A Study on Seaweed Bed Restoration Using Deep Ocean Water

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A phenomenon that seaweed bed changes into barren ground is called *Isoyake* in Japanese. It has been reported that the deep ocean water discharge may restores seaweed bed from *Isoyake* condition at Muroto coastal area in Shikoku Island. In this study, field survey, biological experiment and ecosystem modeling are performed to clarify the mechanism of the recovery of seaweed bed. The results of these investigations show that the nutrient concentration and grazing pressure, which depend on the deep ocean water content, are the important factors for the seaweed bed recovery.

INTRODUCTION

In some Japanese coastal areas, seaweed beds have recently declined and changed into barren ground. This phenomenon is called *Isoyake* in Japanese [1]. One of the causes of *Isoyake* in southwest coast of Hokkaido is a reduction of nutrient load from land. Fujita [2] reported that an over grazing of *Strongylocentrotus nudus* (Kitamurasakiuni), a kind of sea urchin, is also an important factor of the *Isoyake* in Hokkaido. On the contrary, it is known that *Isoyake* in pacific coastal areas depends on the rout of Kuroshio Current, which is high water temperature and low nutrient concentration [1]. An approaching of Kuroshio Current leads to a decrease of seaweed growth rate and an increase of herbivore grazing rate.

At Muroto coastal area in Shikoku Island, many of seaweed beds have declined since over fifteen years ago. Watanabe et al. [3] reported that some patches of seaweed beds recovered near deep ocean water discharged points at Kochi Prefectural Deep Seawater Laboratory. Deep ocean water (DOW) is low water temperature and high nutrient concentration. This means that the DOW discharge possibly restores seaweed bed from *Isoyake* condition. However, the mechanism of the recovery of seaweed bed has not been clarified yet, because the effect of discharged DOW on the seaweed bed ecosystem is complicated.

Japan Ocean Industries Association (JOIA) has organized a DOW research project by funding from New Energy and Industrial Technology Development Organization (NEDO) since 1999 (to 2003). The purpose of this project is to design an integrated DOW utilization system with DOW cooling for steam-power plant [4]. The impacts of the discharged DOW to coastal ecosystem including seaweed bed restoration are assessed in this project. The present study is a part of the JOIA project and aims to clarify the mechanism of the recovery of seaweed bed at DOW discharged area. The research approach consists of field survey, biological experiment and ecosystem modeling as shown in Fig. 1. The biomasses of seaweed and herbivore, such as sea urchin and fish are investigated at Muroto coastal area. Some laboratory experiments to obtain the seaweed growth rate and the herbivore grazing rate are also carried out. The obtained data are used for developing an ecosystem model.

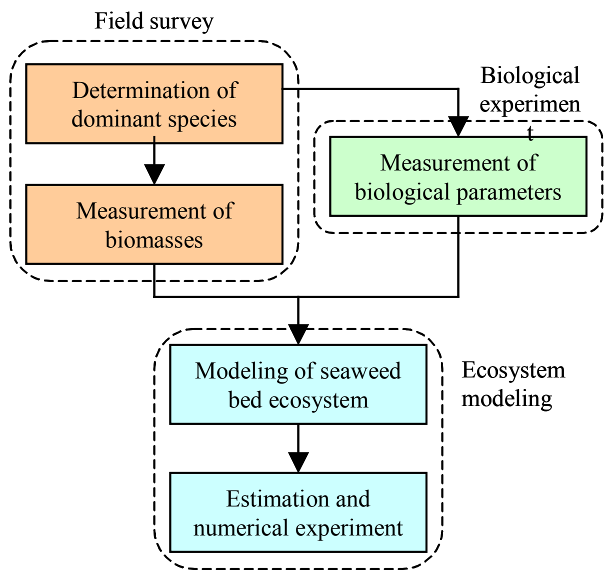

Fig. 1. Research scheme of the study on seaweed bed restoration using deep ocean water.

FIELD SURVEY

A. Research Site

The site in this study is a coastal zone in front of Kochi Prefectural Deep Seawater Laboratory, the Japanese first DOW research center, which was established in 1989 at Muroto city (Fig. 2). The first cold water pipe cans intake 320 m deep seawater with 460 $m^3\ d^{-1}$. In 1994, the second cold water pipe was installed with the same capacity as the first one from 344 m deep sea [5]. This laboratory and Japan Marine Science and Technology Center (JAMSTEC) have investigate fundamental water quality, fisheries applications, air conditioning, and microalgae productions. Distribution of surplus DOW to private companies, which started in 1995, leads to developments of a lot of articles of commerce, such as drinking water, liquor, salt, tofu, pickles, bread, dry fish, health care goods, cosmetics, etc. Watanabe et al. [3]

reported that some patches of seaweed bed recovered near DOW discharged points. This means that the DOW discharge possibly restores seaweed bed from *Isoyake* condition.

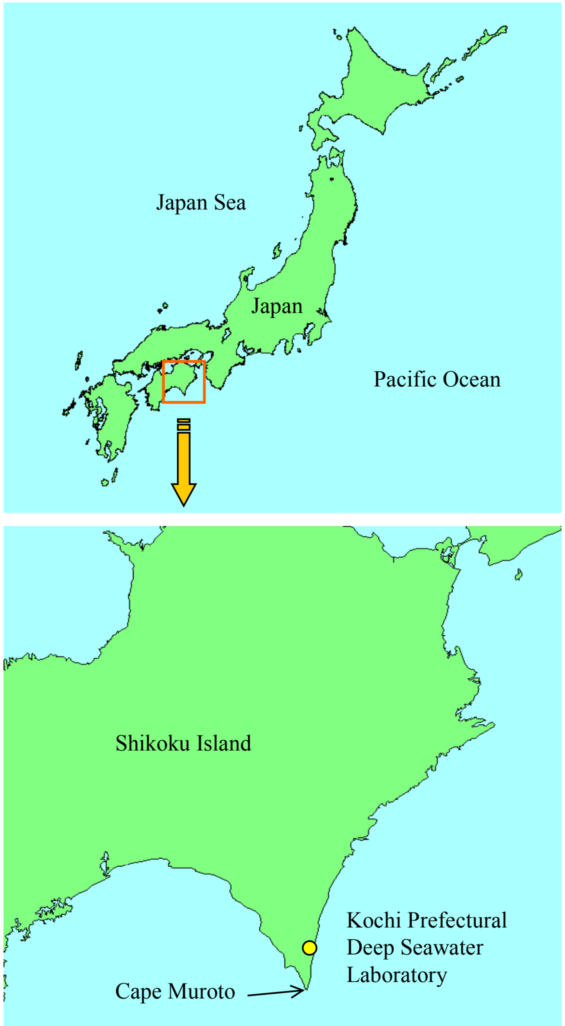

Fig. 2. Location of research site, Muroto coastal area in Shikoku Island.

B. Determination of Dominant Species

In order to develop an ecosystem model of the seaweed bed at the research site, a determination of dominant species of seaweed and herbivore is required. The dominant species of seaweeds and herbivorous sessile animals were investigated by SCUBA diving observations. The dominant species of herbivorous fish were surveyed by analyses of fish catch data, fishermen hearings and examinations of contents of the stomach. From these investigations, three seaweed species, one sea urchin species and four fish species were chosen as the dominant species at Muroto coastal area (Table 1 and Fig. 3). It is noticed that *Eclonia cava* is chosen as a dominant species though it is not be observed at the research site, because this species formed big seaweed bed before changing into *Isoyake* condition.

TABLE 1
DOMINANT SPECIES OF SEAWEEDS, HERBIVOROUS SESSILE ANIMALS AND HERBIVOROUS FISH

	Dominant species	
	Scientific name	Japanese name
Seaweed	1. *Eclonia cava*	Kajime
	2. *Gelidium elegans*	Makusa
	3. *Sargassum micracanthum*	Togemoku
Herbivorous sessil animals	4. Anthocidaris crassispina	Murasakiuni
Herbivorous fish	5. *Girella punctata*	Mejina
	6. *Calotomus japonicus*	Budai
	7. *Kyphosus lembus*	Isuzumi
	8. *Prionurus scalprum*	Nizadai

Fig. 3. Photograph of dominant species (the numbers corresponds to the numbers indicated in Table 1) .

C. Biomasses of Dominant Species

The biomasses of the dominant species of seaweeds were measured by quadrat (0.3m by 0.3m) sampling method. The samplings of *Gelidium elegans* and *Sargassum micracanthum* were performed at the patch of each bed on December 15, 2001. The biomass of herbivorous sessile animals, *Anthocidaris crassispina*, was also measured by quadrat (3m by 3m) sampling method (Fig. 4) from January 19, 2001 to February 21, 2003. The obtained results shown in Table 2 demonstrate that the potential biomasses of *Gelidium elegans* and *Sargassum micracanthum* are 1192 g-wet m^{-2} and 1640 g-wet m^{-2} respectively, and that of *Anthocidaris crassispina* is 504 g-wet m^{-2}.

Fig. 4. Photograph of underwater survey for measurement of sea urchin biomass.

TABLE 2
BIOMASSES OF DOMINANT SPECIES OF SEAWEEDS AND HERBIVOROUS ANIMAL

Date of sampling	*Gelidium elegans* (g-wet m^{-2})	*Sargassum micracanthum* (g-wet m^{-2})	*Anthocidaris crassispina* (g-wet m^{-2})
15-Dec-01	1192	1640	-
19-Jan-01	-	-	57.0
19-Jan-01	-	-	261.6
9-Nov-02	-	-	61.4
16-Jan-03	-	-	504.0
16-Jan-03	-	-	59.5
21-Feb-03	-	-	50.1

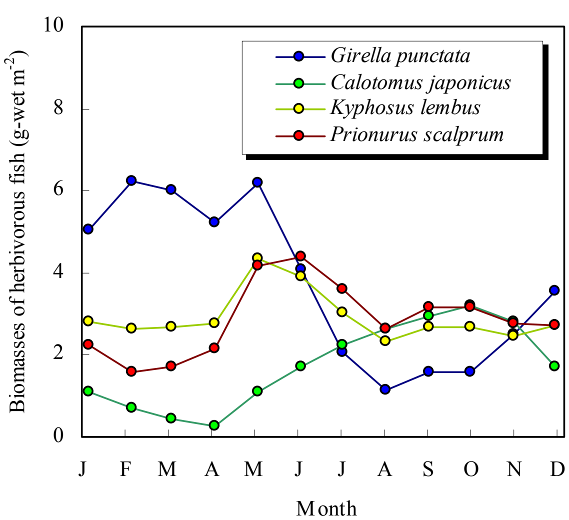

Fig. 5. Estimated biomass of dominant species of herbivorous fish

Fish catch efficiency of a fixed shore net at Muroto coastal area was predicted by the decline of monthly fish catch of *Calotomus japonicus*, a kind of stationary fish, during the fishery season. The biomass of this species can be also estimated from the fish catch data. The biomass of *Girella punctata*, a kind of migratory fish, was estimated by dividing the monthly fish catch by the fish catch efficiency shown before. The biomasses of the other migratory fish, *Kyphosus lembus* and *Prionurus scalprum*, were estimated based on the *Calotomus japonicus* biomass with consideration of seasonal variation, which was determined by fishermen hearings. Fig. 5 shows the obtained seasonal variations of the biomasses. These fish biomass data are used as known functions in numerical simulations.

BIOLOGIOCAL EXPERIMENT

A. Seaweed Growth Rate

Culture experiments to get seaweed growth rate were carried out by researchers in Kochi Prefectural Deep Seawater Laboratory [6][7]. Small pieces of *Eclonia cava* and *Gelidium elegans* were used in these experiments. An example of the results of the experiments for water temperature dependency is shown in Fig. 6. The relative growth rate of *Eclonia cava* has a peak when the water temperature is 15^{o}C. The value of *Gelidium elegans* is higher than that of *Eclonia cava*, and has a peak at higher water temperature range.

B. Sea Urchin Grazing Rate

JOIA constructed a laboratory for fundamental experiments of DOW research in September 2002 at 4 km south from Kochi Prefectural Deep Seawater Laboratory. This laboratory is equipped with five experimental tanks filled with mixed surface and deep seawaters (DOW content = 0%, 25%, 50%, 75%, 100%). The biological experiments to get the grazing rate of *Anthocidaris crassispina* were performed in this laboratory. The experimental tank is shown in Fig. 7. The grazing rate was obtained from the decrease of prey seaweed (*Eclonia cava*) weight during several days. The obtained data shown in Fig. 8 demonstrate that the grazing rate increases with increasing the water temperature.

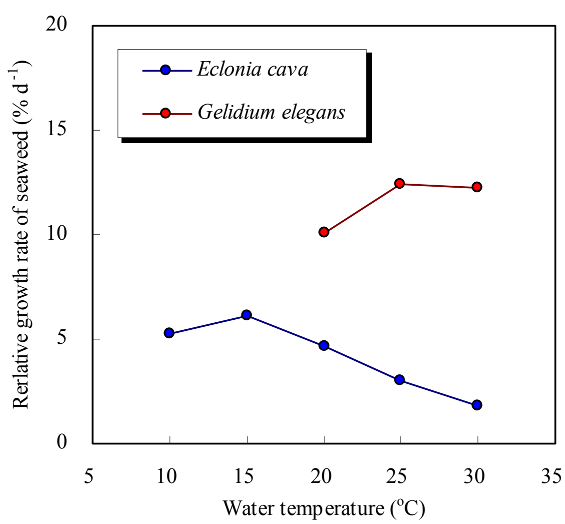

Fig. 6. Relative growth rate of seaweeds relating to water temperature.

Fig. 7. Photograph of experimental tank for sea urchin grazing rate.

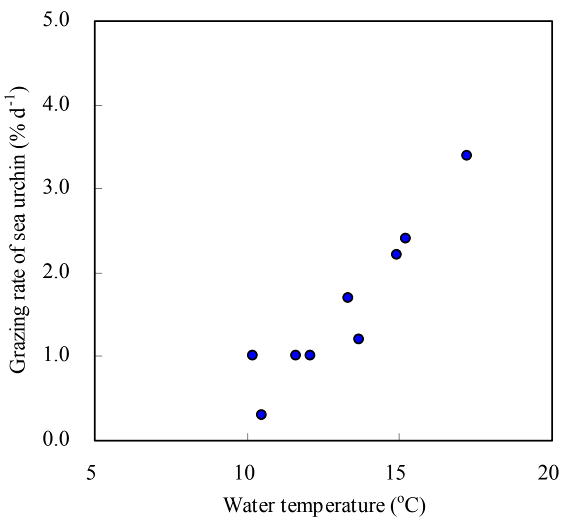

Fig. 8. Grazing rate of sea urchin relating to water temperature.

Fig. 9. Photograph of experimental tanks for fish grazing rate.

TABLE 3
GRAZING RATE OF HERBIVOROUS FISH

Species	*Eclonia cava* (% d^{-1})	*Gelidium elegans* (% d^{-1})	*Sargassum micracanthum* (% d^{-1})
Girella punctata	0.2	0.7	0.2
Calotomus japonicus	11.6	0.2	1.7
Kyphosus lembus	17.0	8.3	4.0
Prionurus scalprum	2.0	1.8	0.7

B. Fish Grazing Rate

Experiments for fish grazing rate are performed at Kochi Prefectural Deep Seawater Laboratory. Fig. 9 shows the experimental tanks for farming the objective fish species. The grazing rates were obtained from the decreases of prey seaweeds weights during 24 or 48 hours. Table 3 shows the results of experiments. The grazing rate of *Girella punctata* is very small, because this species is nervous. *Calotomus japonicus* mainly grazes *Eclonia cava*. The grazing rates of *Kyphosus lembus* are very high for all seaweed species, and reach to 17% in the case of *Eclonia cava*.

ECOSYSTEM MODELING

A. Ecosystem Model

The present ecosystem model is based on a material circulation model, in which fluxes of materials (carbon, nitrogen and phosphorus) between several objective organisms are represented by functions of biological processes, such as relative growth rate of seaweed, grazing of sea urchin and herbivorous fish. The biomasses of these objective organisms can be calculated by integrating the sum of these fluxes in time domain. Eight species, which are chosen as dominant species at Muroto coastal area, are considered as objective organisms as shown in Fig. 10. In this model, only seaweed and sea urchin biomasses are handled as statement variables, and biomasses of herbivorous fish are given as known seasonal functions.

Biomasses of seaweeds are the most important statement variables in this model. The change of seaweed biomass is expressed by the difference between the relative growth and the sum of sea urchin and fish grazing and natural death. The relative growth is given by functions of water temperature, nutrient concentration and light intensity. The first two parameters depend on the DOW content. The grazing of sea urchin does not depend on only water temperature but also its shell size and gonad index, which is the ratio of the gonad weight to the total weight. A seasonal variation function relating to the shell size and gonad index is obtained from the field data (Fig. 11). The grazing of fish also depends on water temperature and season, because of the seasonal change of the fish biomass. The other fluxes, natural death, respiration and excretion of sea urchin are given by a function of water temperature.

Since the details on the flux equations and biological parameters have been covered in other reports [8], they will not be further discussed here.

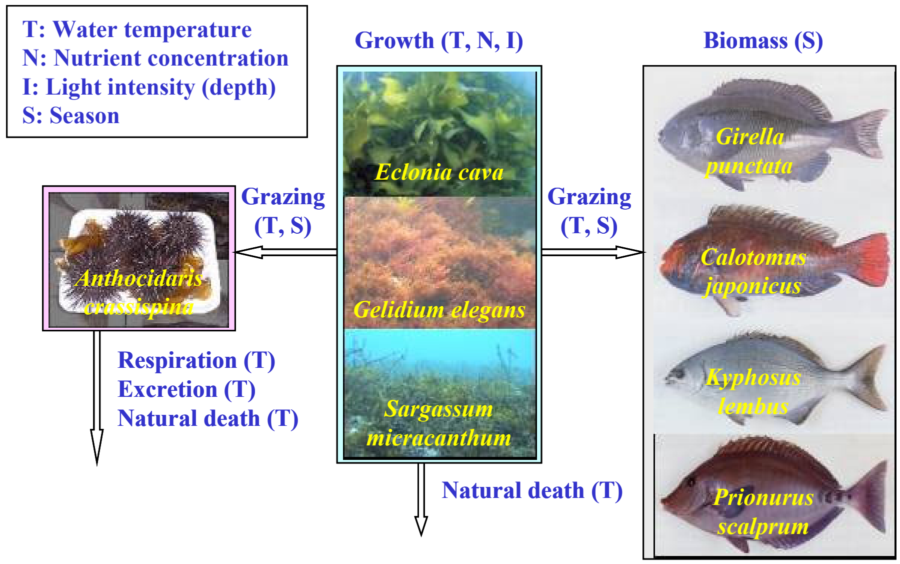

Fig. 10. Conceptual diagram of ecosystem model of seaweed bed at Muroto coastal area.

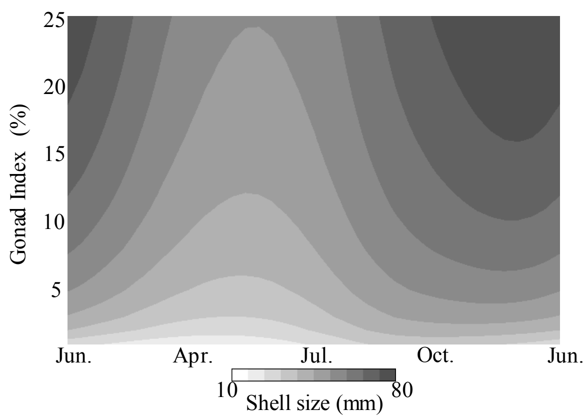

Fig. 11. Seasonal variation function relating to shell size and gonad index of *Anthocidaris crassispina*.

B. Numerical Experiments

DOW discharge leads to decrease of water temperature and increase of nutrient concentration. In order to compare the water temperature effect with the nutrient concentration effect, numerical simulations with independently changing these two parameters are performed.

Figure 12 shows the simulated biomasses of *Eclonia cava* at steady state conditions for various DIN concentrations. In this calculation, the water depth is 3.0m and grazing effect is not considered. *Eclonia cava* is habitable at water temperature lower than 22°C, and the habitable water temperature range expands with increasing DIN concentration. This suggests that the low water temperature and high nutrient concentration DOW may effectively restores *Eclonia cava* bed.

Figures 13 and 14 show the results of simulations for almost the same conditions as those of Fig. 12, but the water depth are 6.0m and 9.0m respectively. The habitable water temperature range and the value of biomass decrease with increasing the water depth because of the damping of light intensity.

The simulated results for grazing effect are shown in Fig. 15. In this case, the water depth is 3.0m, and the same as that of Fig. 12. The habitable water temperature range significantly decreases for low DIN cases. This suggests that the grazing pressure is also one of the important factors for the seaweed bed recovery. For high DIN case, however, the biomass keeps almost the same level as that of the case without grazing, even when the water temperature is 22-26°C. This also demonstrates the effectiveness of DOW discharge for the seaweed bed recovery.

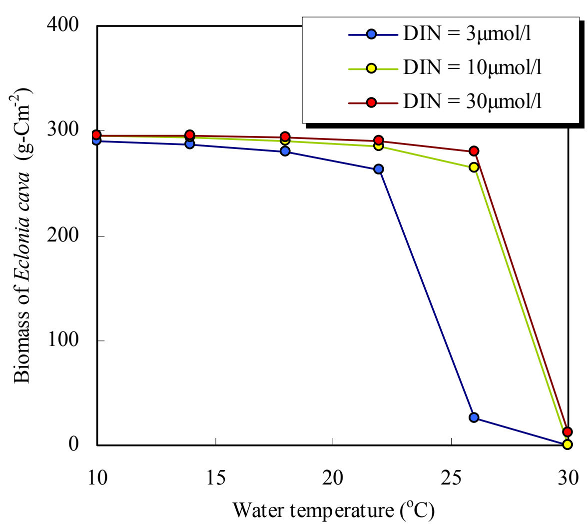

Fig. 12. Simulated biomass of *Eclonia cava* for depth of 3.0m without grazing effect.

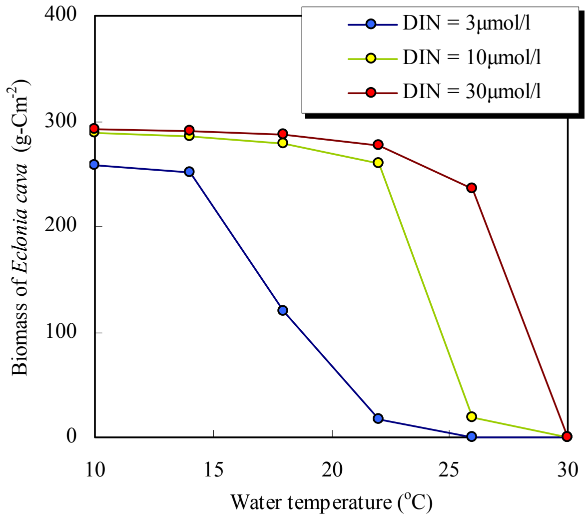

Fig. 13. Simulated biomass of *Eclonia cava* for depth of 6.0m without grazing effect.

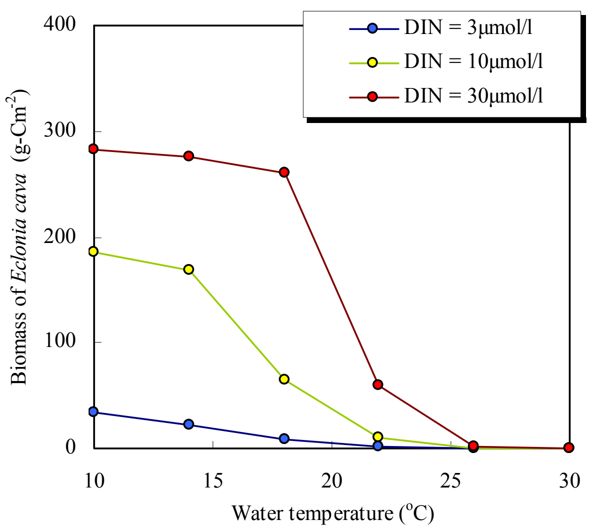

Fig. 14. Simulated biomass of *Eclonia cava* for depth of 9.0m without grazing effect.

SUMMARY

In order to clarify the mechanism of the recovery of seaweed bed at DOW discharged area, field survey, biological experiment and ecosystem modeling have been carried out. From the results of field survey, dominant species of seaweed, sea urchin and herbivorous fish have been determined. Some biological parameters, such as seaweed growth rate, sea urchin and fish grazing rates, have been obtained by the biological experiments. An ecosystem model of the seaweed bed has been developed based on the field survey and biological experiments. The numerical results have shown that the nutrient concentration and grazing pressure, which depends on the DOW content, are important factors for the seaweed bed recovery.

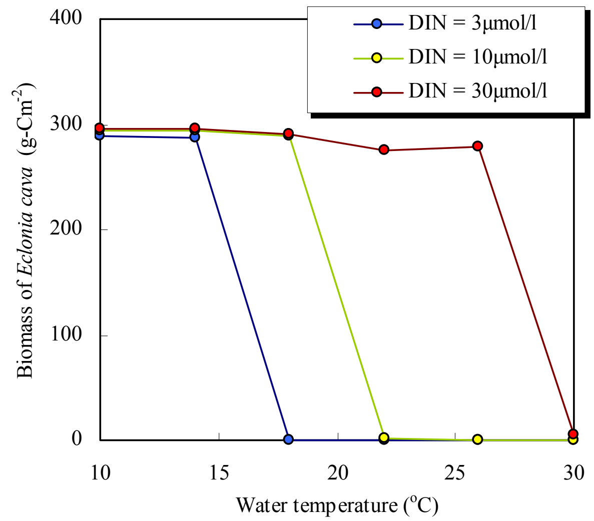

Fig. 15. Simulated biomass of *Eclonia cava* for depth of 3.0m with grazing effect.

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