Asian Fisheries Science **27** (2014): *248-259*

ISSN 0116-6514
E-ISSN: 2073-3720
https://doi.org/10.33997/j.afs.2014.27.4.002

The Journal of the Asian Fisheries Society

Age Composition of Japanese Spanish Mackerel *Scomberomorus niphonius* (Cuvier 1832) Caught off Hyogo Prefecture, South-western Sea of Japan, as Determined by the Otolith Cross-section Method

TETSUYA NISHIKAWA[1*], YUKINOBU NAKAMURA[2] and SATOSHI KATAYAMA[3]

[1]Tajima Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, Kasumi, Kami, Mikata, Hyogo 669-6541, Japan
[2]Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, Minami-Futami 22-2, Futami, Akashi, Hyogo 674-0093, Japan
[3]Fisheries Biology and Ecology, Graduate School of Agricultural Science, Tohoku University, Amamiya-machi 1-1, Tsutsumidori, Aoba-ku, Sendai, Miyagi 981-8555, Japan

Abstract

The age composition of Japanese Spanish mackerel *Scomberomorus niphonius* (Cuvier 1832) caught off Hyogo Prefecture, south-western Sea of Japan, was investigated based on the otolith cross-section method. The age analysis demonstrated that the method was useful to clarify and accurately determine age of Japanese Spanish mackerel. The method revealed that annual structures on otoliths were mainly formed in June, which was closely associated with the spawning peaks in the East China Sea. In the Sea of Japan, a large proportion of the catch consisted of age 0 fish, of which most of the fork length (FL) modes were from 350 to 500 mm. The ratio of males and females was in equal proportion in the age 0 fish, but the female ratio increased in the age 1 group and older fishes. The increase of the female proportion in older fish could be related to differences in the age of maturity and migration for spawning. In the southwestern Sea of Japan, age 0 fish that were first caught in September or October were all larger than 250 mm FL, suggesting that fish caught in this area hatch around June and migrate from another area in autumn after growing to more than 250 mm FL.

Introduction

Japanese Spanish mackerel *Scomberomorus niphonius* (Cuvier 1832) is widely distributed in the East China Sea, Bohai Sea, Yellow Sea and around southwest Japan. It is an important fisheries resource, particularly in the Seto Inland Sea, Japan (Takeda 1996), where many studies have been conducted on the general biology, such as early life (Shoji et al. 1997, 1999), distribution (Kishida et

*Corresponding author. E-mail address: tetsuya_nishikawa@pref.hyogo.lg.jp

al. 1985a; Kishida 1989), age composition and growth (Kishida et al. 1985a; Chiba et al. 2008).

The catch in the Sea of Japan increased in 1999 and has remained high, reaching 10,000 tonnes in 2007, which comprised over 50% of the total catch in Japan. This area is now an important fishing ground, in addition to the Seto Inland Sea and East China Sea. There are two subpopulations of Japanese Spanish mackerel in the Seto Inland Sea and East China Sea, and the populations caught in the Sea of Japan belong to the latter (Tameishi et al. 2005; Inoue et al. 2007). Two factors could be responsible for the marked increase of fish in the Sea of Japan; the high resource level of the subpopulation in the East China Sea and changes in oceanographic conditions such as increase in water temperature. Katoh et al. (2006) revealed that the marked increase in water temperature occurred twice in the Sea of Japan, during 1988/89 and 1997/98. Increase of Japanese Spanish mackerel was observed right after the second incidence of increase in temperature. Tameishi et al. (2005) suggested that the migration of Japanese Spanish mackerel from the East China Sea was associated with a climate regime-shift, and the fishing ground spread over the Sea of Japan in the late 1990s.

In recent years, Inoue et al. (2007) and Tojima et al. (2011, 2013) have studied the fishery biology of Japanese Spanish mackerel in the Sea of Japan. However, fishery biology of Japanese Spanish mackerel remains poorly understood in this area; more information is needed to effectively manage the population, especially off Hyogo Prefecture, south-western Sea of Japan, where three large-scale set-nets are operated, and where there is minimal information about this species (Nishikawa 2013).

Both surface and cross-section methods were used for age determination (e.g. Hamasaki 1993; Katayama et al. 2010). However, Doiuchi et al. (2007) reported an underestimation of age using the surface method. Since then the otolith cross-section method has been used to study age and growth of fish such as threeline grunt *Parapristipoma trilineatum* (Thunberg 1793) (Doiuchi et al. 2007; Yamada et al. 2011), rabbitfish *Siganus fuscescens* (Houttuyn 1782) (Katayama et al. 2009) and flatfishes (Yamamoto et al. 2008, 2009; Katayama et al. 2010). Previous studies were done to determine the age of Japanese Spanish mackerel by surface observation of otolith (Hamasaki 1993; Inoue et al. 2007); however, the annual structure of otolith is frequently not clear when observed by surface method (Hamasaki 1993). In the present study, the cross-section method was used for the first time to determine the age of Japanese Spanish mackerel. The investigation on the fisheries biology of Japanese Spanish mackerel, included the fork length distribution, age composition and gonad index to better understand the catch off Hyogo Prefecture.

Materials and Methods

Sampling and measurements

Specimens of Japanese Spanish mackerel caught by the set-net at Amarube off the Hyogo

Prefecture were sampled at the Kasumi fishing port from August 2009 to March 2012 (Fig. 1). The fork length (FL) was measured to the nearest 10 mm of more than 100 fish that were selected at random, at the port every month. In addition, 30 fish samples of various sizes were collected at random in each month throughout the study period. In the laboratory, the FL, body weight (BW) and gonad weight (GW) of each specimen was measured to the nearest 1 mm and 0.1 g. Sexes were identified from macroscopic examination of the gonads. The gonad maturity was estimated using the gonad index (GI), which was calculated as follows:

$$GI=GW\times FL^{-3}\times 10^{7}$$

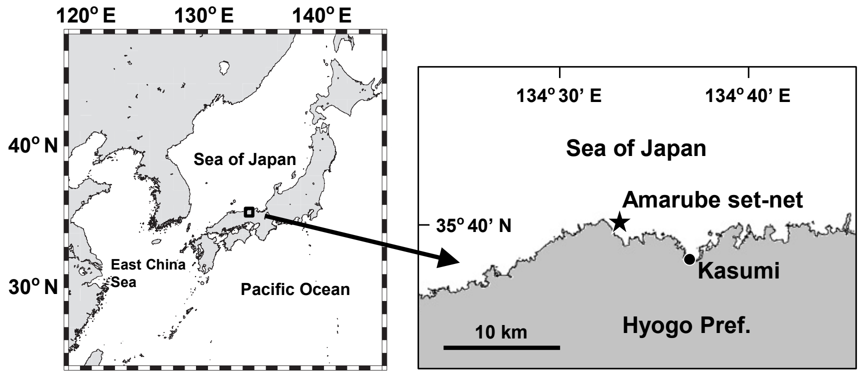

Fig. 1. Sampling location of Japanese Spanish mackerel off Hyogo Prefecture, southwestern Sea of Japan.

Age determination

The paired sagittal otoliths from 1,117 fish that were sampled monthly from September 2009 to February 2012, were removed, cleaned, dried, and stored in natural conditions until further observation. The left otolith was used for a cross-section analysis, but if it was damaged, then the right otolith was used. Cross sections of otoliths were prepared according to the procedure described by Doiuchi et al. (2007) and Katayama et al. (2010). Otoliths were mounted and embedded in polyester resin and cut at 0.3 mm thick transverse sections with a diamond saw (Leica SP1600, Leica Microsystems GmbH, Wetzlar, Germany). Sections were mounted on glass slides with sticky wax. The surfaces were ground using carborundum paper and etched with 0.2-N HCl for approximately 60 s. Age counts were made using a light microscope (BX50, Olympus, Tokyo, Japan). For specimens collected from mid-May to July, during the formation of annual structures (opaque zone) (Hamasaki 1993; Inoue et al. 2007), the age was determined by the surface method using the right otoliths which was then compared with the cross-section method. In the surface method, opaque zone was counted against a black background using a light microscope (SZX12, Olympus, Tokyo, Japan).

Results

A total of 2,422 FLs of Japanese Spanish mackerel were measured from August 2009 to March 2012 (Fig.2). Fork lengths ranged from 260 mm to 1,010 mm in September 2009 and January

2012 respectively, and most were between 350 to 500 mm. Some fish were larger than 800 mm FL, and fish smaller than 250 mm FL were not observed. A new mode with a peak around 400 mm appeared in September or October of each year. The peak of the mode gradually increased and reached around 450 mm in December, and remained constant from January to May.

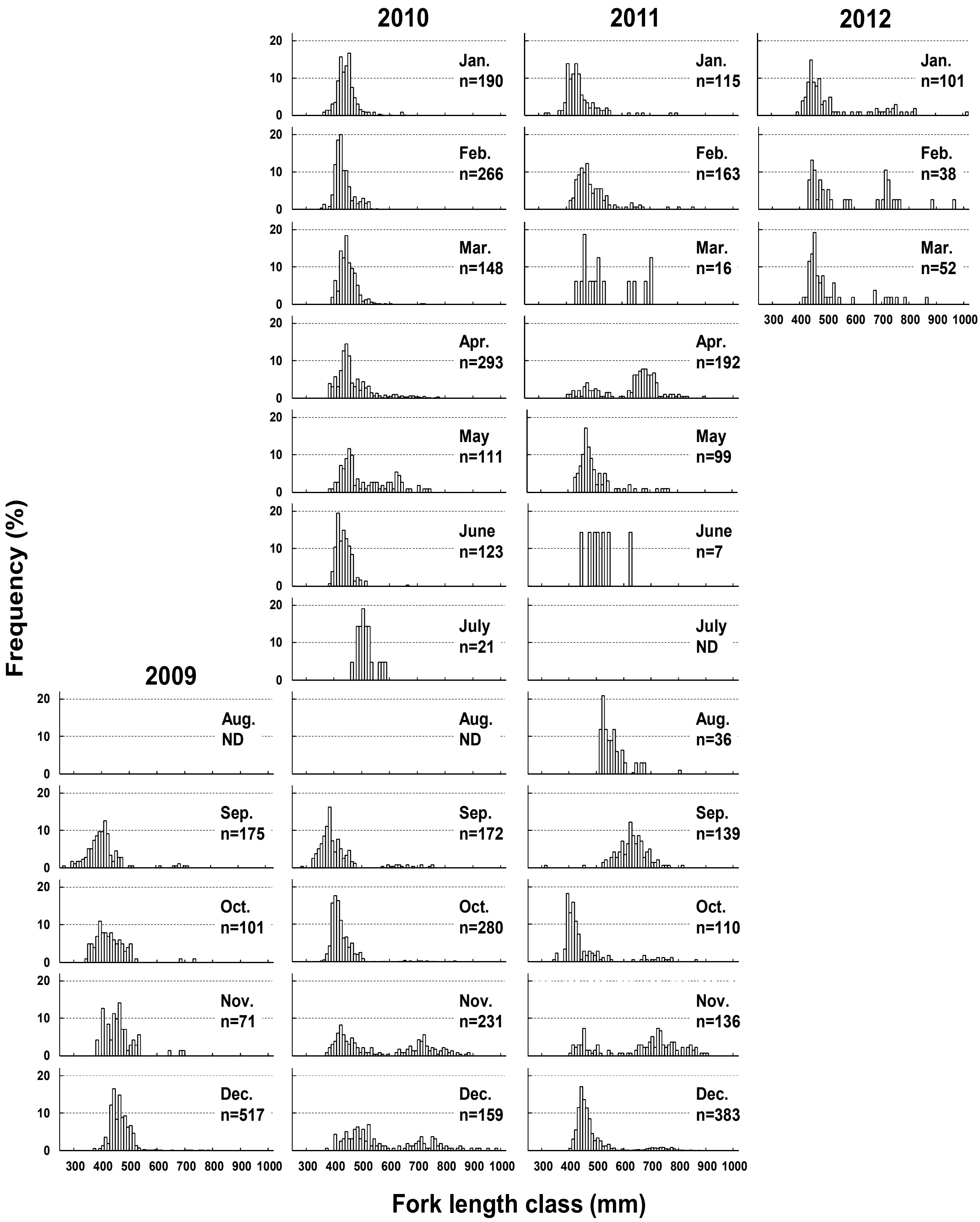

Fig. 2. Monthly changes in fork length composition of Japanese Spanish mackerel caught off Hyogo Prefecture, southwestern Sea of Japan, from August 2009 to March 2012.

In most of the months, one major mode occurred at 350-500 mm, and during a few months, another mode occurred around 700 mm FL. When large numbers of fish were caught in September and October, only one major mode was observed. Fork length was not measured during the summer months especially in July and August when only a small number of fish were caught.

In the present study, 1,116 otoliths (from 668 females and 448 males) were readable by the cross-section method (Fig. 3).The first opaque zone started to form at the edge of otolith from mid-May to early June (Fig. 4A) and was clearly visible in July (Fig. 4B). In the 2009 year class, the opaque zone on the otolith margin appeared in June 2010 and 2011 (Fig. 5). The specimens had no opaque structure on the otolith until May 2010, but all specimens had one opaque zone between June 2010 and May 2011, and had two structures after June 2011. In addition, the opaque zone of the 2010 year class appeared in May 2011, and all otoliths contained a single opaque zone in June 2011. None of the specimens in each age classes had newly formed opaque zone on the otolith between August and April in each year.

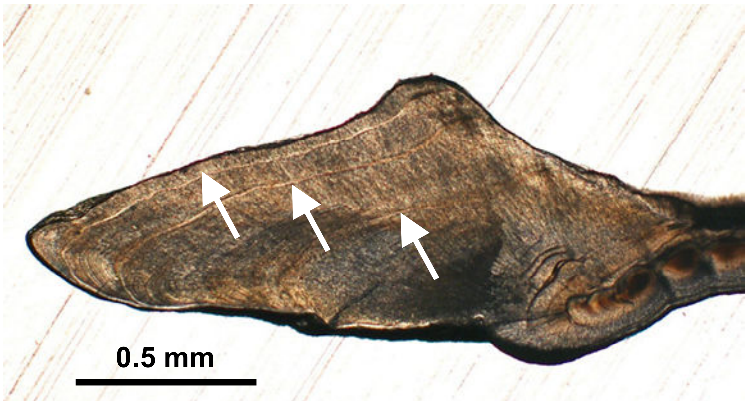

Fig. 3. Otolith section of an age 3 Japanese Spanish mackerel (920 mm FL, female, December 2010). The solid arrows indicate annual checks.

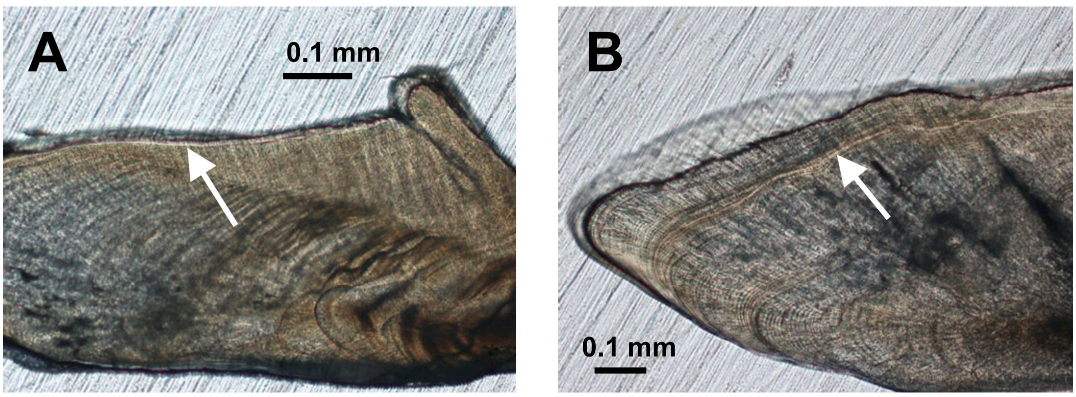

Fig. 4. Otolith sections of age 1 Japanese Spanish mackerel (A: 407 mm FL, male, June 2010, B: 473 mm FL, female, July 2010). The solid arrows indicate annual checks.

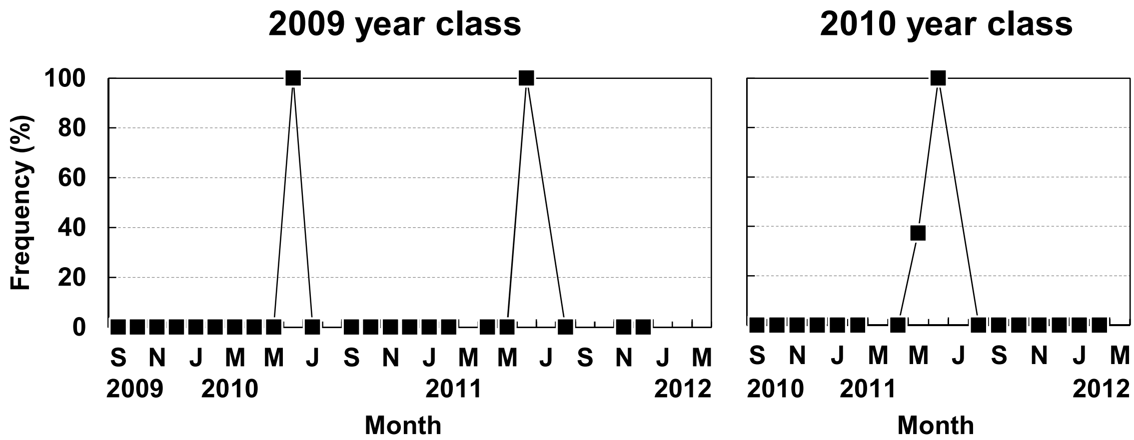

Fig. 5. Monthly changes in the occurrence frequency of opaque zone at the edge of otolith in 2009 (n=647) and 2010 year classes (n=315) of Japanese Spanish mackerel caught off Hyogo Prefecture, southwestern Sea of Japan.

In the cross-section method, observations on otoliths collected in mid-May of 2010 did not show opaque structure (Fig. 6). The opaque zone was observed in 10 and 61% of specimens collected in mid and late May 2011 respectively, and in all specimens after June in both years (Fig. 6). In contrast, based on the surface method observation, all specimens collected in May and June had no or unreadable opaque structures in both years. The opaque zone was observed only in 76% of specimens collected in July 2010.

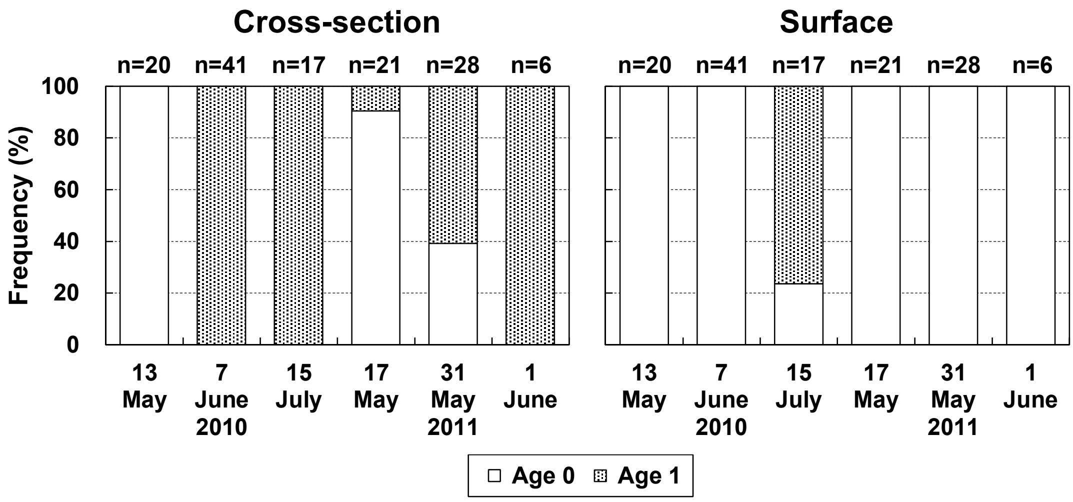

Fig. 6. Comparison of age determination between cross-section and surface methods using specimens of Japanese Spanish mackerel collected off Hyogo Prefecture, southwestern Sea of Japan, during the period from mid-May to July in 2010 and 2011.

Judging from the age determination by cross-section method, most of the specimens were age 0 (71.4% of the samples) or age 1 (27.2%). No females age 4 and above were found, and only one age 3 female was collected. All males were age 0-2, and only one age 2 male was observed; it had just reached age 2 in June.

On the assumption of a birth date of June 1, a graph was plotted for the relationship between FL and age for females and males separately (Fig. 7). Females and males of all ages grew fastest during July to December. Age 0 fish measured 294-490 mm FL in females and 284-435 mm in males in September, and grew to 377-575 mm and 373-530 mm in December, respectively. Age 1 fish, which were 381-531 mm in females and 389-457 mm in males in June, also reached 631-820 mm and 630-769 mm, respectively, after 6 months. However, growth was stagnant from January to May; FLs ranged from 360 to 633 mm in females and from 370 to 561 mm in males at age 0, 596-850 mm in females and 551-785 mm in males at age 1. Growth curves were not calculated because no fish age 4 or older were observed, and it was difficult to assume the asymptotic length based on such a young age composition.

In age 0 fish, the sex ratio was almost equal (Fig. 8). However, the percentage of females increased with age (chi square test, $p < 0.05$), reaching 70.6% in age 1 fish and 93.8% in age 2 and above.

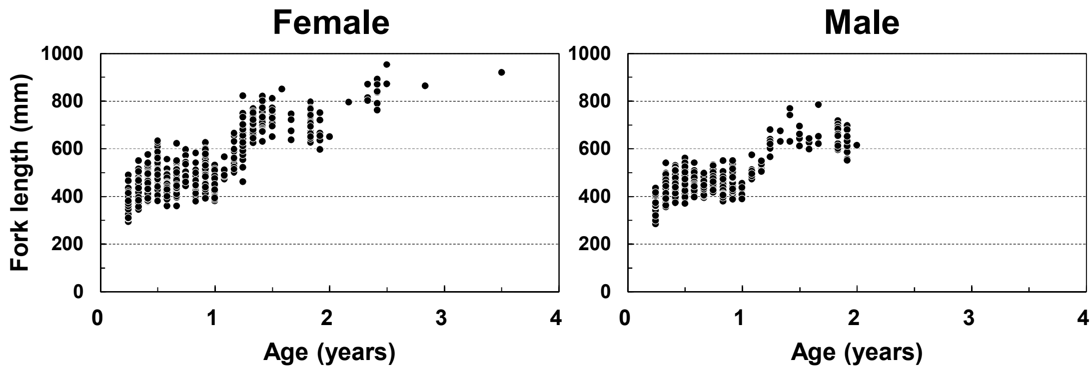

Fig. 7. Age-fork length relationship for female and male of Japanese Spanish mackerel caught off Hyogo Prefecture, southwestern Sea of Japan, from August 2009 to March 2012.

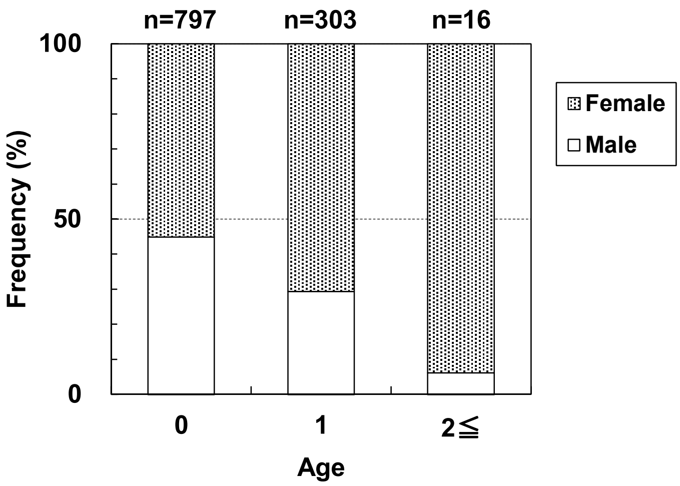

Fig. 8. Sex ratio in each age of Japanese Spanish mackerel caught off Hyogo Prefecture, southwestern Sea of Japan, from August 2009 to March 2012.

Gonad index values were low from July to March in both sexes (Fig. 9). The GI values increased in fish approaching age 2 in both sexes and in some males approaching age 1 in April and May. However, the maximum GI values in females and males were lower than 5 and 6, respectively.

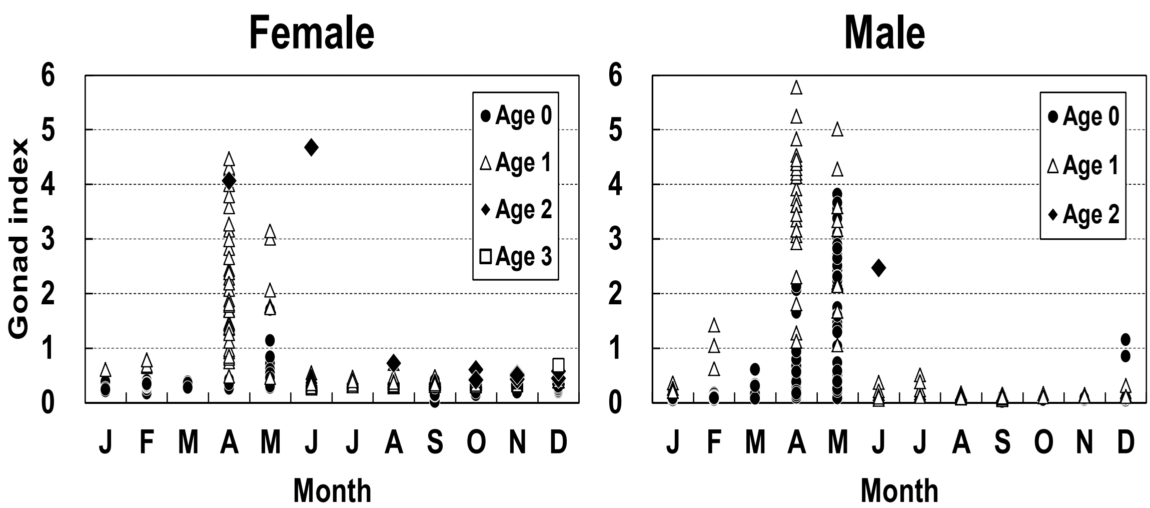

Fig. 9. Monthly changes in gonad index (GI) for females (n=668) and males (n=448) of Japanese Spanish mackerel caught off Hyogo Prefecture, southwestern Sea of Japan, from August 2009 to March 2012.

Discussion

In the present study, the age analysis by cross-section demonstrated that the opaque zone on the otolith formed once a year between May and June, and our validation for age determination of Japanese Spanish mackerel is considered reliable. There were, however, differences in the detection period of annual structure formation on the otolith between the cross-section and surface methods. The cross-section method revealed that specimens collected in mid and late May were beginning to form the opaque zone at the edge of the otolith. In contrast, the detections of opaque zone by the surface method were seen 1 month later than those seen by cross-section. Inoue et al. (2007) obtained results that were similar to the present study using the surface method in specimens caught off Kyoto Prefecture, in the Sea of Japan. Differences in the age determination between the two aging methods have been reported in other fish such as threeline grunt (Doiuchi et al. 2007) and three-lined tongue sole *Cynoglossus abbreviates* (Gray 1834) (Yamamoto et al. 2008). For instance, Doiuchi et al. (2007) indicated that the surface method frequently provided a lower age count than the cross-section method. In Japanese Spanish mackerel, it is frequently difficult to observe the annual structure by the surface method (Hamasaki 1993). In contrast, using the cross-section method made it easy to read the opaque zone. Thus, the cross-section method is useful to clarify and accurately determine the age of Japanese Spanish mackerel.

The results of the present study revealed that a large proportion of the catch consisted of age 0 fish. In a study in the Seto Inland Sea, Kishida et al. (1985b) reported that the oldest female and male collected were age 6 and 4, respectively. Other studies have reported that catches in the Seto Inland Sea consist mainly of age 2 fish in spring and age1 fish in autumn (Chiba et al. 2008; Kishida 1990). Therefore, the rate of young fish caught in the present study area was higher than in other areas. Similar catch of young fish have also been reported from another part of the Sea of Japan (Inoue et al. 2007; Tojima et al. 2011, 2013), suggesting that it was a general trend in this area. The present resource level of Japanese Spanish mackerel is relatively high in the subpopulation of East China Sea. Moreover, it is thought that there is little possibility of size selectivity or over-fishing because most of the fish were caught by set-nets in this area (Nishikawa 2013).The differences between the Sea of Japan and Seto Inland Sea in the age compositions of catch seem to be attributed to other reasons such as the differences in the migration behavior in each area.

In the present study, the age determinations by the cross-section method revealed that annual structure formations were observed mainly in June, which was associated with the spawning peaks in the East China Sea and the Yellow Sea. On the other hand, seasonal changes of GI values suggest that maturation began in April and May, and the maximum values in females and males were lower than 5 and 6 although the values in the East China Sea and Yellow Sea were over 10 in both sexes (Hamasaki 1993). In addition, the present results indicated that the male and female ratio in age 0 fish was nearly equal, but in fish older than age 1 showed abundance of females. Judging from the increase in the GI value, females presumably mature as they approach age 2, while some males mature as they approach age 1. This might be related to differences in the age maturity and migration for spawning between females and males in the Sea of Japan. The sex ratio differences seen in older fish could be due to early maturation of the males that start migrating southwest ward before the females. Inoue et al. (2007) did not collect any females that had either just spawned or were about to spawn in their study in the Sea of Japan off Kyoto Prefecture, suggesting that females migrate elsewhere such as the East China Sea to spawn. Fujiwara et al. (2013) examined maturity and spawning of female Japanese Spanish mackerel collected from many areas in the Sea of Japan, and also suggest that this species leave the Sea of Japan for spawning. However, based on the previous and the present study, it is difficult to establish the migration behavior in the Sea of Japan. Further large-scale studies using tagging methods, covering the whole of the Sea of Japan including the East China Sea area, are needed to clarify this uncertainty.

During the present and previous studies, new modes of age 0 fish that were first caught in autumn revealed the absence of fish smaller than 250 mm FL in the Sea of Japan (Inoue et al. 2007; Tojima et al. 2011, 2013). In contrast, larvae and juveniles were collected in previous studies in the Seto Inland Sea, which is the spawning ground for this species (Shoji et al. 1997; Kishida 1991). The early life stages of Japanese Spanish mackerel are piscivorous and they grow rapidly (Shoji et al. 1999). Early juveniles grow1.03 $mm \cdot day^{-1}$ between 4 and 20 days after hatching (Shoji et al. 1999), and the total length reaches 300 mm in 80 days after hatching (Fukunaga et al. 1982).We believe that this species caught in the Seto Inland Sea hatch around June and migrate from another area in autumn after growing to around 300 mm FL.

Conclusion

The present results demonstrated that the otolith cross-section method is useful to clarify and accurately determine the age of Japanese Spanish mackerel. In the Sea of Japan, a large portion of the catch consisted of age 0 fish, and few fish were age 2 and older. It is suggested that this species migrate elsewhere such as the East China Sea to spawn, and new year classes hatch around June and migrate to this area in autumn.

Acknowledgments

We thank the set-net fishermen of the Amarube Fishermen's Production Association and the staff of the Tajima Fisheries Cooperative Association for their kind help in sampling and data collection. We also thank Dr. Takashi Tojima, Fisheries Technology Department, Kyoto Prefectural Agriculture, Forestry and Fisheries Technology Center and Dr. Shigeaki Gorie, Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, for their helpful advice and valuable discussions on our research, and Dr. John R Bower of Hokkaido University for kindly reviewing the initial manuscript. This study was partly supported by the Agriculture, Forestry and Fisheries Research Council, Japan (Research and development projects for application in promoting new policy of agriculture, forestry and fisheries).

References

Chiba, M., T. Katou and Y. Kouno.2008. Seasonal changes in age composition and growth of Spanish mackerel landed in Ehime Prefecture from Iyo-nada of the Seto Inland Sea. Bulletin of the Japanese Society of Fisheries Oceanography 72:182-183.

Doiuchi, R., T. Kokubo and M. Ogawa.2007. Age and growth of threeline grunt *Parapristipoma trilineatum* along the south-western coast of Kii Peninsula, Japan. Fisheries Science 73:777-783.

Fujiwara, K., S. Satou, T. Tojima and H. Kidokoro. 2013. Maturity and spawning of female Spanish mackerel *Scomberomorus niphonius* in the Sea of Japan. Bulletin of the Kyoto Institute of Oceanic and Fishery Science 35:13-18.

Fukunaga, T., N. Ishibashi and N. Mitsuhashi.1982. Artificial fertilization and seeding propagation of Spanish mackerel. Technical Reports of Japanese Sea Ranching Programs 11:29-48. (in Japanese)

Hamasaki, S. 1993. Age and growth of Japanese Spanish Mackerel in the East China Sea and Yellow Sea. Bulletin of Seikai National Fisheries Research Institute 71:101-110.

Inoue, T., Y. Wada, T. Tojimaand K. Takeno. 2007. Age and migration of the Japanese Spanish mackerel (*Scomberomorus niphonius*) in the coastal water of Kyoto Prefecture. Bulletin of the Kyoto Institute of Oceanic and Fishery Science 29:1-6.

Katayama, S., S. Akiyama, M. Naganuma and R. Shibata. 2009. Age and growth of rabbitfish *Siganus fuscescens* in Tateyama Bay, Japan. Aquaculture Science 57:417-422.

Katayama, S., M. Yamamoto and S. Gorie. 2010. Age compositions of flatfish stocks as determined by a new otolitho metric method, its application in the estimation of growth, spawning potential and fisheries management. Journal of Sea Research 64:451-456.

Katoh, O., N. Nakagawa, S. Matsui, H. Yamada and T. Watanabe. 2006. Long-term fluctuations of water temperature in the Japan Sea and the Tsushima Strait shown by data from prefectural oceanographic observations along the coastal and offshore measurement lines. Bulletin on Coastal Oceanography 44:19-24.

Kishida, T., Y. Kamijo, Y. Yokomatsu, S. Hayashi, K. Hara, S. Hiyama and K. Ueda. 1985a. Distribution and migration of Japanese Spanish mackerel in the Sea of Suo. Bulletin of the Nansei Regional Fisheries Research Laboratory 18:25-37.

Kishida, T., K. Ueda and K. Takao.1985b. Age and growth of Japanese Spanish mackerel in the central and western waters of the Seto Inland Sea. Bulletin of the Japanese Society of Scientific Fisheries 51:529-537.

Kishida, T. 1989. Distribution and migration of Japanese Spanish mackerel based on the catch and effort data in the central and western waters of the Seto Inland Sea. Bulletin of the Nansei Regional Fisheries Research Laboratory 22:13-27.

Kishida, T. 1990. Relationship between growth and population density of Japanese Spanish mackerel in the central and western waters of the Seto Inland Sea. Bulletin of Nansei National Fisheries Research Institute 23:35-41.

Kishida, T. 1991. Fluctuations in year-class strength of Japanese Spanish mackerel in the central Seto Inland Sea. Nippon Suisan Gakkaishi 57:1103-1109.

Nishikawa, T. 2013. Rapid increase of Japanese Spanish mackerel *Scomberomorus niphonius* caught off the coast of Tajima region, southwest part of the Sea of Japan. Bulletin of the Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries (Fisheries Section) 43:7-12.(in Japanese)

Shoji, J., T. Kishida and M. Tanaka. 1997. Piscivorous habits of Spanish mackerel larvae in the Seto Inland Sea. Fisheries Science 63:388-392.

Shoji, J., T. Maehara and M. Tanaka. 1999. Short-term occurrence and rapid growth of Spanish mackerel larvae in the central waters of the Seto Inland Sea, Japan. Fisheries Science 65:68-72.

Takeda, Y. 1996. Recent poor catch of the Japanese Spanish mackerel *Scomberomorus niphonius* (Cuvier), in the Kii Channel and its adjacent areas. Bulletin of the Japanese Society of Fisheries Oceanography 60:18-25.

Tameishi, H., S. Fujii and A. Maebayashi. 2005. Relationship between regime-shifts of SST and fisheries condition (Spanish mackerel and yellowtail) in Japan Sea. Bulletin on Coastal Oceanography 42:125-131.

Tojima, T., Y. Kumaki and T. Inoue. 2011. Fishing conditions of Japanese Spanish mackerel *Scomberomorus niphonius* in coastal areas of Kyoto Prefecture in recent years. Bulletin of the Kyoto Institute of Oceanic and Fishery Science 33:1-6.

Tojima, T., T. Oota, K. Kodama , H. Kidokoro and K. Fujiwara. 2013. Migration and distribution patterns of Spanish mackerel *Scomberomorus niphonius*in the Sea of Japan, estimated from catch data and tagging experiments in recent years. Bulletin of the Kyoto Institute of Oceanic and Fishery Science 35:1-12.

Yamada, H., S. Katayama, A. Takada, Y. Anraku and Y. Sanada. 2011. Age, growth and age composition of the landings of threeline grunt *Parapristipoma trilineatum*, in the western Bungo Channel, Japan. Bulletin of the Japanese Societyof Fisheries Oceanography 75:161-169.

Yamamoto, M., S. Katayama, H. Makino and H. Takemori. 2008. Age, growth and age composition of tongue fish, *Cynoglossus abbreviatus*, in the central Seto Inland Sea, Japan. Bulletin of the Japanese Society of Fisheries Oceanography 72:174-181.

Yamamoto, M., S. Katayama, H. Makino and H. Takemori. 2009. Age and growth of red tongue sole (*Cynoglossus joyneri*) in the central Seto Inland Sea, Japan. Aquaculture Science 57:341-342.

Received: 01/09/2014; Accepted: 17/11/2014 (MS14-96)