北水試研報　71,63－68（2006）
Sci.Rep.Hokkaido Fish.Exp.Stn.

北海道南西部日本海沿岸における海藻植生とキタムラサキウニの生殖巣発達の関係

津田藤典*1・干川　裕*1・吾妻行雄*2・谷口和也*2

Gonad production of the sea urchin *Strongylocentrotus nudus* in relation to algal vegetation in shallow waters along the Sea of Japan, southwestern Hokkaido, Japan

Fujinori TSUDA*1, Hiroshi HOSHIKAWA*1, Yukio AGATSUMA*2 and Kazuya TANIGUCHI*2

Gonad production of the sea urchin *Strongylocentrotus nudus* in relation to the algal vegetation was clarified through gut content analysis in three sites(Yaoi, Rokujo and Biya)in Suttsu Bay along the Sea of Japan coast in southwestern Hokkaido from May to August 2001. The main food algae leading to gonad production were Sargassaceae and *Desmarestia viridis* (Yaoi), *D. viridis* and *Colpomenia sinuosa* (Rokujo) and Laminariales and *D. viridis* (Biya), coinciding with the algae with abundant standing crop that grew at each site, respectively. The gonad index (gonad wet weight×100 / body wet weight) was the highest in the *Laminaria religiosa*-dominated site with high algal standing crop. It is considered that gonad production is affected by the nutritive value of the food algae and ease of grazing and by drifts of detrital algae that originate in shallow waters.

Key words : gonad production, *Strongylocentrotus nudus*, algal vegetation, gut contents, Laminariales, Sargassaceae

Introduction

Growth and gonad production of sea urchin have been shown to be dependent on algal food species and the standing crop[1-9]. Rapid growth and high gonad production of *Strongylocentrotus* spp. are found in Laminariales-dominated beds, whereas growth and gonad production are poor in crustose coralline area[7,9,10].

The growth of Laminariales and Fucales brown algae is restricted to the area between the lower littoral to the shallow sublittoral, below the shallow sublittoral crustose corallines are widely distributed in the Sea of Japan coast in southwestern Hokkaido[11-13]. The sea urchin *Strongylocentrotus nudus* densely distribute in crustose coralline area as the settlement and metamorphosis of *S. nudus* larvae are strongly induced by dibromomethane, which is constantly produced by crustose coralline algae[14]. However, as little foliose food algae are available for the sea urchins in crustose coralline area, the dense distributions of *S. nudus* in the crustose coralline area[7,12,15] and hatchery-raised juveniles of *S. intermedius* have been transplanted to the Laminariales- or Fucales-dominated beds to promote the growth and gonad production of the sea urchins due to increase in the

Accepted : August, 8, 2006. Contribution A406 from the Hokkaido Fisheries Experiment Station
報文番号A406（2006年8月8日受理）

*1　北海道立中央水産試験場（Hokkaido Central Fisheries Experiment Station, Yoichi, Hokkaido 046-8555, Japan.）
*2　東北大学大学院農学研究科（Graduate school of Agricultural Science, Tohoku University, Sendai, Miyagi 981-8555, Japan.）

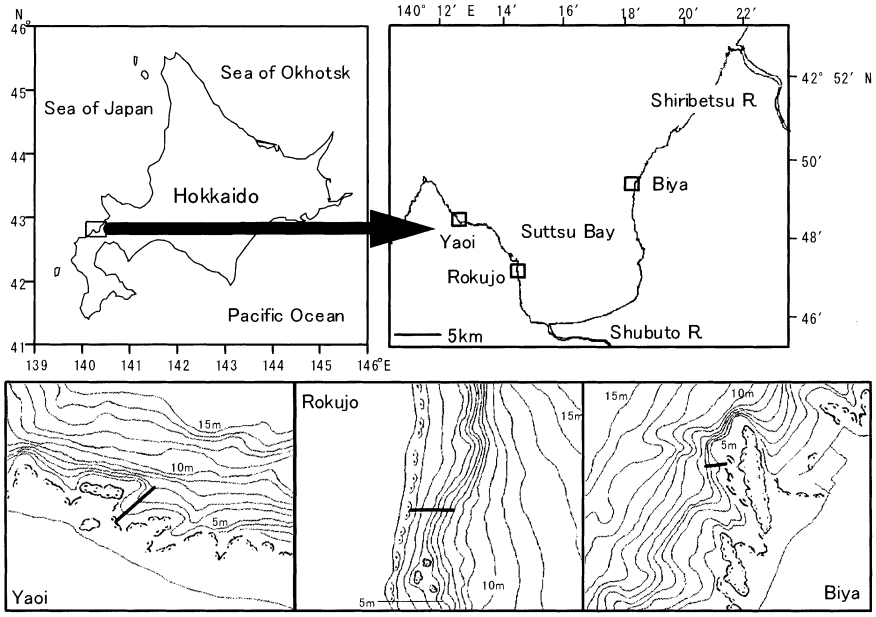

Fig.1. Location of study sites.

fishery production.

The gonads of *S. nudus* shift from the growing stage in spring to the maturing stage in summer under active grazing activity and increase in size in marine forest areas consisting of large brown algae, where available foods are ensured[16]. However, the effect of the species composition in algal communities attributing to the increase in gonad production has not been examined in the field. The effect of the species composition in algal communities on gonad production should be clarified to make the criteria for suitable sites for transplanting the sea urchin.

In the present study, we studied the gonad production and gut contents of *S. nudus* in relation to algal standing crop along shallow bathymetric gradient areas in southwestern Hokkaido.

Material and Methods

This study was carried out in the three sites, Yaoi and Rokujo along the western coast, and Biya along the eastern coast in Suttsu Bay along the Sea of Japan coast in southwestern Hokkaido (Fig. 1). At depths of 1, 3 and 7 m in a transect line perpendicular to the coastline in each study site, the sea urchin *S. nudus* and foliose algae were monthly collected by SCUBA diving from May to August 2001. At each depth in three sites, three adult *S. nudus* with > 50 mm test diameter[17] were collected. In the dominant vegetation at each depth in each site, a 50 × 50 cm quadrat was placed and foliose algae in the quadrat were collected. No sea urchin and algae was collected at a depth of 1 m at Rokujo in August due to strong wave action. From each sea urchin, gut with its contents was put on a petri dish and the gut wall was removed. The gut contents were preserved in 5% neutralized formaldehyde solution in a 50 ml calibrated bottle. When gut contents were less than 5 ml, all the contents were examined, while it would be subsampled into 1/4 or 1/8, if it were 5-10 ml or > 10 ml, respectively. The algae in the gut contents were sorted to the taxon: species, genus and family under a stereoscopic microscope. Algal fragments were identified by the characteristics of color, morphology, cell shape and tissue structure according to Yoshida[18]. The material other than algae, such as shell and animal fragments, sea grass, terrestrial plants and sand, summed up as others. The dry weight of each taxon was measured using the electronic balance (to the nearest 0.1 mg) after 12 hrs at 80℃ in a convection oven. The foliose algae collected at each depth in each site were identified according to Yoshida[18], and the wet weight by species was measured using an electronic balance (to the nearest 0.1 g).

In addition, 10-44 adult *S. nudus* with > 50 mm test diameter were collected at each depth in each site in late June or early July 2001, corresponding to the period of increase in the gonad size[16]. The body and gonad wet weight were measured and the gonad index (gonad wet weight × 100 / body wet weight) was calculated.

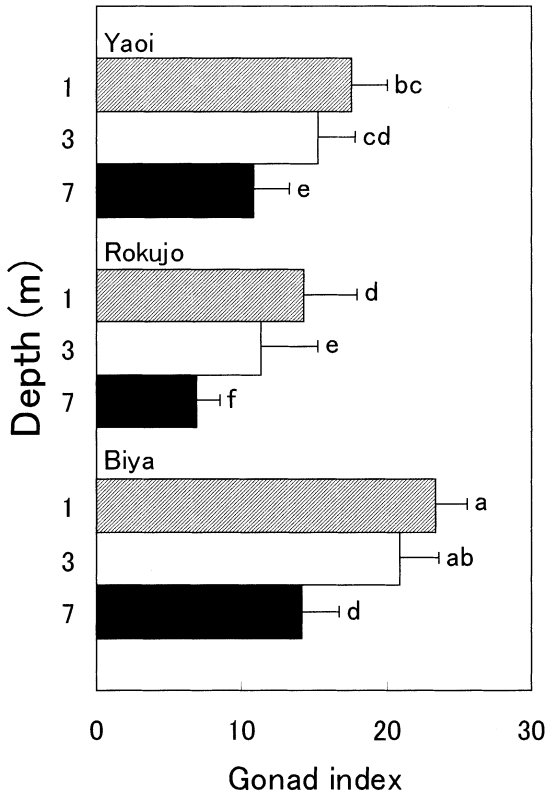

Fig.2. Gonad indices of *Strongylocentrotus nudus* collected in Yaoi, Rokujo and Biya along the southwestern coast of Hokkaido from late June to early July 2001. Bars indicate the standard deviation.Different letters indicate significant difference by Tukey's HSD test.

Significant difference in gonad indices among three depths in the each site and three sites at the each depth was tested by Tukey's HSD.

Results

The gonad indices of *S. nudus* collected in Yaoi, Rokujo and Biya are shown in Fig. 2. The gonad indices at a depth of 7 m were significantly lower than those at 1 m and 3 m in Yaoi and Biya ($p<0.01$). The gonad indices significantly decreased with the increase in depth in Rokujo ($p<0.05$). The gonad indices at each depth in Biya, Yaoi and Rokujo significantly decreased in those order ($p<0.01$).

The standing crops of foliose algae at depths of 1, 3 and 7 m in Yaoi, Rokujo and Biya from May to August 2001 are shown in Fig. 3. At 1 m in Yaoi, *Sargassum confusum* grew during the study period, this alga dominated there in May, July and August. At 3 m, *Dictyopteris divaricata* dominated in May, June and August. At 7 m, *Desmarestia viridis* dominated there in May and June, the foliage algae did not grow and the sea bottom was covered with crustose coralline red algae in July and August. From the algal zonation in Yaoi, the standing crops of foliose algae tended most abundant at 1m.

At a depth of 1 m in Rokujo, *D. viridis*, *Laminaria religiosa* and *Symphyocladia latiuscula* dominated in May, June and July, respectively. At 3 m, *Colpomenia sinuosa* dominated there in June and July. At 7 m, *D. viridis* dominated there in May, *C. sinuosa* dominated there in June and July. At 3 m and 7 m, the foliage algae did not grow and the sea bottom was covered with crustose coralline red algae in August. The standing crops at each depth were lower than those in Yaoi and Biya.

In Biya, *L. religiosa* consistently grew at the depth of 1m and 3 m. At 7 m, D. viridis grew from May and June, the foliage algae did not grow and the sea bottom was covered with crustose coralline red algae in July and August. The standing crops tended to highest because of the persistence of *L. religiosa*-dominated beds.

Compositions of the main components in the gut contents of *S. nudus* at each depth in Yaoi, Rokujo and Biya from May to August 2001 are shown in Fig. 4. In Yaoi, at a depth of 1 m where *S. confusum* dominated, a high percentage of *D. viridis* was found in the gut contents and the percentage of Sargassaceae, likely to be *S. confusum* was low in May and June, whereas the percentage of Sargassaceae increased in July and August. At 3 m where *D. divaricata* grew, high percentage of *D. viridis* was found in the gut contents from May and June, and the percentage of crustose coralline was high in July and August. At 7 m, the percentage of *D. viridis* in the gut contents was high from May to July, and that of crustose coralline was high in August. In July and August, Sargassaceae in the gut contents abundantly appeared at 3 m and 7 m.

In Rokujo, high percentages of *D. viridis* in May and Laminariales in June were found in the gut contents at a depth of 1 m, reflecting the growth at this depth of *D. viridis* and *L. religiosa*, respectively. In addition, high percentage of *C. sinuosa* in May was found. In July, the percentage of crustose coralline was high regardless that *S. latiuscula* grew at this depth. At 3 m and 7 m, high percentages of *D. viridis* in May and June were found, and high percentages of *C. sinuosa* in July were found, reflecting the growth of *C. sinuosa*. The percentages of crustose coralline tended to increase at each depth from

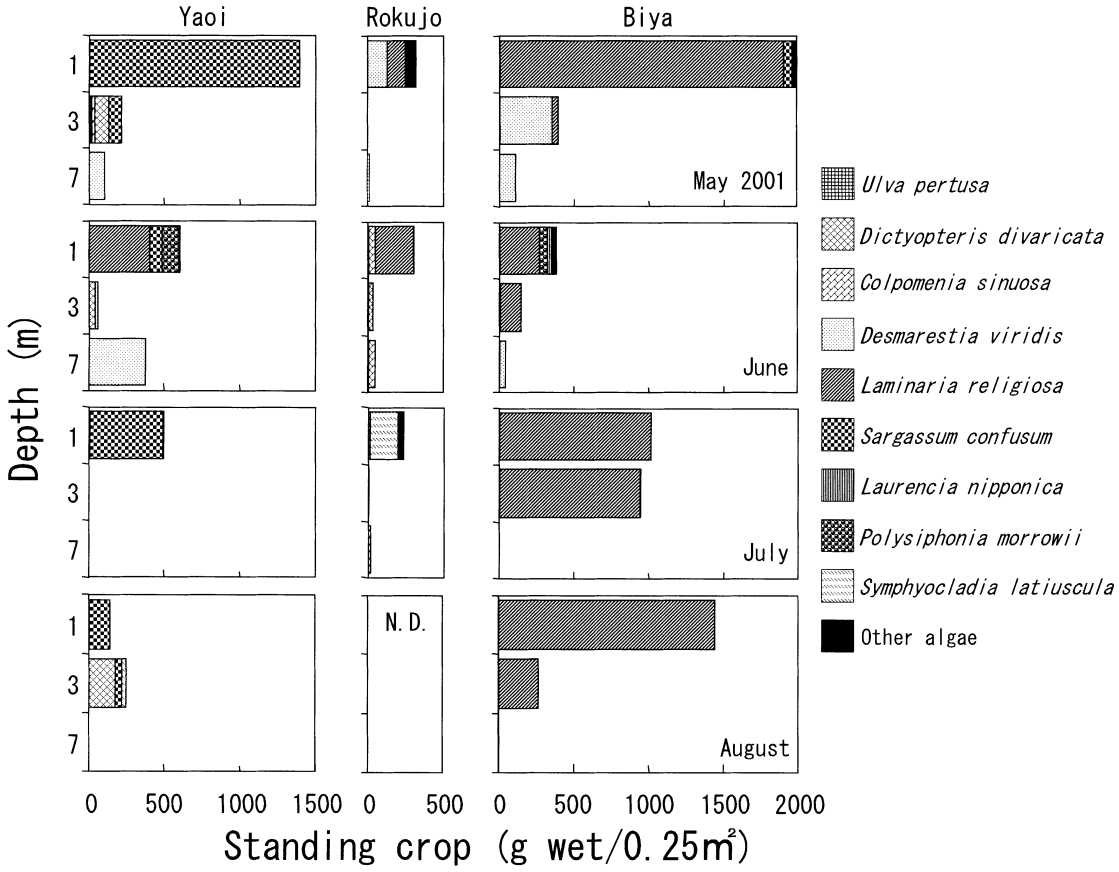

Fig.3. Monthly changes in foliose algal standing crop at different depths in Yaoi, Rokujo and Biya from May to August 2001.

May to August.

In Biya, Laminariales abundantly appeared in the gut contents at the depth of 1 m and 3 m where *L. religiosa* consistently dominated. At 7 m, the percentage of *D. viridis* besides Laminariales was high from May to July. In August, the percentage of *Ulva pertusa* besides Laminariales was high at 7 m. At each depth, the percentage of crustose coralline tended to increase from May to August.

Discussion

Growth and gonad production are greatly affected by algal species as foods and the standing crops[1-9]. Hence, this suggests that the growth and gonad production in the field are dependent on the algal assemblages in the sea urchin's habitat.

In the present study, gonad indices of *S. nudus* at each depth in Biya, where *L. religiosa* dominated with the most abundant standing crops, were higher than those in Yaoi and Rokujo. Those in Yaoi where *S. confusum* grew were high. The lowest gonad indices were found in Rokujo where the annual algae such as *D. viridis* and *C.sinuosa* seasonally grew with extreme low standing crops. In each site, the gonad indices were high in shallow waters where the foliose algae grew and low in deep waters where crustose corallines dominated. These results agree with the reports that gonad sizes of *Strongylocentrotus* spp. in Laminariales-dominated beds were significantly higher than those in crustose corallines area[7,9,10] and gonad production of *S. nudus* fed *L. angustata* was more clearly promoted than individuals fed *S. confusum* or *D. viridis*[8].

Comparison between growing algae and food algae in the gut contents of *S. nudus* showed that *L. religiosa*, *D. viridis* and *C. sinuosa*, which grew in the sea urchin habitat are taken as foods. Contrary to this, *S. confusum* which also grew in the sea urchin habitat were not taken in May and June. However, as *S. confusum* growing in shallower waters appeared abundantly in the gut contents of *S. nudus* at each depth and increased in July and August during the senescence period of this alga[19], it is likely that the seceded thalli are grazed. It is considered that living *S. confusum*

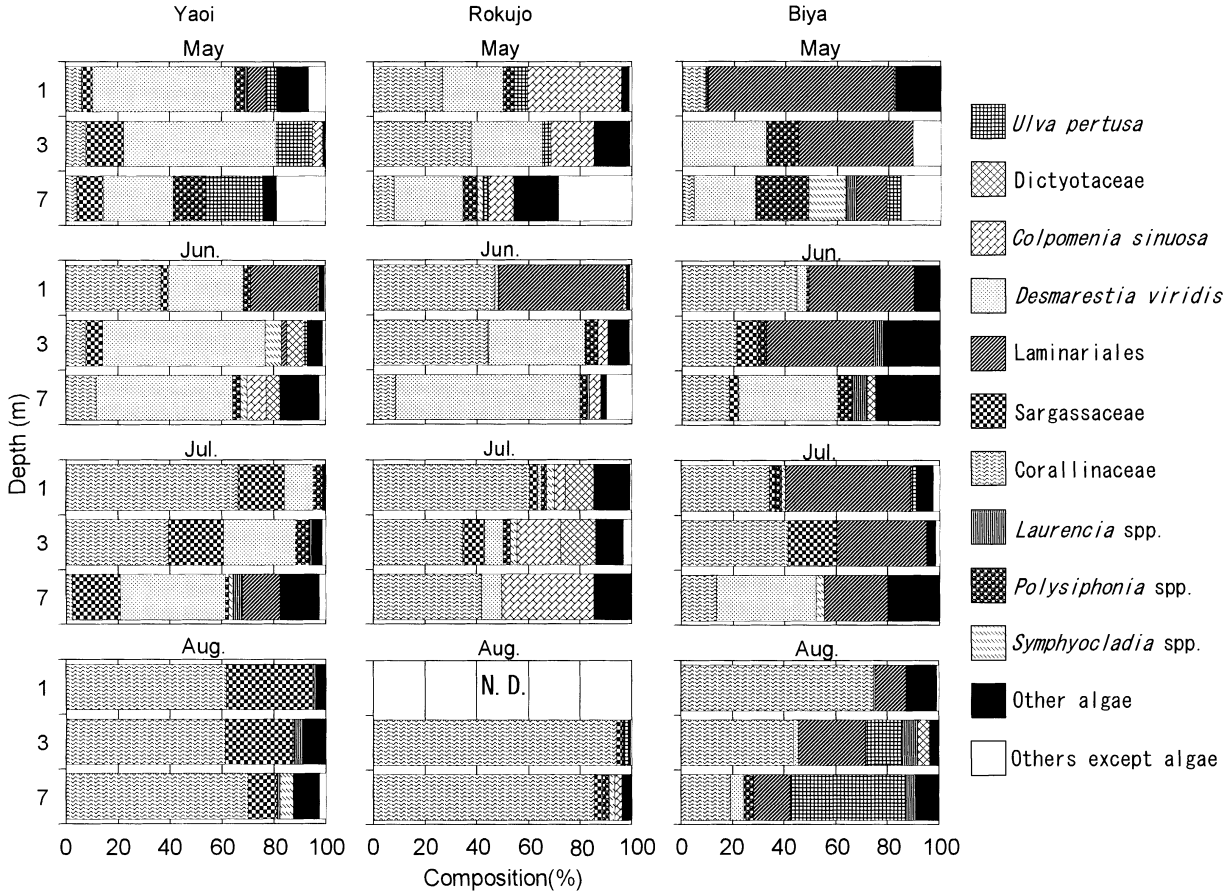

Fig.4. Monthly changes in compositions of the main components in the gut contents of *Strongylocentrotus nudus* in Yaoi, Rokujo and Biya.

is hard to be grazed by sea urchin as it remains erect due to the buoyancy of vesicle[8]. In addition, Fucales brown algae may defend their thalli from grazing of sea urchin by producing polyphenol as a feeding deterrents[20].

Also, low amounts of *D. divaricata* and *S. latiuscula* were found in the gut contents regardless of their evident co-occurrence with *S. nudus*. It is considered that low amounts of *D. divaricata* which grew at a depth of 3 m in Yaoi was found in the gut contents, as it is clarified that this alga defends their thalli from grazing of sea urchin by producing sesquiterpene as a feeding deterrents[21]. It is possible that *S. latiuscula* which grew at a depth of 1 m in Rokujo also minimizes grazing by producing chemicals deterrents.

The gonad indices of *S. nudus* at a depth of 7 m where crustose corallines dominated were highest in Biya where *L. religiosa* grew in the shallow waters, subsequently in Yaoi where *S. confusum* grew also in shallow water. The indices were lowest in Rokujo. Appearance of the two brown large algae in the gut contents at a depth of 7 m show that drifts of detrital algae that originate in shallow waters contribute to promote gonad production.

In the present study, it was clarified the gonad index of *S. nudus* was highest in Biya where the main food algae were Laminariales and *D. viridis*, subsequently, those in Yaoi where the main food algae were Sargassaceae and *D. viridis* were high and the gonad index in Rokujo where sea urchins mainly grazed *D. viridis* and *C. sinuosa* was lowest. It is suggested that those differences in gonad indices are also affected by nutritive value and ease of consumption of those main food algae.

Acknowledgements

Thanks to the staff of the Suttsu Fisheries Cooperative Association and the staff of the Shiribeshi-nanbu Fisheries Technical Guidance Office for their cooperation during the field survey. This study was financially supported in part by the Fisheries Agency of Japan.

References

1）Fuji,A. : Ecological studies on the growth and food consumption of Japanese common littoral sea urchin, *Strongylocentrotus intermedius* (A. Agassiz). *Mem. Fac. Fish. Hokkaido Univ.* 15, 83-160 (1967)

2）Leighton,D.L. : “Grazing activities of benthic invertebrates in southern California kelp beds”. The biology of giant kelp beds (*Macrocystis*) in California. Beihefte zur Nova Hedwigia 32. Lehre, J. Cramer Publisher, 1971, 421-453

3）Kawamura,K. : Fishery biological studies on a sea urchin, *Strongylocentrotus intermedius* (A. AGASSIZ). *Sci. Rep. Hokkaido Fish. Exp. Stn.* 16, 1-54 (1973)

4）Lawrence,J.M. : On the relationships between marine plants and sea urchins. *Oceanogr. Mar. Biol. Ann. Rev.* 13, 213-286 (1975)

5）Vadas,R.L. : Preferential feeding: an optimization strategy in sea urchin. *Ecol. Monogr.* 47, 337-371 (1977)

6）Larson,B.R., Vadas,R.L. and Keser,M. : Feeding and nutritional ecology of the sea urchin *Strongylocentrotus droebachiensis* in Maine, USA. *Mar. Biol.* 59, 49-62 (1980)

7）Agatsuma,Y. : Ecological Studies on the population dynamics of the sea urchin *Strongylocentrotus nudus*. *Sci. Rep. Hokkaido Fish. Exp. Stn.* 51, 1-66 (1997)

8）Nabata,S., Hoshikawa,H., Sakai,Y., Funaoka,T., Oohori,T. and Imamura,T. : Food value of several algae for growth of the sea urchin *Strongylocentrotus nudus*. *Sci. Rep. Hokkaido Fish. Exp. Stn.* 54, 33-40 (1999)

9）Sano,M., Omori,M., Taniguchi,K. and Seki,T. : Age distribution of the sea urchin of Strongylocentrotus nudus (A. Agassiz) in relation to algal zonation in a rocky coastal area on Oshika Peninsula, northern Japan. *Fisheries Science* 67, 628-639 (2001)

10）Gonor,J.J. : Reproductive cycles in Oregon population of the echinoid, *Strongylocentrotus purpuratus* (Stimpson). I. Annual gonad growth and ovarian gametogenic cycles. *J. Exp. Mar. Biol. Ecol.* 12, 45-64 (1973)

11）Nabata,S., Abe,E. and Kakiuchi,M. : On the ‘Isoyake’ condition in Taisei-cho, southwestern Hokkaido. *Sci. Rep. Hokkaido Fish. Exp.* Stn. 38, 1-14 (1992)

12）Agatsuma,Y., Matsuyama,K., Nakata,A., Kawai,T. and Nishikawa,N. : Marine algal succession on coralline flats after removal of sea urchin in Suttsu Bay on the Japan Sea coast of Hokkaido, Japan. *Nippon Suisan Gakkaishi* 63, 672-680 (1997)

13）Akaike,S., Yoshida,H., Matsuda,T., Yagi,H. and Tomiyama,M. : Year-to-year variation of areas of macroalgal and crustose coralline algal communities interpreted from aerial photographs and SCUBA along the western coast of Shakotan Peninsula, Hokkaido, Japan. *Sci. Rep. Hokkaido Fish. Exp. Stn.* 56, 125-135 (1999)

14）Taniguchi,K., Kurata,K., Maruzoi,T. and Suzuki,M.: Dibromomethane, a chemical inducer of larval settlement and metamorphosis of the sea urchin *Strongylocentrotus nudus*. *Fisheries Science* 60, 795-796 (1994)

15）Agatsuma,Y. : ” Marine afforestation off the Japan Sea coast in Hokkaido”. The Ecological Mechanism of 'Isoyake' and Marine Afforestation. Tokyo, Kouseishakouseikaku, 1999, 84-97

16）Agatsuma,Y. : ” Ecology of *Strongylocentrotus nudus*”. Edible Sea Urchin: Biology and Ecology. Amsterdam, Elsevier Science, 2001, 347-361

17）Fuji,A. : Studies on the biology of the sea urchin. II. Size at first maturity and sexuality of two sea urchin, *Strongylocentrotus nudus* and *S. intermedius*. *Bull. Fac. Fish. Hokkaido Univ.* 11, 43-48 (1960)

18）Yoshida, T. : Marine algae of Japan. Tokyo , Uchidarokakuho, 1998, 1222p

19）Tsuda,F. and Akaike,S. : Annual life cycle and productivity of *Sargassum confusum* population off the coast of western Shakotan Peninsula in southwestern Hokkaido, Japan. *SUISANZOSHOKU* 49, 143-149 (2001)

20）Steinberg,P.D. : Feeding preferences of *Tegula funebralis* and chemical defenses of marine brown algae. *Ecol. Monogr.* 55, 333-349 (1985)

21）Shiraishi,K., Taniguchi,K., Kurata,K. and Suzuki,M.: Effects of the methanol extracts from the brown alga *Dictyopteris divaricata* on feeding by the sea urchin *Strongylocentrotus nudus* and the abalone *Haliotis discus hannai*. *Nippon Suisan Gakkaishi* 57, 1945-1948 (1991)