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Reduction of *Eisenia bicyclis* bed by a grazer *Strongylocentrotus nudus* off Oshika Peninsula: as an example of urchin barren in northeastern coast of Honsu, Japan.

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Abstract : The reduction of seaweed beds (Isoyake) has been known nearly all over the country in Japan. In northern Japan, reduction of kelp beds has significant consequences on the local fishing community dependent on the kelp and herbivores such as sea urchins and abalone. Hearing to prefectural governments by Fisheris Agency has shown that the major factor causing the reduction of kelp beds in northern Japan is sea urchin grazing. As an example of a receding kelp bed in the cold temperate waters , I show the results of a local ecological survey of *Eisenia bicyclis* bed and the sea urchin (*Strongylocentrotus nudus*) and abalone (*Haliotis discus hannai*) on the rocky coastal area in Tomarihama of Oshika Peninsula, Miyagi Prefecture (northern Japan). This survey indicated that the high grazing pressure of sea urchins reduced the survival of juvenile *E. bicyclis* sporophytes near the lower limit of the bed, thus impeding the recruitment of juvenile in the area formerly occupied by adult sporophytes.

Key words : grazing, *Eisenia bicyclis*, sea urchins, *Strongylocentrotus nudus,* degeneration, kelp beds, monitoring

Introduction

Seaweed beds play an important role as one of the primary producers in temperate coastal ecosystems; they provide a place for marine animals to spawn and grow, and supply food to herbivores such as sea urchins and abalone (e.g. Dayton, 1985; Steneck *et al.*, 2002). In northern Japan, kelp (Laminariales) including *Saccharina*, *Eisenia* and *Ecklonia* are extensively distributed on rocky coastal areas. Abalone and sea urchins mainly graze kelp, so the reduction of kelp beds has significant consequences to the local fishing community dependent on these resources. In particular, *Eisenia* and *Ecklonia* beds, which account for approximately 20% of the kelp beds extending along the coastline of Japan (Nature Conservation Bureau, 1994), have been recognized as very important kelp beds for the coastal fisheries because of their high productivity and their high food value for sedentary herbivores. On the other hand, *Saccharina* spp. (Kombu in Japanese) beds are very important not only for food of the herbivores but also for human consumption. *Saccharina* spp. is used as one of the main ingredients for *dashi*, the seafood based stock used extensively in Japanese traditional food.

Loss or decline of kelp beds has been reported on a worldwide scale. The main reasons have been considered to be overgrazing by sea urchins (Lawrence, 1975; Elner and Vadas, 1990; Sivertsen, 2006) and by herbivorous fish (Harris *et al.,* 1984). It was reported that on the coasts of Japan, 2,194ha of beds of *Saccharina*, *Eisenia* and *Ecklonia* spp. have disappeared in the 13 years after 1978 (Nature Conservation Bureau, 1994).

Figure 1 indicates the factors reducing seaweed beds along the coast of Japan (Fisheries Agency, 2007). This figure shows the major factor in southwest Japan is herbivorous fish grazing. On the other hand, in northern Japan, the main factor is sea

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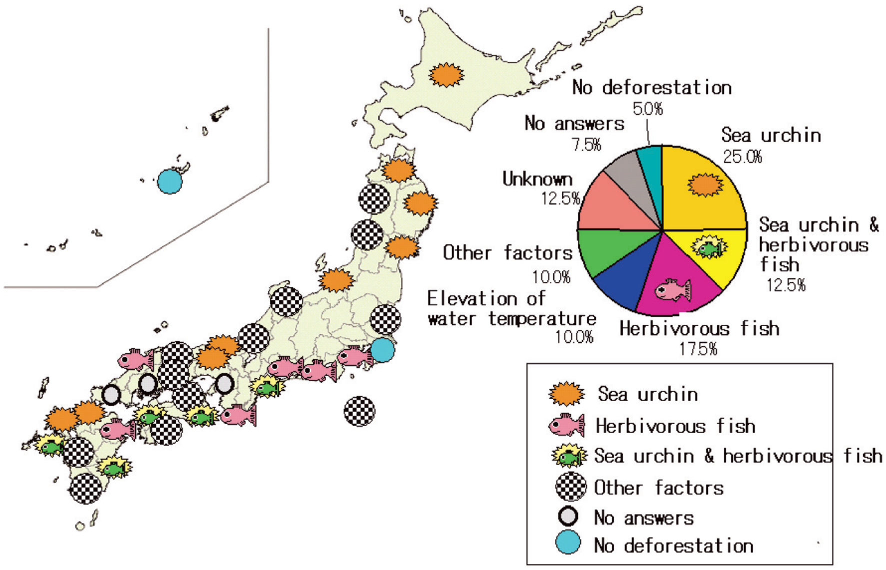

Fig. 1. The factors causing reductions of seaweed beds in Japan (Fisheries Agency, 2007)

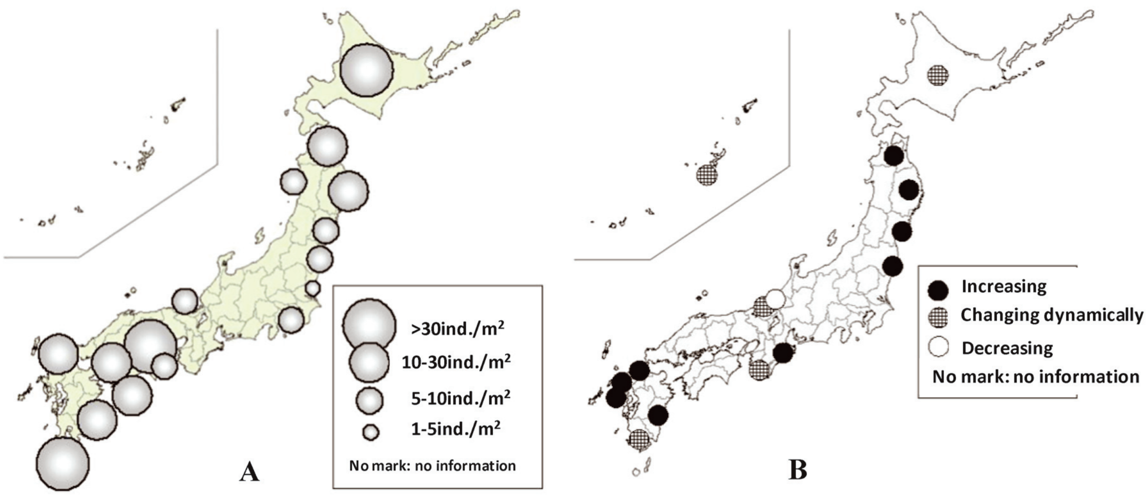

Fig. 2. The densities (A) and the changes (B) of sea urchins in Japan (Fisheries Agency, 2007)

urchins grazing.

Figure 2 indicates the densities (A) and the recent trends of abundance (B) of sea urchins in the rocky coastal areas of Japan. It is clear that the densities remain high (over 5 individuals / m^2) and are increasing in Sanriku Coast, northern Japan.

Recently, gradual receding from the offshore side has been observed in some *Eisenia bicyclis* beds off the coast of southern Sanriku Coast (Taniguchi, 1996). Because reduction of kelp beds directly affect the harvest of economically high-valued inshore resources in this coast, particularly *Strongylocentrotus nudus* and *Haliotis discus hannai* which feed on seaweeds as their main food sources, the degeneration of *E. bicyclis* beds has significant consequences to both the ecosystem and the local fishing community dependent on these resources. In this paper, in order to explore the changes and their causes in *E. bicyclis* beds on the rocky coast in Tomarihama, the Oshika Peninsula in Miyagi Prefecture (northeastern part of Honshu, Japan) was selected as the monitoring site and an ecological survey was conducted on *E. bicyclis* and the major herbivores *S. nudus* and *H. discus hannai*. Using the data,, the relationship between the extent of the coverage of the *E. bicyclis* bed and the occurrence and density of the grazing species was examined (Muraoka, 2008).

Materials and Methods

The rocky coastal area in Tomarihama on the Oshika Peninsula, Miyagi Prefecture (northern Japan) was set up as the monitoring site (Fig. 3). At the start of the survey, the *E. bicyclis* bed was distributed in the depth range of 2–5m. *Sargassum yezoense* beds were also seen at a depth around 2m. From 5 to 10m in depth, crustose coralline algae were dominated.

In 1999, dan buoys were set at the starting point (0m; inside of the *E. bicyclis* bed) and the terminal point (150m; inside the coralline flats) on the bottom of the sea (Fig. 3). From 1999 through 2001, a 150-m long measuring rope (fixed line) was connected between 0m point and 150m point and used for each investigation. The following survey was conducted:

E. bicyclis Ecological Survey

In August 1999, July 2000, and February, May and July 2001, SCUBA diving surveys were conducted and the number and location of all *E. bicyclis* juveniles (< one year old without dichotomous branching) and adult (> one year old with dichotomous branching) sporophytes growing within 1 m width (i.e. 0.5m either side) of the 150m-long fixed line. Juvenile and adult sporophytes were distinguished using the method of Taniguchi and Kato (1984). At the same time, arm length (the length between top of stipe and base of frond) of all *E. bicyclis* individuals was measured, and the age was estimated using the method developed by Taniguchi and Kato (1984).

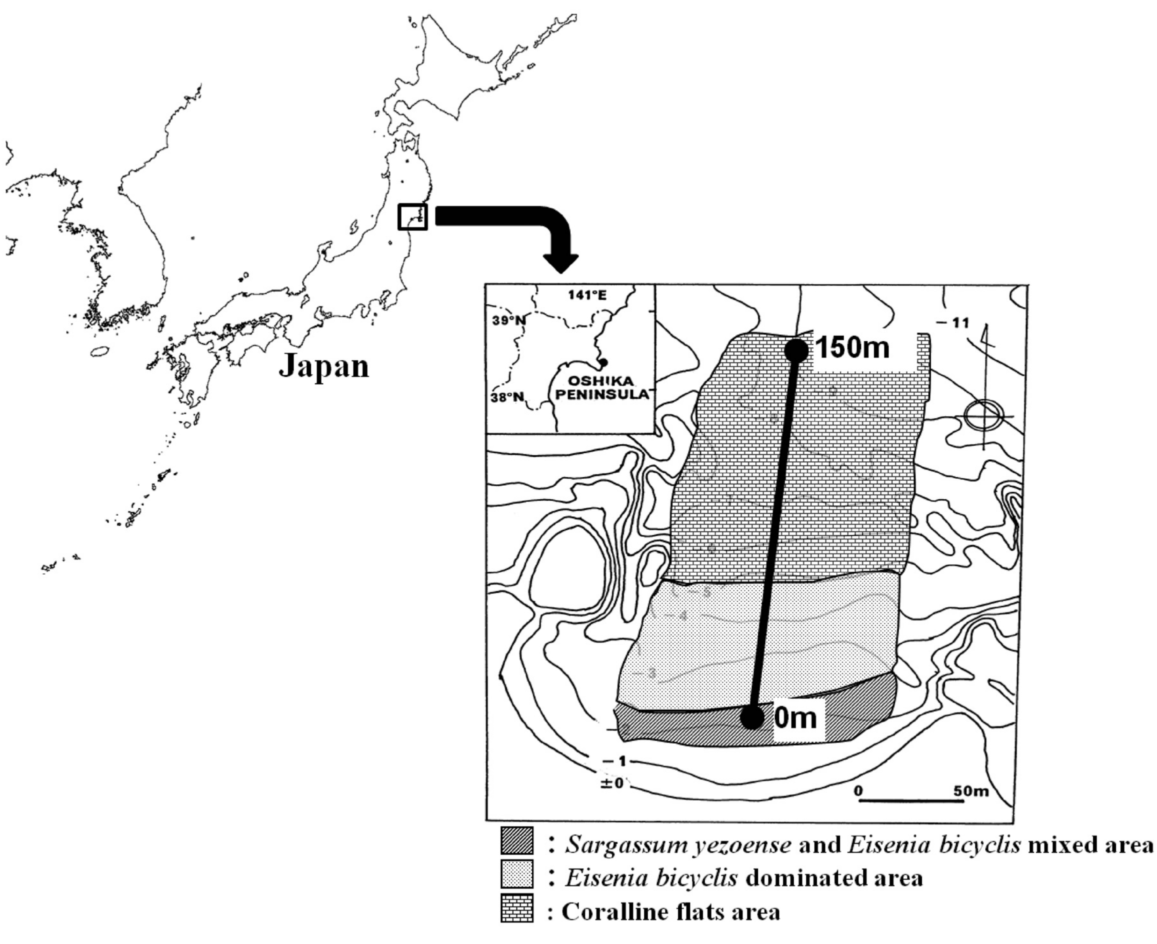

Fig. 3. The survey area and location of the fixed line at Tomarihama, Miyagi Prefecture.

Ecological Survey of *S. nudus* and *H. discus hannai*

In October of 1999, 2000 and 2001, all *S. nudus* and *H. discus hannai*, which were observed within the 1m-width of the 150m-long fixed line, were collected by SCUBA diving. They were carried up from the bottom of the sea to the boat. On the boat, every *S. nudus* and *H. discus hannai* was recorded on its location using the fixed line to pinpoint their exact location and the test diameter was also recorded. Furthermore, in the October 2001 survey, the total weight of *S. nudus* and *H. discus hannai* were measured at intervals of 10m on the fixed line. After measurement, all of *S. nudus* and *H. discus hannai* was returned to the places where they were originally taken from.

Results

E. bicyclis Ecological Survey

Figure 4 shows the distribution of the density of *E. bicyclis* individuals (juvenile and adult sporophytes) at an interval of 10 m along the line for each survey, and the lower limit of *E. bicyclis* adult sporophytes. The densities of adult *E. bicyclis* in the bed ranged 1.08 (July 2000) to 1.80 (February 2001) individuals /m^2. At the start of the survey (August, 1999), the *E. bicyclis* bed extended to 64m on the fixed line. Although the lower limit of adult sporophytes receded to 61m in July 2000, however the settlement of the juvenile sporophytes could be seen up to 80m. However, the juvenile sporophytes that settled at 60-80m had all disappeared by February of 2001; the lower limit of adult sporophytes was 53m in the May 2001 survey. In the July 2001 survey, the settlement of a large number of juvenile sporophytes (283 individuals) was observed at 0-60m on the fixed line. Yet, no settlement could be confirmed at 60-80m. Also, only a few isolated macrophytes could be observed in areas deeper than the lower limit of *E. bicyclis* bed, thus forming a coralline flat.

S. nudus and *H. discus hannai* Ecological Survey

Fig. 5 shows the density distribution of *S. nudus* and *H. discus hannai* in October of 1999, 2000 and 2001. The two species at the survey site, *S. nudus* accounted for 91.1% (1999), 97.3% (2000) and 96.8% (2001) of the total number of individuals, revealing that the major herbivore in the survey area was *S. nudus*. The total number of *S. nudus* was different from year to year, 448 individuals in 1999, 829 individuals in 2000 and 1400 individuals in 2001. Moreover, in terms of the distribution on

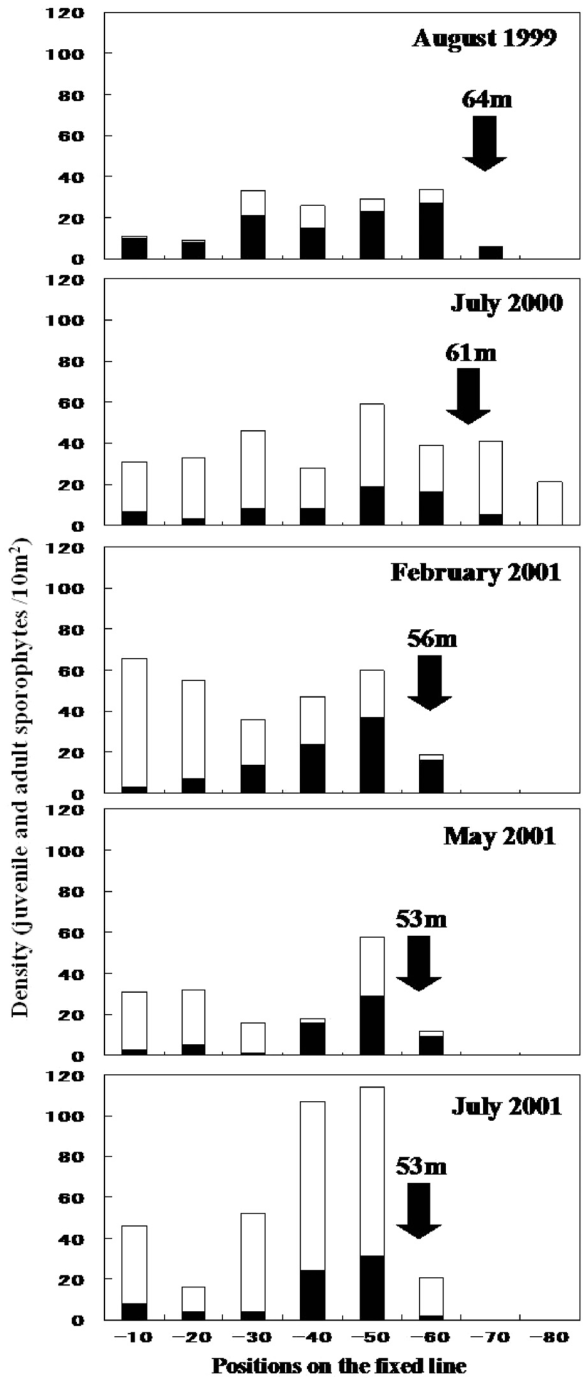

Fig. 4. Density of *E. bicyclis* sporophytes (■ :adult, □ : juvenile) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line (in Tomarihama), ; the arrows denote the position of lower limit of *E. bicyclis* adult sporophytes

the fixed line, the distribution of the two species differed between years, with the boundary around the 50-60m site, which was the lower limit of the *E. bicyclis* bed. For this reason, whereas *H. discus hannai* were distributed at a relatively high frequency on the shallow side (inside the *E. bicyclis* bed), most of *S. nudus* were found on the deeper side (within the coralline flat; Fig. 5). For example, the density of *S. nudus* inside the *E. bicyclis* bed was 3.5 individuals /m^2 in October 2001. On the other hand, the density inside the coralline flat was 12.9 individuals /m^2.

As a result of surveying the test diameter of *S. nudus*, it was found that, although there was dispersion in the number of individuals by survey year, a large number of small individuals with <4cm test diameter were inhabited the coralline flat that spread in areas deeper than *E. bicyclis* bed (Fig. 6). In October 2001, a relatively larger number of *S. nudus* individuals were observed within the *E. bicyclis* bed. Also, 86.7% of the individuals within the *E. bicyclis* bed were large individuals with 4cm or larger test diameter. On the other hand, in the coralline flat, 66.9% of *S. nudus* individuals were less than 4cm in test diameter.

In the 2001 weight measurement, the total weight of *S. nudus* corresponded to 95.6% of the total weight of two herbivores (Fig. 7). For *S. nudus,* the

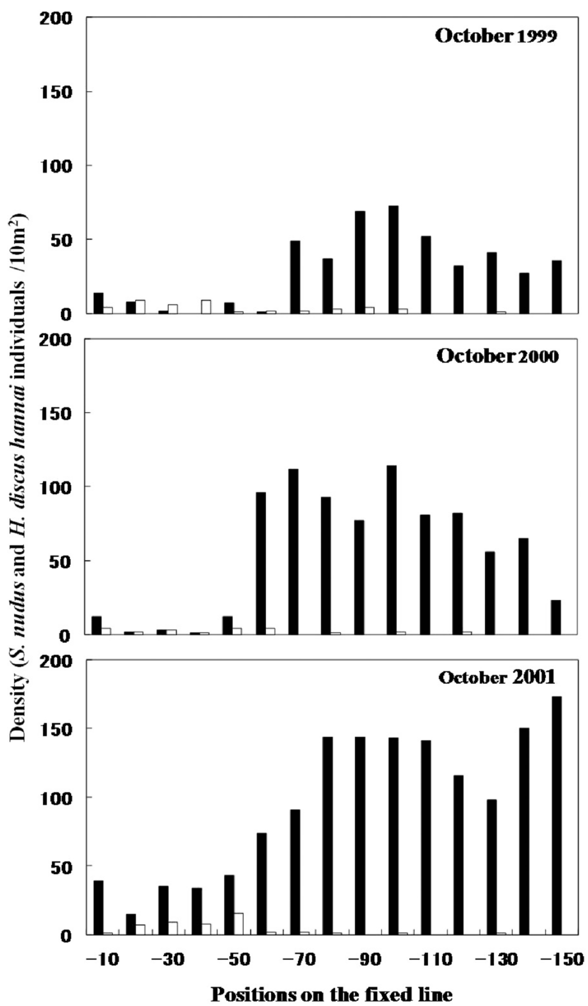

Fig. 5. Density of individuals of *S. nudus* (■) and *H. discus hannai* (□) recorded at an interval of 10 m within a 1m-width of the 150m-long fixed line (in Tomarihama)

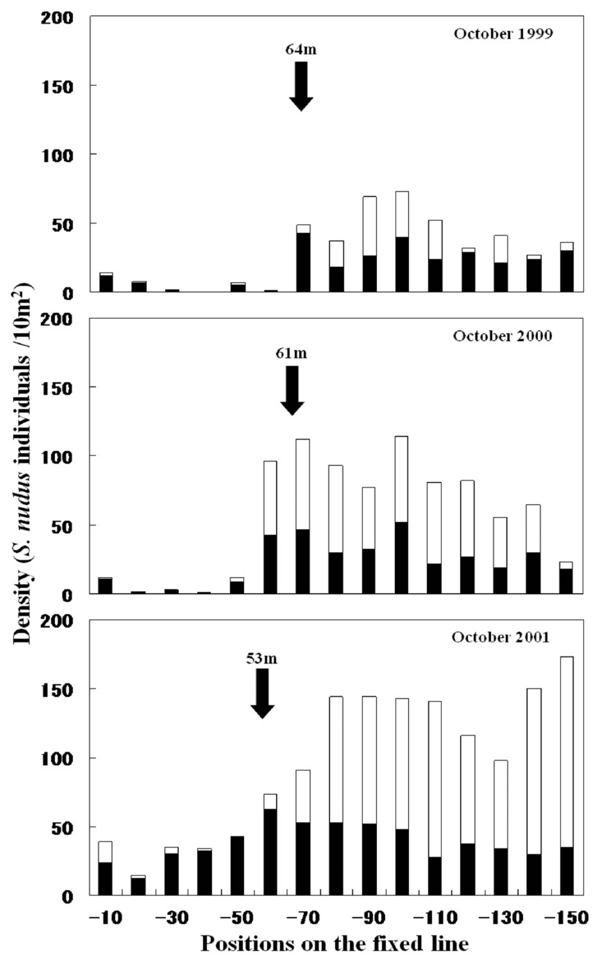

Fig. 6. Density of individuals of *S. nudus* (■ : ≥4cm in diameter; □ : <4cm in diameter) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line (in Tomarihama); the arrows denote the positions of lower limit of *E. bicyclis* adult sporophytes in each year

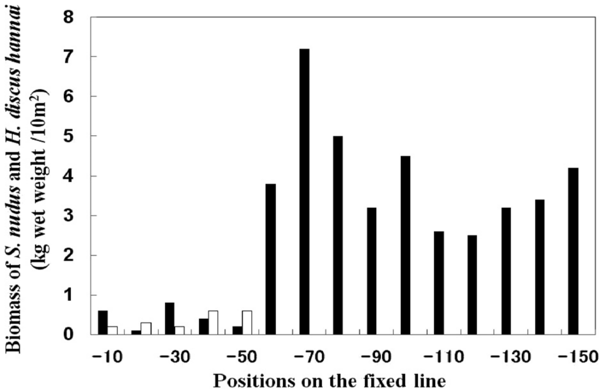

Fig. 7. Biomass of *S. nudus* (■) and *H. discus hannai* (□) recorded at an interval of 10m within a 1m-width of the 150m-long fixed line in October 2001 (in Tomarihama)

biomass of *S. nudus* inside the E. bicyclis bed was 0.06kg /m^2, while the biomass on the coralline flat was 0.40kg /m^2. From the weight measurement survey of *S. nudus* conducted on the line in October of 2001, the biomass obtained from 60-70m site on the fixed rope was 7.2kg, the maximum value, which was followed by 5.0kg, at the 70–80m site (Fig. 7).

Discussion

Sebens (1985) indicated that colonies of erect algae could be changed into coralline flat by grazing of sea urchins. The survey in this study revealed that in the two years from August, 1999 through July, 2001, the lower limit of the *E. bicyclis* bed (adult sporophytes) had receded 11m towards the shoreline (Fig. 4). There is also data that, as of 1981 in Tomarihama, the *E. bicyclis* bed exist from shore to 8m in depth (Taniguchi *et al.,* 1987). 8m depth in the test area is situated at approximately 120m along the fixed line. If this is the case, the bed has retreated approximately 67m in 20 years. The disappearance of kelp (including *E. bicyclis*) beds has been shown to occur because after the existing individuals die of old age, disappear during storms and/or are grazed, the recruitment of the next generation of individuals does not occur for some reason (Kawamata, 1998). The reason could be that there was no supply of spores from the parent seaweed in the first place or for some other reason; i.e., the juvenile sporophytes that had been generated did not survive to become adult. Thus, it became clear that the cause of the receding of the lower limit of the *E. bicyclis* bed in the monitored area was because the juvenile sporophytes do not survive to become adult. This is supported by the fact that the growth of the *E. bicyclis* juvenile sporophytes at the 60-80m site, observed in July of 2000, completely disappeared by February 2001 (Fig. 4). *S. nudus,* the major herbivore in the area occurred mainly from the lower limit of the *E. bicyclis* bed to the coralline flat. Kawamata (1998) suggested that the sweeping action of kelp fronds in turbulent flow was an effective mechanism to deter urchin invasion. It might be one of the reasons why most *S. nudus* were not found inside the *E. bicyclis* bed but on the coralline flat. The results of the weight measurement, at 60–80m where the juvenile sporophytes of *E. bicyclis* had disappeared, showed the maximum biomass (Fig. 7). Based on these findings, it can be inferred that the receding of the lower limit of the *E. bicyclis* bed in the test sea area has occurred in the following way: after the *E. bicyclis* adult sporophytes growing near the lower limit of the *E. bicyclis* bed individuals died of old age, disappeared during storms and/or were grazed, the settled juvenile sporophytes of *E. bicyclis*, which typically would mature as adult, were consumed by the high grazing pressure of *S. nudus* and thus they did not survive to become adult sporophytes. Agatsuma *et al.,* (1997) removed sea urchins from a coralline flat on the Hokkaido coast of the Sea of Japan and confirmed that seaweeds would colonize there if the urchin grazing pressure was removed. Vega *et al.,* (2005) reported that an abrupt change in the spatial-temporal patterns of abundance of the black sea urchin *Tetrapygus niger,* the most conspicuous benthic grazer in northern Chile, produced local extinctions and compression of bathymetric distribution of *Macrocystis integrifolia* and *Lessonia trabeculata* (Laminariales, Phaeophyceae). On the seaward face of Port Erin (Isle of Man, U. K.) large algae on the breakwater do not occur on the lowest 3m. The density of sea urchin *Echinus esculentus* was high, but after removal of the sea urchin, a kelp *Laminaria hyperborea* and other algae occurred in the lower area (Jones and Kain, 1967). In California, after the mass mortality due to disease of a localized population of a sea urchin *Strongylocentrotus franciscanus*, the formation of kelp forest was followed by the rapid seaward expansion of 4 species of brown algae (Pearse and Hines, 1979). These reports show that the grazing pressure of sea urchins directly affects the colonization of kelp beds.

Most of *S. nudus* inhabiting on the coralline flats were small individuals, while large individuals were dominant within the *E. bicyclis* bed. This finding is consistent with the behavioral pattern of *S. nudus*, which is believed to settle onto a coralline flat area due to the effect of the settlement inducer dibromomethane (Taniguchi *et al.,* 1994), and then move into kelp beds in order to find food to grow (Agatsuma and Kawai, 1997; Sano *et al.*, 1998).

In this area, observations were further continued after 2001, but the expansion of *E. bicyclis* beds has not been verified. Therefore, in order to understand the mechanism of *E. bicyclis* bed fluctuations more clearly, longer-term observations (including oceanographic events) are necessary.

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