WORLD aquaculture

DECEMBER 1996
VOLUME 27(4)

- Echinoculture
- Totoaba culture
- Abalone culture
- Marketing

Nils T Hagen

Echinoculture:

from fishery enhancement to closed cycle cultivation

The green sea urchin, *Strongylocentrotus droebachiensis*

The average wholesale price of fresh Japanese sea urchin roe is approximately 14 000 ¥/kg, making it one of the most valuable seafoods in the world. Increasing demand for sea urchin roe in Japan has spurred the development of extensive domestic fishery enhancement techniques.[36,42,49] It has also provided the incentive for a worldwide expansion of sea urchin fisheries.[2-4,14-16,22-24,27,35,42,45]

With a total production of 60 000 tonnes whole-live-weight per year, the world supply of wild sea urchins has reached a plateau. However, this production level is probably not sustainable at current levels since declining productivity of exploited sea urchin stocks no longer can be offset by further geographical expansion of the fishery. To maintain or expand the world supply of high quality sea urchin roe is a major aquaculture opportunity awaiting commercial scale trials.

The term echinoculture refers to the cultivation of echinoderms; i.e. to both sea urchins (Echinoidea), and to a lesser extent sea cucumbers (Holothuroidea). Nevertheless, sea urchins are more valuable than sea cucumbers, and their cultivation is more advanced. This paper will concentrate, therefore, on sea urchins, although the cultivation of sea cucumbers will be considered.

Catch and consumption

The total Japanese catch of sea urchins (6 species, Table 1), and sea cucumber (*Stichopus japonicus*), peaked in the late 1960s at approximately 27.5 thousand tonnes per annum for sea urchins and 13 thousand tonnes for sea cucumber (Fig. 1). Over the two next decades sea urchin landings fluctuated between 20 and 27 thousand tonnes, until by 1991 the catch had dropped to 14 thousand tonnes. The cause of this recent decline remains unknown, although it coincides with observations of disease related sea urchin mortality. Even so, sea urchin landings remain 2-3 times higher than the steadily declining sea cucumber landings (Fig. 1).

The gonads are the primary soft tissue and only edible part of the sea urchin. The harvested gonads of both female and male sea urchins are called "roe" regardless of sex. As the most important market for sea urchins, Japan imports approximately 5 thousand tonnes of sea urchin gonads per annum (Fig. 2), the equivalent of 40-50 thousand tonnes of whole live sea urchins. In addition there is a moderate import of whole live sea urchins (Fig. 3). Total Japanese consumption then, including the domestic catch, is approximately 60 000 tonnes of whole sea urchins per annum (Fig. 3). The second largest consumer nation is France with an annual consumption of approximately 1000 tonnes of whole sea urchins.[33]

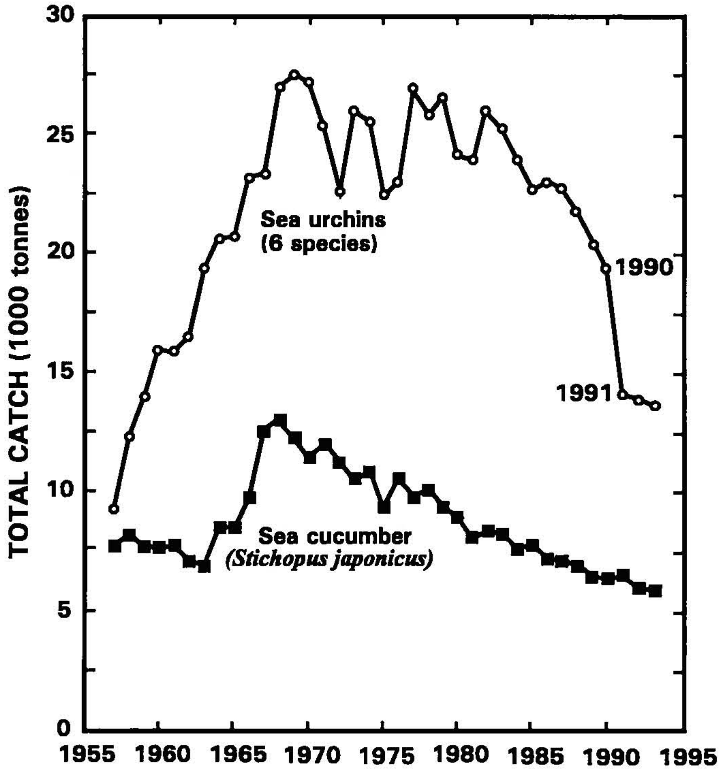
Price

The wholesale price of whole Japanese sea urchins (6 species) was similar to the price of the Japanese sea cucumber in the 1960s, but although the price of both urchins and sea cucumber contin-

Table 1. Exploited Japanese sea urchins

Japanese name	Scientific name
Aka Uni	*Pseudocentrotus depressus*
Bafun Uni	*Heterocentrotus pulcherrimus*
Ezo Bafun Uni	*Strongylocentrotus intermedius*
Kita Murasaki Uni	*Strongylocentrotus nudus*
Murasaki Uni	*Anthocidaris crassispina*
Shirahige Uni	*Tripneustes gratilla*

Figure 1. Japanese echinoderm landings



ued to increase, by 1990 the urchins were twice the price of sea cucumber, reflecting increasing demand for quality urchin gonads (Fig. 4). Fresh sea urchin gonads fetch approximately 10 times the price of whole live sea urchins, with the average wholesale price being almost 14 000 ¥/kg in 1993. Fresh imported sea urchin gonads fetched an average wholesale price of only 6000 ¥/kg the same year due to their inferior quality (Fig. 5). These quality problems are related to the nutritional and reproductive status of the source population, as well as the processing and shipping routines of the suppliers. However, some harvested species of sea urchins do not produce superior quality gonads under any circumstances.

Sea urchin cultivation

Sea urchin aquaculture in Japan is part of a multispecies fisheries enhancement effort organised by local fishery cooperatives. The three limiting factors of the sea urchin fishing industry have been identified as: 1) insufficient food supply; 2) lack of suitable habitat; and 3) insufficient recruitment.

The green sea urchin, *Strongylocentrotus droebachiensis* (top), yields quality gonads (roe) under proper conditions. Roe quality is judged on the basis of color, (attractive orange, lower photograph), shape, consistency and taste.

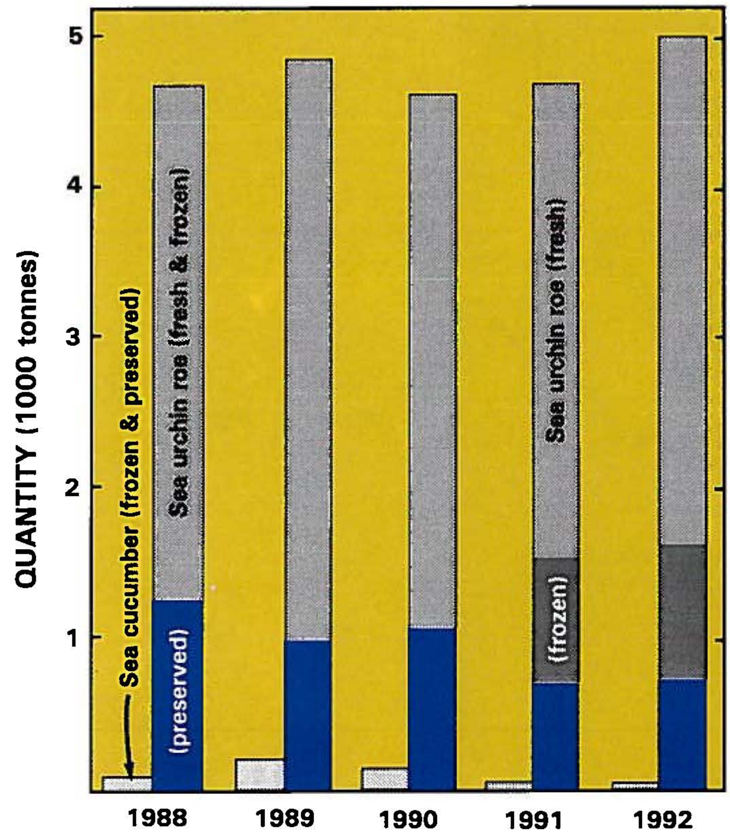


Figure 2. Japanese echinoderm imports.

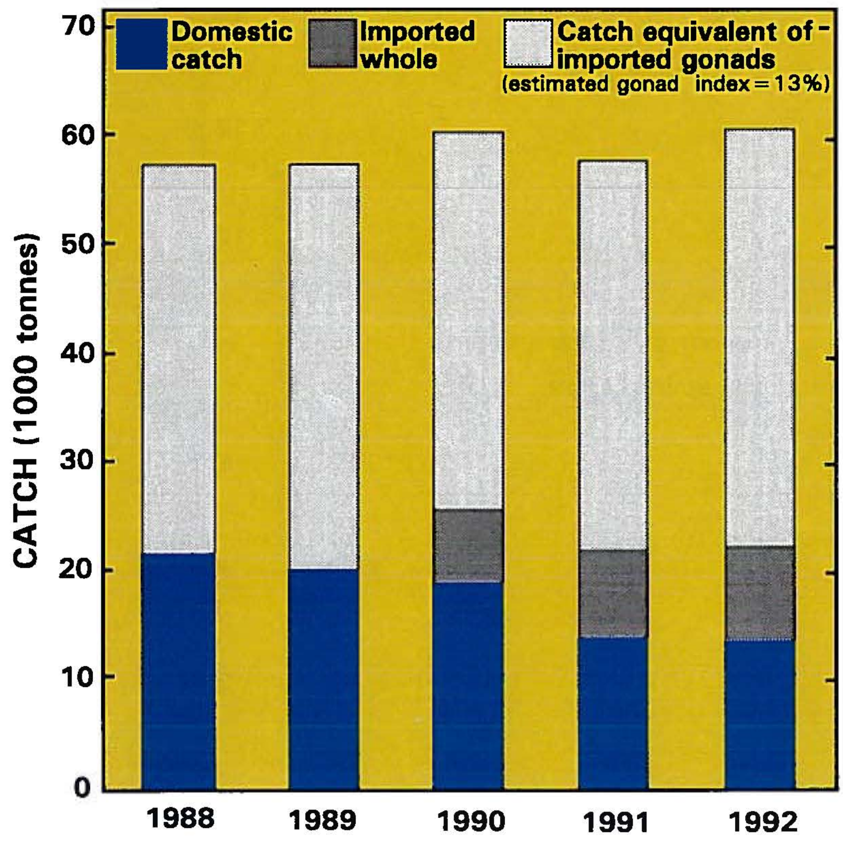


Figure 3. Japanese sea urchin consumption from domestic catch and imports. The gonad index value is a conservative estimate based on the average gonad yield in commercial sea urchin fisheries in northern Japan.

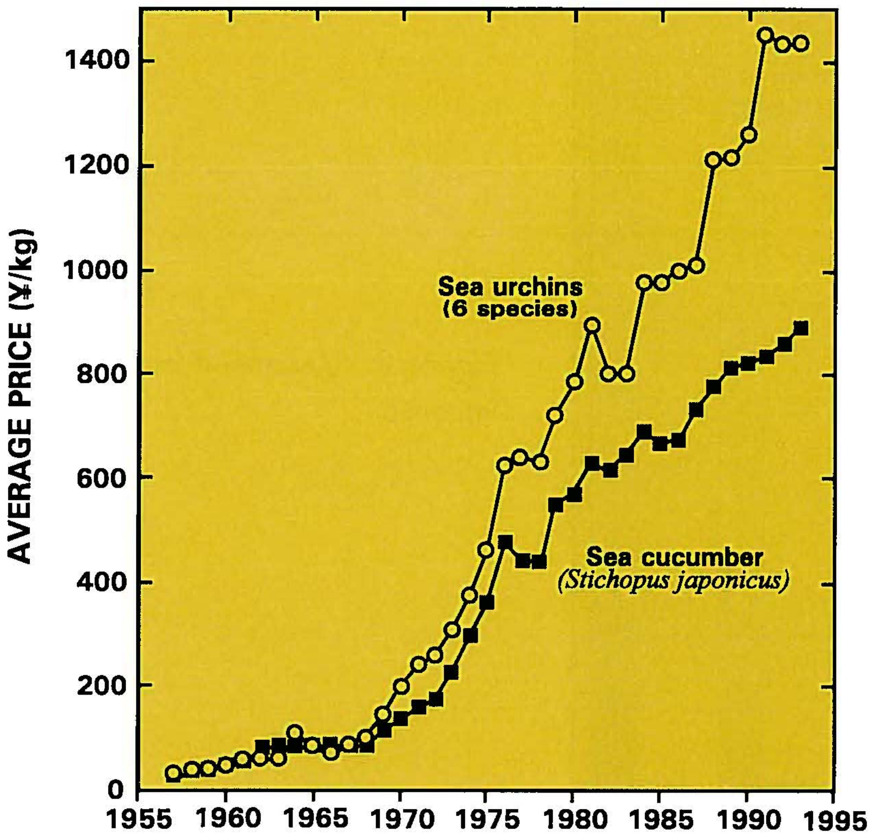


Figure 4. Echinoderm prices in Japan.

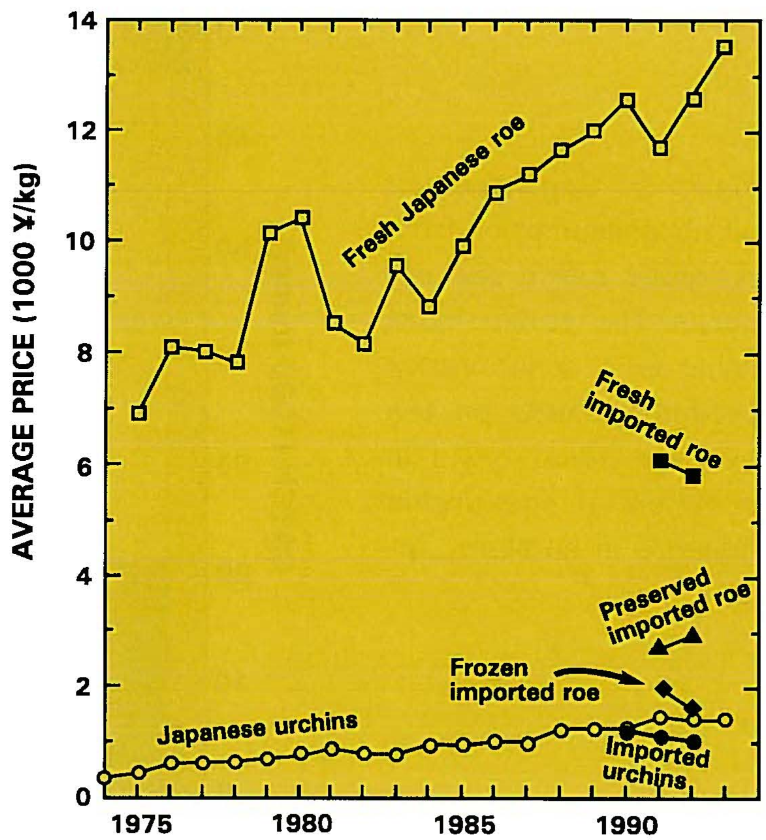


Figure 5. Sea urchin prices in Japan.

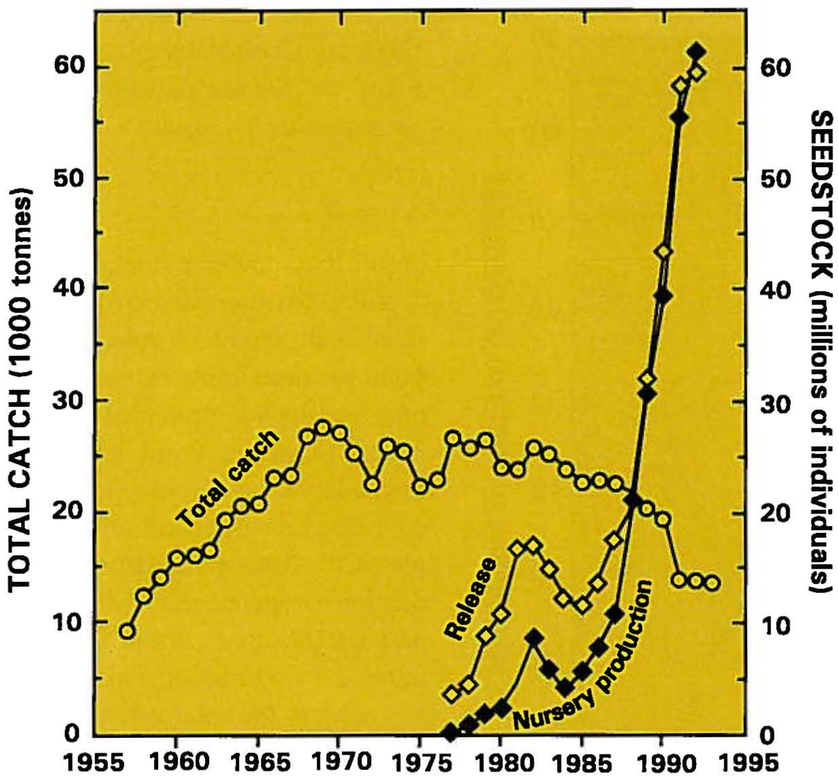
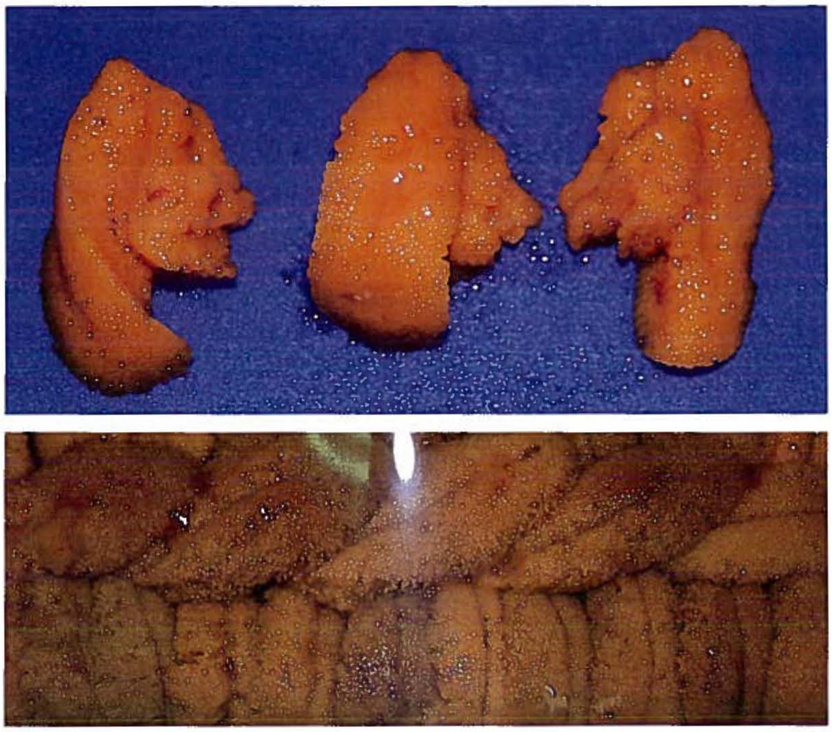


Figure 6. Catch and cultivation of Japanese sea urchins.

Sea urchin transplantation and seaweed reforestation are aimed at improving the gonad yield of undernourished adult sea urchins by providing increased access to food. Undernourished sea urchins, transplanted from barren grounds off the north-western coast to seaweed dominated feeding grounds off the north-eastern coast, are usually ready for recapture after 3 months.[41] The objective of seaweed reforestation is to improve the local food supply of undernourished sea urchin stocks by establishing algae in barren areas through a combination of algal cultivation and overgrazing control.[25] Seaweed reforestation is still an experimental technique, and transplantation of adult sea urchins is gradually being replaced by release of juvenile seedstock. Feeding of captured sea urchins



Helen K Marshall

Food and reproductive condition are major factors in roe quality. The most valuable roe has a high glycogen level and a rich orange color (top). Roe of lesser quality lacks this rich orange coloration (bottom).

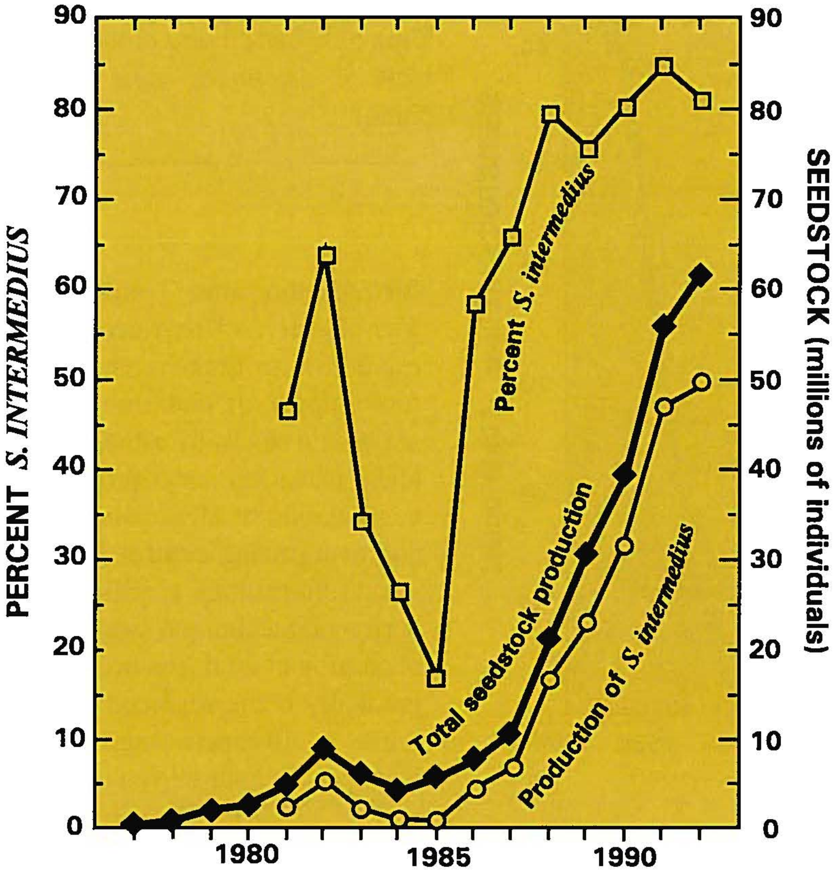


Figure 7. Seedstock production of *Strongylocentrotus intermedius* in Japan

is also being attempted on a small scale.

Habitat improvement and habitat creation is part of a larger ongoing fisheries enhancement program primarily aimed at artificial reef construction.[15,37] The main purpose of artificial reefs is to improve the productivity of soft substrates by creating new fishing grounds for the kind of flora and fauna normally associated with rocky shore habitats, e.g. edible seaweed, abalone, top shells, sea urchins, rockfish, etc. In a related effort the effective surface area and habitat complexity of existing reefs has been increased by blasting, by adding rocks, or by constructing shallow channels with wave-powered water circulation.[7,39,49]

The third limiting factor, insufficient recruitment, is still a major problem even though the Japanese sea urchin fishery is strictly regulated to ensure that spawning stocks are not depleted. To improve recruitment a large scale seedstock release program has been implemented. Juvenile seedstock is produced in land based nurseries from hatchery reared larvae, and from wild larvae collected on suspended settlement plates.[41] Although seedstock production has increased rapidly in the past decade, to a current level of more than 60 million individuals per annum, the total catch of sea urchins has remained at a relatively low level since 1991 (Fig. 6).

The single most important sea urchin in Japan, *Strongylocentrotus intermedius* (*ezo bafun uni*), accounts for approximately 80% of the total seedstock production (Fig. 7). The rest is shared among 5 other species, of which *Pseudocentrotus depressus* (*aka uni*) is the most important (Table 1).

Broodstock management

Japanese sea urchin cultivation is based on the spawning of wild broodstock (Fig. 8), with the availability of mature sea urchins, in most places, restricted to the annual breeding season. However, a local population of *S. intermedius*, in the southern part of its distributional range, has biannual reproduction which allows some hatcheries to produce two annual batches of sea urchin larvae. For example, the largest sea urchin nursery in Japan (located in Shikabe municipality, south-eastern Hokkaido) obtains broodstock from this source

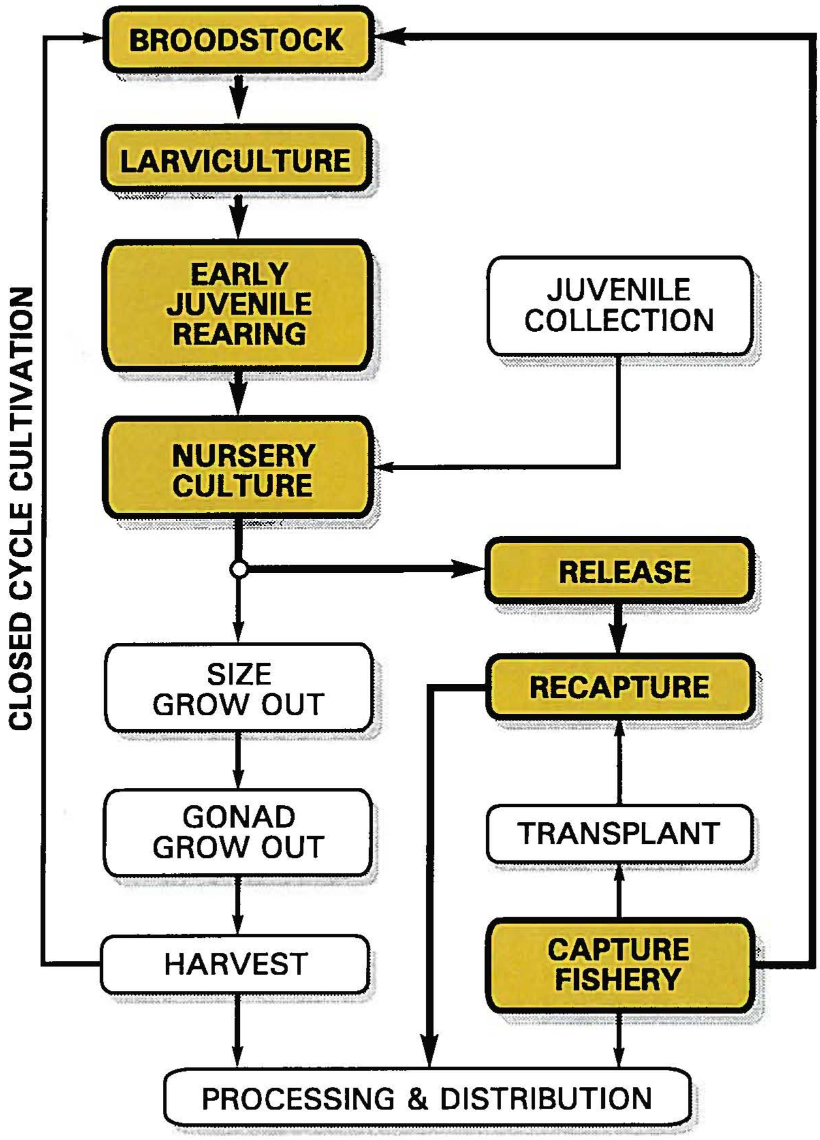


Figure 8. Principal sea urchin cultivation techniques.

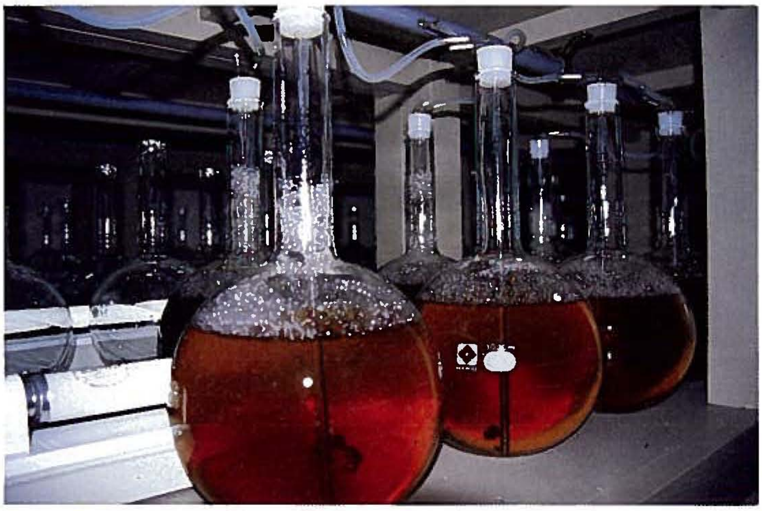
Mature sea urchins are easily induced to spawn by injecting 1-2 mL of a 0.53 mol. KCl solution.[17,48] A new technique for individual identification of sea urchins using electronic PIT (Passive Induced Transponder) tags, has the potential to facilitate cultivated broodstock management.[11,12]

Larviculture

Larviculture in Japanese hatcheries commences with the mixing of gametes from several animals. Excess sperm is rinsed off, and the fertilised eggs hatch after approximately 20 hours. Three to four days later they have developed to the early pluteus stage which requires planktonic microalgae as food. The diatom *Chaetocerus gracilis* is commonly used in commercial sea urchin hatcheries, whereas the green flagellate *Dunaliella tertiolecta* is popular in research laboratories.[48] *C. gracilis* is cultivated in 3-liter batches in a separate microalgae cultivation room, and fed to the larvae at an initial rate of 1.5 liter (5000 cells/mL)/tank/day. The amount is gradually increased to 10 liters/tank/day in the final stages of cultivation. The larvae are cultivated in 1000 liter tanks with continuos flow of 1 µm filtered seawater. The water flow is increased from 15% water

population and produces one batch of juveniles in the spring and another in the fall for a total of 11 million juvenile *S. intermedius* per annum.[41]

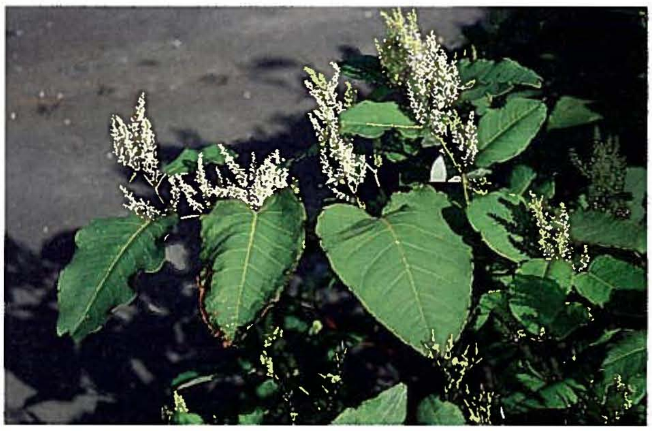
The factors controlling reproductive maturation are incompletely known for most sea urchin species, but photoperiod and water temperature are considered to be important.[40,44,51] Experimental broodstock cultivation has shown that multiple spawning is possible when well fed sea urchins are cultivated in darkness in relatively warm water.[30]



Larval sea urchins are commonly fed the diatom *Chaetoceros* in commercial hatcheries. *Chaetoceros* can be cultured in 3-liter batches (top left) and fed at a rate of 4.5 - 15 million cells per tank per day, depending on larval stage.

The larvae metamorphose to juveniles and settle on polycarbonate plates (above) covered with algae or diatoms, which provide food for the juveniles. Once they reach 4-5 mm they are transferred to nursery tanks with open mesh cages (middle left), to habitat modules created from opaque polycarbonate plates (lower left), or to hanging cages suspended beneath the surface of the sea.

—All photos, Helen K Marshall



In nursery culture, the preferred food for juvenile sea urchins is kelp, but because of the scarcity of kelp it is often necessary to utilize other seaweeds, processed food pellets (above), and knotweed leaves (upper right), which are placed in the tank with the sea urchins (right).

—All photos Helen K Marshall

exchange/day to 100% at the time of settlement, 16-30 days after fertilisation depending on water temperature. Circulation in the larvae tanks is provided by two large airstones with a gentle flow, one on the bottom and another near the surface. The central water outlet is covered by 100 µm plankton net (later 150 and 200 µm). The density is initially 1.5 larvae/mL, but decreases to 0.8 larvae/mL at the time of settlement. The metamorphosed juveniles are approximately 0.3 mm in size.[1,43,49]

Early juvenile rearing

Settlement is induced by introducing wavy settlement plates covered with the minute green alga *Ulvella lens,*[43] or the benthic diatom *Navicula ramosissima,*[19] which serves as the initial food source for the juvenile sea urchins. The plates are made of transparent polycarbonate which facilitates the growth of benthic microalgae on both sides of the plates. The settlement plates are prepared in tanks inoculated with the desired algae. Nutrient salts are added to stimulate algal growth, and the tanks are occasionally drained and rinsed to eliminate unwanted benthic diatoms. Feeding with soft seaweed such as *Ulva lactuca* commences when the juveniles reaches 3-4 mm size.[1,43,49]

Nursery culture

The larvae are transferred from the settlement plates to nursery culture at 4-5 mm size. Most juveniles are transferred to nursery tanks with open mesh cages, or to habitat modules made from non-transparent wavy plates, but some are transferred to nursery cultivation in hanging cages which are suspended 1-2 m below the surface. The juveniles are fed with kelp (*Laminaria* spp, *Undaria pinnatifida, Eisenia bicyclis*) and other locally available seaweed, supplemented by food pellets or knotweed leaves (*Oita dori, Polygonum* sp.). Food pellets come in different sizes, but their food value is still inferior to fresh kelp. Some juveniles are released 6 months after fertilisation when they are 7-10 mm. Six months of additional nursery cultivation produces larger (15-20 mm) seedstock with higher survival rates. The large juveniles are ready for recapture 2 years after release when they have reached a diameter of more than 40 mm. Survival rates are variable, but have been estimated at 20-50% for large seedstock. Approximately 80% of the survivors are captured, yielding a total recovery rate of 16-40%.(41,42)

Closed-cycle cultivation

Closed-cycle cultivation requires growout facilities. These can be constructed by expanding existing nursery techniques, by adapting technology developed for the intensive cultivation of abalone,(5) or by the development of new technology. The French adopted the last alternative and developed a prototype of a multilayered growout tank which consists of four stacked, sloping shelves. Water is pumped up to the top shelf from a reservoir tank under the shelves, and then runs down through the stack of shelves in a zigzag pattern. The accumulation of sea urchin faeces in the reservoir tank is siphoned off at regular intervals. The recirculated water is gradually replenished by marine groundwater.(31,32)

An important factor when considering closed-cycle cultivation is the choice of a good target species. The gonads of the green sea urchin, *Strongylocentrotus droebachiensis*,(10) for example, are popular in Japan, despite quality problems commonly caused by food limitation of wild stocks. Highly similar to the *S. intermedius,* which occurs only in the northwestern Pacific, *S. droebachiensis* is a cold water species with a wide distribution throughout the North Atlantic and the Northeastern Pacific.(20) The larvae of *S. droebachiensis* must be cultured at temperatures below 10-11°C,(13,47) but juveniles and adults can tolerate somewhat higher temperatures.(12,28,29) Other potential candidates for closed-cycle cultivation are the Chilean sea urchin *Loxechinus albus* (8,9) and the European sea urchin *Paracentrotus lividus*.(6,31,32)

A commercial-scale grow out facility would require a stable food supply, with kelp being the major ingredient. Kelp is necessary for good flavour and colouring of the sea urchin gonads, but a protein supplement can enhance growth and improve overall food conversion.(6,9,18,26) The most important determinant of gonad quality, besides food, is the reproductive state of the sea urchin. Sexually mature gonads have a undesirable soft consistency and bitter taste due to the reduced number of glycogen-containing nutrient cells. Closed-cycle reproduction offers the potential to inhibit sexual maturation through manipulation of photoperiod and temperature, thereby extending the harvesting season, improving gonad quality, gonad yield and food conversion rates. Closed-cycle cultivation also offers the opportunity for growth acceleration through systematic broodstock selection and breeding.

Helen K Marshall

Adult Japanese sea cucumber, *Stichopus japonicus.*

Closed-cycle cultivation is capital intensive and has high operational costs, but requires only a modest investment in R&D. Full scale hatchery and nursery technology is well established in Japan, and prototype growout facilities already exist in France. A recent profitability analysis of a hypothetical Norwegian growout facility, using pessimistic, realistic and optimistic parameter estimates, was unable to demonstrate non-profitability. In fact, there was a large profit potential when realistic and optimistic parameter estimates were used.[50]

Sea cucumber cultivation

Sea cucumbers are consumed in Japan, as well as in Chinese markets including Singapore, Hong Kong and Taiwan. The Japanese sea cucumber market is largely self sufficient, whereas the Chinese markets are more import oriented. Sea cucumber landings peaked at 13 thousand tonnes in the late 1960s, subsequently declining to the present level of approximately 6 thousand tonnes. To supplement natural recruitment, seedstock production commenced in the early 1980s, but is still at a modest level of 2-3 million individuals per annum (Fig. 9). Most of the seedstock is being released, but some is being used for experimental closed-cycle aquaculture.

Sea cucumber broodstock is captured in spring when sexually mature. Spawning is induced by temperature shock, for example by raising the water temperature by 5°C from 16° to 21°. The planktonic larvae are then cultivated in 1000-liter tanks and fed a planktonic microalgae, most commonly the diatom *Chaetocerus gracilis*. Settlement occurs after approximately 2 weeks. At this stage the larvae measure approximately 800 µm, but after metamorphosis they measure only about 200 µm. These tiny juveniles are then fed an initial diet of mixed assemblage benthic diatoms (*Navicula* spp.) before being transferred to outdoor nursery tanks with unfiltered seawater. There they feed on the natural growth of benthic diatoms on the tank walls, supplemented with dried seaweed powder (*wakame*, *Undaria pinnatifida*). Mortality is high during the hatchery/nursery stage. The juveniles are released after 6 months when they measure 2-8 cm, and recaptured 1 year later when they measure approximately 20 cm.

Sea cucumbers feed on detritus and suspended particulate matter, including the faecal pellets of sea urchins. Intensive polyculture of sea urchins and sea cucumbers appears feasible, but has yet to be investigated.

In conclusion, it appears that closed-cycle cultivation of sea urchins for the Japanese market is an emerging cold water aquaculture opportunity awaiting commercial trials, whereas sea cucumber cultivation is still in the experimental

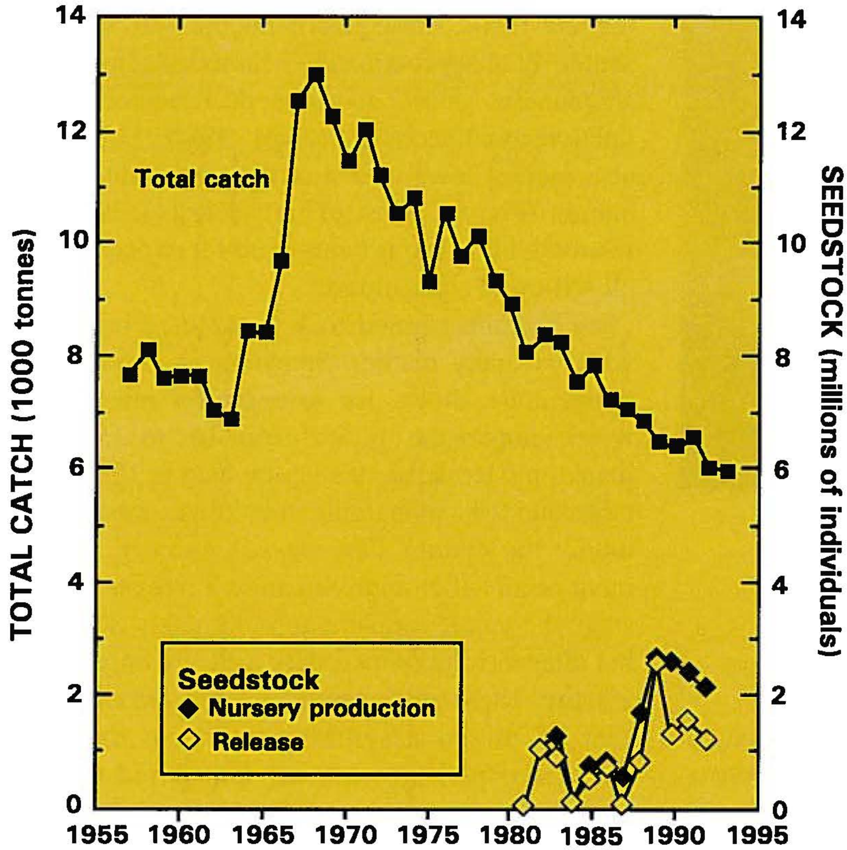


Figure 9. Catch and cultivation of the Japanese sea cucumber.

stage. However, joint development of urchin/cucumber polyculture is an interesting possibility since sea urchin waste can be used as sea cucumber food. In addition, echinoculture has the potential to become a long-term sustainable industry with ecologically and environmentally sound production, since both sea urchins and sea cucumbers are primarily herbivorous organisms.

Notes and References

1. **Anonymous**, 1992. Ezo bafun uni aquaculture manual. New edition (in Japanese). No. Hokkaido Saibai Gyogyo Sogo Center (Hokkaido Institute of Mariculture, Shikabe, Hokkaido, 041-14, Japan).
2. **Campbell A**, Harbo RM, 1991. *In* Biology of Echinodermata. Proc. 7th Int. Echinoderm Conf. (T Yanagisawa, I Yasumasu, C Oguro, N Suzuki, T Motokawa, eds), p. 191-199. Atami, Japan, 9-14 September 1990. Balkema, Rotterdam.
3. **Chiu ST**, 1986. *In* Proc. 1st. Asian fisheries forum (JL Maclean, LB Dizon, LV Hsillos, eds), p 361-366. Manila, Philippines, 26-31 May 1986.
4. **Conand C**, Sloan NA, 1989. *In* Marine invertebrate fisheries: their assessment and management (JF Caddy, ed.), p. 647-663. J. Wiley & Sons.
5. **Ebert EE**, 1992. *In* Abalone of the world: biology, fisheries, and culture. (SA Shepher, MJ Tegner, SA Guzman del Proo, eds), p 570-582. Fishing news books/Blackwell, Oxford,
6. **Fernandez C**, Caltagirone A, 1994. *In* Echinoderms through time (B David, A Guille, J-P Féral, M Roux, eds), p 655-660. Balkema, Rotterdam,
7. **Funano T**, 1981. Sci. Rep. Hokkaido Fish. Exp. Sta. 23:9-52.
8. **Gonzales LP**, Castilla JC, Guisado C, 1987. J Shellfish Res 6(2):109-115.
9. **González ML**, Pérez MC, López D, Pino CA, 1993. Aquaculture 115:87-95.
10. **Hagen NT**, 1990. Kråkebolleoppdrett. Ny nordnorsk kystnæring? (in Norwegian). No. NF-nr. 20.08/90. Nordlandsforskning (Nordland Res. Inst.), P.O. Box 6003, N-8002 BodØ, Norway.
11. **Hagen NT**, 1991. *In* Biology of Echinodermata (T Yanagisawa, I Yasumasu, C Oguro, N Suzuki, T Motokawa, eds), p 257 (Abstract only). Proc. 7th International Echinoderm Conf., Atami/9-14 Sept., 1990. Balkema, Rotterdam.
12. **Hagen NT**, 1995. Aquaculture 239:271-284.
13. **Hart MW**, Scheibling RE, 1988. Mar. Biol. 99:167-176.
14. **Hartstone DC**, 1984. A study of the Japanese market for New Zealand sea urchin roe. Marketing study No. EM. 60. New Zealand Fishing Industry Board.
15. **Hasegawa Y**, 1976. J. Fish. Res. Bd. Canada 33:1002-1006.
16. **Himmelman JH**, Lavergne Y, Axelsen F, Cardinal A, Bourget E, 1983. Can. J. Fish. Aquat. Sci. 40:474-486
17. **Hinegardner RT**, Rocha Tuzzi MM, 1981. *In* Laboratory animal management, marine invertebrates, p. 291-302. National Academy Press, Washington, D.C. USA.

18. **Hoshikawa H**, 1993. Uni ni daizuo tabesazeru hanashi (in Japanese). Hokusuishi Daiyori (Hokkaido Exp Stn News) 22:9-14.

19. **Ito Y**, Ito S, Kanamaru H, Masaki K, 1987. Nissuishi Bull. Jap. Soc. Sci. Fish. 53(10):1735-1740.

20. **Jensen M**. 1974. Sarsia 57:113-148.

21. **Johnson CR**, Mann KH, 1982. *In* Echinoderms (JM Lawrence, ed), p 277-283. Proc. Int. Echinoderm Conf., Tampa Bay. Balkema, Rotterdam.

22. **Kato S**, 1972. Sea urchin fishery starts. Comm. Fish. Rev. US. Dept. Comm. Publ. 34:36.

23. **Kato S**, 1973. Sea urchins: a new fishery develops in California. Mar. Fish. Rev. US. Dept. Comm. Natl. Ocean Atmosph. Adm., Natl. Mar. Fish. Ser. 34:23-30.

24. **Kato S**, Schroeter SC, 1985. Biology of the red sea urchin, *Strongylocentrotus franciscanus*, and its fishery in California. Mar. Fish. Rev. US Dept. Comm. Natl. Ocean. Atmosph. Adm., Natl. Mar. Fish. Ser. 47:1-20.

25. **Kito H**, Kikuchi S, Uki N, 1980. *In* Proc. Int. Symp. Coast. Pacific Mar. Life, p. 55-66. Bellingham, Washington 98225: Western Washington Univ.

26. **Klinger TS**, Lawrence JM, Lawrence AL, 1994. J. World Aquaculture Soc. 25(4):489-496.

27. **Kramer DE**, 1980. Can. Industry Rep. Fish. Aquat. Sci. 114:1-16.

28. **Kramer DE**, Nordin DMA, 1978. Physical data from a study of size, weight and gonad quality for the green sea urchin (*Strongylocentrotus dröbachiensis*) over a one-year period. Fish. Mar. Service Manuscript Rep. Fish. Environment Can. 1476, 68p.

29. **Kramer DE**, Nordin DMA, 1979. Studies on the handling and processing of sea urchin roe. I. Fresh product. Fish. Mar. Service Manuscript Rep. Fish. Environment Can. 870, 47p.

30. **Leahy PS**, 1978. J. Exp. Zool. 204:369-380.

31. **LeGall P**, 1990. *In* Aquaculture (G Barnabé, ed.), p. 443-462. Ellis Horwood, New York, p. 443-462.

32. **LeGall P**, Bucaille D, 1989. *In* Aquaculture - a biotechnology in progress (N De Pauw, E Jaspers, H Ackefors, N Wilkins, eds), p 53-59. European Aquaculture Soc., Bredene, Belgium.

33. **Lines R**, Hammervold T, 1988. Høyt henger de, men er de sure? - En analyse av det franske kråkebollemarkedet (in Norwegian). Økonomi No. 9130. Fiskeriteknologisk Forskningsinstitutt (Institute of Fishery Technology Research).

34. **Machiguchi Y**, 1992. Bull. Hokkaido Natl. Fish. Res. Inst. 56(March):61-70 (in Japanese with English abstract).

35. **MacKay AA**, 1976. The sea urchin roe industry on New Brunswick's Bay of Fundy coast. No. Marine Research Associates Report to the New Brunswick Department of Fisheries, Fredricton, New Brunswick, Canada.

36. **Matsui I**, 1968. The propagation of sea urchins. Fish. Res. Bd. Can. Trans. Ser., Biol. Sta. Nanaimo, BC., 1063:1-172.

37. **Mottet MG**, 1976. The fishery biology of sea urchins in the family Strongylocentrotidae. Washington Dep. Fish. Tech. Rep. 20:1-66.

38. **Nagai Y**, Kaneko K, 1975. Mar. Biol. 29:105-108.

39. **Noma T**, 1983. Enhancement of seawed and sea urchin by utilization of wave energy. Tech. Rep. National Res. Inst. Fish. Eng. Aquaculture and Fishing Port Engineering 4:1-10

40. **Pearse JS**, Pearse VB, Davis KK, 1986. J.Exp. Zool. 237:107-118.

41. **Saito K**, 1992. *In* The management and enhancement of sea urchins and other kelp bed resources: a Pacific rim perspective(CM Dewees, ed), p 1-38. Publication no. T-CSGCP-028, California Sea Grant College, Univ. Calif., La Jolla, CA 92093-0232.

42. **Saito K**, 1992. Sea urchin fishery of Japan. In: Dewees C M (ed.) The management and enhancement of sea urchins and other kelp bed resources: a Pacific rim perspective. Publication no. T-CSGCP-028, California Sea Grant College, Univ. Calif., La Jolla, CA 92093-0232, p. 1-11

43. **Saito K**, Yamashita K, Tajima K, Obara A, Nishihama Y, Sawasaki M, Kawamata K, Kawamura K, 1985. Manual of artificial seed production of sea urchin, *Strongylocentrotus intermedius* (in Japanese). No. Hokkaido Institute of Mariculture, Shikabe, Hokkaido, 041-14, Japan.

44. **Sakairi K**, Yamamoto M, Ohtsu K, Yoshida M, 1989. Zool Sci 6(4):721-730.

45. **Schram Stokke O**, 1987. Det japanske markedet for kråkebollerogn (in Norwegian). IFF/UiTØ Rap. No. Institute of Fisheries, University of Tromsø.

46. **Sloan NA**, 1985. *In* Echinodermata (BF Keegan, BDS O'Connor, eds), p 109-124. Proc. 5th Int. Echinoderm Conf. Galway. A.A. Balkema, Rotterdam.

47. Stephens RE, 1972. Biol. Bull. 142:145-159.

48. **Strathmann MF**, 1987. *In* Reproduction and development of marine invertebrates of the Northern Pacific Coast: Data and methods for the study of eggs, embryos, and larvae (MF Strathmann,ed), p 511-534. Univ. Washington Press, Seattle and London.

49. **Tegner MJ**, 1989. Mar. Fish. Rev. 51:1-22.

50. **Vareide K**, Hagen NT, 1992. Økonomi i oppdrett av kråkeboller (in Norwegian). No. NF-Rap. nr. 19/92-20. Nordlansforskning, P.O. Box 6003, N-8002 Bodø, Norway.

51. **Yamamoto M**, Ishine M, Yoshida M, 1988. Zool. Sci. 5:979-988

52. **Acknowledgements.** Thanks to my Japanese friends, teachers and colleagues for their support during my visits as MONBUSHO scholarship recipient, conference delegate, and STA fellow. Thanks also to the Aquaculture Association of Canada for inviting me to their annual meeting, and to H.K. Marshall for improving the logical flow and linguistic content of the manuscript and providing photographs for this article. The National Research Institute of Aquaculture, Mie, Japan provided access to Japanese fishery statistics and time for manuscript preparation.

***Nils T. Hagen** is with the Department of Fisheries and Natural Science, Bodø College, N-8002 Bodø, Norway.* •