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Vertical Distribution of Juvenile Skipjack Tuna *Katsuwonus pelamis* in The Tropical Western Pacific Ocean

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Abstract

The vertical distribution of juvenile skipjack tuna *Katsuwonus pelamis* was investigated in the tropical western Pacific (0-25°N and 130-160°E) based on midwater trawl sampling from October to December in 1992 to 1996. Most juveniles were sampled between depths of 40 and 120 m, that is, at depths ranging immediately above and below the thermocline, and at temperatures between 20 and 30°C. Relatively lower temperatures were observed in the pelagic zone of the research area from 1992 to 1994 (period of a shallow thermocline), in contrast to relatively higher temperatures from 1995 to 1996 (with a deep thermocline). The vertical distribution of skipjack juveniles became shallower from 1992 to 1993, whereas it became deeper in 1995 and 1996. These findings suggest that the vertical distribution of skipjack tuna during the juvenile period changed annually relative to the vertical temperature profile. Moreover, fluctuations in vertical temperature are believed to affect the expansion or contraction of the vertical habitat of skipjack juveniles in the pelagic zone. The mean standard length of juveniles collected in 1994 at a depth of 80-100 m in the North Equatorial Counter Current area was significantly larger than that of juveniles collected at 40-60 m. These findings suggest that the vertical distribution of juvenile skipjack tuna becomes deeper in line with their growth.

Discipline: Fisheries
Additional key words: annual change, habitat, North Equatorial Current, North Equatorial Counter Current, thermocline

Introduction

The pelagic zone of the tropical Pacific Ocean is known as the main spawning ground of skipjack tuna *Katsuwonus pelamis* (Matsumoto et al. 1984). The region also ranks as the world's largest fishing ground of skipjack stock (FAO 2014). Distribution patterns and recruitment levels of skipjack tuna in the region fluctuate with large environmental changes, such as El Niño and La Niña (Bertignac et al. 1998, Lehodey 2001, Lehodey et al. 1997, Lehodey et al. 1998, Lehodey et al. 2003). To explore this phenomenon, research must be conducted on the early life ecology of this species. Previous studies have reported that tuna larvae no longer than 10 mm (and less than 10 days old after hatching) are mainly distributed in the epipelagic zone of the depth above 60 m, where the sea surface temperature is higher than 24°C (Strasburg 1960, Ueyanagi 1969). However, very little is known about the vertical and

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horizontal distributions of skipjack tuna during the juvenile period, largely due to their ability as strong swimmers that makes them difficult to collect with the standard nets used to sample small micronekton (Tanabe et al. 2001). Clarifying such biological information as distribution, movement, growth and survival during the juvenile period is essential for understanding the recruitment process of this species in the tropical ocean. The objective of this study was to identify the vertical distribution of juvenile skipjack tuna longer than 10 mm (and more than 10 days old after hatching) relative to oceanographic conditions, and thus contribute to the advancement of recruitment studies on this species in the tropical western Pacific Ocean.

Materials and Methods

1. Field sampling and observation

Sampling was conducted in the area between 0-25°N and 130-160°E from late October to early December during 1992 and 1996 (Fig. 1). The fisheries training ships *Tanshu-Maru* from Kasumi Senior High School and *Omi-Maru* from Yamaguchi Fisheries High School were chartered by the Fisheries Agency of Japan for the 1992-1993 and 1994-1996 cruises, respectively. A midwater trawl net (TANSYU-type, Nichimo Co. Ltd., Japan) was used in this study, measuring about 72 m in total length with a mouth opening of 20 x 20 m, coupled with an 8 x 8 mm mesh at its cod end (Tanabe & Niu, 1998). The net was towed horizontally for one hour at 1.8-2.6 m/s (3.5-5 knots) at various times during both the day and night. The net was towed at three to six different depths, randomly chosen between 0 and 300 m at 15 to 31 stations, except in 1994 (Table 1). In 1994, tows were made at 40-60 m and 80-100 m at 27 stations. Sampling depth was simultaneously monitored by an acoustic net-depth recorder (FNR-200, Furuno Electric Co., Ltd., Japan) attached to the head rope of the net. The trawl net was not equipped with opening–closing devices; consequently, samples were contaminated with material from the upper portion of the water column. To minimize this contamination, the ship speed was slowed to 1.0-1.5 m/s (2-3 knots), thereby reducing the channeling effect of the otter boards during casting and retrieval of the trawl (Watanabe et al. 1999). The volume of water filtered by the net was calculated from the estimated mouth area and the towing distance at each operation.

Each sample was weighed and sorted into skipjack,

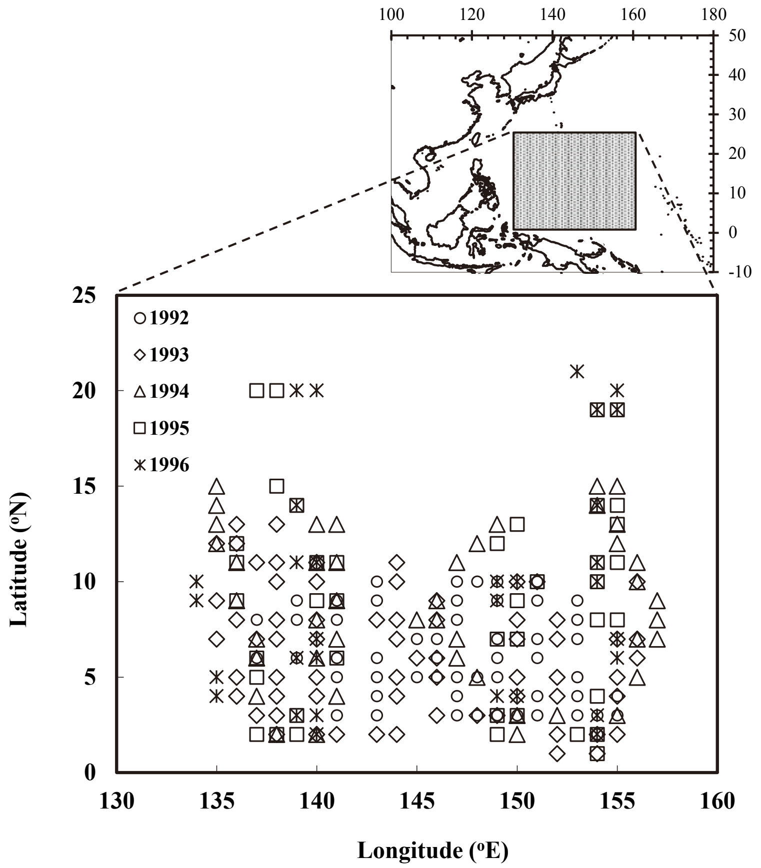

Fig. 1. Sampling locations in the tropical western Pacific Ocean during October and December 1992-1996.

Table 1. Number of the midwater trawl net tows at each depth stratum during October and December, 1992-1996

NEC area	1992		1993		1994		1995		1996	
	D	N	D	N	D	N	D	N	D	N
0-20 m							1			
20-40 m	1			1			2	2		3
40-60 m		2	2	1	7	9	2	3	1	1
60-80 m		1	1	1			2	2	1	2
80-100 m		1	2	4	4	8	1	2		2
100-120 m			2					2	1	2
120-140 m				2				1	1	2
140-160 m			1	1						
160-180 m							1	2	1	1
180-200 m							1	2	2	2
200-300 m									2	2

NECC area	1992		1993		1994		1995		1996	
	D	N	D	N	D	N	D	N	D	N
0-20 m	1	5	1	4			1	2		1
20-40 m	1	11	5	5			2	2		2
40-60 m		18	4	8	17	16	3	2		3
60-80 m	4	11	3	7			1	4		
80-100 m	3	7	6	7	13	16	2	3	2	3
100-120 m	2	3	3	7			2	2	2	2
120-140 m		2	2	4			1	3	2	1
140-160 m	1		2	2			1	2	2	2
160-180 m		1	1	2				2	1	1
180-200 m	1		2	2				4	1	1
200-300 m									3	3

NEC: North Equatorial Current; NECC: North Equatorial Counter Current; D: Day; N: Night.

other tuna juveniles, and other major taxa. Tuna specimens were counted and preserved in 80% ethanol. Temperature and salinity data were obtained by a conductivity-temperature-depth profiler (CTD; SBE-19, Sea-Bird Electronics, Inc., USA) from the surface down to 1000 m at each sampling station. Velocity data from the acoustic Doppler current profiler (ADCP; CI-30, Furuno Electric Co., Ltd., Japan) were collected at two-minute intervals at 10, 50, and 100 m during the cruises in 1995 and 1996.

2. Laboratory treatment of samples

After each sampling cruise, the standard length (SL) of juvenile skipjack tuna was measured to the nearest 0.1 mm with calipers. Juvenile skipjack tuna was identified according to Matsumoto et al. (1984). The number of juveniles caught (Cj) in each tow was corrected by the following equation:

$$Cj = N / (A \times L)$$

where N denotes the number of juvenile skipjack tuna collected, A the estimated area of the mouth of the trawl net, and L the distance of each net tow. Cj at the 20-m interval depth strata with temperature profiles was used for comparisons of the vertical distribution of juveniles among the sampling years and study areas. Cj was also compared between day and night samples. The length data of juveniles were also analyzed for a comparison between day and night, and among the sampling depth strata in this study.

Results

1. Oceanographic conditions

ADCP data confirmed the existence of westward and eastward currents to the north and south of 10°N (Fig. 2). Based on the ADCP measurements, the study area was divided into two sub-areas: the North Equatorial Current (NEC) area north of 10°N and the North Equatorial Counter Current (NECC) area south of 10°N. The vertical distribution of juvenile skipjack tuna estimated by using the midwater trawl sampling data was compared between both areas.

The surface zone of the study area was characterized by waters of higher temperature (28-30°C) and lower salinity (around 34 PSU) (Fig. 3). Relatively lower temperature (< 12°C at 200 m) was observed around 7-8°N, indicating the existence of an upwelled water mass from a deeper zone in the equatorial region of the Pacific Ocean (Mann & Lazier 2006). Drastic changes in salinity were found at 4-5°N and 11°N, indicating the formation of salinity fronts. Waters of lower temperature appeared in the pelagic zone of the sampling area from 1992 to 1994 (period of a shallow thermocline), whereas waters of relatively higher temperature were found from 1995 to 1996 (with a deep thermocline). The Japan Meteorological Agency reported lower values (between -1.4 and 0.2) of the Southern Oscillation Index (SOI) during the research period from 1992 to 1994, in contrast to relatively higher SOI values (between -0.1 and 0.7) that were reported in 1995 and 1996 (http://www.data.jma.go.jp/gmd/cpd/data/elnino/index/soi.html). Thus, the annual change in temperature in the pelagic zone of the sampling area seems to be reflected by El Niño Southern Oscillation (ENSO) events.

2. Vertical distribution of juvenile skipjack tuna

Juvenile skipjack tuna was collected at depths between 0 and 240 m. Most of the juveniles were sampled at depths between the lower part of the mixed layer to the upper portion of the thermocline (between depths of 40 and 120 m). In Fig. 4, (a) plots Cj indices larger than 1.0 with temperature at the sampling depth. Skipjack juveniles were frequently collected at temperatures between 20 and 30°C. These findings suggest that differences in the number of tows at the depth stratum, for example, absent of a net tow at depths deeper than 160 m in the NEC area in 1992 and 1993, need not be considered in analyzing the vertical distribution of juvenile skipjack tuna in the present study. In Fig. 4, (b) shows that the temperature frequency distribution at depths of the midwater trawl net tows indicated peaks at 26-28°C in the NEC area, and at 28-30°C in the NECC area.

The vertical distribution of juveniles varied annually, but became shallower from 1992 to 1993 (Fig. 5). In the NECC area, the maximum Cj was observed at a depth of 80-100 m in 1992 and at 40-60 m in 1993 during both the day and night. In contrast, their vertical distribution became deeper in 1995 and 1996. The upper-limit depth of the thermocline also became shallower from 1992 to 1993 and deeper in 1995 and 1996. These results suggest that the

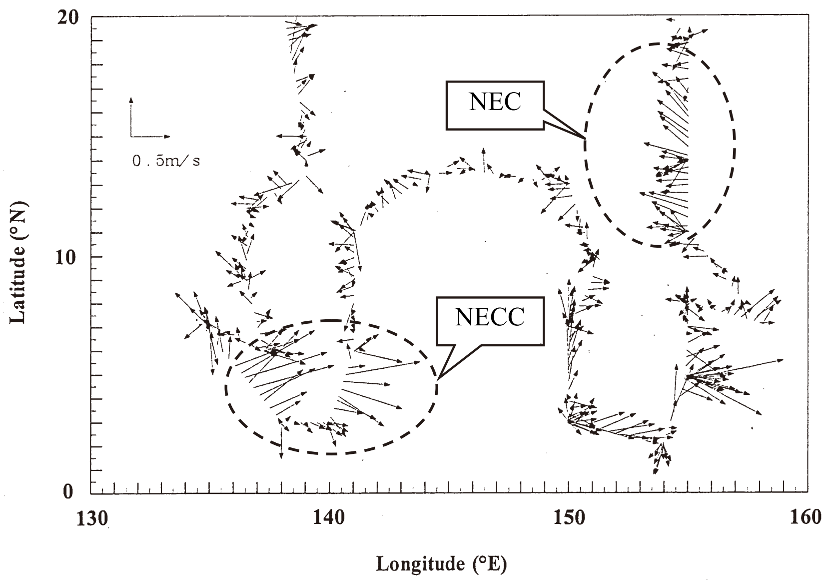

Fig. 2. Current direction and speed at 100-m depth as measured by the ADCP during October and December 1995. The North Equatorial Current (NEC) and the North Equatorial Counter Current (NECC) were observed to the north and south of 10°N, respectively.

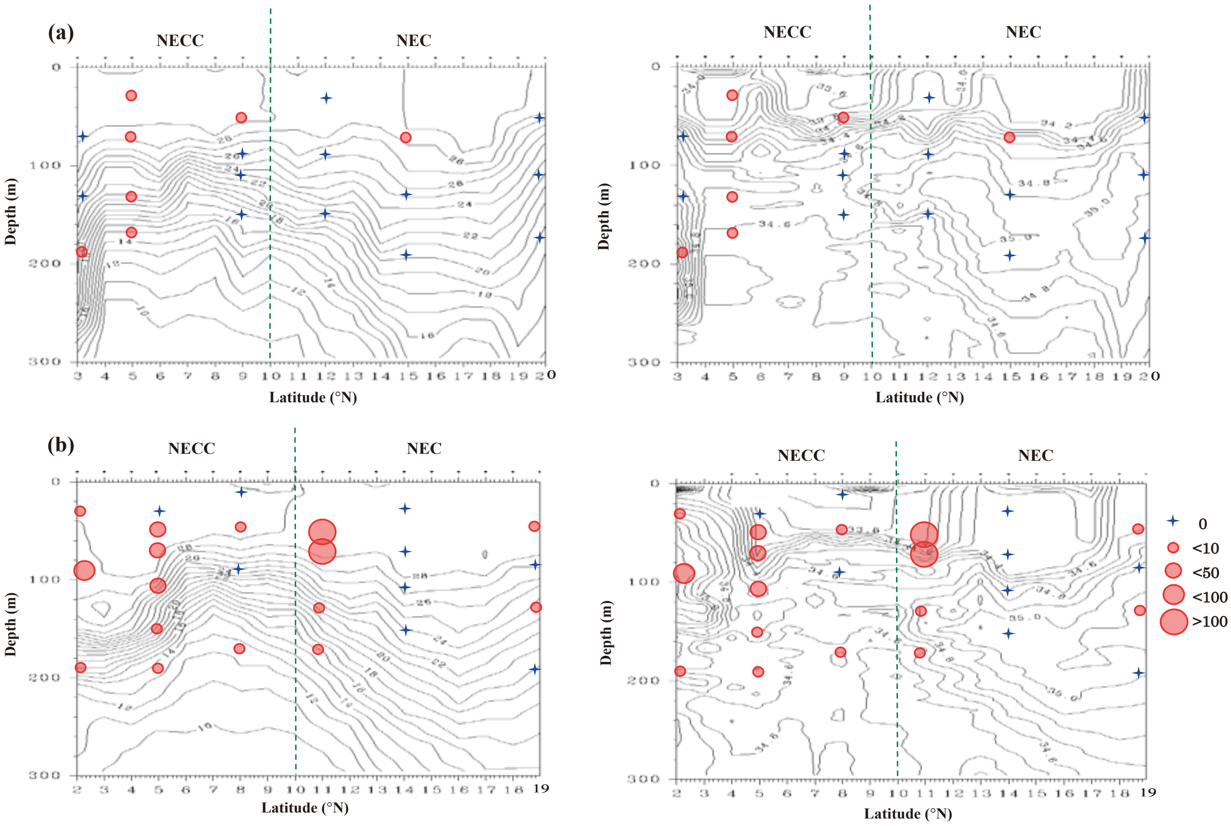

Fig. 3. Vertical distributions of temperature and salinity along the western (a: 3-20°N, 136-139°E) and eastern (b: 2-19°N, 154-155°E) transects in 1995.
Circles indicate catches of juvenile skipjack tuna. Crosses indicate no catches of juveniles.

vertical distribution of juvenile skipjack tuna varies relative to the vertical distribution of temperature.

Cj in the NEC area was relatively lower than that in the NECC area (Wilcoxon rank sum test, $p < 0.05$). Annual changes in the vertical distribution of juveniles in the NEC area could not be examined as a sufficient number of juveniles was not collected from the area. The same depths of the maximum Cj between the day and night in the NECC area in 1992, 1993, and 1994 were observed. Based on these findings, this study did not recognize a diel change in the vertical distribution of juvenile skipjack tuna. The highest Cj throughout the sampling years was obtained at 60-80 m in the NEC area and at 80-100 m in the NECC area during the day in 1995. A large number of juveniles was collected from the area near the salinity fronts located at 5°N and 11°N in 1995 (Fig. 3).

3. Length of juvenile specimens

Most of the juveniles were between 10 and 50 mm in SL during the research period (Fig. 6). Juveniles longer than 100 mm in SL (large juveniles) were collected only at night in the NECC area from 1992 to 1994. A small number of large juveniles was found at 40-60 m and 60-80 m in 1992, at 40-60 m in 1993, and at 40-60 m and 80-100 m in 1994. The lengths of juveniles collected at night in the NECC area were significantly longer than those of juveniles collected during the day (Welch t-test, $p < 0.001$). A relatively small number of juveniles was collected from the NEC area, with no significant difference being observed in juvenile size between day and night specimens collected in the area (Welch t-test, $p > 0.05$). In the NECC area in 1994, the lengths of juveniles collected at 80-100 m were significantly longer than those of juveniles collected at 40-60 m during both the day and night (Welch t-test, $p < 0.01$, Fig. 7). In 1995, the lengths of juveniles increased at depths ranging from 20-40 m to 100-120 m during the day. However, those tendencies were not seen in 1993. At night, the largest mean length of juveniles was observed at 40-60 m in 1992, at 100-120 m in 1993, at 20-40 m in 1995, and at 80-100 m in 1996.

Discussion

Skipjack larvae were abundantly distributed at a depth between 20 and 60 m (Boehlert & Mundy 1990, Davis et al. 1990, Strasburg 1960, Ueyanagi 1969). Higgins (1970)

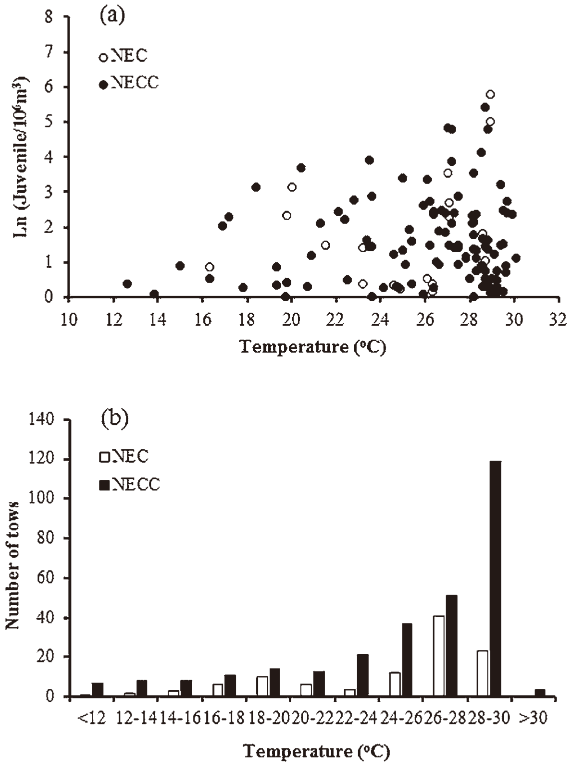

Fig. 4. Catch of juvenile skipjack tuna at sea temperature of the sampling depth in the North Equatorial Current (NEC, open circles) area and the North Equatorial Counter Current (NECC, solid circles) area (a).

Data on the Cj index (number of juveniles caught at each tow of 10^6 m^3 filtered seawater) larger than 1.0 was used in Figure 4 (a). Temperature frequency distribution at depths for all the midwater trawl net tows in the NEC and NECC areas (b).

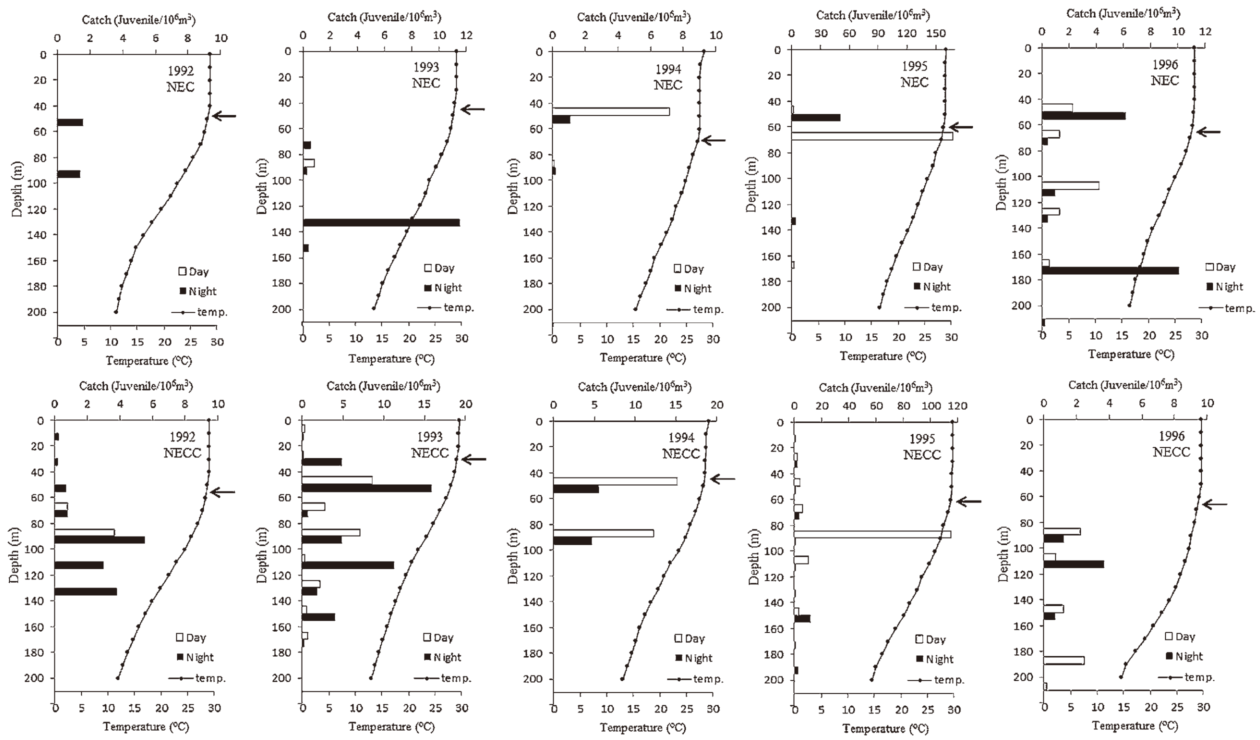

Fig. 5. Vertical distribution of juvenile skipjack tuna in the North Equatorial Current (NEC) area and the North Equatorial Counter Current (NECC) area in the tropical western Pacific Ocean.

Mean temperatures are plotted in each sampling depth stratum. Arrows indicate the upper limits of the thermocline.

described that the distribution depths of skipjack tuna during the early life period increased in line with their growth. In our research, skipjack juveniles were mainly collected at depths between 40 and 120 m. The mean SL of juveniles collected at 80-100 m in the NECC area in 1994 was significantly longer than that of juveniles collected at 40-60 m. These findings suggest that the vertical distribution of skipjack tuna becomes deeper with the development from larvae to juveniles. With growth, their bodies may be able to better tolerate lower temperatures in the deeper zone. The development of swimming ability along with growth might result in a vertical expansion of their habitat and possible

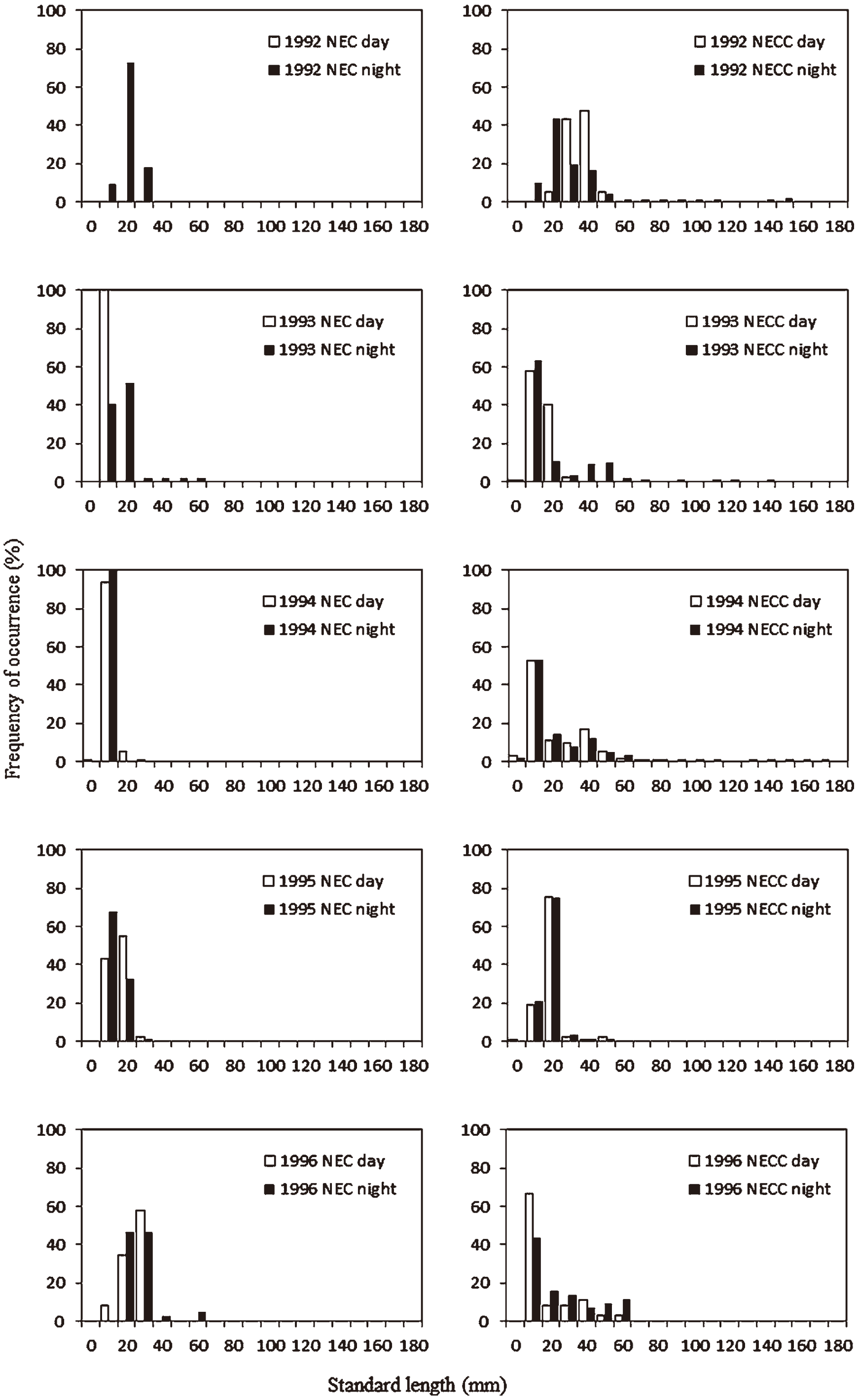

Fig. 6. Length frequency distributions of juvenile skipjack tuna collected by the midwater trawl net in the North Equatorial Current (NEC) area and the North Equatorial Counter Current (NECC) area during October and December 1992-1996.

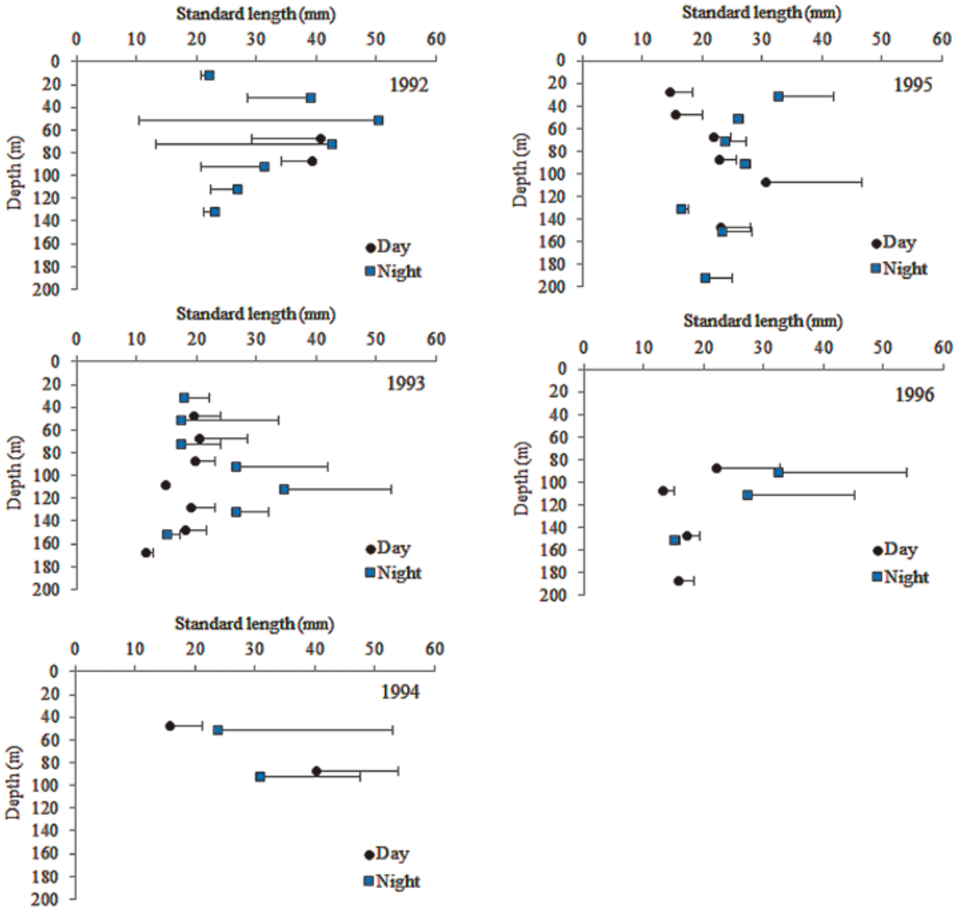

Fig. 7. Mean lengths with standard deviations of juvenile skipjack tuna by depth strata in the North Equatorial Counter Current (NECC) area from 1992 to 1996.

food utilization.

Diel vertical migration of juvenile skipjack tuna was not recognized in the present study. During the larval period, diel changes in the vertical distribution of skipjack tuna were reported in early studies (Strasburg 1960, Higgins 1970). However, Boehlert & Mundy (1990) later described that diel vertical migration was not evident for skipjack and other tuna larvae. They used a 1-m^2 multiple opening-closing net and an environmental sensing system (MOCNESS) for sampling tuna larvae, and thus the development of sampling gear could achieve advances in research on the early life of tuna.

The vertical distribution of larval skipjack tuna relative to the vertical temperature profile was reported by Strasburg (1960), Boehlert & Mundy (1994), and Davis et al. (1990). However, those past studies did not report on the relationship between the vertical distribution of larvae and the annual changes in temperature profiles. In our study on juveniles, skipjack tuna was preferably distributed in waters ranging in temperature between 20° and 30°C, and their vertical distribution varied in relation to annual fluctuations in the vertical temperature profiles. These findings support a conclusion that fluctuations in temperature affect the vertical range in the pelagic zone of the tropical ocean relative to the habitat of juvenile skipjack. Therefore, the sampling of larval and juvenile tuna should be planned and conducted in consideration of annual changes in temperature distribution. Differences in the vertical distribution between the NEC and NECC areas were not examined in this study due to the limited catch of juveniles in the NEC area. However, a similar tendency was observed regarding the annual change in the total catch of juveniles. A common relationship between the vertical distribution of juvenile skipjack tuna and the vertical temperature profiles apparently exists in northern and southern areas of the tropical western Pacific.

The mouth opening and towing speed of sampling gear are important determinants of the size of tuna catches in their nursery grounds (Tanabe & Niu 1998). Previous studies have reported that the lengths of specimens caught by using larval nets having a mouth opening of 1-2 m, a mesh size smaller than 1 mm, and at a towing speed of 1.5-2 knots were mostly less than 10 mm in SL (Nishikawa et al. 1978, Strasburg 1960). The present study showed that a midwater trawl net having a 20 x 20 m mouth opening with an 8 x 8 mm mesh at its cod end, and moving at a towing speed of 3.5-5 knots was effective for collecting juveniles between 10 and 50 mm in SL. A limited number of specimens longer than 100 mm in SL was collected by the midwater trawl net, indicating that larger juvenile skipjack tuna tended to avoid the net.

The daily growth rate during the early life period of skipjack tuna increases remarkably from the larva to juvenile stages (Tanabe 2002). The relationship between the growth of juvenile skipjack tuna and their distribution depth was not examined in this study. However, the growth rate and survival opportunities in the early life period of skipjack tuna might be influenced by an expansion or contraction of its vertical habitat caused by such large environmental events as El Niño and La Niña. Therefore, further study on the early life ecology of skipjack tuna should focus on the relationship between the spatial and temporal distribution patterns of juvenile skipjack tuna and large-scale oceanographic fluctuations, in order to better understand the recruitment process of this species in the tropical ocean.

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