

Isoyake Studies in Shizuoka Prefecture, Japan

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Abstract: A type of isoyake in which *Ecklonia* forest died suddenly has been known in Izu Peninsula in Shizuoka Prefecture since 1911. On the Hainan Coast, the kelp forest which was the biggest in Japan has disappeared by isoyake in Japan. We struggled for the establishment of restoration of kelp and for clarification of the cause of the isoyake of Hainan Coast. The isoyake on Hainan coast was not affected by the high water temperature as was reported in Izu Peninsula of the Shizuoka Prefecture, but was thought as follows. The light condition deteriorated as a background of the isoyake. As a result, the productivity in the *Ecklonia* population was lowered. In addition, browsing by rabbitfish joined as a factor of the persistence of isoyake. By the observation on the alteration of generation in isoyake area in Izu in 2004, it was thought that the browsing of the parrotfish seemed to be a factor of isoyake.

The marine forest which is the biggest in Japan

Hainan Coast, around Cape of Omaezaki in Shizuoka Prefecture is facing to Gulf of Suruga in the east and the Enshunada in the west (Fig. 1). The shoreline is a sandy beach, while the offing

is the bedrock. Large brown algae (*Ecklonia cava* and *Eisenia arborea*, Fig. 5) grew thick well on the bedrock, forming the kelp forest. The kelp forest was as large as 8,000 ha, which was reported to be the largest kelp bed in Japan.

Various marine organisms inhabited the kelp

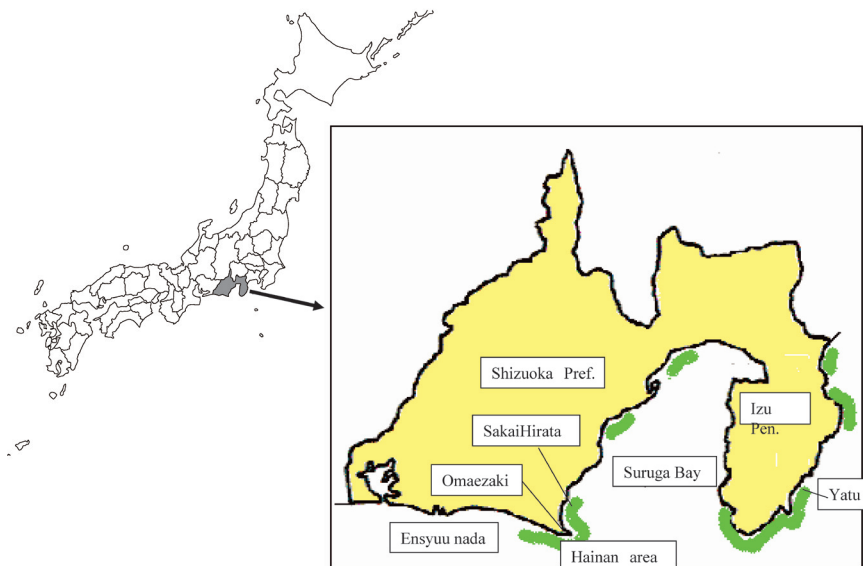


Fig. 1. Map showing Shizuoka Prefecture and its marine forest (green zone)

forest. Particularly, the forest of *Ecklonia* was a good fishing ground of the abalones. Abalone fishery by the helmet diving apparatus began in the Meiji era (1867-1911). Later the fishermen have continued fishing 10-20 ton of abalone while 100,000-400,000 juveniles have been released (Fig. 2). In addition, the *Eisenia* has been gathered as food for a long time (from perhaps, Nara era). The changes in the harvest of *Eisenia* after 1981 in the Jitougata and the Sakai-Hirata Fishermen's Cooperatives which share most of the harvest in Fig. 2. The catch of around 20-40 ton was in the golden age in both fishermen's cooperatives.

The outbreak of isoyake

On Hainan Coast, isoyake occurred from 1985. *Ecklonia* and *Eisenia* suddenly died and the kelp forest has disappeared afterwards. The isoyake must be the largest in Japan because it was the disappearance of the biggest kelp forest in Japan. That the restoration of *Ecklonia* forest has been partially succeeded, resulting in the establishment of a small forest around the project area since 2005.

Isoyake in *Ecklonia* forests has been known in Izu Peninsula in Shizuoka Prefecture (Fig. 1) since Yendo (1903). However, we have not experienced such a large isoyake as about 8,000 ha before.

According to the monitoring by Izu Branch of Shizuoka Prefectural Fisheries Experiment Station, the isoyake of *Eisenia* forests occurred from about 1985 and that in the *Ecklonia* forest from about 1990. As *Eisenia* itself is the commercial species, isoyake directly damaged the fishery (Fig. 2). Furthermore, the catch of abalone which depends on *Eisenia* and

Ecklonia as food also decreased (Fig. 2) and gave the local fishery production a big blow. The amount of the direct damage was estimated to be about 100-200 million yen (@ 7,000 yen) in abalone fishery and about 40-80 million yen (@ 2,000 yen) in *Eisenia* harvest. Among the damage of isoyake, direct damages in coastal fishery can be calculated as shown above. However, few studies have been done about productivity and the environmental safeguard of the fishing ground through the kelp ecosystem and the indirect damage has been evaluated. Furthermore, the indirect damage of isoyake has not been estimated in quantity. If values of seaweed resources and environment in kelp forests are estimated, the restoration of kelp forest will be promoted not only as the necessity in fishery but as the necessity in society.

The causative agent of isoyake on Hainan Coast

As the fishermen of Hainan has proposed Shizuoka Prefectural Government to reveal the causative agents of isoyake and to restore the kelp beds. We have struggled for the establishment of restoration techniques and clarification of the phenomenon on the Hainan Coast since 1996.

We divided the causes of isoyake into two factors, trigger and persistence. There is a study of the pioneer work of Kawajiri *et al.*, (1981) about the trigger of isoyake in Shizuoka Prefecture. According to their study, isoyake of the *Ecklonia* forest in southern coast of the Izu Peninsula occurred along with the great meandering of the Kuroshio Current.

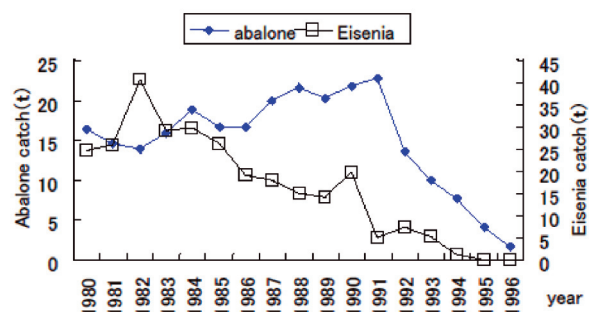


Fig. 2. Catch of abalone and harvest of *Eisenia* in Hainan area

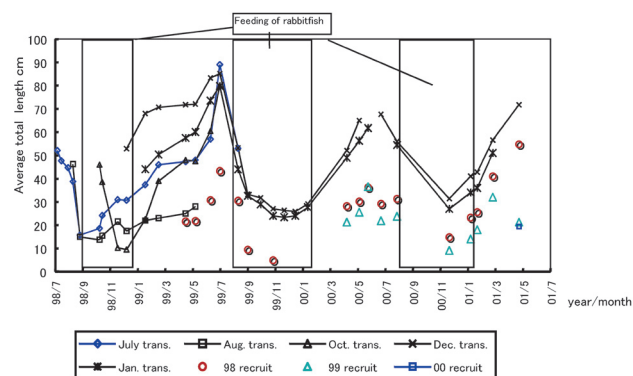


Fig. 3. Changes in total length of *Ecklonia* in transplantation examination

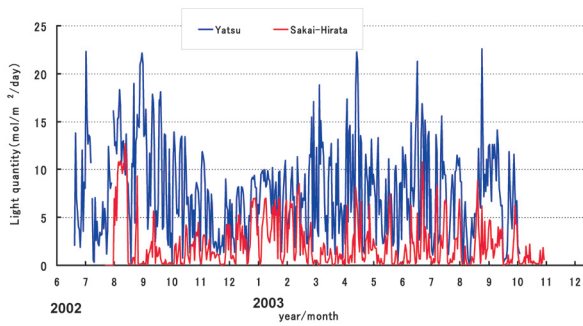


Fig. 4. Comparison of light quantity in *Ecklonia* stands in Izu (yatsu) and Isoyake area in Hainan (Sakai-Hirata)

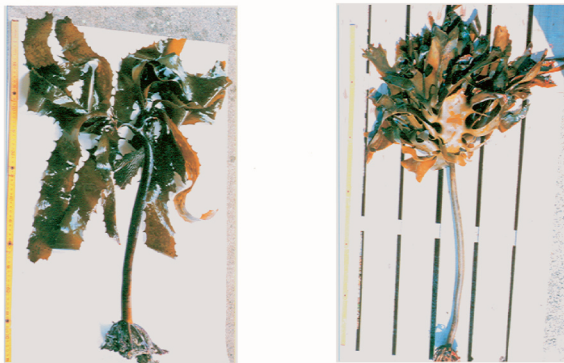


Fig. 5. *Eisenia arborea* (left) and *Ecklonia cava* (right)

The Kuroshio Current approached Izu Peninsula periodically several times in a century. They pointed out that the coming onshore of the warm current caused the persistence of high water temperature which in turn deteriorated the kelp forests along the coast.

At first, the author examined whether the isoyake on the Hainan Coast was similar to that of the southern coast of the Izu Peninsula, namely the isoyake was caused by high water temperature derived from the approach of Kuroshio Current. However, the isoyake on the Hainan Coast was too complicated than was expected. Before starting, I thought that we should clarify the cause of isoyake before practicing restoration projects. However, because the fishermen's demand for the restoration was enough big, restoration trials were preceded to the clarification of the causative agents. The first trial was the transplantation of *Ecklonia* thalli and the monitoring of their survivals.

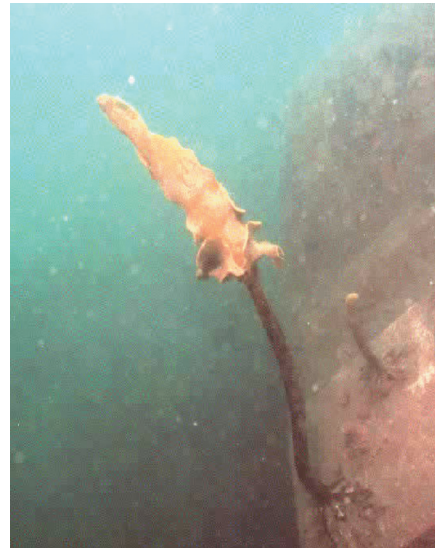


Fig. 6. *Ecklonia* on which leaf is lost in the transplant examination

The *Ecklonia* transplantation was done in Sakai Hirata (Fig. 1) in July, August, October, December 1998, and January 1999 (Hasegawa *et al.*, 2003).. Changes in total length of the transplanted thalli and recruits were shown in Fig. 3. The decrease of the total length means disappearance of the blades, while the increase means luxuriant growth of blades.

The observation of the transplanted thalli for three years revealed that environmental conditions were not out of range of *Ecklonia* growth and that recruits appeared on Hainan Coast. In addition, the author found the disappearance of blades of *Ecklonia* thalli from summer to autumn as shown in Fig. 6. There was a bite mark of the arc in the blades left on the thalli. The mark well agreed with the series of teeth of rabbit fish *Siganus fuscescens* which was known to be herbivorous. Actually, we could observe the scene of browsing on *Ecklonia* thalli by the rabbit fish. These observations strongly suggested that the disappearance of blades from summer to winter was caused by rabbit fish. This is now believed to be one of factors to persist isoyake at Sakai Hirata on Hainan Coast.

In addition, only during one month from October to November in 1999, the blade of *Eisenia* has disappeared at Omaezaki where *Eisenia* stands were left even after the occurrence of isoyake on Hainan coast (Fig. 8). *Eisenia* stands have been observed since 1995 (Hasegawa *et al.*, 2003) and the stands

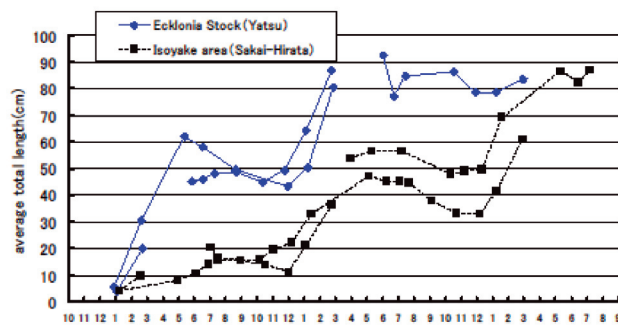


Fig. 7. Comparison of *Ecklonia*'s growth of *Ecklonia* stock in Izu (yatsu) and Isoyake area in Hainan (Sakai-Hirata)

(about 38ha) have remained after the disappearance of kelp forest as large as about 8,000ha.

Nevertheless, in October 1999, the blades of *Eisenia* grown thick disappeared before November 1999 (Fig. 8). There was again loss of blades which left characteristic arc on the survived blades. The detached *Eisenia* blades were found as abundant drifts on the bottom. Mark of the teeth was recognized when the edge of arc on the blade was observed. The characteristic bite marks on *Eisenia* thalli were confirmed to be made by rabbit fish in a feeding experiment in the land-based tank and in observation during diving along the coast.

The survival rate of the *Eisenia* adult was 63% in April 2000. The blades grew thick from spring to summer in 2000. However, the *Eisenia* was browsed again in autumn 2000 by rabbit fish. The density of the *Eisenia* decreased to 1 to 3 individuals/ m² in July 2001. Afterwards, survived thalli of *Eisenia* was hardly seen and disappeared at last. As stated

above, it was suggested that the feeding by rabbit fish affected greatly to the expansion of isoyake at least during the decline of the population.

In addition, if the diving observation were done on the coast of Hainan, one might notice the low transparency because of high turbidity of the waters. There is a possibility that the turbidity on the coast may also cause isoyake. Relation among the environmental factors (water temperature and light intensity), growth of *Ecklonia*, and browsing by rabbit fish was investigated as the next stage. The growth of *Ecklonia* was examined while observing light intensity and water temperature for a long term in the *Ecklonia* populations in Izu peninsula (Yatsu, Fig. 1) and the deforested area (Sakai Hirata, Fig. 1) in Hainan (Shimomura *et al.*, 2005). As a result, a large difference was detected in light intensity between the two sites (Fig. 4) and in the growth of *Ecklonia* (Fig. 7). The relation among the growth of the *Ecklonia*, water temperature and the light intensity was shown in Fig. 9. The growth of *Ecklonia* decreased in higher water temperature, while it increased in lower water temperature. Light related to the growth of *Ecklonia* in lower water temperature. *Ecklonia* thalli grew well when light intensity was high, while they grew little when light intensity is low. The growth of *Ecklonia* was thought to be always inferior because the light environment was bad on the coast of Hainan. If browsing by rabbit fish exceeds the production of *Ecklonia* under such a situation, isoyake can be easily occurred.

The isoyake on the coast of Hainan can be recognized from the result of the above-mentioned research as follows. A light environment deteriorates



Fig. 8. Situation of *Eisenia* Stock around Omaezaki November 5, 1999

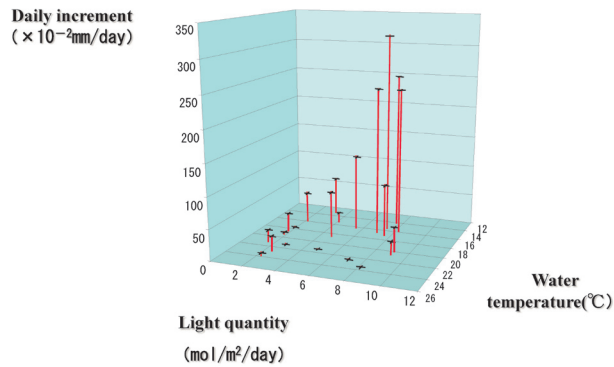


Fig. 9. Relation among the growth of the *Ecklonia* (one year old), water temperature and the light intensity on Hainan Coast.

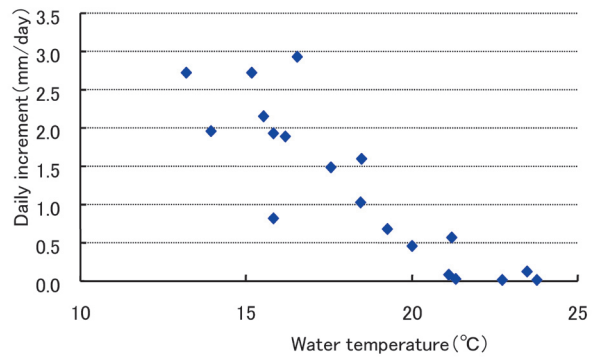


Fig. 10. The relation between the growth of *Ecklonia* (one year old) and water temperature on the coast of Hainan.

as a background of isoyake. As a result, the productivity in *Ecklonia* population was lowered, which in turn caused browsing by rabbit fish to damage the kelp bed.

Is the cause of isoyake in the Izu peninsula a fish?

The Kuroshio Current flowed in the passage of the great meandering after an interval of 13 years in August 2004. Water temperatures were higher than the averaged values from autumn to winter. The water temperature has decreased after a delay

of 15 to 20 days compared with the usual year. And, isoyake in the southern coast of the Izu Peninsula was generated as was in the past finding (Kawajiri *et al.*, 1981). As a result of the observation on the generation process of isoyake, it was thought that the browsing by parrotfish might cause the outbreak of isoyake (Hasegawa *et al.*, 2005).

The feeding behavior of the parrotfish to the *Ecklonia* was observed in the field and the die of the parrotfish could cause in the *Ecklonia*.

As for the growth of *Ecklonia*, it related greatly to water temperature, and the growth of a central

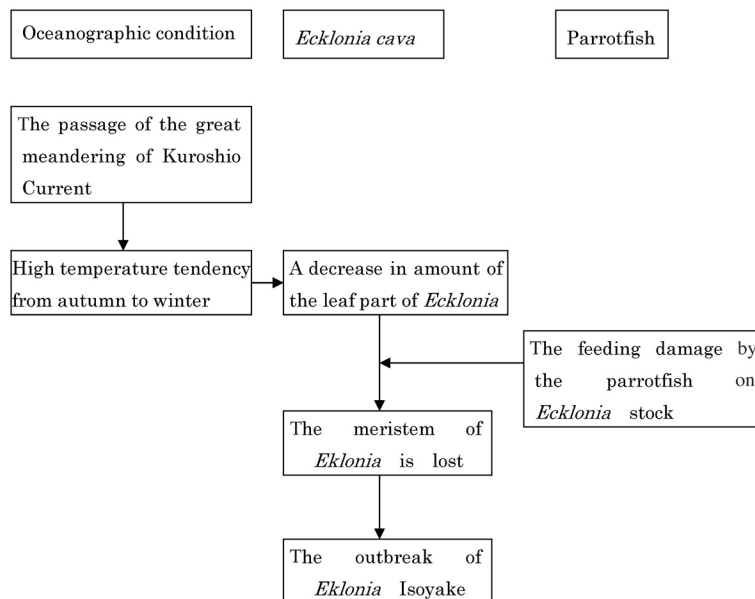


Fig. 11. Cause of isoyake along the coast of the Izu Peninsula.

blade in low water temperature was large (Fig. 10). In addition, the *Ecklonia* releases the swimming zoospores in autumn and the blades fall partially. Therefore, it is known the amount of the *Ecklonia* is minimized in December and January (Iwahashi 1968). Because the amount of growth of a central blade was large at a low water temperature, it is thought that the recovery of the blade is closely related to the water temperature.

The blade grew thick when the water temperature decreased earlier. If water temperatures were higher than the average values of the usual years from autumn to winter as 2004, it will be delayed to grow thick in the blade and the stock of the *Ecklonia* decreases.

At this time, if the browsing by parrotfish is synchronized, even the meristem of the *Ecklonia* is lost. If the water temperature decreases earlier, even if there is the feeding damage of the parrotfish, the damage and the blades growing thickly do the balance. As a result, data showed us that the meristem was not lost.

From the above-mentioned, the outbreak mechanisms of the isoyake drive the passage of the great meandering of Kuroshio Current in 2004 (Fig. 11).

Originally, the herbivorous fish like the rabbit fish and the parrotfish have lived in the rocky reef on the Pacific Coast from central to southwest of Japan. Why herbivorous fishes have come to relate greatly to the isoyake? Because the investigation by divers came popular, is herbivorous fishes' feeding behavior clarified? Or, because the sea might become turbid, did the balance of the *Ecklonia* production and the feeding damage collapse? If the seawater temperature rises by global warming, it is possible for herbivorous fishes to reproduce, and

to have increased the population. In the future, the study on the herbivorous fishes is necessary to think about the rocky reef ecosystem on the sea in the Kuroshio Current. The feeding damage control of the herbivorous fishes is an important problem to develop restoration of kelp beds in the isoyake area.

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