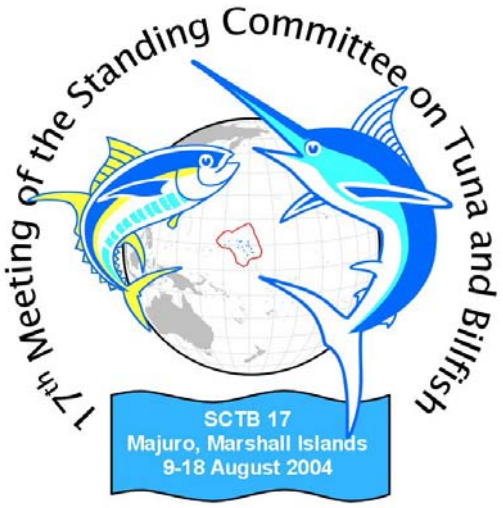

SCTB17 Working Paper

BIO–7

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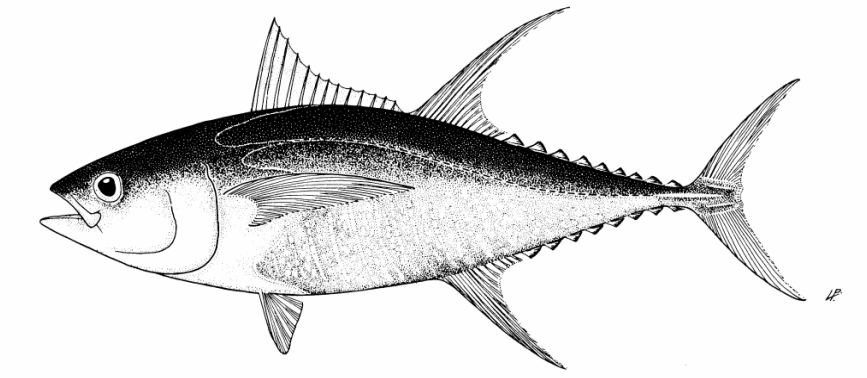

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Movements and stock discrimination of skipjack tuna, *Katuwonus pelamis*, in the western Pacific by otolith Sr:Ca ratios

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Abstract

The strontium (Sr) and calcium (Ca) concentrations in the otoliths of the skipjack tuna *Katsuwonus pelamis*, collected in the western Pacific Ocean were examined by wavelength dispersive X-ray spectrometry on an electron microprobe. Otolith Sr:Ca ratios of the tuna collected off Marshall Islands were kept to be constant throughout the otolith. In contrast, the rates of most tuna collected off Sanriku in October fluctuated from low to high in 1300-1800 μm points from the core. The similar fluctuation of otolith Sr:Ca ratio was found in a tagged skipjack tuna off Sanriku, and thereafter recaptured off Palau Islands being low to high in the ratio. Therefore, at least two migratory routes of the skipjack of both global migration toward northern temperate regions and local movement remaining around tropical regions, are suggested in the western Pacific Ocean.

Introduction

Skipjack tuna Katsuwonus pelamis is a highly migratory pelagic species occurring in all tropical and subtropical waters of the world. The tuna spawns throughout the year, and after hatching, the tuna migrates globally from the equatorial spawning areas to the northern and southern temperate regions (Collette and Nauen 1983).

Migrations of skipjack tuna have been examined in the Pacific Ocean. Several migratory routes of the tuna have been reported, and there are a number of semi-independent stocks of skipjack tuna in the Pacific Ocean (Matsumoto 1974, 1975). Furthermore, Hilborn and Sibert (1988) suggested that a large number of skipjack tuna did not show the long-distance movement remained around tropical spawning area without movement toward the northern and southern temperate regions. Thus, its migratory pattern throughout its life cycle is variable and complicated. Information regarding individual migratory histories would provide basic knowledge for both fish migration studies and fishery management, allowing effective and sustainable use of skipjack tuna resources.

Otolith chemistry is increasingly used as a technique to differentiate stocks and reconstruct the migrate history of individual fish (Campana 1999, Arai 2002). Otoliths precipitate as the fish grows and elements from the individual's surroundings are integrated into the aragonite-protein matrix. Because otoliths are metabolically inert, resorption or remobilization of newly deposited elements during ontogeny is negligible. Therefore, the

chemical composition of otoliths may serve as natural tags or chemical signatures that reflect differences in the chemical composition of the individual's habitat. Recently, the approach has been used to assess stock specificity of tunas, and findings suggest that otolith elemental analysis has promise for assessing the population connectivity of pelagic stocks (Rooker et al. 2001).

The objectives of the present study are to examine the otolith Sr:Ca ratios in the skipjack tuna collected in the western Pacific Ocean. The results provide a basis for discussion of the movements and stock identification of the species.

Materials and Methods

Skipjack tuna were collected by the purse seine and the pole and line from both tropical (1-6 °N, 141-153 °E) and temperate (38-39 °N, 145-179 °E) waters during February and October, 2003 in western Pacific Ocean (Table 1). Surface water temperatures in the sampling site of tropical and temperate waters were 29.0 – 29.7 °C and 19.0 – 22.0 °C, respectively. A skipjack tuna, collected and tagged off Sanriku on 25 September 2002, and thereafter recaptured off Palau Islands on 3 June 2003, was involved in this study (Table 1). A total of 24 specimens were used in the present study, which included each 12 specimen from tropical and temperate waters. Fork length and body weight were measured (Table 1).

Sagittal otoliths were extracted from each fish, embedded in epoxy resin (Struers, Epofix) and mounted on glass slides. The otoliths were then ground to expose the core in the frontal plane, using a grinding machine equipped with a diamond cup-wheel (Struers, Discoplan-TS), and polished further with 6 μm and 1 μm diamond paste on an automated polishing wheel (Struers, Planopol-V). Finally, they were cleaned in an ultrasonic bath and rinsed with deionized water prior to being examined.

For electron microprobe analyses, all otoliths were Pt-Pd coated by a high vacuum evaporator. The life-history transect analysis of strontium (Sr) and calcium (Ca) concentrations were measured along the longest axis of each otolith from the core to the edge using a wavelength dispersive X-ray electron microprobe (JEOL JXA-8900R), as described in Arai et al. (1997). Calcite ($CaCO_3$) and strontianite ($SrCO_3$) were used as standards, and the accelerating voltage and beam current were 15 kV and 1.2×10^{-8} A, respectively. The electron beam was focused on a point 10 μm in diameter, with measurements spaced at 10 μm intervals.

Results

Life history transects of skipjack tuna off Marshall Islands

The Sr:Ca ratios measured along a transect from the core to the edge of the tuna samples collected on 14 February 2003 showed consistently Sr:Ca values of $5.06 \times 10^{-3} \pm 0.32 \times 10^{-3}$ (mean ± SD) suggesting continuous residence in a tropical habitat after hatching (Fig. 1A). Otolith Sr:Ca ratios collected on 13 September showed also constant Sr:Ca values, while the mean values was different among samples (Fig. 1B), i. e. four of six samples had higher values of $4.97 \times 10^{-3} \pm 0.05 \times 10^{-3}$ (mean ± SD) than those other two samples of $2.30 \times 10^{-3} \pm 0.05 \times 10^{-3}$.

Life history transects of skipjack tuna off Sanriku

Otolith Sr:Ca ratios in five of six specimens collected on 25 August 2003 showed consistently Sr:Ca values of $5.11 \times 10^{-3} \pm 0.32 \times 10^{-3}$ (mean ± SD). One maximum size(44.5 mm in fork length) of six specimens showed a lower Sr:Ca ratio phase from the core to a point around 1500 μm (Phase L), averaging 4.63×10^{-3}. Thereafter, the ratios increased, averaging 5.96×10^{-3}, and maintained at the higher levels until the outermost regions (Phase H, Fig. 1 C). A significant difference occurred between the Sr:Ca ratios between the Phase L and the Phase H (Mann-Whitney U-test, $p < 0.0001$). Four of six specimens collected on 16 October 2003 had a high Sr:Ca phase between the point 1300-1800 μm from the core to the otolith edge with a little drop around the edge (Fig. 1 D, Fig. 2). Significant differences were found in the Sr:Ca ratios between the former phase from the core to the point 1300-1800 μm (Phase L) (mean ± SD; $4.61 \times 10^{-3} \pm 0.27 \times 10^{-3}$) and the latter phase from the point 1300-1800 up to the edge (Phase H) (mean ± SD; $6.32 \times 10^{-3} \pm 0.38 \times 10^{-3}$) (Mann-Whitney U-test, $p < 0.0001$) in those specimens. Otolith Sr:Ca ratios in the other two small size (42.2 mm and 46.4 mm in fork length)of six specimens showed constant Sr:Ca values of $4.52 \times 10^{-3} \pm 0.06 \times 10^{-3}$ (mean ± SD).

Life history transects of skipjack tuna off Palau Islands

Sr:Ca ratios measured along a transect from the core to the otolith edge of a tagged and recaptured tuna showed a fluctuation pattern similar to that of four specimens off Sanriku collected in October (Fig. 1E). The tuna showed a lower Sr:Ca ratio phase from the core to a point around 1000 μm (Phase L), averaging 4.30×10^{-3}. Thereafter, the ratios increased, averaging 5.66×10^{-3}, and maintained at the higher levels until the outermost regions with a further increase in the ratio around 2500 μm (Phase H, Fig. 1E). A significant difference occurred in the Sr:Ca ratio between the Phase L and the Phase H (Mann-Whitney U-test, $p < 0.0001$). The fluctuation pattern of a sample from the same site showed similar to a tagged tuna with a significant difference occurred in the Sr:Ca ratios between the Phase L (4.46×10^{-3} in average) around 1500 μm from the core and the Phase H (5.76×10^{-3} in average) from the point up to the edge of otolith (Mann-Whitney U-test, $p < 0.0001$).

Discussion

In the present study, Sr:Ca ratios along the life history transect in the otoliths of the skipjack tuna, in the western Pacific Ocean, revealed the existence of two different Sr:Ca ratios patterns, suggesting the alternative two movement styles. Otolith Sr:Ca ratios of all tuna collected off Marshall Islands maintained constantly throughout the otolith. In contrast, most tuna collected off Sanriku in October had a transition point (TP) from Phase L to Phase H in the otolith Sr:Ca ratios and thereafter, maintaining constantly high Sr:Ca ratios toward the edge, although few tuna collected off Sanriku in August had a TP in their otoliths. Surface water temperature off Sanriku was about 10 °C less than that of off Marshall Islands (Table 1). The effect of temperature on otolith composition has been studied more than any other variable, and elements incorporated into aragonitic structures (corals, otoliths) appear to vary as a function of temperature. Substantial temperature effects have been reported

for several elements, most notably Sr (e. g., Kalish 1989, Townsend 1992, Hoff and Fuiman 1993). Salinity is also known to considerably affect Sr:Ca ratios in some diadromous fishes (Arai 2002), while the range of salinities that were presumably experienced by skipjack tuna may have been too small to warrant the pattern. In the present study, we could include a tagged and recaptured specimen. The tuna migrated from off Sanriku to off Palau Islands after tagging. It suggested that the tuna experienced both high and low temperature environments in the life. And, the fish had a TP from low to high Sr:Ca ratios in the life history transect of otolith. Therefore, difference in water temperature between tropical and temperate regions might affect the incorporation of Sr in the skipjack tuna otoliths as a indication of movement between the two different water masses. Another tuna collected off Palau Islands had a TP, thus the tuna might also migrate from north or south cooler temperate area. According to those results, the fluctuation pattern of otolith Sr:Ca ratio from low to high in the otolith of an individual skipjack tuna collected off Sanriku in October suggested that it migrated from tropical spawning area to frontal zone between warm Kuroshio Current and cool Oyashio Current, and further immigrated into Oyashio water being northward migration. The two smaller tunas (42.2 mm and 46.4 mm in FL) in October did not have a TP. This might due to these fishes still remain in the Kuroshio water without further northward migration into the Oyashio water. Few tuna collected off Sanriku in August had a clear TP. This might be as a result of timing; the fishes may have recently immigrated into the frontal zone off Sanriku without further northward migration into Oyashio Current. The largest tuna (44.5 mm in FL) in August had a TP. This fish might move across the frontal zone, and further migrate into Oyashio water. Nihira (1995) suggested that the skipjack tuna generally immigrated into Oyashio water moving across the frontal zone was more than 45 cm in FL after the enough feeding in the Kuroshio water. This migratory behaviour is almost consistent with the present result. According to those results, all fishes collected off Marshall Islands might remain in tropical area just before collection without northward or southward movement because no fish had a TP. These results lead to the conclusion that TP is a good indicator for the movement of the skipjack tuna.

A tagged skipjack tuna collected off Palau Islands might have two TPs, because the fish moved different water environment between warm and cool temperature twice; the first was northward migration from tropical to temperate waters, and the second was southward migration for spawning in tropical waters. Therefore, these movements might be reflected into the otolith, although both low and high temperature effects showed similar positive correlations to the otolith Sr:Ca ratios. For Sr, positive, negative, and non-significant correlations between otolith Sr concentrations and temperature have been reported (Campana 1999, Arai 2002). Thus, the variety of results may indicate that the effect of temperature on Sr concentration in otoliths is not linear and that responses are species-specific. The present study suggests that both low and high temperatures might positively relate with otolith Sr incorporation in the skipjack tuna otolith.

In addition to the oceanographic factors such as water temperature and salinity, physiological parameters (metamorphosis, maturation, somatic growth) potentially affect Sr:Ca ratios (Kalish 1989, Campana 1999). In the skipjack tuna otolith; however, the Sr:Ca ratio did not seem to be significantly affected by physiological condition, because the large tuna more than fully matured 50 cm in fork length collected off Marshall Islands

showed constant Sr:Ca ratios with little fluctuation. In the present study, there were differences in mean Sr:Ca ration among the samples collected off Marshall Islands in September 2003 (Fig. 1B). Such a differences in Sr:Ca ratio present in skipjack tuna otoliths may be associated with differences in ambient chemistry among nursery grounds. Further studies to clarify environmental and physiological effects on otolith chemical formation in the skipjack tuna are necessary to provide valid inferences for those changes in otolith Sr:Ca ratios.

In conclusion, Sr:Ca ratios of the otoliths differed among collection sites, and could be used as an environmental indicator to detect experienced water temperature in each fish during their migratory history. At least two migratory patterns of the skipjack, i.e. the one is global migration from the equatorial spawning areas to the northern temperate regions, and the other remain around tropical spawning area without northward or southward movement, are suggested in the western Pacific Ocean using the otolith elemental fingerprints.

Acknowledgements

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Table 1. Specimens used for otolith microchemistry analyses

Sampling location	Sampling date	water temperature (° C)	fishing gear	No. fish examined	Fork length (cm)		Body weight (g)	
					Mean ± SD	Range	Mean ± SD	Range
off Marshall Islands	14 Feb 2003	29.2	purse seine	4	53.2 ± 1.8	51.2 - 55.0	3435 ± 244	3140 - 3740
off Marshall Islands	13 Sep 2003	29	purse seine	6	39.6 ± 1.8	36.1 - 41.2	1267 ± 182	920 - 1400
off Sanriku	25 Aug 2003	22	pole and line	6	40.0 ± 5.8	32.2 - 44.3	1378 ± 543	680 - 1775
off Sanriku	16 Oct 2003	19	purse seine	6	51.2 ± 5.7	42.2 - 57.0	3170 ± 1018	1720 - 4160
off Palau Islands (tagged)	3 Jun 2003	29.7	purse seine	1	57.8		4320	4320
off Palau Islands	3 Jun 2003	29.7	purse seine	1	56		3720	3720

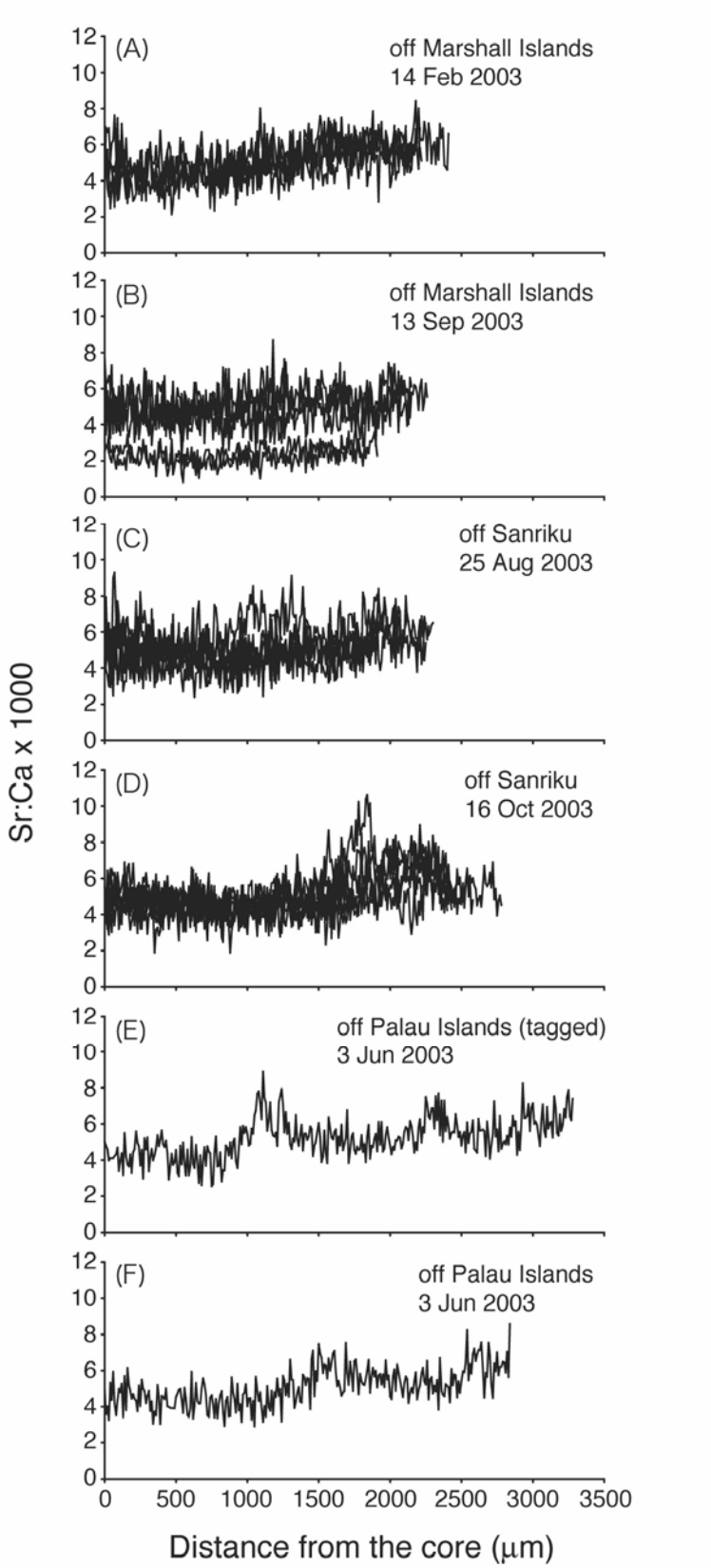

Fig. 1. Typical changes in otolith Sr:Ca ratio along line transects from the core (0 μm) to the edge in the frontal plane of sagittal otoliths of specimens collected at various localities. The sampling location and date is shown. Life history analyses based on otolith Sr:Ca ratios for all specimens in the study are shown.

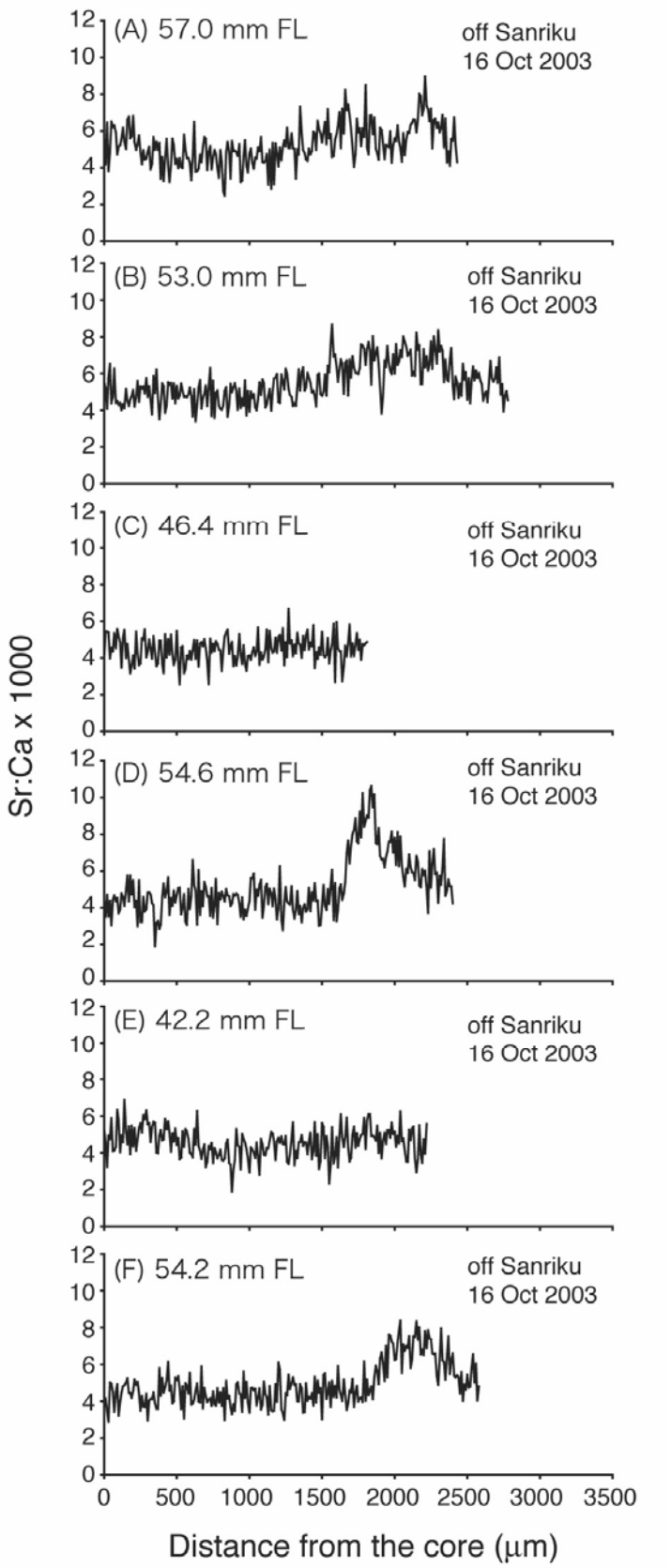

Fig. 2. Typical changes in otolith Sr:Ca ratio along line transects from the core (0 μm) to the edge in the frontal plane of sagittal otoliths of each specimen collected off Sanriku in October 2003. Four of six specimens had a transition point (TP).