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Restoration of *Ecklonia cava* forest on Hainan coast, Shizuoka Prefecture

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Abstract: Along the coast of Hainan, extending from Sagara to Omaezaki on the west coast of Suruga Bay, Shizuoka Prefecture, the largest kelp forests comprising of *Eisenia arborea* Areschong and *Ecklonia cava* Kjellman have reduced since around 1985 and almost disappeared by 2000. As the result, catches of abalone and other marine fish and shellfish declined sharply along the coast. In order to avoid extinction of the kelp forest, Shizuoka Prefecture implemented a 'Fisheries Infrastructure Development Project' by deploying blocks implanted with *E. cava* thalli on the barren bottom formerly inhabited by the kelps. Furthermore, we also implemented another project to establish new methods of transplantation to cope with browsing by herbivorous fishes. In the project, restoration of *E. cava* forest was tried using ropes implanted with *E. cava* juveniles and removal of herbivorous fish by fixed net and gill net. The shoreline survey conducted in February 2008 revealed that 55 ha of *E. cava* forest was restored along the coast.

Key words: *Ecklonia cava,* kelp forest, herbivorous fish, browsing, transplantation, gill net, fixed net

Introduction

The kelp forests comprising of *Eisenia arborea* Areschong and *Ecklonia cava* Kjellman along the Hainan coast extending from Sagara to Omaezaki on the west coast of Suruga Bay, Shizuoka Prefecture, was one of the largest stipate kelp forest in Japan.

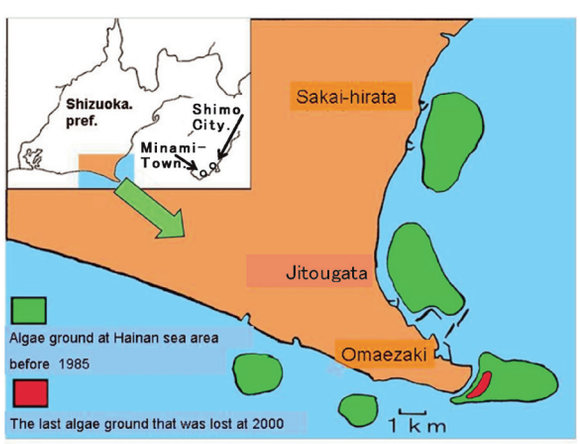

Fig. 1. Reduction of marine forest area

However, the kelp forest has reduced since around 1985 and almost disappeared by 2000. As the result, catches of abalone and other marine fish and shellfish declined sharply along the coast (Hasegawa 2005).

Shizuoka Prefecture, mainly Izu Branch of Research Institute of Fishery carried out investigations to identify the causative agents of the reduction of the kelps and to restore the kelp forest. The restoration trials started in 1996 as a course of Kelp Forest Reconstruction Environmental Research Project.

We implanted *E. cava* on two concrete blocks and transported to a shallow bottom (6m in depth) along the Hainan coast in 1998 (Hasegawa. *et al.,* 2003). As an examination, we deployed a concrete block in the kelp forest of *E. cava* of Shirahama, Shimoda City for 5 months (From November, 1999 to March, 2000) and the block covered with wild *E. cava* juveniles (originated from wild population) was transported to the barren bottom along the Hainan Coast by ship.

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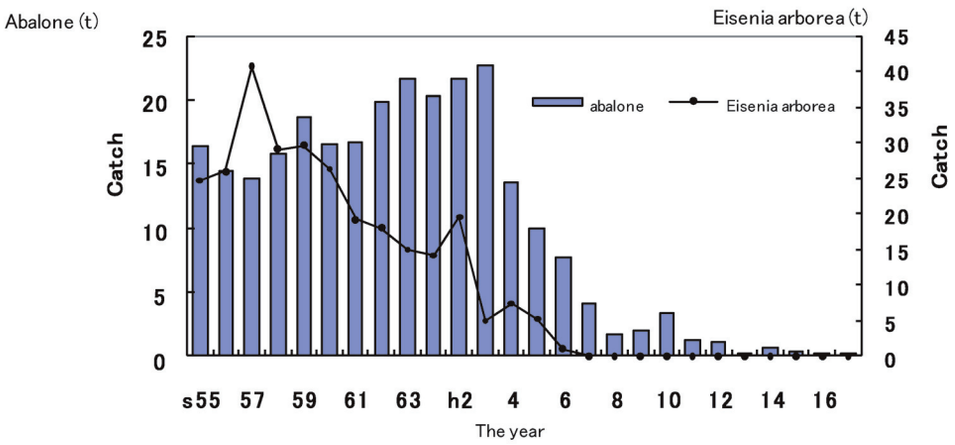

Fig. 2. Catch of abalone *Haliotis* spp. and harvest of *E. arborea* Areschong

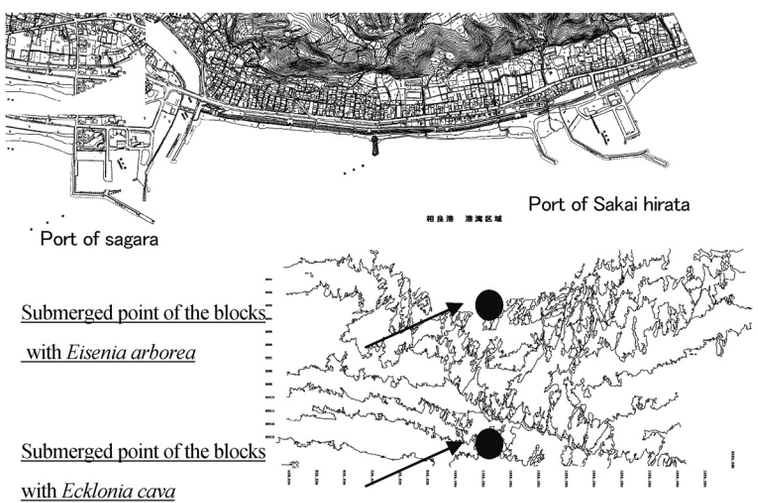

Fig. 3. Points where the blocks with *Eisenia arborea* and *Ecklonia cava* were deployed.

After deployment, we protected *E. cava* from browsing by herbivorous fishes by surrounding the block with a gill net. We succeeded in the persistence of the *E. cava* stock on the block more than a year (Hasegawa 2005).

Then, we started a large-scale transplantation project of *E. cava* from 2002. In addition, we examined a new method of transplantation and investigated the extent of browsing by herbivorous fish from 2004.

Fig. 4. Browsing by brassy chub *Kyphosus* at Hainan

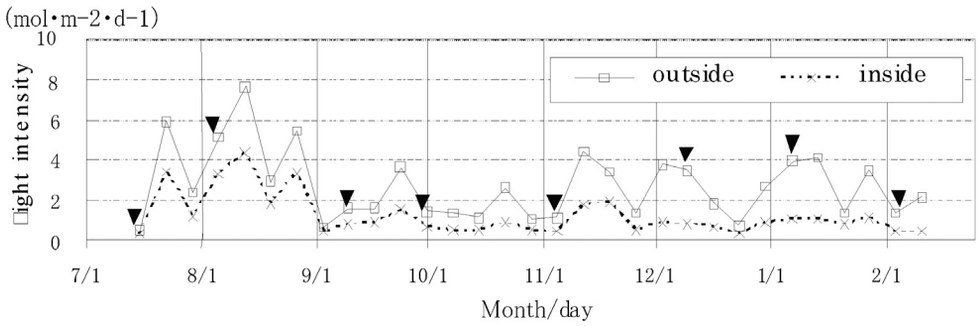

Fig. 5 The change of light intensity inside and outside of the wire cage deployed on Hainan Coast from July 15, 2007 to from Feb. 15, 2008. ▼ : cleaning day

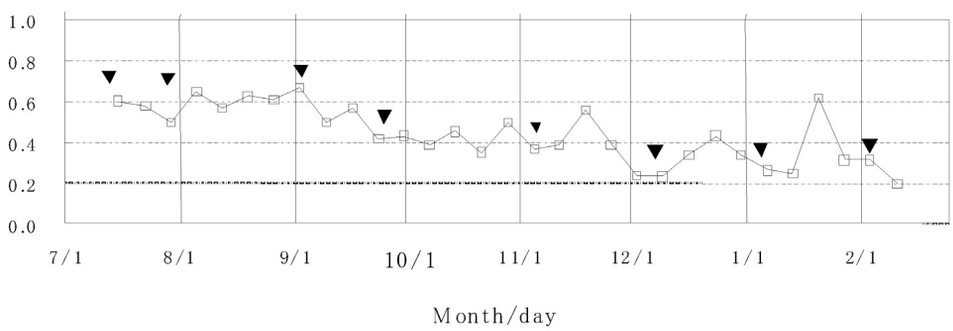

Fig. 6 The change of light intensity by means of inside/outside ratio of the wire cage deployed on Hainan Coast from July 15, 2007 to Feb. 15, 2008.
▼ : cleaning day

The summary of Fisheries Infrastructure Development Project and the examination of the new transplantation method

The summary of Fisheries Infrastructure Development Project.

In 2002 to 2003, we deployed concrete blocks off Minami-izu Town to obtain juveniles from wild *E. cava* forests, and transported these blocks to Hainan. In summer of 2004, just after the transportation of the blocks, the Kuroshio meander occurred and the *E. cava* on the concrete blocks was deteriorated because of high water temperature. Therefore, we suspended the project in 2005, and examined new transplantation method of *E. cava* and *E. arborea*.

The examination of the new transplant method of *E. cava* and *E. arborea* sampling

In addition, we could not transplant *E. arborea* at Minami-Izu because its distribution is restricted to Hainan. On this account, we started examination to implant *E. cava* and *E. arborea* juveniles on concrete blocks manually and deployed them to the bottom of Hainan at 2005.

We implanted juveniles of *E. cava* and *E. arborea* onto 19 concrete blocks using adhesive and deployed them at a depth of 6m. We also implanted *E. cava* on 21concrete blocks and deployed at a depth of 10m.

As the result of monitoring, we confirmed the growth of the transplanted *E. cava* and *E. arborea* juveniles as well as the appearance of *E. cava* recruits in 2006. Therefore, we adopted the transplantation method for further studies. However, no successful transplantation has been achieved in *E. arborea* yet.

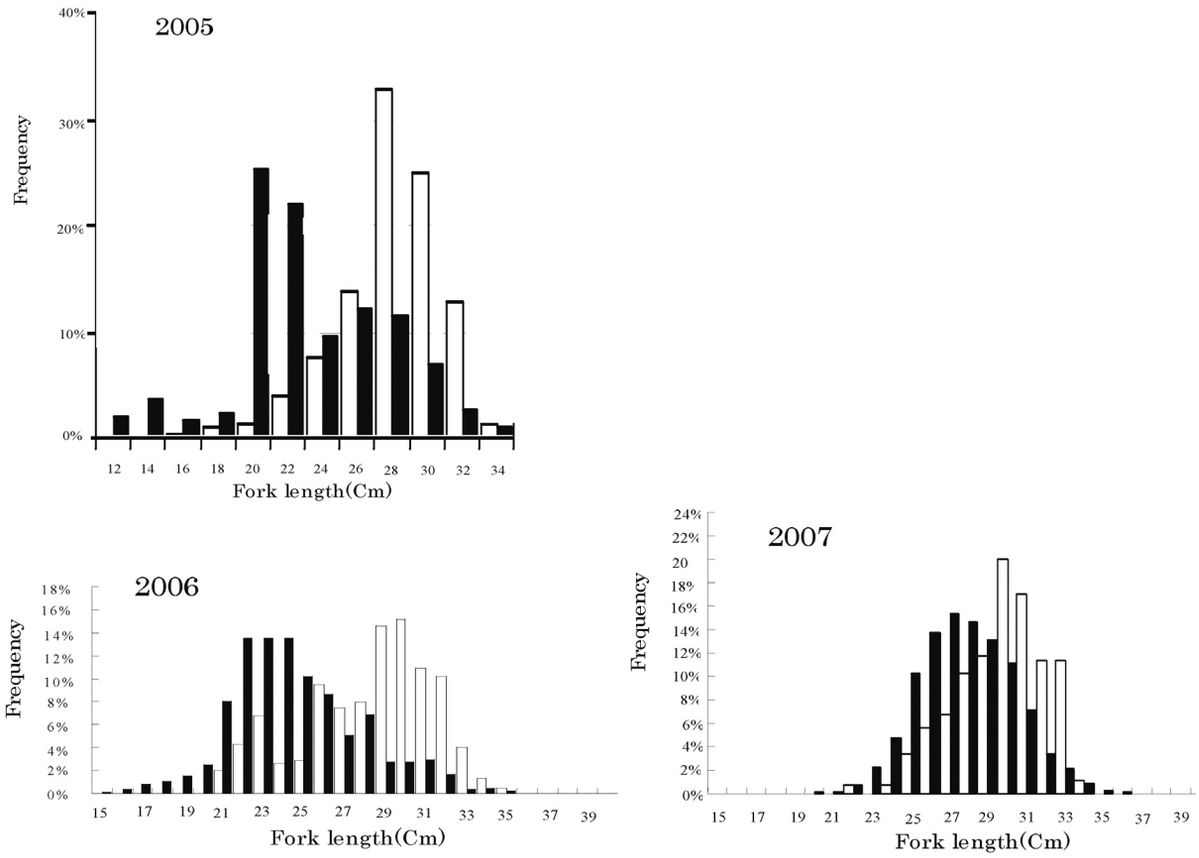

Fig. 7 Frequency distribution for the fork lengths of the rabbit fish. (2005－2007)
□ : Gill net ■ : Fixd net

The browsing on marine algae by herbivorous fishes

The stomach contents of fish caught by the gill net

On Hainan Coast, we investigated the stomach contents of fishes, caught by gill net. We caught 3796 fishes of 95 species in the 132 trials of gill net from June to December 2005. In the investigation, among the fishes, a rabbit fish *Siganus fusucescens,* a parrot fish *Calotomus japonicus* and a surgeon fish *Prionulus scalpus* contained abundant fragments of marine algae in the stomachs. The rabbit fish and surgeon fish was found to eat brown and red algal fragments, while the stomach contents of a parrot fish was occupied by green, brown and red algae.

The feeding behavior of fish monitored with underwater VTR

We filmed the feeding behavior of the fish browsing on *E. cava* with underwater VTR on Hainan Coast for 24 hours. We confirmed that one rabbit fish *Siganus fuscescens* and six brassy chubs *Kyphosus gibbus* browsed *E. cava* in August and September, respectively.

All of these data showed that the causative browsers on Hainan Coast were parrot fish, rabbit fish, surgeon fish, and brassy chub.

Protection of seaweeds from browsing

We carried out two measures to protect *E. cava*, caging with wire and removal of the herbivorous fish by gill nets.

Wire cage and its problems

We built a cage with wire on the concrete pedestal and installed the block on which *E. cava* were transplanted with adhesive. The caged block was deployed at a depth of 8 m on Hainan Coast.

Using the caged block, *E. cava* survived, but could not grow because of poor light condition (Fig. 5, 6).

Fig. 5 shows the changes of light intensity inside (dotted) and outside (solid) of the cage from July 15, 2007 to February 15, 2008. The light intensity was lower inside than outside of the cage. Fig. 6 shows the changes of light intensity by means of inside/outside ratio of the wire cage. The ratio decreased from around 60% to 20-30% after 6 months though the cage was cleaned periodically.

Removal of herbivorous fishes

In order to decrease the amount of browsed thalli, we kept on removing herbivorous fish, by using the gill net and fixed net since 2005 to 2007. In Table 1, the numbers of herbivorous fishes caught by these nets were summarized.

The numbers of herbivorous fishes caught by the fixed net and by the gill net were 8,686 to 4,032 and 627 to 242, respectively. The results show that the fixed net seems to be the better way of removing herbivorous fishes from the vicinity of the target seaweed beds.

Fig. 7 shows the frequency distribution in fork length of the rabbit fish *S. fuscescens* caught by the fixed net and the gill net from 2005 to 2007. The mode of the fork length of fishes caught by the gill net were 30cm in 2007, 31cm in 2006 and 28cm in 2005, while the mode of the fork length of the fishes caught by fixed net was 27cm in 2007, 25cm in 2006, and 20cm in 2005. The minimum of the fork length of the fish caught by fixed net were 21cm in 2007, 15cm in 2006 and 12cm in 2005.

Table 1. The numbers of herbivorous fishes caught by gill net and fixed net

Year	2005	2006	2007
Gill net	283	627	242
Fixed net	5740	8686	4032

Recovery and expansion of the *E. cava* forest in Hainan sea area.

We carried out shoreline survey in order to monitor the effect of the project of *E. cava* transplantation combined with removal of herbivorous fishes by gill net and fixed net in August 2007 and February 2008. The length of the line was 10,000 meters and 196 points were monitored on 20 lines extended rectangular to the shoreline (Fig. 8).

Shoreline survey at August 2007

Fig. 9 shows the result of the survey in August 2007. We confirmed recovery of *E. cava* at 100 of 196 points on the 20 survey lines. Both adult and juvenile of *E. cava* were found at each point, particularly abundant at the central part of the survey area. Using the data, the recovery area of *E. cava* was estimated at about 39 ha.

Shoreline survey in February 2008

Fig. 10 shows the result of the shoreline survey in February 2008. We confirmed the occurrence of *E. cava* at 136 of 196 points on the 20 survey lines.

The ratio of adult *E. cava* containing lateral blade increased comparing with at the result in August 2007. The estimate of the recovery area of *E. cava* was about 55 ha, showing the expansion during the half past year.

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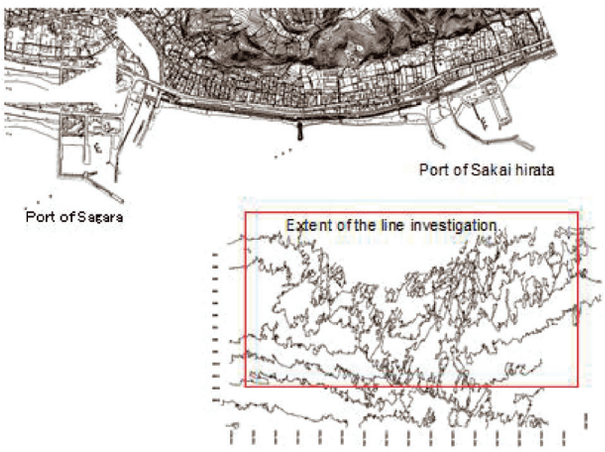

Fig. 8. The range of the shoreline survey.

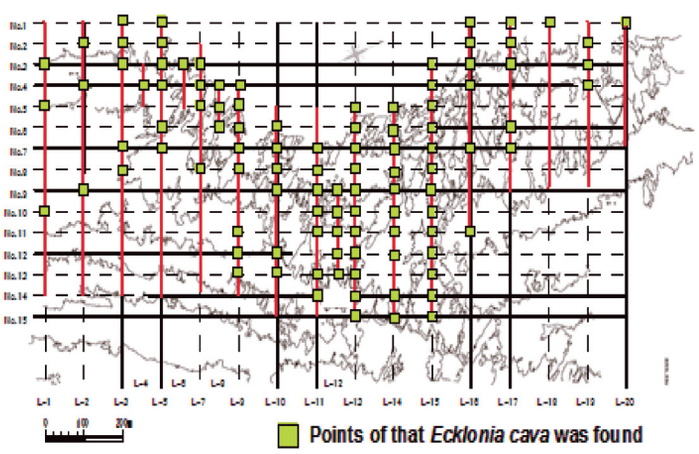

Fig. 9. The distribution of *E. cava* of Hainan coast in August 2007.

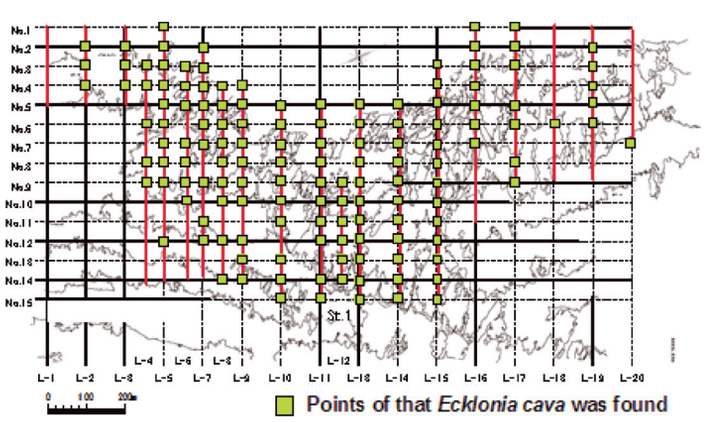

Fig. 10. The distribution of *E. cava* on Hainan Coast in February 2008.