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Maturation Control of the Short-Spined Sea Urchin, *Strongylocentrotus intermedius*, by Low Temperature Rearing Using Deep-Sea Water, with the Aim of Extending the Market Season

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Abstract: The short-spined sea urchin *Strongylocentrotus intermedius*, is a valuable commercial species and one of the most popular and expensive seafoods in Japan. Serving local short-spined sea urchin to visitors during the summer tourist season in Rausu, located in a world natural heritage site "Shiretoko," has long been desired. However, it has not been feasible during the sea urchin spawning season (July to September), resulting in quality degradation in gonads, the edible part of sea urchins, due to maturation. Therefore, the Hokkaido Research Organization and the Rausu Fishery Cooperative Associations cooperatively investigated the possibility of suppressing gonadal maturation and maintaining high quality sea urchin gonads by low temperature rearing using deep-sea water. Unripe sea urchins captured before the spawning season were reared under two temperature conditions from June to September. In groups reared at ambient temperatures (2–18℃), gametogenesis in both sexes progressed rapidly with increased temperature, and almost all sea urchins reached full maturity by late July. Whereas in groups reared at low temperatures (2–5℃), gametogenesis progressed slowly and over 60% of the sea urchins had not reached maturity even by early September. This result suggests that the progress of gametogenesis in the short-spined sea urchin is effectively suppressed by rearing under low temperature conditions. Additionally, we also examined the effects of feeding on gonadal development in sea urchins reared under low temperature conditions, and revealed that feeding with live *Saccharina diabolica*, which were cultured as food in Rausu, could increase the gonadal volume efficiently to commercially preferable size, while suppressing the progress of gametogenesis. Moreover, the results of chemical analysis and tasting test proved that the quality of gonads were very excellent in sea urchin fed with live *S. diabolica*. Consequently, we demonstrate that low temperature rearing, supplemented with feeding live *S. diabolica*, is effective in suppressing gametogenesis to allow for the harvesting of high quality sea urchins during the summer tourist season. At present, this aquaculture method is being put to practical use by Rausu Fishery Cooperative.

Key words: short-spined sea urchin *Strongylocentrotus intermedius*, gametogenesis, deep-sea water, low temperature rearing, sea urchin aquaculture

The short-spined sea urchin *Strongylocentrotus intermedius*, which is distributed on the northern coast of Japan, is a valuable commercial species and is one of the most popular and expensive seafoods in the country; more than 2000 tons of the sea urchin are caught annually in Hokkaido, the main harvest region for this species. *S. intermedius* has bright orange gonads with a rich taste, and the gonads

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are preferred especially as an attractive raw food material, such as “Sushi” or “Sashimi (Uni-don)”. *S. intermedius* has also become one of the important tourist resources of Hokkaido, because many tourists visit Hokkaido in anticipation of the tastes of fresh sea urchin every year.

Since the edible part of the sea urchin is usually restricted to the gonads, its quality as food varies dramatically with gonadal growth and maturation. In general, the superior quality of gonads, defined by attractive taste, color, and shape, is only present during the term of the unripe phase when gametogenesis is limited. The mature gonad has an unpleasant taste due to the gamete contents and a melting appearance caused by the flow of gametes (Unuma, 2002). Therefore, the best season for harvesting *S. intermedius* is very short—less than three months per a fishery region —in spite of an annual market demand. There would be considerable commercial value in developing an aquaculture technique to control the timing of gonadal maturity so as to ensure a supply of high quality sea urchins over a longer period.

Rausu town, located on the Shiretoko Peninsula in east Hokkaido, is a prominent production region of *S. intermedius* in Japan (Fig. 1). After Shiretoko Peninsula was registered as a world natural heritage site in 2005, increasing numbers of tourists have visited Rausu, especially during the summer, from July to September. In Rausu, there is a huge demand for serving *S. intermedius* to visitors during the summer tourist season. However, it has been exceedingly difficult to supply high quality sea urchins during the summer, because the spawning season of sea urchins in Rausu is from July to September and the quality of gonads degrades on maturation. Moreover, in Rausu, as a resource conservation measure, harvesting sea urchins from July to September is legally prohibited by local government fishing regulations. Therefore, it is necessary to develop a method for culturing *S. intermedius* caught before the closed season, so as to maintain their food quality by suppressing maturation.

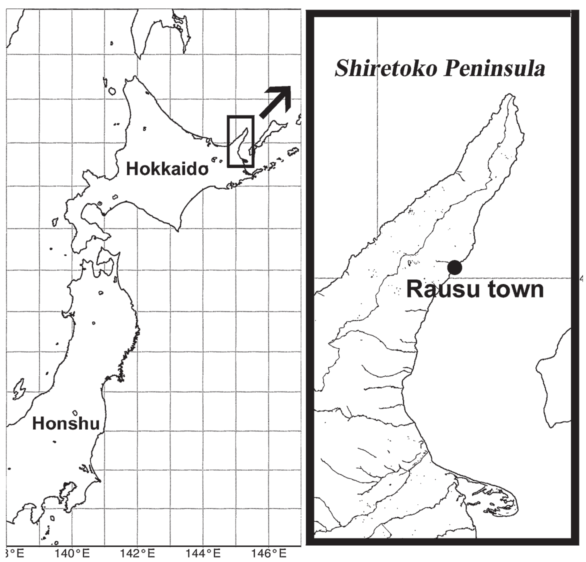

Fig. 1. Location of Rausu town on the Shiretoko Peninsula in east Hokkaido, Japan.

Annual reproductive cycles of sea urchins are regulated by environmental factors, such as water temperature (Yamamoto *et al*., 1988; Sakairi *et al*., 1989), photoperiod (Pearse *et al*., 1986; McClintock and Watts, 1990; Walker and Lesser, 1998; Böttger *et al*., 2006), and lunar period (Horii, 1997; Coppard and Campbell, 2005). Water temperature in particular has been shown to have a strong effect on the progress of gametogenesis in sea urchins. In some Japanese urchin hatcheries, temperature control is used to induce broodstocks of *Pseudocentrotus depressus, Hemicentrotus pulcherrimus*, and *S. intermedius* to mature out of the normal spawning season (Ito *et al*., 1989; Masaki and Kawahara, 1995; Noguchi *et al*., 1995). The gonadal development of wild *S. intermedius* tends to be correlated with a rise in water temperature from spring to summer (Tomita *et al*., 1984). Accordingly, it may be possible to suppress gametogenesis by rearing sea urchins under low temperature conditions during that period.

Generally, using electric cooling devices in aquaculture is limited because of its high costs. Fortunately, a facility for collecting deep-sea water is available in Rausu. The deep-sea water is defined as seawater that is pumped from a depth of greater than 200 m, and has certain advantageous properties: stable low temperature, low in suspended particles and bacteria, and rich in nutrient salts (Nakasone and Akeda, 2000). More than ten facilities capable of drawing deep seawater have been constructed in Japan, where it is used for aquaculture, handling of captured fishes, the food industry, medical treatment, and agriculture (Takahashi, 2006). In Rausu, deep seawater is drawn from a depth of 350 m and has been used mainly as a raw material for refining mineral water and as rearing water to temporarily hold captured salmon. Additionally, there is a sufficient supply of deep-sea water, such that it has been collected constantly and used for aquaculture in Rausu. Fig. 2 indicates variations in water temperature between the deep-sea water and ambient sea water drawn from the surface. The water temperature of deep seawater is stable at lower degrees from March to September compared with the ambient seawater, ranging from 2 to 5℃. Therefore, taking advantage of the available facility, the Hokkaido Research Organization and the Rausu Fishery Cooperative Associations cooperatively investigated the effects of rearing under low temperature conditions on the gametogenesis of *S. intermedius*, in an effort to develop reliable techniques for maintaining gonads in good quality during the summer tourist season in Rausu, as a model (Kayaba *et al*., 2012). In this proceeding, we describe new aquaculture technique of sea urchin and its possibility in the future, adding further data to the results which have been reported in Kayaba *et al.* (2012).

The effects of rearing under low temperature conditions on gametogenesis

To determine the effect of water temperature on suppressing gametogenesis, rearing experiments were conducted under two types of water temperature conditions from 2008 to 2010 (Kayaba *et al*., 2012). Unripe sea urchins (weighing 54.0–81.3 g), were collected from the coastal fishery ground at Rausu in March – May. They were divided into four experimental cages (100 × 100 × 80 mm) at densities of 150 individuals per cage, and transferred to the experimental environment on June 1 of each year. Two cages of sea urchins were maintained with running ambient sea water (2.8 – 19.6℃) until September 1 (ambient temperature group), while the other two cages were maintained with running deep-sea water (2.5 – 4.9℃) over the same period (deep seawater temperature group). In addition, for determining the effects of feeding on gametogenesis and gonad size, individuals in one cage of both temperature groups were reared without feeding (non-feeding cage), while individuals in the other cages were given a surplus of commercial dry wakame (*Undaria sp*., obtained from the Riken Vitamin Company, Tokyo) every day (feeding cage). Both groups of sea urchins were reared in the dark throughout the experimental period, except

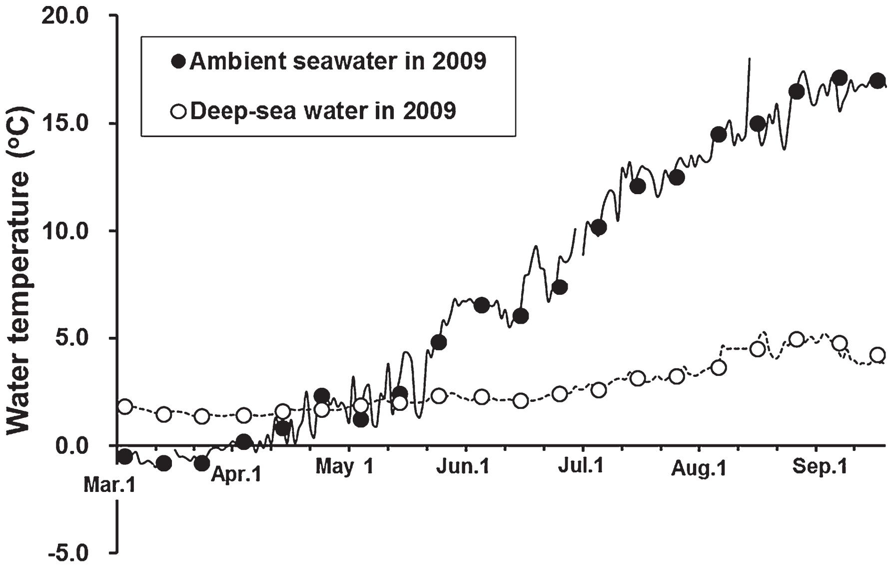

Fig. 2. Variations in temperature of the ambient sea water drawn from the surface of the Rausu coast and that of the deep-sea water drawn from a depth of 350 m off the coast of Rausu, in 2009.

for during feeding and cleaning of excreta. Twenty individuals were sampled from each group monthly for histological observation of gonads. Maturational status of ovaries and testes was classified into five stages according to Fuji (1960); stage 1 (before gametogenesis), stage 2 (early gametogenesis), stage 3 (mid-gametogenesis), stage 4 (fully mature) and stage 5 (spent). Gonads at stages 1 to 3 are commercially favorable. On the other hand, the fully mature gonads (stage 4) were not suitable for consumption because of the unpleasant taste caused by the gamete contents and a melting appearance caused by the flow of gametes via breakage of the gonoduct (Unuma, 2002). The spent gonads (stage 5) were also unsuitable for food, because they were shrunken.

Table 1 shows the frequency of maturation stage of female and male sea urchins during the experiment in 2009. In the ambient temperature group, gametogenesis progressed rapidly with increased temperature and almost all sea urchins reached full maturity (stage 4) by 27 July, about 2 months after the initiation of the experiment. In contrast, gametogenesis in both ovaries and testes progressed slowly in the deep seawater temperature group, and about 60 % of the sea urchins were maintained at an unripe stage (stages 1–3) until 31 August. In spite of distinct differences in maturity among two rearing temperature conditions, significant differences in the distribution of maturation stage could not be found between sea urchins in feeding cages and non-feeding cages in both sexes. These results strongly suggest that the progress of gametogenesis in *S. intermedius* is closely related to environmental temperature, and is effectively suppressed by rearing sea urchins under low temperature conditions. Following repeated tests over three years, it was proven that rearing at deep seawater temperatures could extend the harvest season two months or longer beyond that of the wild population (Kayaba *et al.*, 2012). Therefore, the techniques used in our study, for maintaining unripe sea urchins under low temperature conditions, are likely candidates for an efficient method for inhibiting gonadal maturation and serving sea urchins with good quality during summer tourist season.

Table 1. The frequency of maturation stage of female and male sea urchins reared at ambient temperature or deep seawater temperature during the experiment performed in 2009 (based on data from Kayaba *et al.*, 2012).

Sex	Feeding condition	Date	Ambient temperature group					Deep seawater temperature group				
			Favorable maturity			Unfavorable maturity		Favorable maturity			Unfavorable maturity	
			Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Female	Feeding	27-May	0.00	0.71	0.21	0.07	0.00	0.00	0.71	0.21	0.07	0.00
		1-Jul	0.00	0.50	0.50	0.00	0.00	0.00	0.67	0.33	0.00	0.00
		27-Jul	0.00	0.00	0.22	0.78	0.00	0.00	0.29	0.43	0.14	0.14
		31-Aug	0.17	0.00	0.00	0.33	0.50	0.10	0.00	0.70	0.20	0.00
	Non -feeding	27-May	0.00	0.71	0.21	0.07	0.00	0.00	0.71	0.21	0.07	0.00
		1-Jul	0.00	0.20	0.60	0.20	0.00	0.00	0.33	0.50	0.17	0.00
		27-Jul	0.00	0.00	0.30	0.70	0.00	0.00	0.27	0.45	0.27	0.00
		31-Aug	0.00	0.00	0.00	0.33	0.67	0.00	0.20	0.40	0.20	0.20
Male	Feeding	27-May	0.00	0.38	0.38	0.25	0.00	0.00	0.38	0.38	0.25	0.00
		1-Jul	0.00	0.00	0.38	0.63	0.00	0.00	0.43	0.57	0.00	0.00
		27-Jul	0.00	0.00	0.00	1.00	0.00	0.00	0.08	0.77	0.15	0.00
		31-Aug	0.00	0.00	0.00	0.75	0.25	0.00	0.00	0.60	0.40	0.00
	Non -feeding	27-May	0.00	0.38	0.38	0.25	0.00	0.00	0.38	0.38	0.25	0.00
		1-Jul	0.00	0.00	0.50	0.40	0.10	0.00	0.00	0.80	0.20	0.00
		27-Jul	0.00	0.00	0.00	0.71	0.29	0.00	0.00	0.67	0.33	0.00
		31-Aug	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.53	0.33	0.13

Improvement in quality of short-spined sea urchins reared under low temperature conditions

In general, the sea urchins with larger-sized unripe gonads are commercially preferred for consumption. Therefore, for aquaculture of sea urchins, it is also important to determine the rearing condition by which gonads grow faster to a commercial size. For echinoderms, it has been established that nutritive condition is closely related to gonadal development. Nutrients derived from ingested food are stored in nutritive phagocytes inside the ovary and testis, and are utilized for production or growth of germ cells (Unuma, 2002; Walker *et al.*, 2006). In the rearing experiment mentioned above, obvious increases in gonad volume were observed only in the sea urchins reared with feeding: the gonad indexes (GIs) of sea urchins reared with feeding were significantly higher than those without feeding (Fig. 3). This result indicates obviously that rearing with feeding under low temperature conditions is the best way to accelerate the accumulation of nutrients without proceeding gametogenesis in gonads of *S. intermedius*.

Accordingly, as a next step, we examined the dietary effects of two available diets in Rausu, commercial dry wakame and live brown macroalgae, *Saccharine diabolica*; the former had the advantage of low price and ready availability, while the later was the primary food plant for wild *S. intermedius* and was flourishingly cultured as food in Rausu (Kayaba *et al.*, 2012). *S. intermedius* were reared with four feeding regimes at deep-sea water temperatures from June 1 to September 1 in 2009. In the first group, the sea urchins were reared without feeding during the experimental period as a control. In the second and third groups, the sea urchins were fed a surplus of dry wakame from June 1 to September 1 (feeding for 3 months) and from August 1 to September 1 (feeding for 1 month), respectively. In the fourth group, the sea urchins were fed an unlimited amount of live brown macroalgae, *S. diabolica* from August 1 to September 1 (feeding for 1 month). In comparing GIs from each treatment, when sea urchins were fed live *S. diabolica*, the growth rate of gonads was three times as fast as that when they were fed dry wakame (Table 2). The daily food consumption for each diet was almost the same, suggesting that for *S. intermedius, S. diabolica* may be easier to assimilate. Several feeding experiments have shown that the *Laminariales* are the most nutritionally valuable algae among several algae distributed along the coast of Hokkaido for promoting gonadal growth and

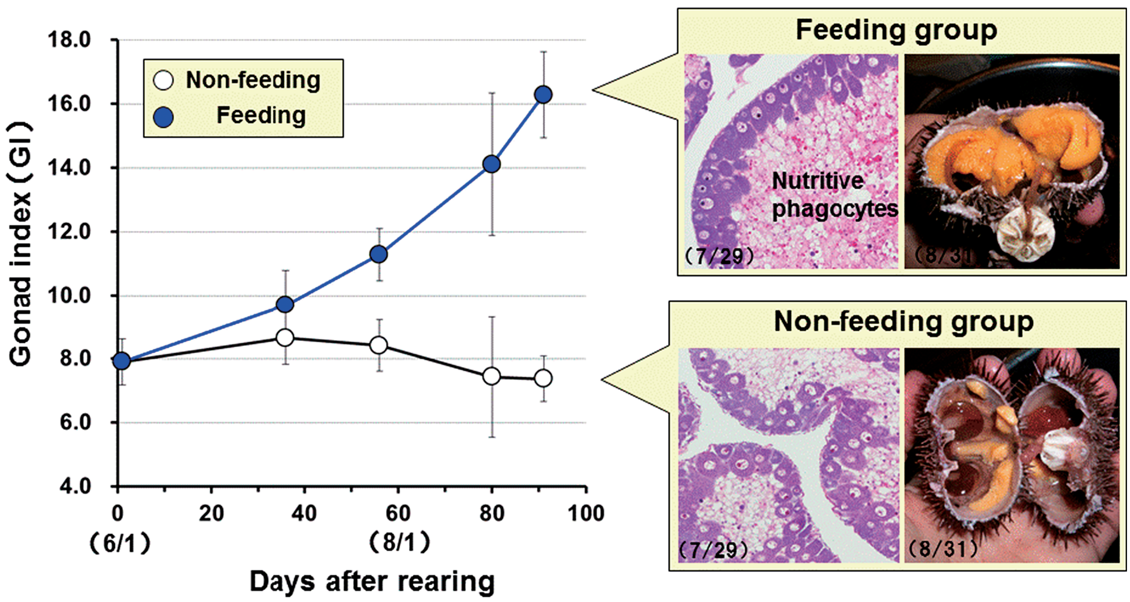

Fig. 3. Changes in the gonad index (GI) and histological structures of *S. intermedius* reared at deep seawater temperature under different feeding regimes during the experiment performed in 2009. Values represent the mean ± standard deviation (based on data from Kayaba *et al.*, 2012).

Table 2. Changes in the gonad index (GI) of *S. intermedius* reared with four feeding regimes at low temperatures during the experiment performed in 2009 (based on data from Kayaba *et al*., 2012).

Values represent the mean ± standard deviation. Mean values with different letters are significantly different at the 0.05 level within each sampling day. (GIs were arcsine-transformed before analysis and reported as back-transformed values. When a treatment effect was significant, Tukey's multiple range comparison test was applied to identify differences among experimental groups.)

Sampling date		1	2	3	4
	Test group	1	2	3	4
	Diet	Non-feeding	Dry wakame	Dry wakame	Live *S. diabolica*
	Feeding term	—	3 months	1 month	1 month
	Feeding period	—	1 Jun — 1 Sep	1 Aug — 1 Sep	1 Aug — 1 Sep
27-May (Initial)		7.9 ± 0.7	7.9 ± 0.7	7.9 ± 0.7	7.9 ± 0.7
1-Jul		8.5 ± 0.8	9.7 ± 1.1	8.7 ± 0.8	8.7 ± 0.8
27-Jul		8.4 ± 0.8 **b**	11.3 ± 0.8 **a**	8.2 ± 0.8 **b**	8.4 ± 0.8 **b**
20-Aug		7.4 ± 1.9 **c**	14.1 ± 2.2 **a**	10.7 ± 0.9 **b**	9.9 ± 0.5 **b**
31-Aug		7.4 ± 0.7 **c**	16.3 ± 1.4 **a**	11.0 ± 1.4 **b**	15.6 ± 1.6 **a**

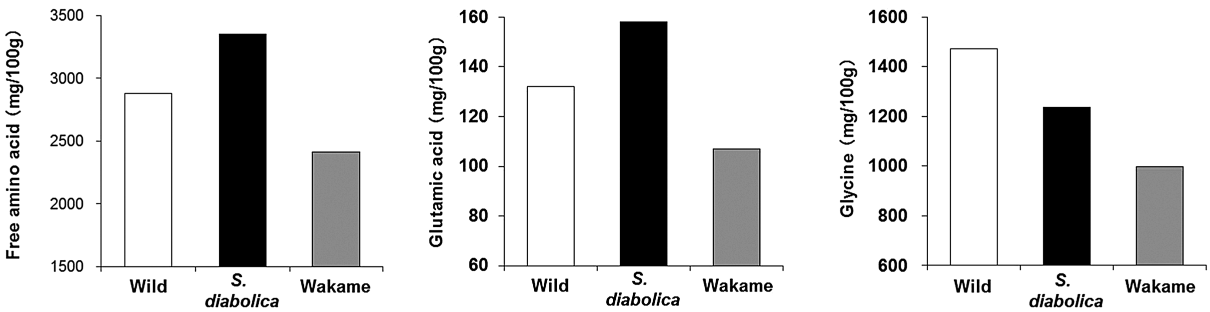

Fig. 4. Effect of diet on the free amino acid content of gonads in *S. intermedius* reared under different feeding conditions. Wild: wild sea urchins captured from the fishing ground in Rausu, *S. diabolica*: sea urchins reared and fed live *S. diabolica* for one month, Wakame: sea urchins reared and fed commercial dry wakame for one month

improving the taste of gonads in the northern sea urchin *Strongylocentrotus nudus*, a sub-arctic species like the *S. intermedius* (Agatsuma *et al*., 1993; Nabata *et al*., 1999). Accordingly, as demonstrated in our experiments with *S. intermedius*, it may be possible, by feeding with live *S. diabolica*, to promote gonadal growth efficiently even under low temperature conditions, while suppressing the progress of gametogenesis.

Moreover, we also investigated the characteristic of taste in sea urchins reared with feeding live *S. diabolica* by chemical analysis (free amino acids) or tasting test directed to tourists in Rausu. As a result, the gonads of sea urchins fed live *S. diabolica* contained in rich amount of glutamic acid flavoring "Umami taste" and glycine flavoring "Sweetness", comparing with those fed dry wakame (Fig. 4). Furthermore, tasting test proved that the taste of gonads in sea urchin fed with live *S. diabolica* were very preferable to customers (Fig. 5). These results clearly indicate that live *S. diabolica* is an essential diet for rearing *S. intermedius* to not only enlarge their gonad volume, but also to improve the quality of gonads. Generally, it has been suggested that the largest limiting factor for the success of sea urchin aquaculture on a commercial scale is the difficulty of obtaining sufficient macroalgae for feeding. Fortunately, in the cultivation of *S. diabolica* in Rausu town, a large amount of surplus algae is produced every early summer by thinning to accelerate its growth. It will be capable of producing commercially viable sea urchins sustainably and at a

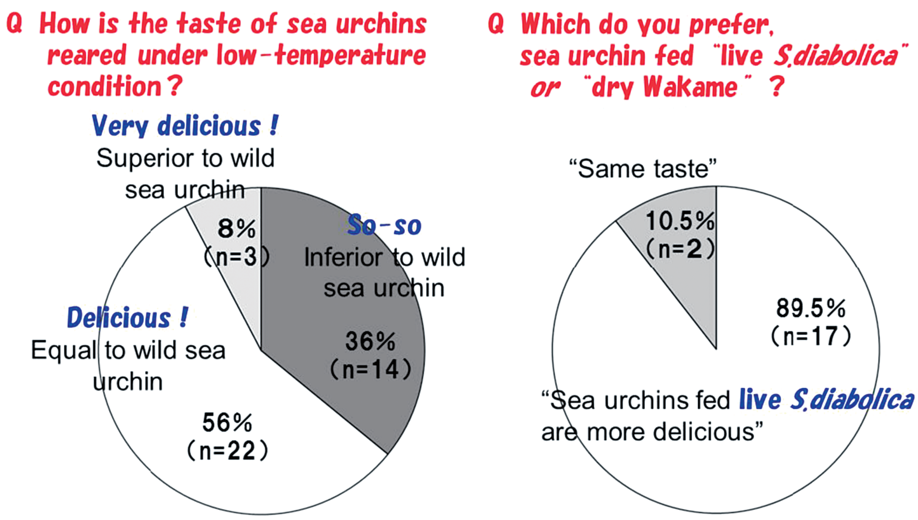

Fig. 5. A questionnaire to ask the tourists visited to Rausu in August 2010, for investigation of the practicability of low-temperature rearing system in *S. intermedius*.

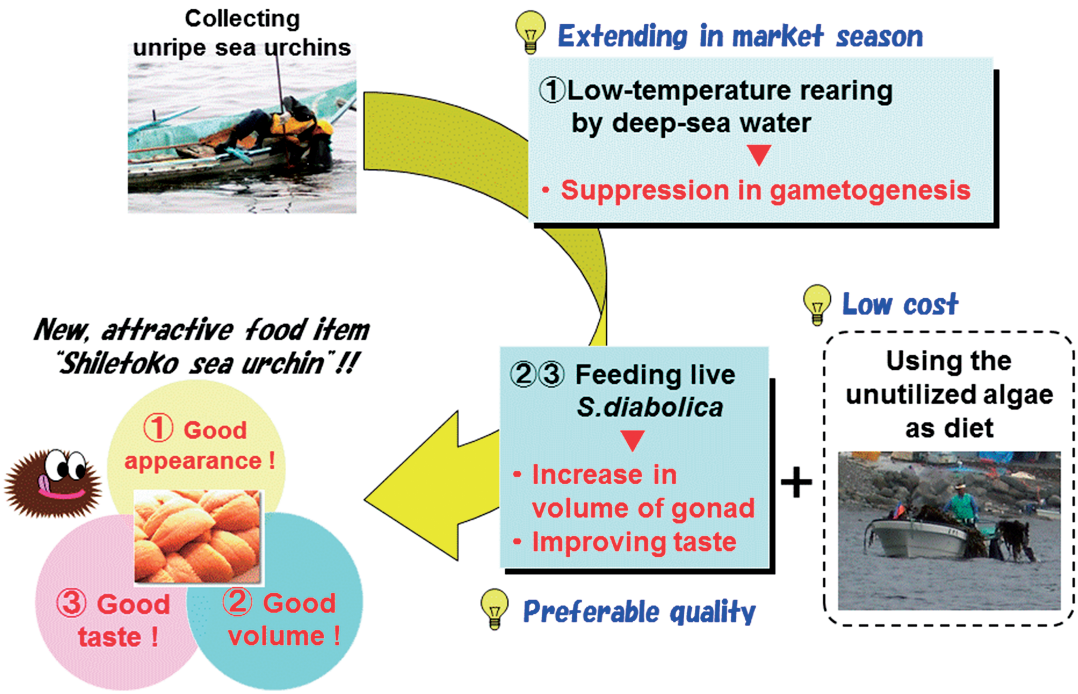

Fig. 6. The best practical use of *S. intermedius* in Rausu, with the aim of extending market season.

lower cost by using this source of unutilized algae as a diet.

In conclusion and future prospects

Our present study was initiated to suppress the gametogenesis of unripe *S. intermedius* captured before the spawning season by low temperature rearing using deep-sea water. We succeeded in extending the harvest season of sea urchins reared with deep-sea water two months longer than that of the wild population, and proved that serving them during the summer tourist season was certainly possible. The best practical use of *S. intermedius* in Rausu would include the following steps: 1) a large number of *S. intermedius* are caught from the wild toward the end of the fishing season (late June), 2) sea urchins are reared in tanks supplied with deep-sea water to suppress their maturation until harvest, and 3) sea urchins are fed mainly on live *S. diabolica* for one month before harvest to improve gonadal growth (Fig. 6). During August, the peak of the summer tourist market in Rausu, the probability of harvesting sea urchins suitable for consumption is approximately 70% per total reared sea urchins. Further detailed studies concerning the rearing conditions of sea urchins would increase that probability in the future.

At present, this aquaculture method is being put to practical use by Rausu Fisheries Cooperative. There is a plan of serving sea urchins at seafood restaurants, hotels, and summer festivals that are visited by many tourists, and they are expected to be a new, attractive food item which will help to promote the popularity of “Shiretoko” as a tourist destination. Should this trial be successful, it will provide a good case for presenting the potential of sea urchin aquaculture to expand not only local fishery production, but also tourism in the local area.

Recently, the extent of barren grounds has increased in coastal areas around Hokkaido. An excessive grazing of seaweeds by wild sea urchins is suspected as one of cause of this phenomenon (urchin-dominated barren ground, called “uniyake” in Japanese) (Fujita, 2008). To recover the luxuriant growth of seaweed, large numbers of sea urchins have been removed from these barren grounds and destroyed, because they have poor gonads due to a shortage of food and have no commercial value (Agatsuma *et al*., 1997; Kuwahara *et al*., 2010). The present culture technique would make it possible to improve the quality of surplus wild sea urchins removed from the barren ground so they are preferred by customers. The technique may also become a useful method to create a balance between the biomass of seaweed and the population of sea urchins in coastal fishing grounds. In the future, it is expected that this culture method will be a valuable tool for conserving the coastal fishing grounds in Hokkaido.

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Walker C. W., and Lesser M. P., 1998: Manipulation of food and photoperiod promotes out-of season gametogenesis in the green sea urchin *Strongylocentrotus droebachiensis*: implications for aquaculture. *Mar. Biol.*, **132**, 663–676.

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The sea urchin gonad contains two main types of cells: nutritive phagocytes (NPs) and germ cells (GCs). NPs store nutrients necessary for gametogenesis, such as proteins, carbohydrates and lipids. The most abundant protein in NPs is a glycoprotein called the major yolk protein (MYP), originally identified as the most predominant component of yolk granules in the eggs. The proportion of NPs and GCs varies with the maturation of the gonads. Before gametogenesis, NPs fill the gonadal lumina and increase in size by accumulating nutrients to the developing GCs and decrease in size. In fully mature gonads, a number of type ova or spematozoa fill the gonadal lumina, whereas, NPs lose their nutrients and shrink. The quality of the gonad as a food product usually deteriorates while GCs proliferate and develop. Promotion of NP growth and suppression of gametogenesis are prerequisites to achieving high profitability in sea urchin aquaculture.

Kayaba T., Tsuji K., Hoshikawa H., Kikuchi Y., Kawabata K., Otaki I., and Watanabe T., 2012: Effect of low temperature rearing, using deep-sea water, on gonadal maturation of the short-spined sea urchin, *Strongylocentrotus intermedius*, in Rausu, Hokkaido. *Fish. Sci.*, **78**, 1263–1272.

It has long been hoped that sea urchins could be served to visitors in seafood restaurants, hotels, and summer festivals in Rausu, located in a world natural heritage site “Shiretoko,” during the summer tourist season. However, to date this has not been feasible because of the sea urchin spawning season (July to September), during which the quality of gonads, the edible part of sea urchins, decreases due to maturation. In this study, we examined the possibility of suppressing gonadal maturation and maintaining high-quality sea urchin gonads by low-temperature rearing using deep-sea water. Unripe sea urchins captured before the spawning season were reared under two temperature conditions from June to September. In those groups reared at ambient temperatures (2.8–19.6℃), gametogenesis in both sexes progressed rapidly with increased temperature, and almost all sea urchins reached full maturity by late July. In contrast, in groups reared at low temperatures (2.1–5.1℃), gametogenesis progressed slowly and over 60% of the sea urchins did not reach maturity even by early September. The feeding experiment also revealed that feeding with live *Saccharina diabolica* could increase the gonadal volume efficiently under low-temperature. These results demonstrate that low-temperature rearing, supplemented with feeding, is effective in suppressing gametogenesis to allow for the harvesting of high-quality sea urchins during the summer tourist season.

Böttger S. A., Devin M. G., and Walker C. W., 2006: Suspension of annual gametogenesis in green sea urchins experiencing invariant photoperiod – Applications for land-based aquaculture. *Aquaculture*, **261**, 1422–1431.

Sea urchin fisheries are valuable commercial resources in the United States with processed gonads sold in Japanese and American markets and maximum U.S. sales of $150M US dollars in 1996. Wild populations of sea urchins on all coasts of the U.S. have been heavily fished. Aquaculture of sea urchins in land-based facilities can help restore commercial populations and preserve this ecologically important herbivore. In this study, we used invariant summer photoperiod to prevent gametogenesis in the North American green sea urchins (*Strongylocentrotus droebachiensis*) maintained in a land-based aquaculture system and provided a commercially available formulated feed that promotes maximum growth of intra-gonadal somatic nutrient storage cells called nutrient phagocytes. Results were compared with individuals fed the same formulated feed under ambient photoperiod in cages in the ocean. Monthly samples of the gonads from both treatments were evaluated for gonad index, volume fractions of cellular constituents of the germinal epithelium, oocyte diameter and taste. Over the 5 months of this study, gonad indices increased significantly ($p < 0.001$) in both treatments from 4.8% ± 0.9 (all values ± SE) initially to 20.5% ± 2.1 under invariant and 23.2% ± 1.4 under ambient photoperiod with no significant difference between treatments ($p = 0.55$). Volume fractions of nutritive phagocytes increased to 80.3% ± 5.9 (initial 37.9% ± 7.1) in males and 71.0% ± 6.7 (initial 10.3% ± 4.0) in females ($p < 0.001$) only under invariant photoperiod. Nutritive phagocyte lengths increased under both photoperiod treatments, but the volume fraction containing nutrients was higher under invariant photoperiod. Volume fractions of gonial/gametogenic cells increased significantly ($p < 0.001$) only under ambient photoperiod from 20.4% ± 5.5 to 37.8% ± 1.8 in males and 0% to 22.6% ± 3.6 in females. The volume of fraction of residual oocytes from last year’s oogenesis increased under invariant photoperiod while that of both residual and new oocytes increased under ambient photoperiod.

Residual oocyte diameters increase from 56.2 μm ± 2.2 initially to 93.5 μm ± 3.7 under invariant and those of residual and new oocytes to 126.0 μm ± 7.3 under ambient photoperiod. Invariant photoperiod yields gonads in both sexes of *S. droebachiensis* that do not initiate fall gametogenesis but attain large size as their nutritive phagocytes grow substantially in size. A Canadian study of wild-collected *S. droebachiensis* indicated that gonads taste best when they contain pre-dominantly nutritive phagocytes and not copious gametes, however gonad taste in our study was unsatisfactory suggesting that the only commercially available sea urchin diet requires modification to support commercial development of land-based aquaculture.

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

Rearing experiments of the sea urchin, *Strongylocentrotus nudus*, were carried out during June to July, 1995 and June to August, 1996, using as food marine algae which settled and grew on the coralline flats after the removal of sea urchins. Feeding rate and growth rate at 17℃ of the sea urchin fed on *Laminaria, Undaria*, and *Costaria* were high and those for *Sargassum, Polysiphonia, Dictyopteris*, and *Desmarestia* were low in the single food item experiment. Among the algae supplied as food, the daily amount of food eaten was high in large-sized groups of the sea urchins, while the small-sized groups show the highest feeding rate. To examine any effect on gonad growth, we fed 3 algae, *Laminaria, Sargassum* and *Polysiphonia* to sea urchins. Two month later, the gonad index was found to be the highest in the *Laminaria* fed group. Among the algae fed, based on the gonad growth, the highest feeding rate and the highest growth rate, we estimated the *Laminariales* are the most nutritionally valuable algae for growth of *Strongylocentrotus nudus*.