水研センター研報，第32号，89－94，平成22年
Bull. Fish. Res. Agen. No. 32, 89-94, 2010

Biological aspects of herbivorous fishes in the coastal areas of western Japan

Atsuko YAMAGUCHI [*1]

Abstract: Seaweed beds in Japanese coastal waters have significantly declined in recent years, and feeding by herbivorous fish has been identified as one of the potential causes of this decline. In the western coastal areas of Kyushu, seaweed consumption by fish species such as the mottled spinefoot, *Siganus fuscescens,* sea chubs, *Kyphosus* spp, and the Japanese parrotfish, *Calotomus japonicus*, has become a matter of concern. Our study group has been investigating the biological aspects of herbivorous fish in the coastal waters around western Kyushu and Okinawa. In this paper, I introduce some of the results of my work focusing on the biology of herbivorous fish, including their distribution, feeding, and behavioral ecology. Investigation of the stomach contents of herbivorous fish revealed that *K. bigibbus* fed mainly on *Sargassum* throughout the year. In contrast, other fish supplemented their diet of seaweed with amphipods and other organisms. Experiments to determine food preference were performed on captive *K. bigibbus*, and their results supported the results of the stomach-content analysis. Both experiments showed that the fish selectively fed on *Sargassum fusiforme* and *Undaria pinnatifida*. Herbivorous fish off the west coast of Kyushu were tracked using a biotelemetry method. The fish inhabited seaweed beds during the daytime. The activity of *S. fuscescens* and *K. bigibbus* markedly declined when the water temperature decreased to approximately 20℃ and 17℃ respectively. It was observed that these fish overwintered in these areas. This study demonstrates that the recent rise in winter ocean temperatures has extended the period of activity of herbivorous fish. The results contradict the hypothesis that herbivorous fish species migrate northward during warm periods.

Introduction

Seaweed beds in Japanese coastal waters have significantly declined in recent years, and feeding by herbivorous fish has been identified as one of the potential causes of this decline. The recent increase the temperature due to global warming is considered to have led to the northward extension of the distribution of herbivorous fish species in western Japanese coastal waters. Moreover, it has been proposed that the change in the distribution of fish populations has lead to an increase in seaweed consumption by these species. However, detailed information on the biology of herbivorous fish has not been obtained. The cause and effect relationships between feeding damage inflicted by herbivorous fish and "Isoyake" have not yet been elucidated. Seaweed biomass in western Japanese coastal waters is considered to have decreased, and it appears that the balance between herbivorous fish populations and seaweeds has been temporarily disturbed.

In the western coastal areas of Kyushu, the increase in seaweed consumption by fish species such as the mottled spinefoot, *Siganus fuscescens*, sea chubs, *Kyphosus* spp., and the Japanese parrotfish, *Calotomus japonicus*, has become a matter of concern (Kiyomoto, 2000; Kiriyama *et al.,* 2005a, 2005b; Fig. 1).

Our research group have been studying the

2010年７月１日受理（Received on July 1. 2010）
*1　Faculty of Fisheries, Nagasaki University, 1-14 Bunkyo, Nagasaki, Nagasaki 852-8521, Japan

distributions, feeding habits, reproductive behavior, growth, migration, population structure, and other biological aspects of herbivorous fishes in coastal waters, including those around western Kyushu and Okinawa (Fig. 2).

Our findings show that *Kyphosus* spp. are very important to understand the feeding damage inflicted on seaweed beds by herbivorous fish. *Kyphosus* species have not been widely studied because they are not very important from the perspective of fishery. In Japan, 4 species belonging to the genus *Kyphosus* are found (Sakai and Nakabo 2004), and all of them are distributed in western coastal Kyushu. *K. pacificus* is a more tropical species, and we usually found it in Okinawa. The most abundant *Kyphosus* species is *K. bigibbus*, which occupies the waters off the coast of Nagasaki, western Kyushu. It is relatively large *Kyphosus* species.

Since the catches of these fish decrease as the water temperature decreases, it was unclear why extensive damage due to feeding by fishes is detected in autumn and winter.

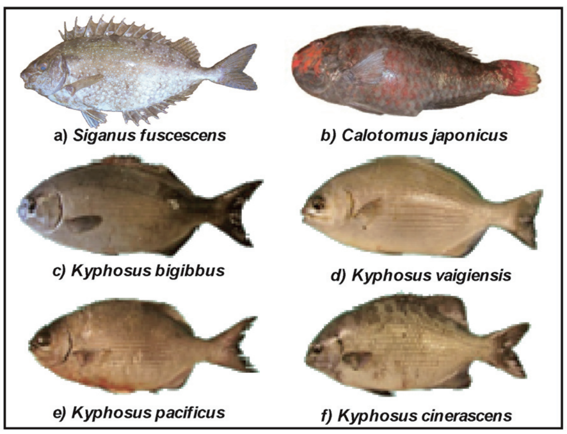


Fig. 1. Main target herbivorous fish species investigated in our study.

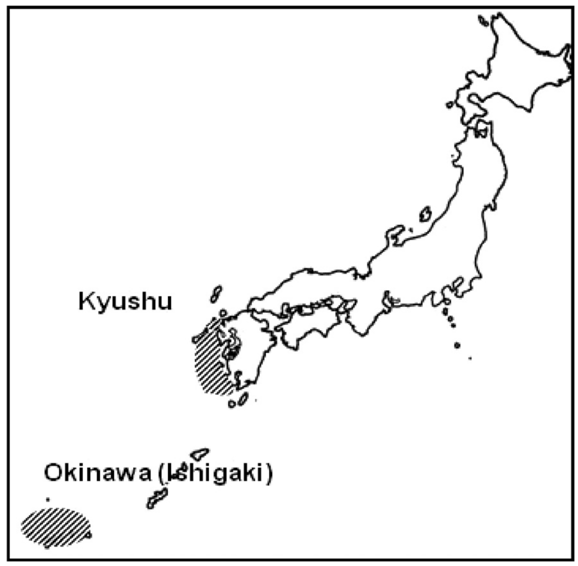


Fig. 2. Main coastal areas investigated in this study

Behavior and migration

In this study, I have attempted to answer the following questions. Do herbivorous fishes migrate from tropical areas? What is their migration range? Do they migrate to seaweed beds for feeding?

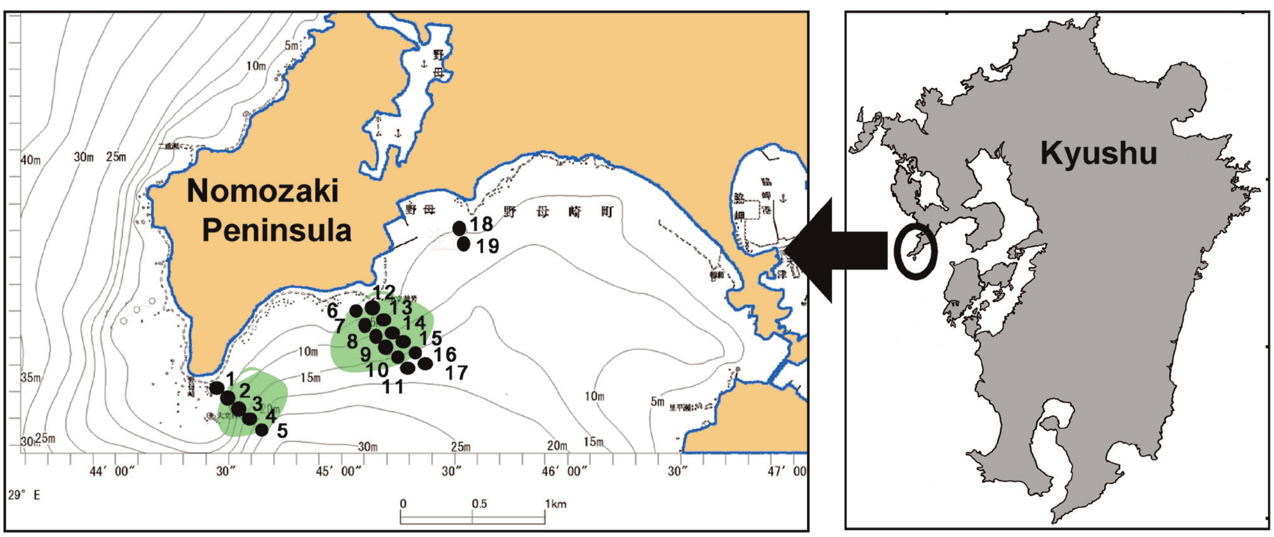


Fig. 3. Study sites in Nomozaki, Nagasaki. The circles and numbers denote the positions of the receivers.

Where do they migrate to during winter? The behavior and migration of the fish were evaluated using ultrasonic telemetry methods (Yamaguchi *et al.,* 2006). Fish were caught using set nets and kept alive for several days. Their dorsal fins were then tagged, and the fish were released. Ultrasonically tagged fish were detected using fixed VR2 monitoring receivers (VEMCO). Transmitter signals were randomly generated at intervals of 45 − 75 seconds; this intermittent signal generation extended the battery life to approximately 150days. Preliminary investigations were conducted to determine the detection range. In our study sites, the receivers accurately detected signals from the transmitters when the former were placed within a distance of 80 m from the latter. Prior to passive tracking of the fish, we tracked the moving range of both *S. fuscescens* and *K. bigibbus* in real time by using some specimens of the 2 species. On the basis of these results and the ecological information previously acquired by our study group, I placed 19 receivers mainly on the seaweed bed in Nagasaki (Fig. 3). A total of 93 individuals (*S. fuscescens,* n = 76; *K. bigibbus,* n = 11; *K. vaigiensis,* n = 5; and *C. japonica,* n = 1) have been tracked since the first examination in November 2004 (Fig. 4).

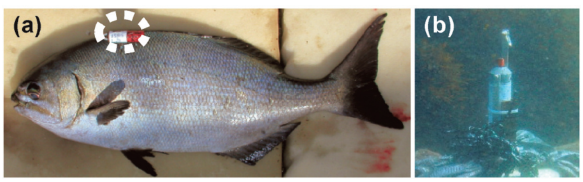


Fig. 4. *Kyphosus bigibbus* with transmitter attached (a) and VR2 receiver (b).

Figure 5 shows the moving ranges estimated using the total number of signals detected by each receiver in 2007 For *S. fuscescens,* most signals were received from the transmitters placed in seaweed beds at Kotate(nos. 6 − 17). Few signals were detected from the seaweed beds in Ootate (nos. 1 − 5). Further, the migration range of *K. bigibbus* was larger than that of *S. fuscescens.*

The typical daily movement patterns in autumn of *S. fuscescens* and *K. bigibbus* have been studied (Yamaguchi *et al.,* 2006). The mottled spinefoot (*S. fuscescens*) did not move at night and stayed close to the receivers placed in deep areas. It began to swim after the sunrise and actively swam in the seaweed areas during the day. After the sunset, it probably returned to the same place close to the receivers in the deep areas and did not move again until the sunrise. In contrast, in the case of *K. bigibbus,* no signals were detected from the seaweed beds in the nighttime. However, it was clear that the fish returned to the seaweed beds in the daytime via a fixed route. It appeared that at sunrise, *K. bigibbus*

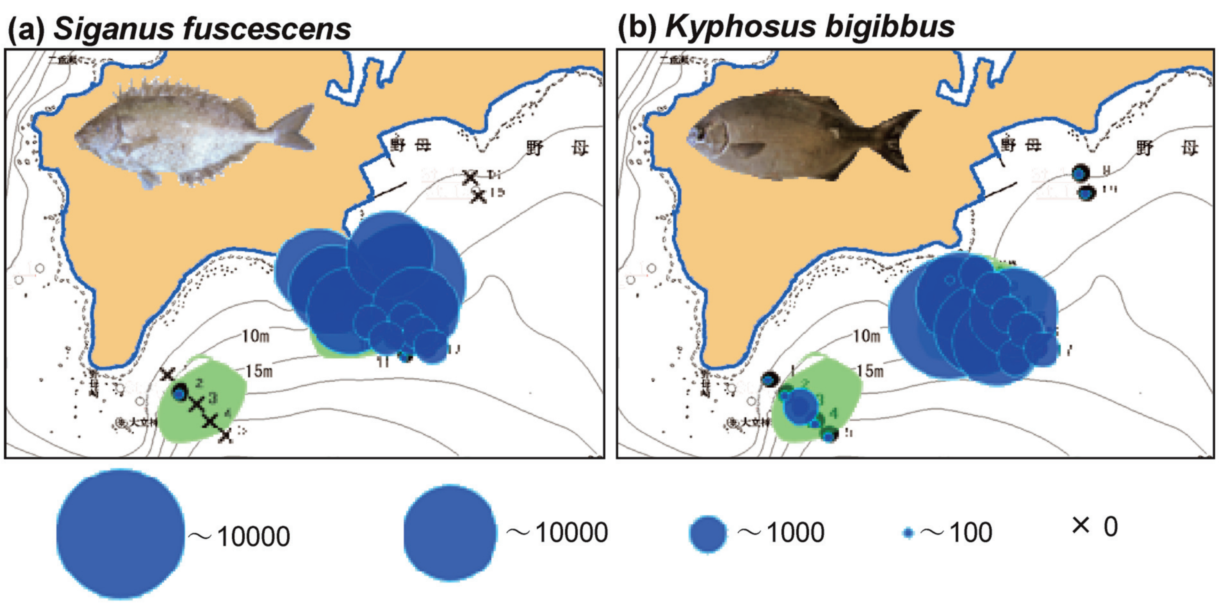


Fig. 5. Total number of signals recorded by each receiver in 2007.

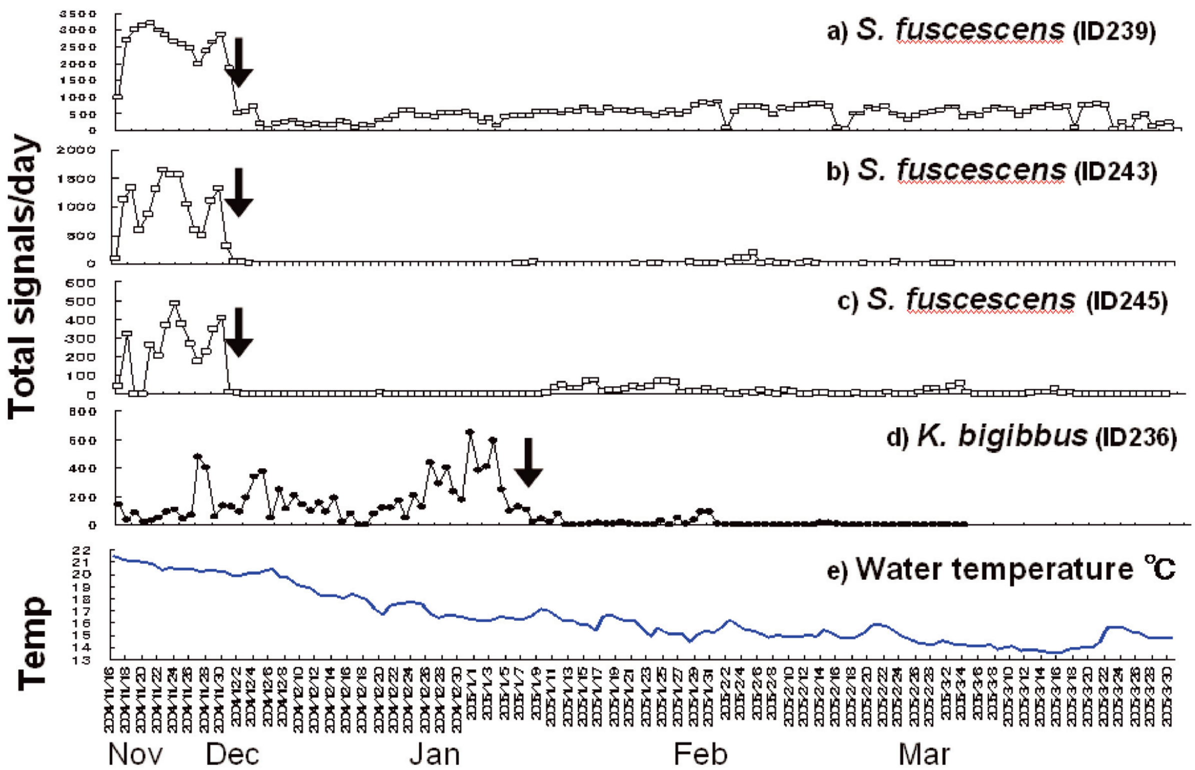


Fig. 6. Total number of signals recorded per day from November 16, 2004 to March 30, 2005 for 4 specimens (a – d) and changes in water temperature in the study area off Nomozaki at a depth of 7 m (e).

approached the seaweed beds from the western side of the peninsula after traveling a relatively long distance. Then, it turned out that a fish returns to the west side of peninsular again after the sunset. The west side is a reef zone; I estimate that *K. bigibbus* inhabits this zone during the night.

However, these typical patterns changed when the water temperature decreased. Although both species inhabited the seaweed beds between December and January, they seemed to be moving slowly. Even though the habitat had not changed much, the home ranges of the fish seemed to be relatively deeper in winter. Figure 6 shows the relationships between the total number of signals per day for *S. fuscescens* and *K. bigibbus*, and the water temperature from November 2004 to March 2005 (Yamaguchi *et al.*, 2006).

As shown in the figure, the number of signals from all *S. fuscescens* individuals markedly decreased from the beginning of December when the water temperature was 20℃. In the case of *K. bigibbus,* the number of signals decreased from the second week of January, when the water temperature was 16 – 17℃. It was found that the activity of both species decreased as the water temperature fell. It is generally regarded that these herbivorous species migrate to southern areas during winter; however, in this study, signals continued to be transmitted from the study sites during winter. This finding indicates that the fish overwinter in same places and that they do not migrate. Further, the decreased activity of these fish species is probably why fish catches decrease during winter. These results, therefore, contradict the hypothesis that herbivorous fishes migrate southward during winter. The water temperature in the coastal areas of western Japan has tended to be high since the mid 90s (Yamaguchi *et al.*, 2006), and has increased by approximately 1 – 2℃ . Thus, our research demonstrated that the rise in recent winter ocean temperatures has extended the period of activity of herbivorous fishes by at least 2 months. This may be the cause of the severe damage to seaweeds.

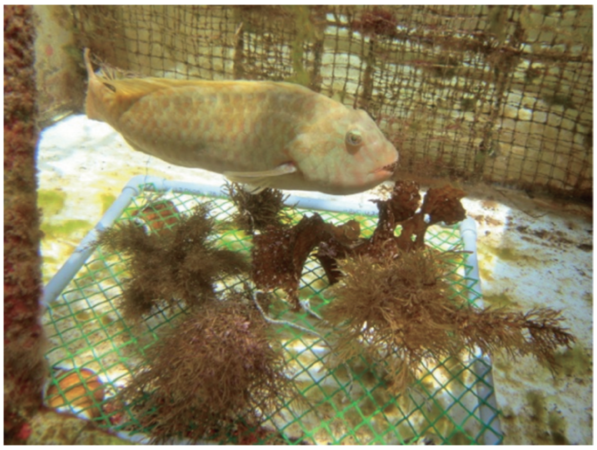
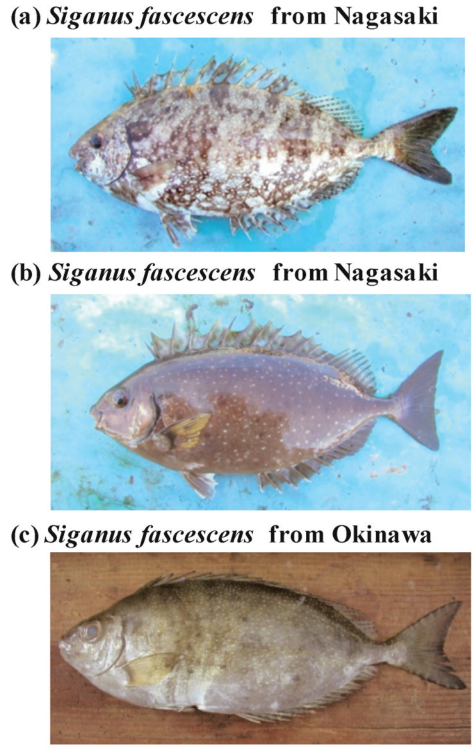


Fig. 7. Japanese parrotfish, *Calotomus japonicus,* swimming in a tank. Herbivorous fishes were kept in captivity in order to study their feeding habits such as selective feeding.



Three mottled spinefoots from Nakasaki (a, b) and Okinawa (c). The morphological characteristics such as white dot patterns and body depth are quite different.

Food preference

It is unclear if herbivorous fishes consume seaweed, and if they do, it should be determined whether they consume seaweed selectively or non-selectively. In our research group, experiments to determine food preferences are performed on captive adult and juvenile individuals of *Kyphosus* species and *C. japonicus* that are kept in tanks (Fig. 7). Investigation of the stomach contents of herbivorous fish revealed that *K. bigibbus* fed mainly on *Sargassum* throughout the year. Therefore, *K. bigibbus* specialized for feeding on seaweeds. In contrast, other fish supplemented their diet of seaweed with amphipods and other organisms. The main food consumed by *S. fuscescens* was also seaweed; it remained in 85% of all, and other organisms, such as skeleton shrimps, were found. Compared with *K. bigibbus* and *S. fuscescens, K. vaigiensis* showed a considerably varied diet. *K. vaigiensis* mainly consumes crustaceans such as skeleton shrimps and seems to be omnivorous rather than herbivorous. In the coastal areas of Kyushu, feeding damage to *Ecklonia kurome* was found, even though these 3 species consumed only small quantities of the seaweed. In fact, only *K. bigibbus* specifically consumed sea algae. *E. kurome* is an important species in the seaweed beds in Kyushu. In our study, *E. kurome* was rarely found in the stomachs of herbivorous fishes, even though it is severely damaged by some fish species in natural environments (Kiriyama *et al.,* 2001). Therefore, the preference captive of herbivorous fishes for 5 species of brown algae was studied using multiple-choice feeding experiments. In the case of *K. bigibbus,* the results of the above experiment supported the results of the stomach-content analysis and showed that *K. bigibbus* selectively fed on *Sargassum fusiforme* and *Undaria pinnatifida*. *E. kurome* was the least preferred by *K. bigibbus*. During winter, the biomass of *S. fusiforme* and *U. pinnatifida* is low; therefore, it is probable that during winter, *K. bigibbus* consumes *E. kurome*. Similar experiments are currently being conducted on other fish species.

Population structure of *S. fuscescens*

Our research group studied the morphometric variations in and the mitochondrial genetic structure of *S. fuscescens* and determined whether or not several populations of *S. fuscescens* exist.

Here, I will focus on the morphological differences between 2 geographic populations of *S. fuscescens* from Nagasaki and Okinawa. The morphological characteristics of the fishes, such as white dot patterns and body depth, were quite different as shown in Fig. 8.

To determine whether locality could be determined solely on the basis of morphometric characteristics, a quadratic discriminant analysis was carried out. The analysis yielded 95% correct assignment of specimens to the locality. The Okinawa population appeared to significantly differ from the Nagasaki population.

The results of genetic studies revealed the significant differences between two populations. Also, they suggested that the Japanese populations were genetically different from Southeast Asian population (Yagishita and Yamaguchi, unpublished data). Therefore, the number of individuals of *S. fuscescens* that migrate from tropical areas such as Okinawa does not appear to be large enough to explain the damage cause to seaweed beds around Japan.

Conclusion

In conclusion, I emphasize the 2 following points: (1) Our results regarding behavior and migration contradicted the hypothesis that herbivorous fish species migrate southward during winter. These fish do not migrate over such a long distance. Further, the results of population genetic studies indicated that the migration of *S. fuscescens* from Okinawa is insufficient to explain the damage caused to seaweed beds around Kyushu. (2) The water temperature in western coastal Japan has tended to be high since the mid 90s. In autumn and winter, especially, the water temperature increases by approximately 1－2 ℃. Thus, our research demonstrates that the recent rise in winter water temperatures has extended the period of activity of herbivorous fish by at least 2 months. In winter, the seaweed biomass is relatively low, but the activities of these fish remain high. This may explain the severe damage to seaweed. Moreover, seaweed biomass seems to have decreased, and it appears that the balance between herbivorous fish populations and seaweed has been temporarily disturbed.

References

Kiriyama T., Noda M., and A. Fujii. 2001: Grazing and bite marks on *Ecklonia kurome* caused by several herbivorous fishes. *Suisanzoshoku* **49(4)**, 431－438. (in Japanese)

Kiriyama T., Fujii A., and Y. Fujita. 2005: Feeding and characteristic bite marks on *Sargassum fusiforme* by several herbivorous fishes. *Aquaculture Science,* **53(4)**, 355 － 365. (in Japanese)

Kiriyama T., Fujii A., and Y. Fujita. 2005: Fish species causing poor growth phenomenon by feeding on *Sargassum fusiforme* along the coastal region of Nagasaki prefecture, western Japan. *Aquaculture Science*, **53(4)**, 419－423. (in Japanese)

Kiyomoto S., Yoshimura T., Arai S., Kiriyama T., Fujii A., and T. Yotsui. 2000: Recovery of *Ecklonia kurome* after the occurrence of blade disappearing phenomenon at Nomozaki, Nagasaki Prefecture. *Bulletin of Seikai National Fisheries Research Institute,* **78**, 57 － 65. (in Japanese)

Sakai K. and T. Nakabo. 2004: Two new species of *Kyphosus* (Kyphosidae) and a taxonomic review of *Kyphosus bigibbus* Lacepède from the Indo-Pacific. *Ichthyological Research,* **51(1)**, 20－32.

Yamaguchi A., Inoue K., Furumitsu K., Kiriyama T., Yoshimura T., Koido T., and H. Nakata. 2006: Behavior and migration of mottled spinefoot *Siganus fuscescens* and grey seachub *Kyphosus bigibbus* off Nomozaki, Kyushu, tracked by biotelemetry method. *Nippon Suisan Gakkaishi,* **72(6)**, 1046－1056. (in Japanese)