep knowledge on the information, and also collect further data in future. Actually, available source for recruitment survey is limited in budget, possible time and space surveyed. Along with new knowledge of SBT distribution will be obtained, survey design of monitoring by trolling or other methods will be corrected for which provide the best effective results within limited time and area surveyed.

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Table 1. Number of SBT individuals in size data collected by year and survey.

Year	Trolling survey in 1990s	R/V Shoyo-maru survey	CSIRO/CCSBT SRP tagging	Acoustic survey	Trolling survey	Total
1988	785	147				932
1989	449					449
1990	1,144	398	3,258			4,800
1991	517	341	1,394			2,252
1992	225	74	1,845			2,144
1993	1,028	103	4,817			5,948
1994			8,686			8,686
1995			10,172			10,172
1996				94		94
1997		191		145		336
1998				148		148
1999				202		202
2000				50		50
2001			2,770	93		2,863
2002			2,979	53		3,032
2003			6,761	35		6,796
2004			5,403			5,403
2005			7,964	301		8,265
2006			10,574	606	211	11,391
2007			5,526		233	5,759
2008			438		311	749
2009			189		201	390
Total	4,148	1,254	72,776	1,727	956	80,861

Table 2. Number of SBT individuals in size data collected by year and month.

Year	Jan	Feb	Mar	Nov	Dec	Total
1988				135	797	932
1989					449	449
1990	27			1,099	3,674	4,800
1991	327			1	1,910	2,252
1992	1,967	48		92	35	2,144
1993	1,321	3,144	1,482			5,948
1994	2,789	2,872	3,025			8,686
1995	2,918	4,812	2,442			10,172
1996	65	29				94
1997	8	328				336
1998	52	96				148
1999	51	134	17			202
2000	10	28	12			50
2001	158	2,669	36			2,863
2002	532	1,669	678		153	3,032
2003	1,802	3,360	1,627		7	6,796
2004	2,472	2,858			73	5,403
2005	4,112	2,925	1,220		8	8,265
2006	4,464	6,654	76		193	11,391
2007	3,379	1,796	523		61	5,759
2008	553	12			184	749
2009	390					390
						0
Total	27,397	33,434	11,138	1,327	7,544	80,861

Table 3. Number of SBT individuals in size data collected by area and survey.

Area	Latitude	Longitude	Trolling survey in 1990s	R/V Shoyo-maru survey	CSIRO/CCSBT SRP tagging	Acoustic survey	Trolling survey		Total
1	23S–	west of 116E		3					3
2	24S–	west of 116E		74					74
3	25S–	west of 116E		81					81
4	26S–	west of 116E		59					59
5	27S–	west of 116E	1	51					52
6	28S–	west of 116E	2	47					49
7	29S–	west of 116E	1	256					257
8	30S–	west of 116E	1	57					58
9	31S–	west of 116E	76	173	1	1	1		252
10	32S–	west of 116E	7	130	192	33	37		399
11	33S–	west of 116E	16	304	38	28	4		390
12	34S–	west of 116E	150	19	39	39	2		249
13	35S–	west of 116E	2		122	5			129
14	south of 34S	116E–	472		131	9	32		644
15	south of 34S	117E–	634		1,663	13	153		2,463
16	south of 34S	118E–	549		2,604	145	116		3,414
17	south of 34S	119E–	1,659		9,201	616	556		12,032
18	south of 34S	120E–	506		8,639	321	40		9,506
19	south of 34S	121E–	31		4,460	517	15		5,023
20	south of 34S	122E–			8,285				8,285
21	south of 34S	123E–	41		23,084				23,125
22	south of 34S	124E–			14,317				14,317
23	south of 34S	125E–							0
Total			4,148	1,254	72,776	1,727	956	0	80,861

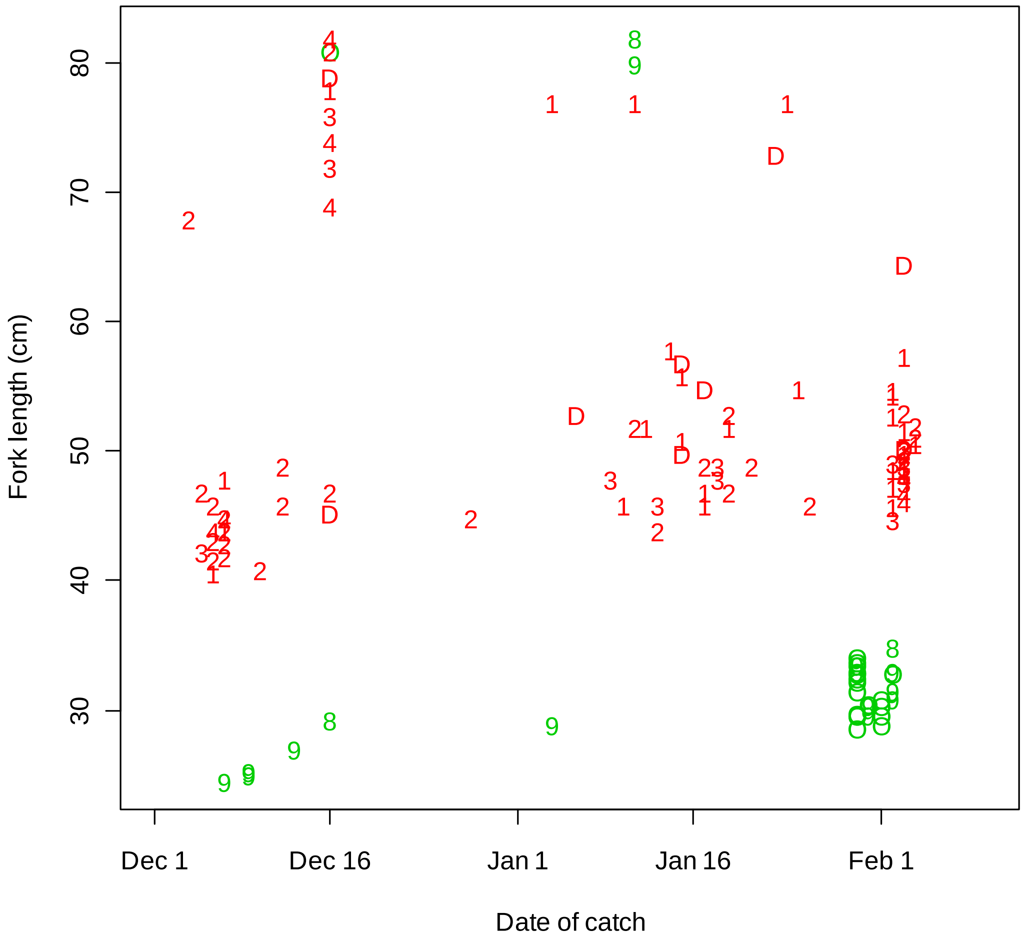

Fig. 1. Plots of fork length and date of catch of southern bluefin tuna in Western Australia of which otolith daily imcrements was counted. The data used in Itoh and Tsuji (1996) were reanalyzed. Months of fertilization from January to September are expressed as numerals and those in October, November and December is expressed as “O”, “N”, and “D”, respectively. Month of fertilization between August and October, which defined as Oct-sub-cohort, is colored in green and that between November and April, which defined as Feb-sub-cohort, is colored in red.

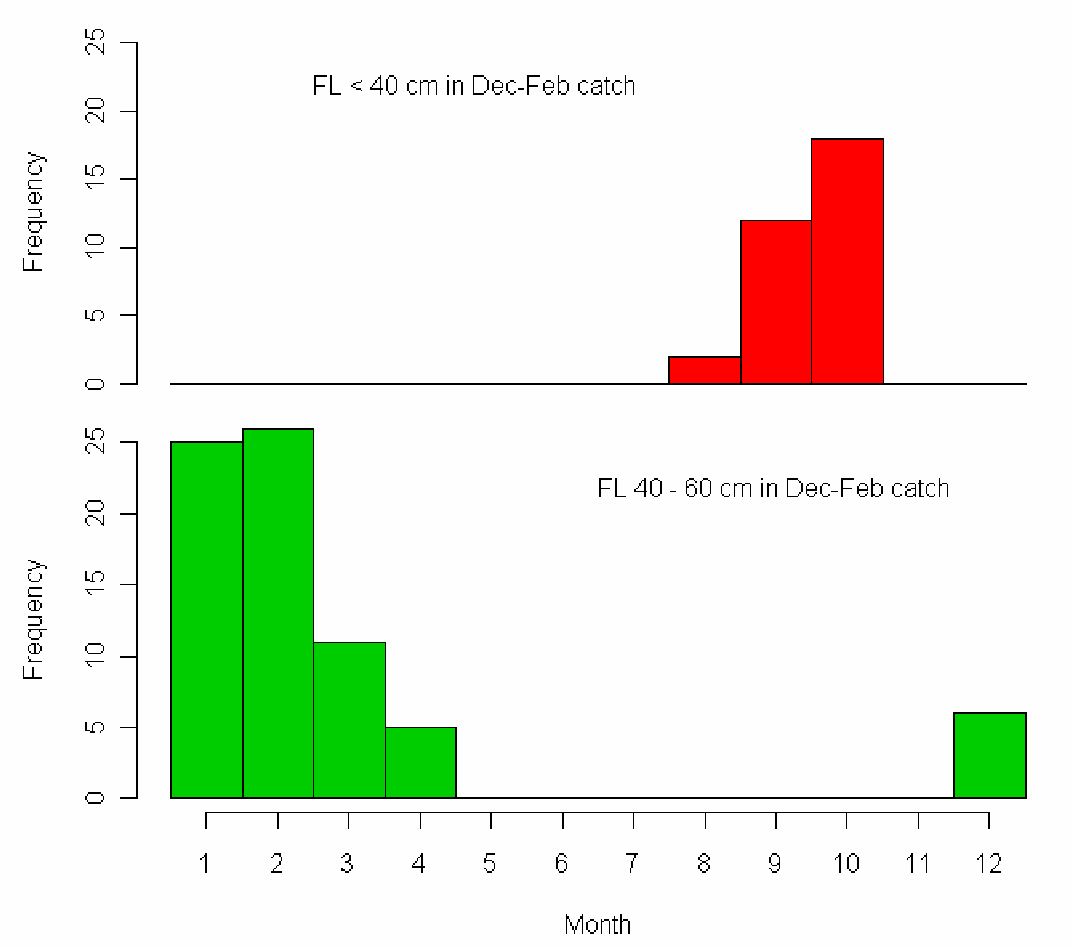

Fig. 2. Frequency of month of fertilized estimated from otolith daily increments for southern bluefin tuna in Western Australia. Upper panel; fish less than 40 cmFL (N=32). Lower panel; fish 40-60 cmFL (N=73). The data are from Itoh and Tsuji (1996).

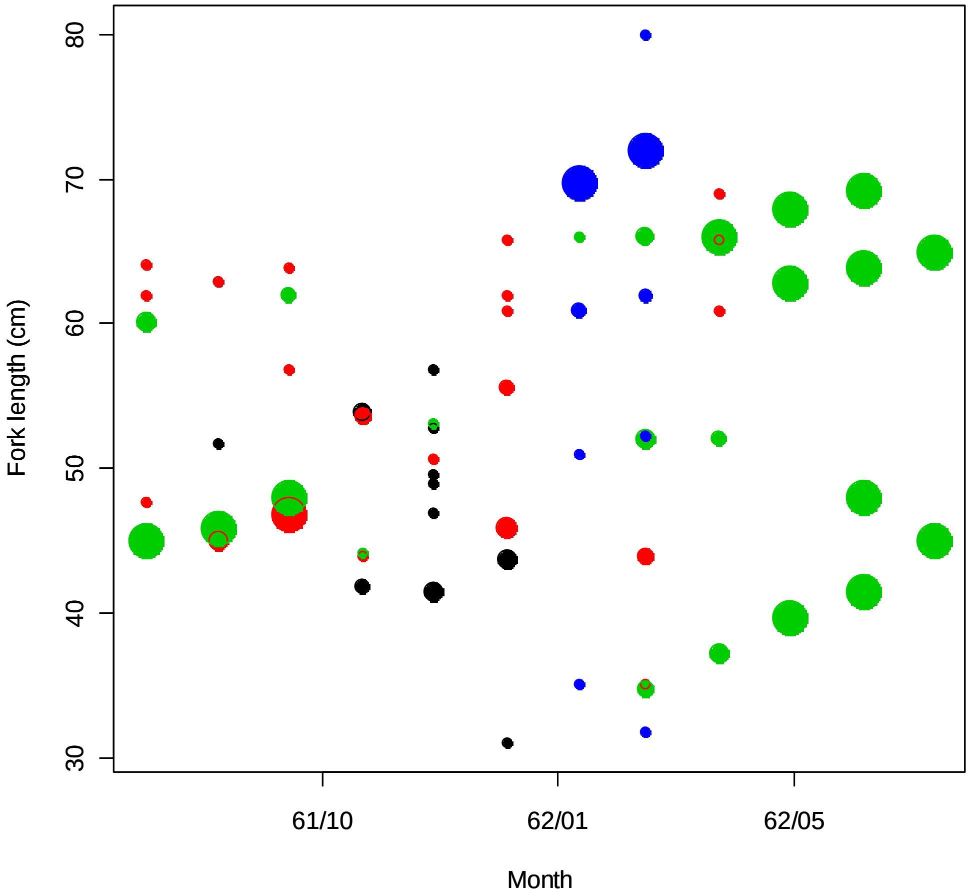

Fig. 3. Modes of body length of southern bluefin tuna in Western Australia in a month. Data are from Figure 5 in Hynd (1965). Different colors show different areas (black: Jurien Bay to Cape Naturaliste, red: Cape Naturaliste to West Cape Howe, green: West Cape How to Bald Islands, blue: Bald Islands to Israelite Bay). Size of circle corresponds to the number of individuals, which is same in size for more than 10 individuals.

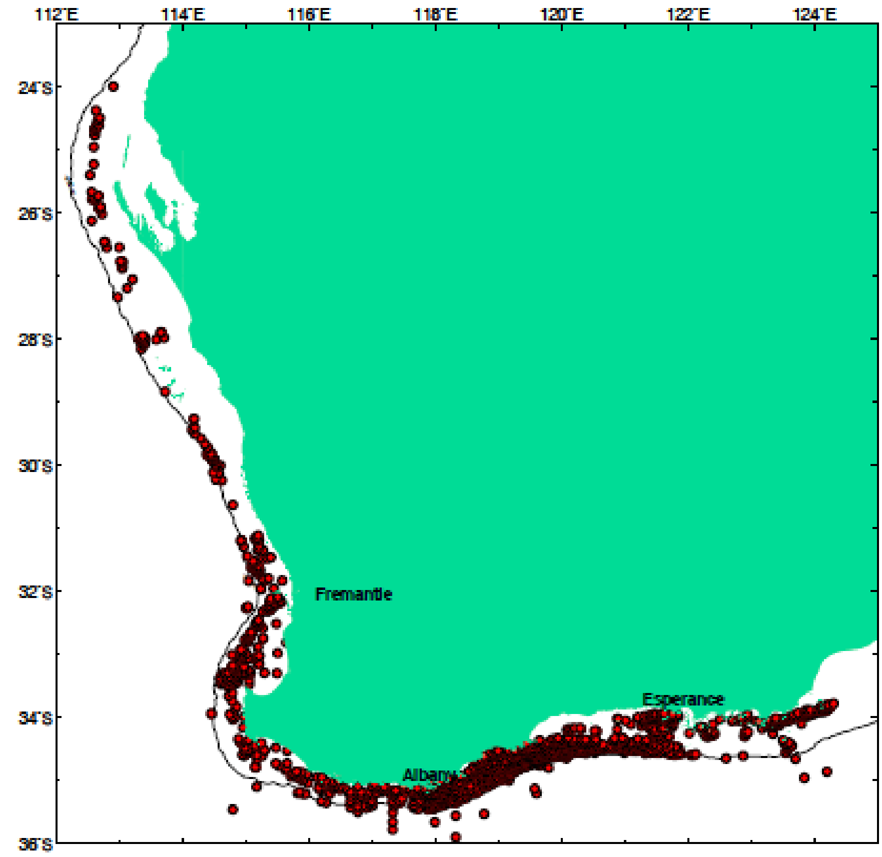

Fig. 4. Location of size data collected for southern bluefin tuna in Western Australia. 200 m isobath is drawn.

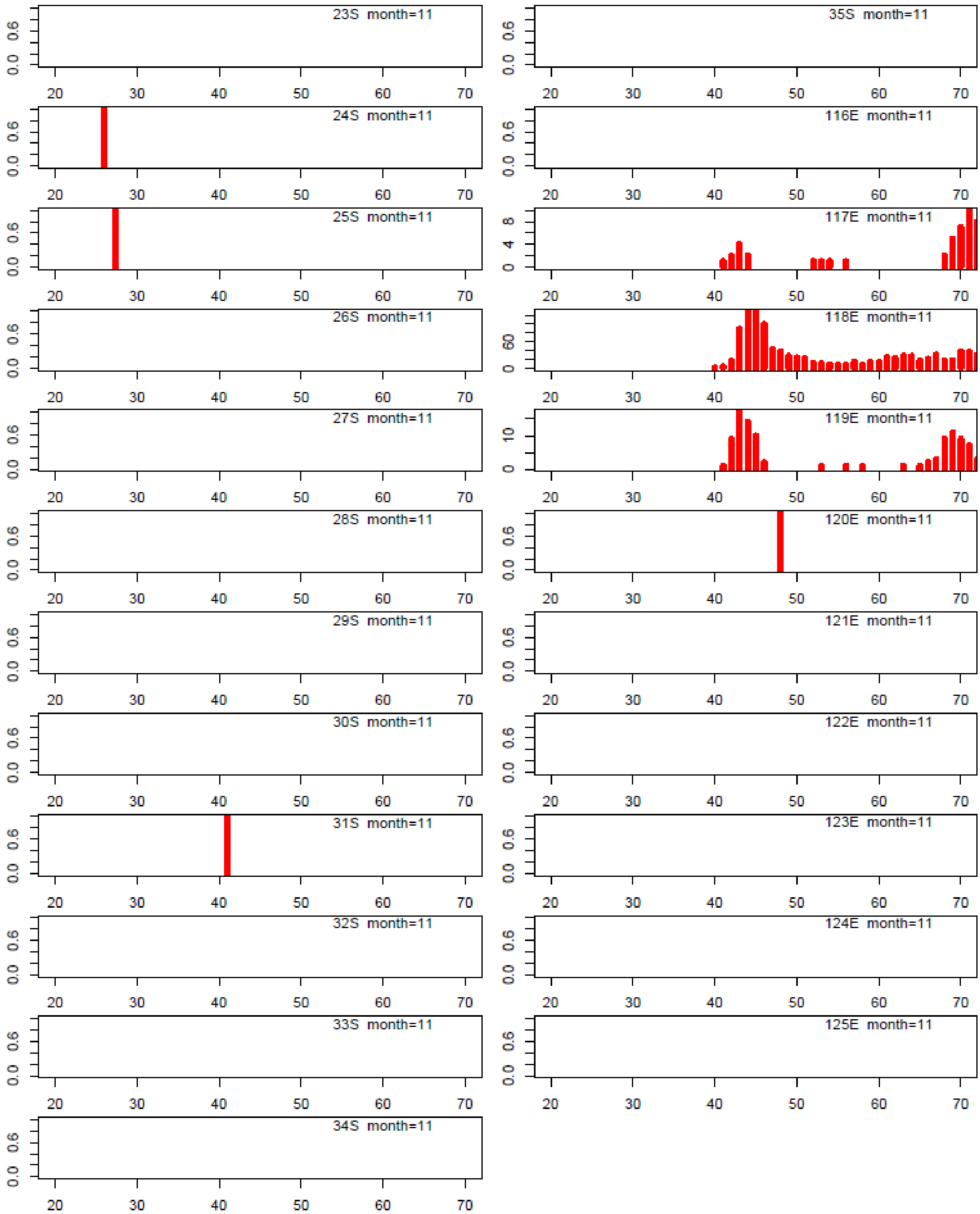

Fig 5. Fork length frequency distributions of southern bluefin tuna in Western Australia by month and area. (November)

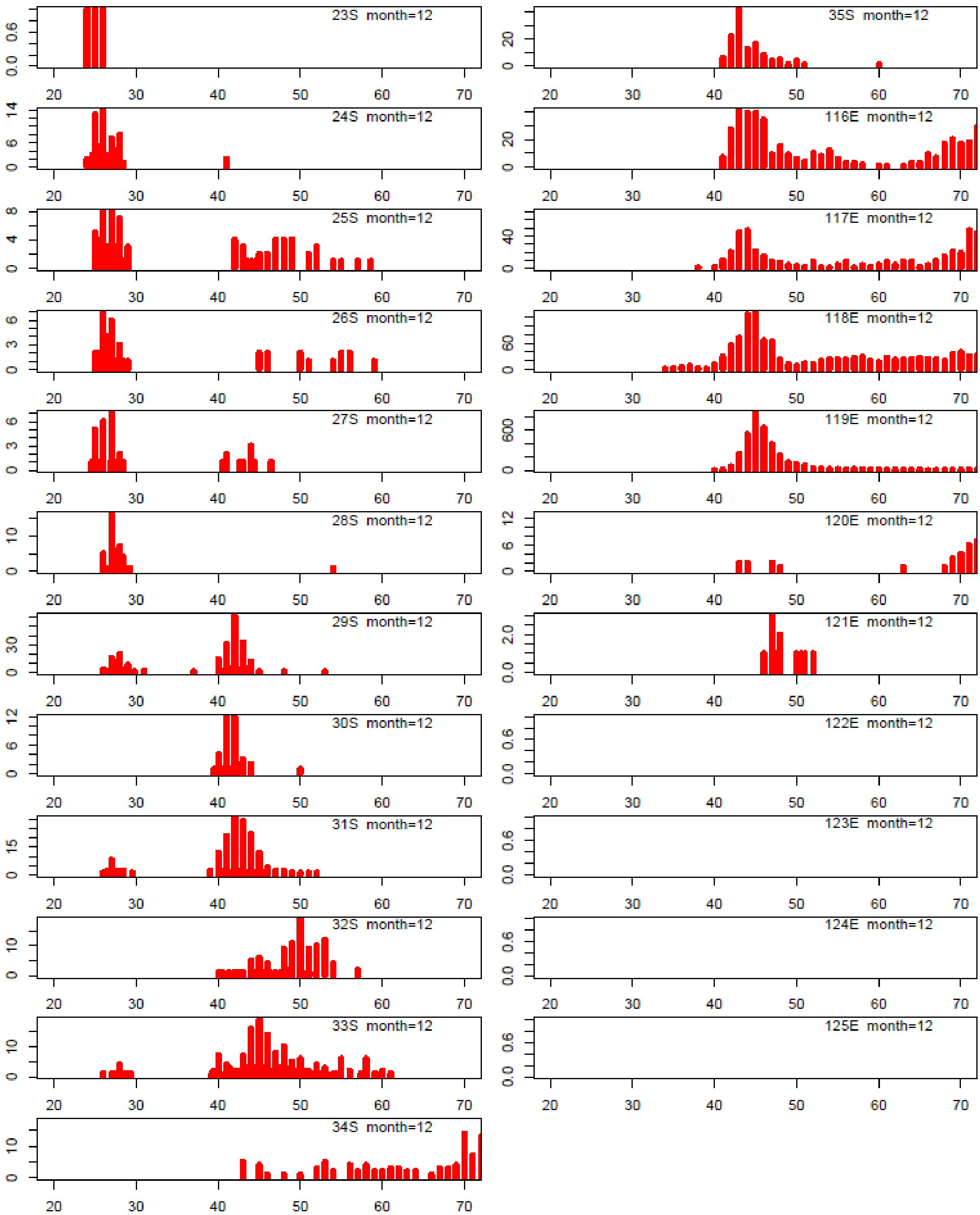

Fig 5. (Cont'd) (December)

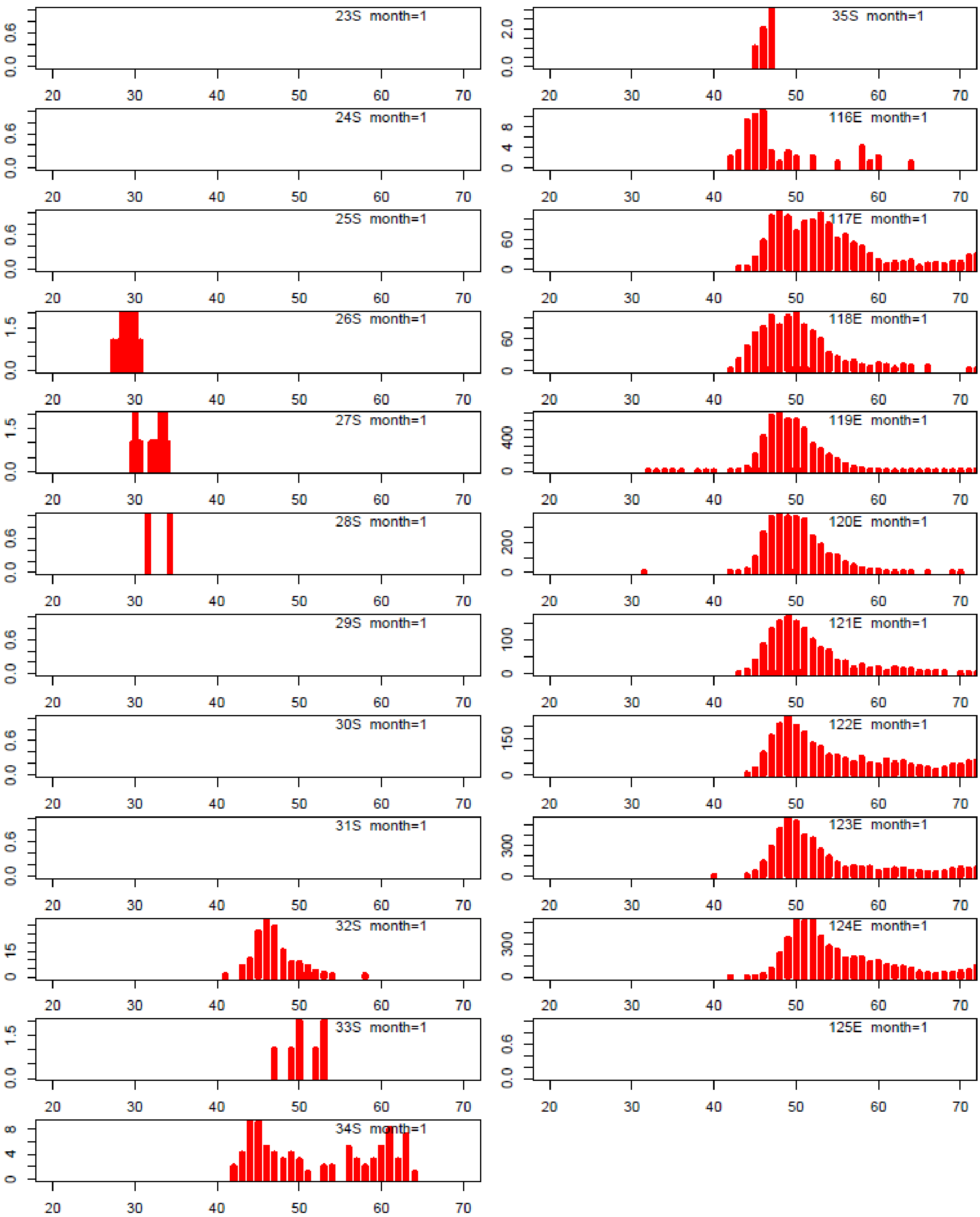

Fig 5. (Cont'd) (January)

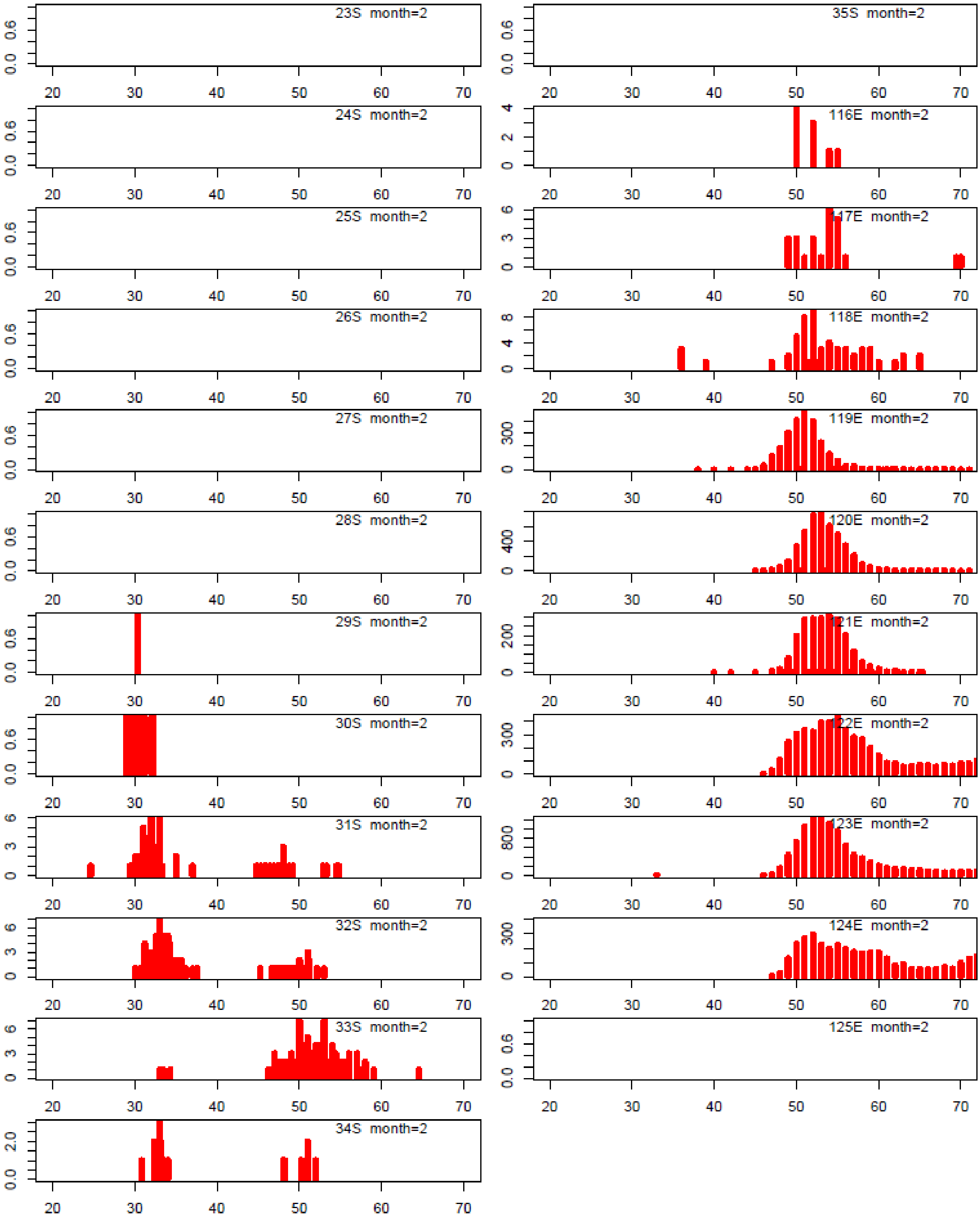

Fig 5. (Cont'd) (February)

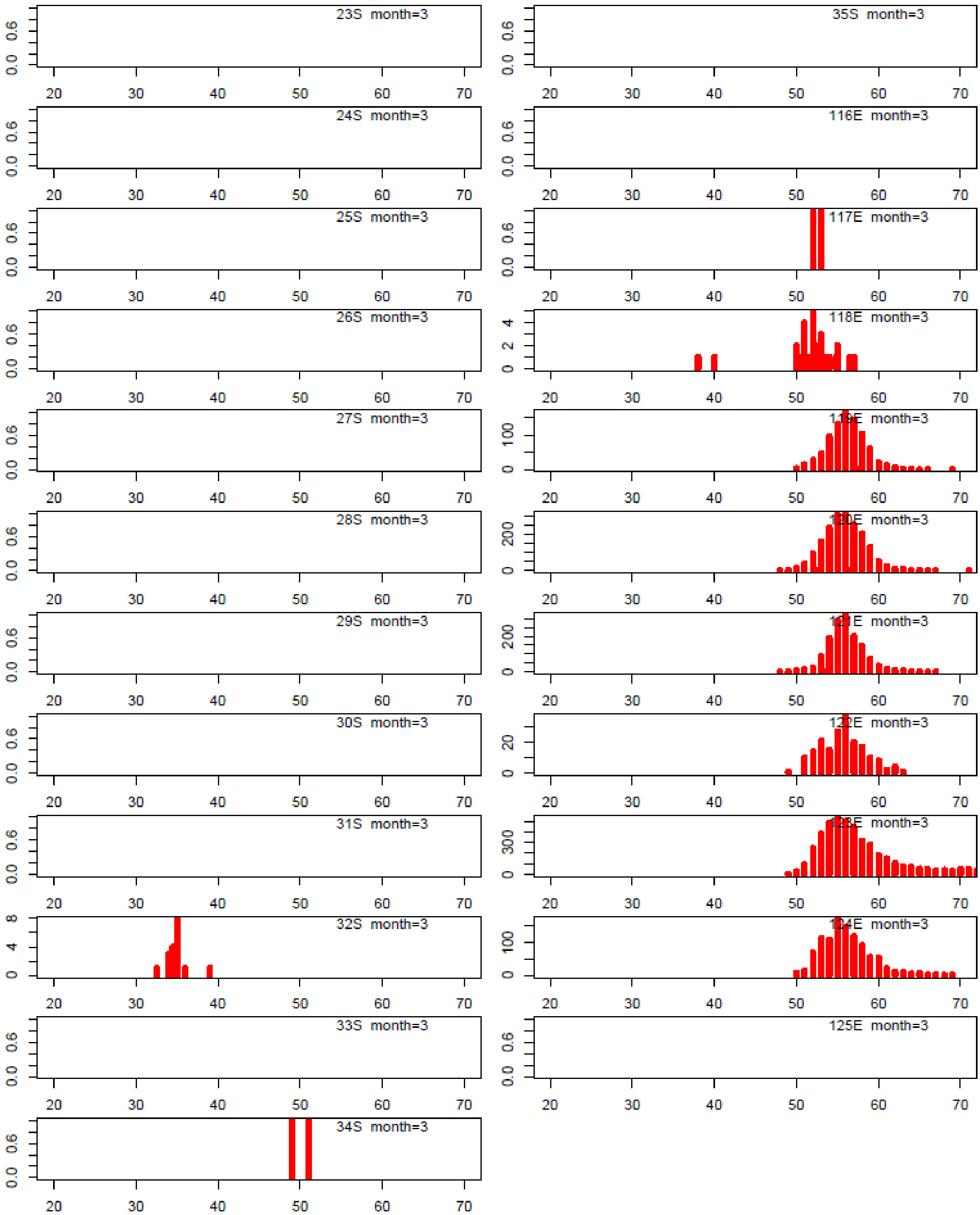

Fig 5. (Cont'd) (March)

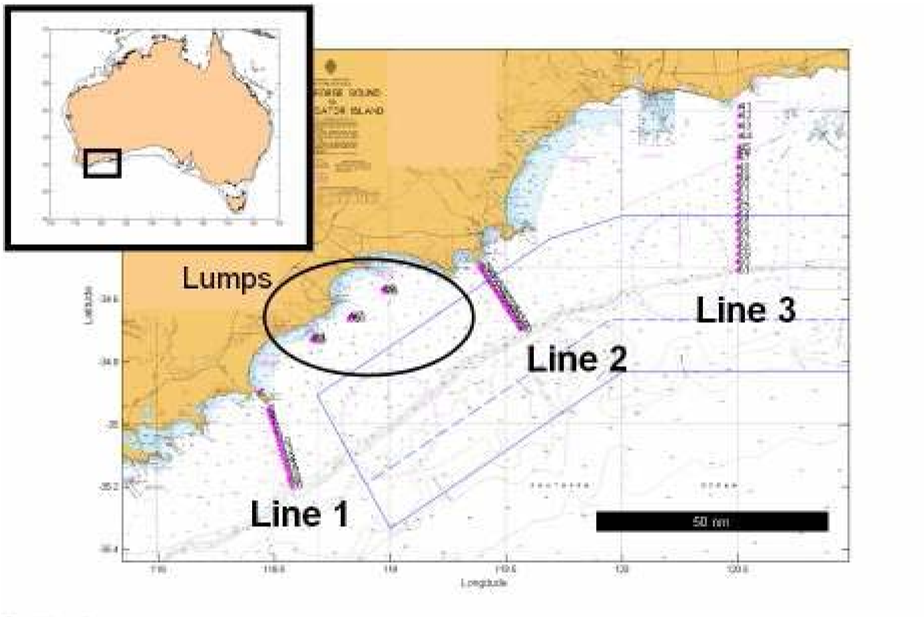

Fig. 6. Locations of listening stations in the southern bluefin tuna acoustic monitoring experiment in southern Western Australia. The acoustic survey area is inside the blue polygon, the dashed line represents the outer boundary of the survey in the years 2002-03. (Referring to Hobday et al. 2008)

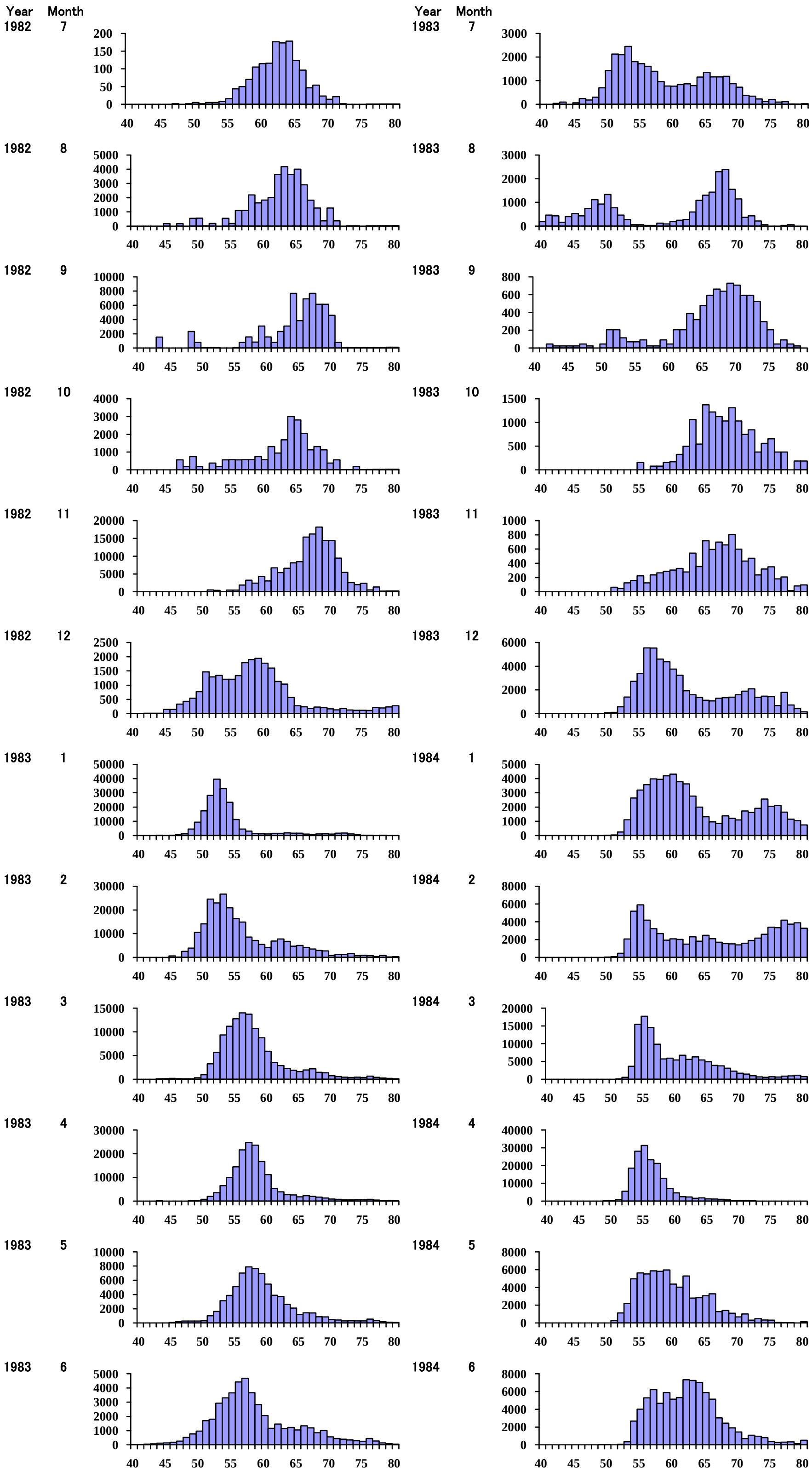

Fig. 7. Fork length frequency distributions of southern bluefin tuna in Western Australia caught by commercial pole-and-line fishery by month and area. Data are from CCSBT size database. Referring to Itoh and Tsuji (2004).

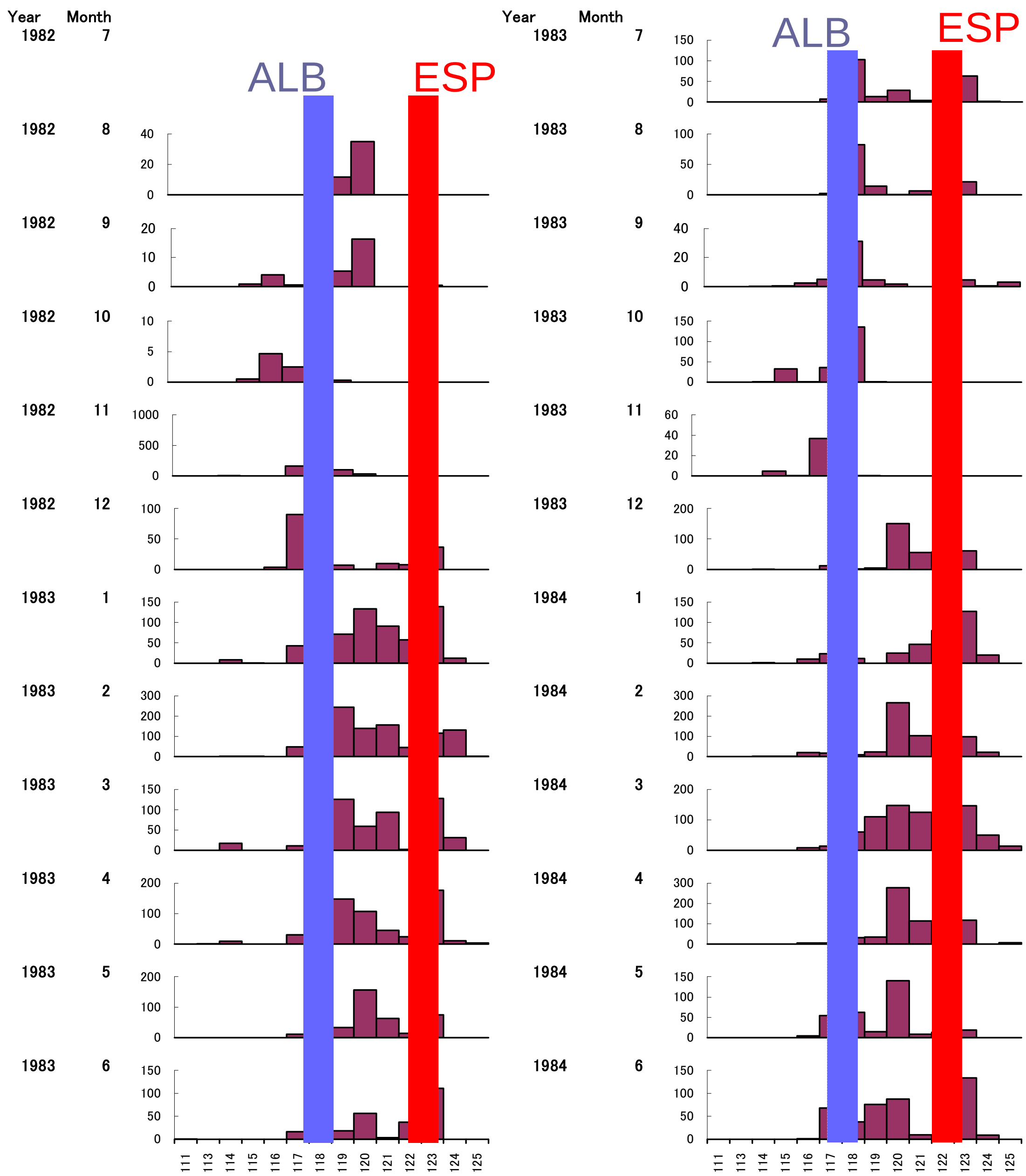

Fig. 8. Catch in ton of southern bluefin tuna caught by commercial pole-and-line fishery in Western Australia by longitude. Albany is on 118E, Esperance is on 122E.Data from catch and effort database of CCSBT. Referring to Itoh and Tsuji (2004).