Seasonal differences in the vertical distribution pattern of Japanese jack mackerel, *Trachurus japonicus*: changes according to age?

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The Japanese jack mackerel, *Trachurus japonicus*, is commercially and ecologically one of the most important fishery resources in Japanese waters. A clear understanding of the age-dependent, vertical distribution pattern is important for the effective and sustainable management of this resource. In this study, acoustic surveys were conducted from June to November 2001 in the western Sea of Japan to clarify seasonal differences. The survey area included a number of artificial reefs at depths >100 m. To identify fish species and determine the characteristics of the water column, simultaneous biological sampling and oceanographic surveys were carried out. The vertical distribution of Japanese jack mackerel varied with their age and size and between seasons. In June and July, aggregations of juvenile (age 0; <10 cm in length) Japanese jack mackerel were found in a layer between 20 and 50 m deep associated with a temperature range of 19–21°C. However, the age-0 aggregations were not observed from August to November. Conversely, the age-1+ schools aggregated around the artificial reefs when the temperature was <19°C. It is suggested that there are seasonal differences in the vertical distribution pattern between the early life and adult stages of Japanese jack mackerel. Because of the different vertical distributions of these life stages, acoustic backscatter information is useful for determining the age of the observed fish.

Keywords: acoustic survey, age/size determination, Japanese jack mackerel, seasonal differences, vertical distribution pattern.

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Introduction

The Japanese jack mackerel, *Trachurus japonicus*, is commercially one of the most important pelagic fish resources in Japan. It has been managed by setting total allowable catches for each year since 1997 (Seikai Institute, 2001). Moreover, Japanese jack mackerel is a major component of the ecosystem, because of its large biomass (Kasai *et al*., 2008). Sassa *et al*. (2006) recently made extensive studies of the larval distribution with sampling nets, such as neuston (Oozeki *et al*., 2001) and bongo nets (Smith and Richardson, 1977). They found that the main spawning grounds of Japanese jack mackerel were in the southern East China Sea (ECS). Part of the population in the southern ECS is transported to the northwestern Pacific off Japan by the Kuroshio Current and to the Sea of Japan by the Tsushima Warm Current, thus bringing recruits into the Japanese fishing grounds (Tsujita and Kondo, 1957; Asami, 1974; Kidokoro, 2004; Uehara and Mitani, 2004; Sassa *et al*., 2006).

Interdecadal fluctuations in the Japanese jack mackerel population are evident in Japanese catch records (Seikai Institute, 2001). During the early to mid-1960s, the yields were 450 000–550 000 t, but a decline set in during 1967, with the yield decreasing to 50 000 t in 1980. The resource gradually recovered from the late 1980s, and from 1990 to 2001, catches amounted to 210 000–330 000 t in southern Japan. However, there are concerns about future prospects, because recent catches consisted mainly of immature fish. The assessment and management of this resource depends on catch data from the offshore purse-seine fisheries and fishery-dependent methods, such as virtual population analysis, which provide little information about the prerecruit biomass of immature fish. This being the case, an effective fishery-independent method to assess the extent of recruitment into the coastal fishing zone was required. Acoustic surveys were carried out to investigate the behaviour of Japanese jack mackerel in terms of seasonal differences in their vertical distributions.

Material and methods

Acoustic survey

Acoustic surveys were conducted monthly during daylight from June to November 2001. The study was done in the western Sea of Japan off Hamada in the Shimane Prefecture. In that area, artificial reefs have been built, and they are influenced by the first or onshore branch of the Tsushima Warm Current flowing northeastwards along the 100-m isobath (Figure 1). It is known that juvenile Japanese jack mackerel are mainly caught in the onshore branch of this current (Kidokoro *et al*., 2005). This suggests that most of the prerecruits are transported to the Sea of Japan from the spawning grounds in the southern ECS by the onshore branch of the Tsushima Warm Current. Therefore, in this study, 17 parallel

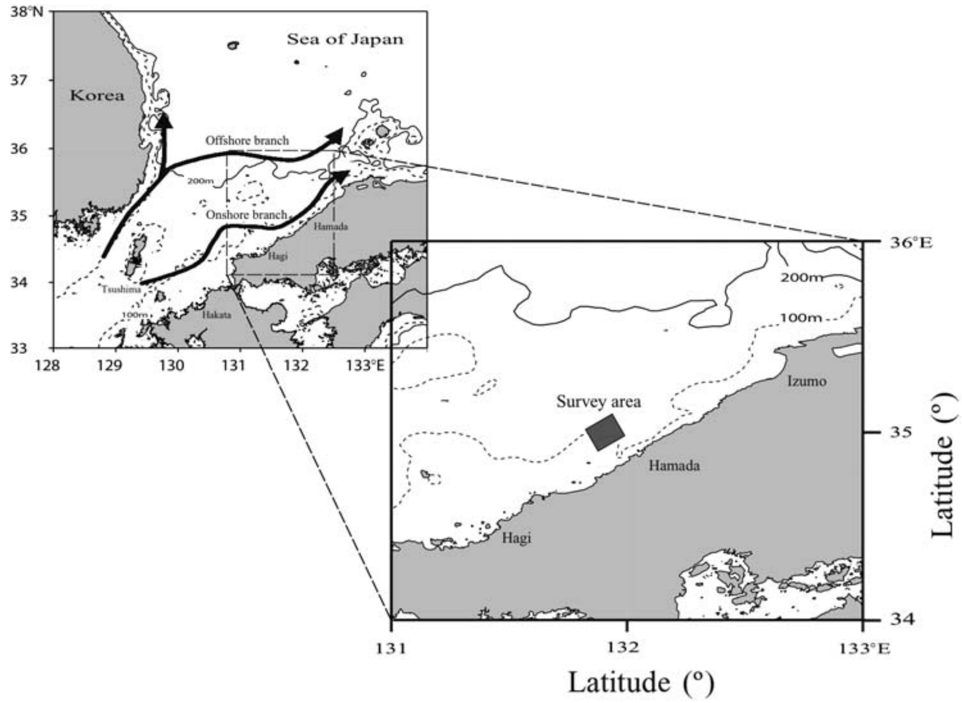

Figure 1. The shaded square in the right panel depicts the survey area. Black, bold arrows indicate the Tsushima Warm Current. Dotted and solid lines indicate the isobaths at 100 and 200 m, respectively.

transects each 1 km long were covered at 100 m intervals around the artificial reefs.

Acoustic data were collected by the RV "Shimane-Maru" (142 t), which was equipped with a Furuno FQ-70, quasi-ideal beam, scientific echosounder (Sasakura and Endo, 1987; Hamano *et al.*, 1996), and a 50-kHz transducer with a beam width of 6.07°. Pulses of duration 0.6 ms were transmitted at 1 s intervals. The vessel's speed during data acquisition was 6 knots on average. The echosounder was calibrated before and after each survey with a 38.1-mm, tungsten-carbide sphere, according to standard procedures (Foote *et al.*, 1987). The echosounder settings are displayed in Table 1. The acoustic data from the echosounder were recorded directly on a computer hard disk in a binary format, through a DAT recorder (SONY, PC208A) connected to an interface (SONY, PCSCANII version 2.20), with an analogue-to-digital converter. The data were then used to create the echogram and determine the volume-backscattering strengths (S_v), using the acoustic post-processing software Echoview v4.30 and DAT2hac (Myriax, Hobart, Australia). A threshold of −70 dB was applied to remove background noise (MacLennan and Simmonds, 1992). Japanese jack mackerel schools close to the artificial reefs are usually hard to distinguish from the reefs. In this study, an efficient method to distinguish between schools and reefs was adopted, the so-called "binarization method" (Hamano *et al.*, 2005). Binarization is a process that reduces S_v for cells to 0 or 1 to distinguish the schools (1) from the artificial reefs (0) optimally, as per Tanoue *et al.* (2008). Hence, for each ping, the objective function was $\sigma_T^{-2}\Sigma\sigma_B^2$, which could be expressed by the following equations

$$\sigma_T^2 = \frac{1}{n}\sum(\bar{x} - x_i)^2, \quad (1)$$

$$\sigma_{B0}^2 = \frac{1}{n}\sum(\bar{x}_0 - x_{0i})^2, \quad (2)$$

$$\sigma_{B1}^2 = \frac{1}{n_0}\sum(\bar{x}_1 - x_{1i})^2, \quad (3)$$

$$\sigma_T^{-2}\sum_{i=0}^{1}\sigma_B^2 = \frac{1}{\sigma_T^2}(\sigma_{B0}^2 + \sigma_{B1}^2), \quad (4)$$

where σ_T^2, σ_B^2, n, and x_i are, respectively, the total variance, the between-class variance, the total number of cells, and the S_v associated with the ith cell. The cell was selected to maximize this

Table 1. Parameter settings of the scientific echosounder.

Parameter	June	July	August	September	November
Frequency (kHz)	50	50	50	50	50
Source level (dB)	219.8	219.8	219.8	219.8	219.8
Receiving sensitivity (dB)	−185.4	−185.4	−185.4	−185.4	−185.4
Equivalent beam width (dB)	−14.5	−14.5	−14.5	−14.5	−14.5
Absorption loss coefficient (dB km^{-1})	12.8	10.4	12.2	11.8	12.5
Pulse duration (ms)	0.6	0.6	0.6	0.6	0.6

The time-varied gain is "20 log R".

function, because the discrimination level (Myriax, 2005) permits cells to be distinguished according to their location (artificial reef or school). Then, the following morphological and bathymetric characteristics of the observed schools were examined, using the school-detection module of Echoview: mean height, mean length, centre depth, mean S_v, and the school distance above the artificial reef. These characteristics were extracted in the manner described by Kang *et al.* (2006). Here, a school was defined by the following parameters: minimum total length = 4 m; minimum total height = 1 m; minimum candidate length = 3 m; minimum candidate height = 2 m; maximum vertical-linking distance = 2 m; maximum horizontal-linking distance = 5 m; minimum S_v threshold = −60 dB; and maximum S_v threshold = −40 dB.

Biological sampling

The echotraces were sampled for species identification during daylight with a midwater trawl, with vertical and horizontal mouth openings of 10–12 m, and also by hook-and-line fishing. The midwater trawl was used in June 2001 only. The trawl was towed for 30 min at a speed of 3–3.5 knots. The geometry of the trawl mouth was monitored with a netsonde. Hand-jigging gear was used from July to November 2001. It had hooks called "Aji-bari" in Japanese, which are designed for catching Japanese jack mackerel. The width of the mouth of the hook was ~6 mm. Ten sets with multihook-jigging gear were used for sampling in each month. The samples were fixed with 10% buffered formalin in seawater. The species composition, size distribution (fork length, cm), and ages of the sampled fish were determined. The entire catch was measured when it was fewer than 100 fish; for larger catches, a subsample of 100 fish was randomly selected for measurement.

Oceanographic survey

Oceanographic data were collected at ten stations concurrently with the acoustic surveys. The water temperature from the surface to the bottom was obtained with a salinity–temperature–depth (STD) profiler (ALEC, ASTD-16). Temperatures between the ten stations were estimated from the STD profiles using the natural-neighbour interpolation methods in Surfer v8.0 (Golden software, CO, USA).

Results

Monthly vertical distribution patterns

Typical echograms obtained off Hamada in the western Sea of Japan from June to November are displayed in Figure 2. There were no results for October, because of prevailing bad weather at that time. The arrows in the echograms indicate the artificial reefs, which are 10 m high. In June, small, diffuse aggregations with S_v of approximately −55 dB were observed at depths ranging from 20 to 50 m (Figure 2a). The July pattern revealed echoes in two groups (Figure 2b). One group (July$_1$) was similar to the diffuse aggregations observed in June, but they were now in a layer between 40 and 60 m with S_v approximately −60 dB. The second group (July$_2$) comprised denser schools, with a maximum S_v approximately −50 dB; they were observed around the artificial reefs at a depth of 110 m. In August, the small, diffuse aggregations had disappeared. Now, there were large and dense fish schools close to the artificial reefs (Figure 2c), with a maximum S_v of approximately −45 dB. These schools were still

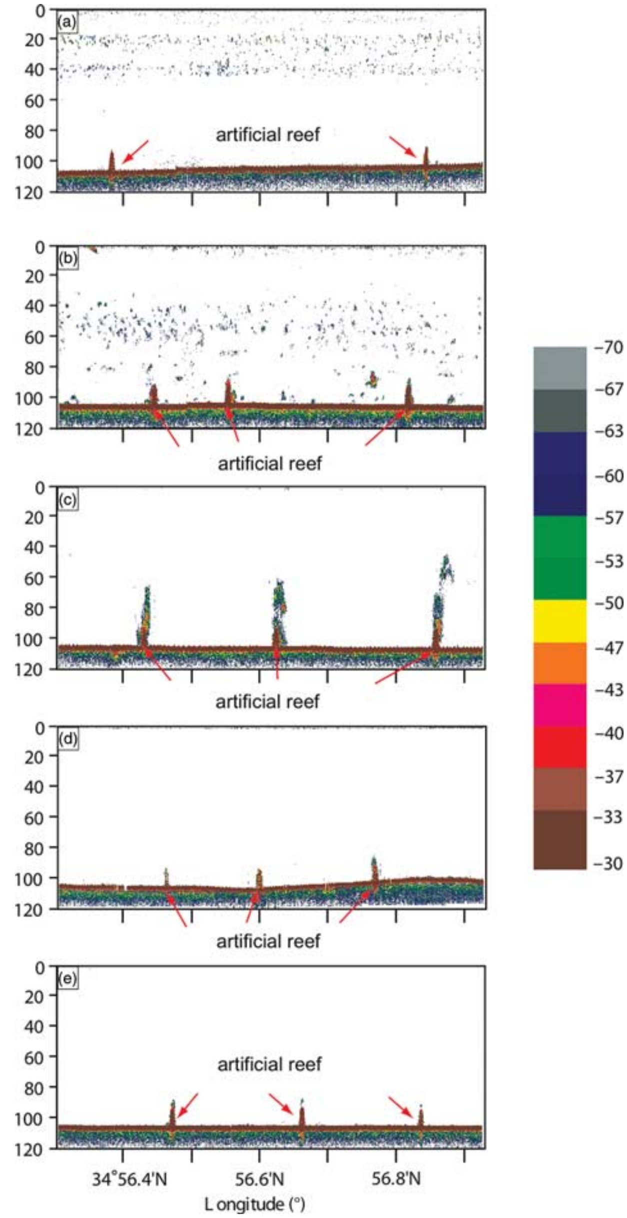

Figure 2. Typical echograms obtained by the scientific echosounder between June and November 2000. Depths in metres are on the left of the echograms; S_v colour scales in dB on the right. The S_v threshold was set at −70 dB. Echograms are presented by month: (a) June, (b) July, (c) August, (d) September, and (e) November. October is missing because of bad weather at that time.

present, but became progressively smaller in September and November (Figure 2d and e).

Morphology and bathymetry of fish schools

The morphological and bathymetric characteristics of the fish schools seen in Figure 2 are presented in Table 2. These data were efficiently discriminated between fish and artificial reefs using the binarization methods of Hamano *et al.* (2005). In June, 201 small, diffuse schools were observed at a distance of 51.6 ± 9.3 m above the top of the reefs. For these schools, the mean heights (±s.d.) were 2.2 ± 0.8 m, and the mean lengths were 14.4 ± 8.9 m (Table 2, Figure 2a). In July, 197 schools were

Table 2. Morphological and bathymetric school characteristics of Japanese jack mackerel by month.

Month	Number of schools	Mean S_v of schools (dB; $\pm$ s.d.)	Mean height of schools (m; $\pm$ s.d.)	Mean length of schools (m; $\pm$ s.d.)	Mean centre-depth of schools (m; $\pm$ s.d.)	Distance from top of the reefs (m; $\pm$ s.d.)
June	201	-55.9 ± 1.7	2.2 ± 0.8	14.4 ± 8.9	41.4 ± 9.3	51.6 ± 9.3
July$_1$	119	-56.9 ± 1.4	3.0 ± 1.3	12.2 ± 7.4	48.7 ± 6.2	44.3 ± 6.2
July$_2$	78	-54.6 ± 2.4	6.0 ± 4.2	21.4 ± 17.5	102.2 ± 5.3	9.2 ± 5.3
August	54	-54.6 ± 3.2	12.5 ± 10.8	29.9 ± 25.4	81.3 ± 17.9	11.7 ± 17.9
September	13	-54.4 ± 2.0	5.3 ± 3.3	10.0 ± 8.5	101.5 ± 4.5	8.5 ± 4.5
November	24	-54.8 ± 1.4	5.2 ± 3.2	14.4 ± 8.5	99.3 ± 4.4	6.3 ± 4.5

detected in the two groups (July$_1$ and July$_2$) noted above. The July$_2$ schools were significantly larger in all respects than those of July$_1$ (Student's t-test: mean height $t = 6.08$, $p < 0.01$; mean length $t = 4.34$, $p < 0.01$; and mean S_v $t = 7.47$, $p < 0.01$). The dense fish schools close to the artificial reefs were largest in August and much smaller in September and November (Table 2, Figure 2c–e). Moreover, the dense fish schools observed close to the artificial reefs in September and November did not differ significantly (Student's t-test: mean height $t = 0.09$, $p > 0.05$; mean length $t = 1.46$, $p > 0.05$; and mean S_v $t = 0.68$, $p > 0.05$).

Size and age composition of the catches

Details of the fish catches from June to November 2001 are presented in Table 3. Japanese jack mackerel was the most abundant species. In June, it constituted more than 95% of the midwater trawl catch in 20–40 m water depth. In all, 84.2% of the fish caught by the hand-jigging gear (July–November) at depths ranging from 20 m to the bottom at 110 m were Japanese jack mackerel. Figure 3 shows the distribution of fork lengths (L_F) and ages of Japanese jack mackerel caught from June to November 2001. The age of Japanese jack mackerel was calculated with the equation of Nakashima (1982) using otolith readings

$$L_F(t) = 38.6(1 - e^{-0.35(t+0.6)}), \tag{5}$$

where t is the age in years and L_F the fork length in centimetres.

In June, the Japanese jack mackerel displayed a mode at $L_F = 4$ cm; this was considered to be age-0 fish (Figure 3a). In contrast, the L_F distribution for July was bimodal (Figure 3b). The mode at 9 cm came from the layer between 40- and 70-m deep and around the artificial reefs. From this sample, 67% was determined as age-0 fish. The fish in the second group had a mean length of 30 cm and were collected near the artificial reefs. Approximately 33% of these were age-2+. In August, ~86% of the Japanese jack mackerel was age-1, with a mean L_F of ~20 cm (Figure 3c), whereas in September, 96% was age-4+, with L_F >30 cm (Figure 3d). In November, 92% of the Japanese jack mackerel was age-1 and age-2, with L_F >20 cm (Figure 3e).

Temperature effects

Figure 4 shows the vertical distribution of Japanese jack mackerel in relation to the water temperature isotherms for each month. The age-0 schools in June were found in water with a temperature ranging between 19 and 21°C (Figure 4a). In July, the age-0 schools were still largely restricted to this temperature range, but now at 40–60 m deep (Figure 4b). In addition, closer to the artificial reefs at 110 m deep, some of the age-0 and all the age-2+ schools were found in water <19°C. The temperature profile for August was different, because it had a thermocline situated between 20 and 40 m. Here, the age-1 schools were densely aggregated near the artificial reefs in the cooler waters below the thermocline (Figure 4c). In September, the schools of age-4+ fish were found close to the artificial reefs, in water <20°C (Figure 4d). In November, the temperature profile was nearly homogeneous at 22°C, and the few schools encountered were all near the artificial reefs (Figure 4e).

Discussion

In this study, seasonal changes in the vertical distribution of Japanese jack mackerel, *T. japonicus*, off Hamada, Shimane Prefecture, in the western Sea of Japan between June and November 2001 were studied using acoustic data. The results revealed that Japanese jack mackerel tend towards deeper water with increasing size and age. Small, diffuse schools of age-0 fish ($L_F = 4$ cm) were distributed in the 20–50-m depth layer in June. By July, the fish were larger, with $L_F = 9$ cm. Some were then at depths between 50 and 70 m, whereas others were close to the artificial reefs at 110 m. No age-0 schools were observed

Table 3. Species composition and number of fish caught by midwater trawl (June 2001) and hand-jigging gear (July–November 2001).

Common name	Scientific name	June	July	August	September	November
Japanese jack mackerel	*Trachurus japonicus*	6 674	61	139	95	41
Black scraper	*Thamnaconus modestus*	–	2	1	13	–
Silver sea bream	*Pagrus major*	–	1	–	–	–
Club mackerel	*Scomber japonicus*	–	–	7	–	1
Longtail tuna	*Thunnus tonggol*	–	–	1	–	1
White chestnut puffer	*Lagocephalus wheeleri*	–	–	1	1	–
Yellowtail	*Seriola quinqueradiata*	–	–	–	1	7
Frigate tuna	*Auxis thazard*	–	–	–	6	8
John dory	*Zeus faber*	–	–	–	1	–
Bullet tuna	*Auxis rochei*	–	–	–	7	–
Japanese tilefish	*Branchiostegus japonicus*	–	–	–	–	–
Japanese Spanish mackerel	*Scomberomorus niphonius*	–	–	–	–	1
Dark rough backed puffer	*Lagocephalus gloveri*	–	–	–	–	1

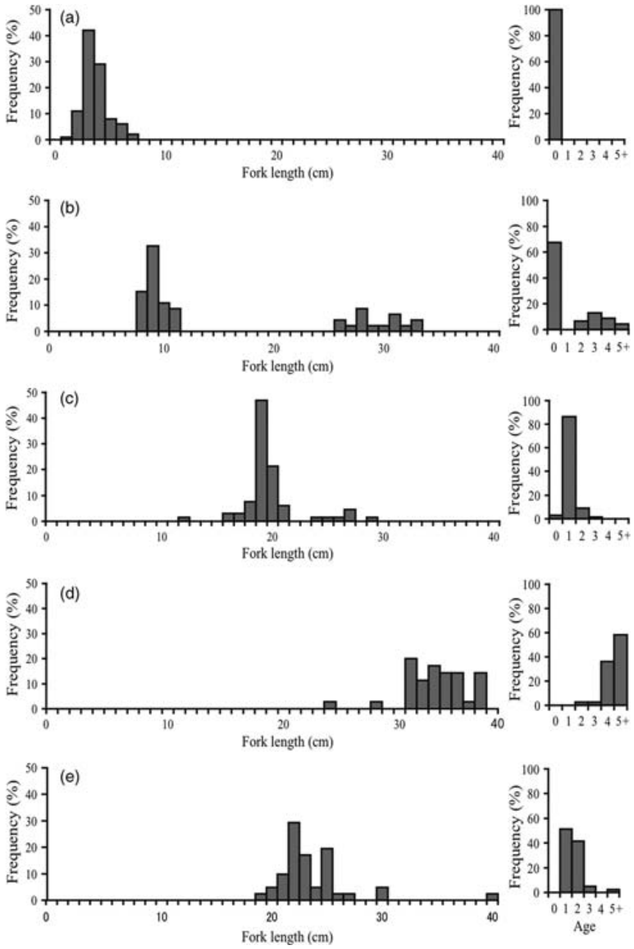

Figure 3. Fork length and age distributions of Japanese jack mackerel from catches by midwater trawl (June 2001) and hand-jigging gear (July–November 2001). Panels (a–e) illustrate monthly results as in Figure 2.

after July. This suggests that most of the age-0 fish schools had left the survey area, carried northeastwards by the Tsushima Warm Current (Katoh, 1994). In contrast, the schools of age-1+ fish observed from August to November were distributed around the artificial reefs in deeper waters (Figure 2, Table 2). Moreover, the schools of age-1+ fish were significantly larger than those of age-0 fish schools, in all respects (Student's t-test: mean height $t = 7.21$, $p < 0.01$; mean length $t = 3.98$, $p < 0.01$; and mean S_v $t = 5.50$, $p < 0.01$). Therefore, it was easy to distinguish the age-0 fish according to their morphological and bathymetric characteristics. It was difficult to discriminate between the older fish, however, because those schools displayed very similar characteristics. The tendency for larger fish to occur in deeper water is well known for demersal species (Haedrich and Rowe, 1977; Shida, 2001). Although Japanese jack mackerel are considered pelagic fish, they tend to move into deeper water with increasing size (Nishida, 2004). However, no field studies have ever been done to establish a link between the vertical distribution of Japanese jack mackerel with size and age groups. Moreover, it is known that Japanese jack mackerel form schools when they are 4.5 cm or larger; they also gather in significant concentrations around reefs (Kawasaki, 1959; Yamada, 1969; Kidokoro, 2004). However, knowledge of the aggregating behaviour and vertical

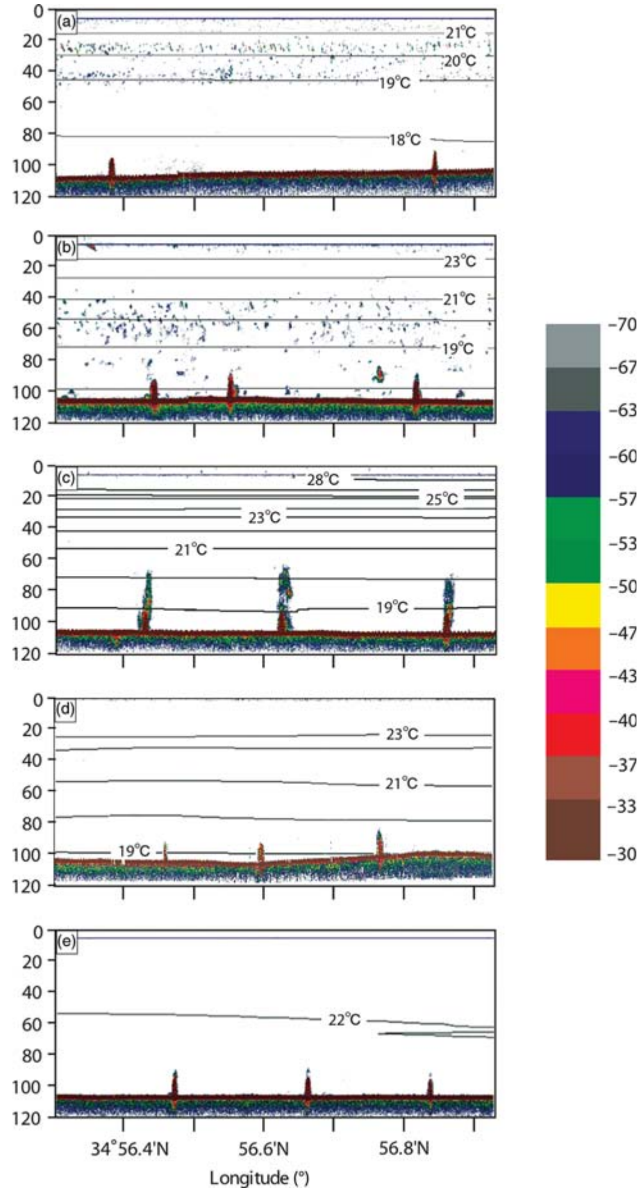

Figure 4. The echograms from Figure 2 overlaid with isotherms indicating the level of stratification. Temperatures at locations between oceanographic stations have been interpolated by the natural-neighbour method (see text for details). Depths in metres are on the left of the echograms; S_v colour scales in dB on the right. (a–e) illustrate monthly results as in Figure 2.

distribution of older Japanese jack mackerel is limited, because of the difficulty in catching fish near reefs and their fast swimming speed.

Acoustic methods using a scientific echosounder could be used to obtain such information over the life cycle from immature to adult fish. Our results agree with those of Hong *et al.* (1996), who conducted a laboratory study on the aggregating behaviour of 9 cm Japanese jack mackerel in relation to a fish-aggregating device. Our findings suggest that Japanese jack mackerel gather at reefs after reaching a fork length of ~9 cm. The observed differences in the vertical distribution of age-0 and age-1+ schools are considered related to certain oceanographic conditions, e.g. water temperature. The vertical distribution of prey, such as macrozooplankton and micronekton, could also be an important factor (Konchina, 1981; Bertrand *et al.*, 2004; Xie *et al.*, 2005). Yamada (1958) reported that the preferred habitat temperature of Japanese jack mackerel depends on its growth stage. Immature fish were found in water 19–25°C, whereas the corresponding range for adult fish was 13–18°C. Moreover, the survival rate of eggs and the larval growth rate of Japanese jack mackerel are higher at 18°C than at 26°C; lower temperatures provide better rearing conditions (Ochiai *et al.*, 1982, 1983). Sassa *et al.* (2006) and Yoda and Sassa (2004) reported that more than 90% of Japanese jack mackerel larvae in the southern part of the ECS, with an average body length of 2.6 mm, was concentrated in the 10–30-m depth layer, with the water temperature ranging from 21 to 23°C. In the current study, the water temperature preferences of the age-0 and age-1+ schools were similar to those reported in previous studies. Therefore, it appears that the eggs and larvae of Japanese jack mackerel hatched in the southern ECS were transported into the survey area by the fish selecting suitable habitat temperatures after they were able to swim actively as juveniles.

This paper is the first to describe field observations of seasonal changes in vertical distribution with growth for Japanese jack mackerel. Further investigations are required to determine whether these findings also apply to other fishing grounds with artificial reefs. It should be noted that although the fish echoes seen around the artificial reefs appeared to be from Japanese jack mackerel, this conclusion was primarily based on hand-jigging catches. This gear was specifically designed to catch Japanese jack mackerel and, therefore, could be highly selective for that species. Perhaps other species and size groups of fish were also present at the artificial reefs. Future research should use less-selective fishing gear to collect biological samples for echo identification. Multifrequency techniques should ultimately be considered for future work. They offer the possibility of better species identification using spectral analyses of acoustic-backscattering (Korneliussen and Ona, 2002; Conti and Demer, 2003; Warren *et al.*, 2003; Kang *et al.*, 2006). In addition, experiments should be done to measure the target strength of Japanese jack mackerel at multiple frequencies, covering the different age groups.

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References

Asami, T. 1974. Distribution of fish eggs and larvae in the southern Japan and its significance of source of the supply of fish stocks. Bulletin of the Japanese Society of Fisheries Oceanography, 25: 176–193.

Bertrand, A., Barbieri, M. A., Cordova, J., Hernandez, C., Gómez, F., and Leiva, F. 2004. Diel vertical behaviour, predator–prey relationships, and occupation of space by jack mackerel (*Trachurus murphyi*) off Chile. ICES Journal of Marine Science, 61: 1105–1112.

Conti, S. G., and Demer, D. A. 2003. Wide-bandwidth acoustical characterization of anchovy and sardine from reverberation measurement in an echoic tank. ICES Journal of Marine Science, 60: 617–624.

Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and Simmonds, E. J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report, 144. 57 pp.

Haedrich, R. L., and Rowe, G. T. 1977. Megafaunal biomass in the deep sea. Nature, 269: 141–142.

Hamano, A., Sasakura, T., Kieser, R., Cooke, K., Kubota, K., and Clay, A. 1996. Target-strength measurements of Pacific hake (*Merluccius productus*) in Canadian waters using quasi-ideal and conventional beam transducers. ICES Journal of Marine Science, 53: 273–279.

Hamano, A., Tanoue, H., and Kieser, R. 2005. The three-dimensional GIS using sonar information for coastal fisheries. ICES Document CM 2005/U: 19. 12 pp.

Hong, W. S., Okamoto, M., Imai, T., and Fuwa, S. 1996. Effect of fish aggregating device (FAD) for gathering juvenile Japanese horse mackerel *Trachurus japonicus*. Bulletin of the Japanese Society of Fisheries Oceanography, 60: 356–362.

Kang, M., Honda, S., and Oshima, T. 2006. Age characteristics of walleye pollock school echoes. ICES Journal of Marine Science, 63: 1465–1476.

Kasai, A., Komatsu, K., Sassa, C., and Konishi, Y. 2008. Transport and survival process of eggs and larvae of jack mackerel *Trachurus japonicus* in the East China Sea. Fisheries Science, 74: 8–18.

Katoh, O. 1994. Structures of Tsushima Current in the southwestern Japan Sea. Journal of Oceanography, 50: 317–338.

Kawasaki, T. 1959. A basic study on the biology of the jack mackerel, *Trachurus japonicus* (Temminck et Schlegel). Bulletin of the Tohoku Regional Fisheries Research Laboratory, 13: 95–107.

Kidokoro, H. 2004. Recruitment process in the Japan Sea. *In* Spawning Ground and Recruitment Process of Jack Mackerel—from the East China Sea to the Coastal Waters of Japan, pp. 83–91. Ed. by I. Hara, and T. Tokai. Koseisha Koseikaku, Tokyo. 115 pp.

Kidokoro, H., Yasugi, S., Shimura, T., and Katoh, O. 2005. Distribution of pre-recruit jack mackerel (*Trachurus japonicus*) in the south-western Sea of Japan and its relation to the Tsushima Current. Bulletin of the Fisheries Research Agency, 14: 1–6.

Konchina, Y. V. 1981. The Peruvian jack mackerel, *Trachurus symmetricus muprhyi*, a facultative predator in the coastal upwelling ecosystem. Journal of Ichthyology, 21: 46–59.

Korneliussen, R. J., and Ona, E. 2002. Synthetic echograms generated from the relative frequency response. ICES Journal of Marine Science, 60: 636–640.

MacLennan, D. N., and Simmonds, E. J. 1992. Fish and Fisheries Series, 5: Fisheries Acoustics. Chapman and Hall, London. 325 pp.

Myriax. 2005. Myriax Echoview User's Manual. Myriax Tasmania Pty Ltd, Hobart.

Nakashima, J. 1982. On the growth and age of three populations of jack mackerel, *Trachurus japonicus*, in the western Seas of Japan. Bulletin of the Seikai Regional Fisheries Research Laboratory, 57: 47–57.

Nishida, H. 2004. Reproductive biology of jack mackerel. *In* Spawning Ground and Recruitment Process of Jack Mackerel—from the East China Sea to the Coastal Waters of Japan, pp. 11–18. Ed. by I. Hara, and T. Tokai. Koseisha Koseikaku, Tokyo. 115 pp.

Ochiai, A., Mutsutani, K., and Umeda, S. 1982. Development of eggs, larvae and juveniles of jack mackerel, *Trachurus japonicus*. Japanese Journal of Ichthyology, 29: 86–92 (in Japanese with English abstract).

Ochiai, A., Mutsutani, K., and Umeda, S. 1983. On the first year's growth, maturity and artificial spawning of cultured jack mackerel. Bulletin of the Japanese Society of Scientific Fisheries, 49: 541–545 (in Japanese with English abstract).

Oozeki, Y., Kimura, R., Kubota, H., and Ishida, M. 2001. Modified neuston net for collecting larvae and juveniles of Pacific saury, *Cololabis saira*. Bulletin of the Japanese Society of Fisheries Oceanography, 65: 1–5 (in Japanese with English abstract).

Sasakura, T., and Endo, Y. 1987. Quasi-ideal beam transducer. Japanese Journal of Applied Physics, 26(Suppl. 1): 94–96.

Sassa, C., Konishi, Y., and Mori, K. 2006. Distribution of jack mackerel (*Trachurus japonicus*) larvae and juveniles in the East China Sea, with special reference to the larval transport by the Kuroshio Current. Fisheries Oceanography, 15: 508–518.

Seikai Institute. 2001. Biological and ecological characteristics of valuable fisheries resources form the East China Sea and the Yellow Sea: comparison between Chinese and Japanese knowledge. Seikai National Fisheries Research Institute, Nagasaki. 503 pp. (in Japanese).

Shida, O. 2001. Seasonal difference in the diel vertical migration patterns of young walleye pollock, *Theragra chalcogramma*, and their impact on acoustic biomass estimation. Proceedings of the International Symposium on Advanced Techniques of Sampling Gear and Acoustical Survey for Estimation of Fish Abundance and Behavior (ACOUSTICGEAR 2000), Hakodate, pp. 172–179.

Smith, P. E., and Richardson, S. 1977. Standard techniques for pelagic fish egg and larval surveys. FAO Fisheries Technical Paper, 175: 1–100.

Tanoue, H., Hamano, A., Komatsu, T., and Boisnier, E. 2008. Assessing bottom structure influence on fish abundance in a marine hill by using conjointly acoustic survey and geographic information system. Fisheries Science, 74: 469–478.

Tsujita, T., and Kondo, M. 1957. Some contributions to the ecology of the mackerel and the oceanography of the fishing grounds in the East China Sea (1). Bulletin of the Seikai Regional Fisheries Research Laboratory, 14: 7–47.

Uehara, S., and Mitani, T. 2004. Recruitment process along the Pacific coast of Japan. *In* Spawning Ground and Recruitment Process of Jack Mackerel—from the East China Sea to the Coastal Waters of Japan, pp. 69–82. Ed. by I. Hara, and T. Tokai. Koseisha Koseikaku, Tokyo. 115 pp.

Warren, J. D., Stanton, T. K., Wiebe, P. H., and Seim, H. E. 2003. Inference of biological and physical parameters in an internal wave using multiple-frequency, acoustic-scattering data. ICES Journal of Marine Science, 60: 1033–1046.

Xie, S., Watanabe, Y., Saruwatari, T., Masuda, R., Yamashita, Y., Sassa, C., and Konishi, Y. 2005. Growth and morphological development of sagittal otoliths of larval and early juvenile *Trachurus japonicus*. Fisheries Science, 66: 1704–1719.

Yamada, T. 1958. Tsushima-danryu Kaihatsu Chosa Hokoku-sho. Fisheries Agency, Tokyo, 4: 145–176.

Yamada, T. 1969. Observation on the distribution and the fishing grounds of jack mackerel *Trachurus japonicus* (Temminck et Schlegel) in the Japan Sea. Bulletin of the Faculty of Fisheries, Nagasaki University, 28: 111–130.

Yoda, M., and Sassa, C. 2004. Spawning grounds of jack mackerel. *In* Spawning Ground and Recruitment Process of Jack Mackerel—from the East China Sea to the Coastal Waters of Japan, pp. 19–30. Ed. by I. Hara, and T. Tokai. Koseisha Koseikaku, Tokyo. 115 pp.

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