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Cover photo of the purple sea urchin Paracentrotus lividus by Evelyn Moylan, Taighe Mara teo, Carna, Co. Galway, Ireland.

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Sea Urchin Culture Workshop

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G. Jay Parsons, Aquaculture, Marine Institute of Memorial University, St. John's, NF Susan L. Waddy, Department of Fisheries and Oceans, St. Andrews, NB

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Introduction

As part of the 13th Annual Meeting of the Aquaculture Association of Canada held in Ottawa from 2-5 June 1996, a special one-day workshop devoted to sea urchin culture was convened on Tuesday 4 June 1996. The Canadian Centre for Fisheries Innovation sponsored the workshop and publication of these proceedings. Speakers were invited from across Canada, the United States and Europe. The workshop was attended by over 75 participants, including representatives from the sea urchin industry, research community, and government, as well as prospective culturists.

The speakers in the morning session presented research dealing specifically with gonad ("roe") enhancement using natural or artificial diets. In the afternoon session, speakers presented papers on sea urchin biology, industry development, marketing, and economics. Also included in this issue is an abstract of a paper presented by N. Hagen in the poster session and an unsolicited manuscript from B.G. and A.I. Hatcher. The latter paper is included in this "proceedings" as it relates to the overall theme of the workshop.

This singular workshop represented a turning point in sea urchin culture in Canada. It brought together a number of the researchers involved in sea urchin culture from Atlantic Canada (Québec, Newfoundland, New Brunswick, and Nova Scotia), western Canada, the United States, and Europe (France, Ireland, and Norway). It offered the opportunity for both researchers and industry to interact and exchange ideas on the current status and future prospects of the industry, and several new collaborations resulted from the day's deliberations.

A number of the presentations and subsequent discussions stressed the need for further research in order to develop and strengthen the industry. The research priorities fit into the following categories: 1. gonad enhancement; 2. reproductive manipulation; 3. culture systems; and, in the long-term, 4. seed supply and whole-animal growth. Some of the specific priorities include:

- Develop a cost-effective commercial diet capable of producing high quality (color, texture, and flavor) gonads acceptable to the market.
- Determine the effect of season and feeding duration on gonad quantity and quality.
- Determine the feeding rates, food conversion ratios and nutritional requirements needed to optimize sea urchin gonad growth and whole-animal growth.
- Establish quality standards to assess gonad color, texture and flavor.
- Examine sea urchin feeding behavior under high stocking density conditions in order to improve gonad quality.
- Determine optimal temperature, photoperiod and feeding regime for the production of out-of-season high quality gonads
- Determine the most cost effective growout system whether it be land-based or sea-based.
- 4a. Determine the optimal conditions (e.g., food, temperature) for the hatchery production of sea urchin larvae and seed.
- 4b. Determine the effect of size-grading on whole-animal growth rates.
- Determine the risk of disease outbreaks for gonad enhancement or grow-out operations.

These research priorities do not preclude the need for discussion and consideration of the many resource management issues related to sea urchin aquaculture involving the availability to lease sites (land-based or sea-based), access to commercial-size sea urchins for gonad enhancement, availability and access to wild food sources (i.e., kelp), and resource assessments.

I look forward to the development of a promising sea urchin culture industry.

G. Jay Parsons

Feasibility trials for sea urchin aquaculture using natural feeds

Robert G. Hooper, (1) Fiona M. Cuthbert (1) and Thomas McKeever (2)

Various experimental diets were fed to sea urchins between the spring of 1994 and the winter of 1996 at the Bonne Bay Biology Station. Experimental trials assessed the merits of common local wild seaweed species. Laminaria digitata was shown to be the most effective at increasing gonad yield and improving quality. L. longicruris was less effective, but still useful. Experiments on ration size have shown that diets provided at considerably below satiation rates produce satisfactory results, with rations as low as 1.5% of the body weight per day giving good results. A mixed diet of L. digitata and L. longicruris gave as good results as L. digitata alone. Trials comparing growth rates during different seasons were initiated in June 1996 and are continuing through the winter. Growth rates during trials starting from June to September were uniformly good, while growth and feeding rates in the winter were significantly reduced. Diets containing fresh fish were investigated and found to produce poor-quality gonads. Large, low-quality sea urchins were shown to respond to feeding in the same manner as smaller, younger sea urchins, but response was slower. No evidence of senescence was found.

Introduction and Objectives

Worldwide production of wild sea urchins has been stalled at about 60,000 t (whole weight) for most of this decade, in spite of high prices and great demand in the Japanese marketplace. These harvest levels reflect maximum production and future harvests may even decline as stocks suffer from overfishing. The combination of valuable markets and limited supplies presents a great opportunity for aquaculture.

During the 1990s a sea urchin (Strongylocentrotus droebachiensis) industry has developed in Newfoundland. Growth of the industry, depending on wild harvest, has been slowed by a number of factors including the disappointing yield and quality of much of the wild stock. The stocks of wild sea urchins mainly occupy sea urchin barrens which support high numbers of large, but undernourished, sea urchins. We decided, with the support of the Canadian Centre for Fisheries Innovation, to determine

whether it was feasible to feed these undernourished sea urchins to produce commercially valuable sea urchins without, initially, having to develop a full aquaculture operation. Also, in the interests of economy, the initial approach was to evaluate common Newfoundland seaweed species as feed. The objectives of the study were:

- To test Laminaria longicruris, L. digitata, Fucus vesiculosus, Ascophyllum nodosum, Agarum clathratum and Alaria esculenta for utility in increasing the yield and quality of sea urchin gonads.
- To determine how ration size influences the rate of growth and quality of sea urchin gonads. This information is important in designing cost-efficient feeding regimes.
- 3. To determine whether providing a mixed diet of *Laminaria digitata* and *L. longicruris* is as effective at increas-

ing gonad yield as a diet of a single species. Both kelps are abundant and often occur together so being able to use a mixture of the two species would allow more efficient harvesting and extend the food resource.

4. To determine seasonal growth characteristics of sea urchins. All previous feeding trials were initiated during the summer months, so trials in this project were initiated in the autumn and winter, as well as the summer, to identify seasonal changes in growth.

To determine how diets containing fish affect gonad growth, yield, and quality.

6. To determine whether there is "senescence" in old, large sea urchins.

This brief report summarizes the results of many trials and experiments. Full details may be found in the original reports. (6,7)

Materials and Methods

All experiments were carried out at the Bonne Bay Biology Station. Trials were duplicated in a land-based seawater system of plastic aguarium tanks and in wire-mesh cages on the seabed. All experimental treatments and controls were replicated. Except in the large sea urchin study, experiments were carried out on sea urchins between 45 and 55 mm diameter to avoid any influence of size. One hundred and twenty sea urchins were used in each tank or cage and 20 animals were sacrificed for each sample period. Gonad vield was expressed as the percentage weight of wet, drained gonad compared to the weight of the entire animal immediately before cracking it open. Gonad quality assessment was more subjective. Grades of A, B, C or D were assigned based on color, texture and flavor, in consultation with processors.(8)

- 1. Seaweed species experiment. In this phase of the project all sea urchins were fed to satiation. These trials ran between June 1994 and April 1995. Whenever the seaweed present in an experimental tank or cage ran low, more was added. Gonad yield and quality were assessed.
- 2. Ration size experiment. One pair of tanks was assigned each of the following *L. digitata* ration sizes: 100% of satiation, 75%, 50%, 25% and 0%. Satiation was a maximum of 5% of body weight per day. This experiment was in-

itiated at the beginning of June 1995 and sampling was done at monthly intervals.

- 3. **Mixed diet experiment**. Sea urchins in one pair of tanks were fed a 50:50 mixture of *Laminaria longicruris* and *L. digitata*. This experiment was conducted between July and December 1995.
- 4. Fresh fish experiment. Sea urchins in two tanks, provided with the coldest deep-seawater, were supplied with a ration of fresh-frozen herring. These experiments started in July 1995 and were terminated in October due to mortality of the experimental animals.
- 5. Seasonal growth rate experiment. These trials started in June, July, August, September, October and December 1995. These data should help to concentrate aquaculture efforts at the most economically effective time of the year.
- 6. Large sea urchin experiment. One set of experiments used animals over 55 mm test diameter to see if any signs of senescence could be detected. These sea urchins were fed to satiation and treated identically to the smaller sea urchins in the other experiments. These experiments were conducted simultaneously with the ration-size experiments between July and December 1995.

Results and Discussion

1. Seaweed species experiment. Agarum clathratum, Alaria esculenta, Fucus vesiculosus and Ascophyllum nodosum were all unsuitable as sea urchin food. They produced little increase in gonad yield and no gonads of acceptable commercial quality. Laminaria spp. were much more satisfactory and L. longicruris and L. digitata were both effective in augmenting sea urchins with low quality gonads and improving gonad quality to commercial grades. L. digitata was very effective at increasing gonad yield in a relatively short time (4-6 weeks to 10%). L. longicruris produced somewhat slower improvements in yield (8-10 weeks to 10%). We do not have the necessary chemical data to determine the differences in growth efficiency. The results with L. digitata compare favorably with other trials using artificial diets. (8,9) The growth rates of our sea urchins were comparable, while our quality was superior.

- 2. Ration size experiments. There was no significant difference in yield improvement or quality improvement among the trials with 100%, 75% and 50% ration size. Even the 25% of satiation trials were quite effective. This demonstrates that assimilation was clearly superior at lower ration sizes, allowing for more economical feeding than the satiation trials would indicate.
- 3. **Mixed diet experiments.** There was no significant difference between the results of feeding pure *L. digitata* compared to a mixture of *L. digitata* and *L. longicruris*. This also helps minimize feeding costs and permits more sea urchins to be fed with the available wild kelp.
- 4. Fish diet experiment. All diets containing fish produced unacceptable quality gonad, although yield was good. Further development of fish diets does not appear worthwhile.
- 5. Seasonal feeding experiment. Feeding trials initiated in June, July, August and September showed similar responses. The trial begun in October had lower feeding and growth, while the winter growth rates were especially poor. There would appear to be little point in attempting to fatten sea urchins during the winter.
- 6. Sea urchin senescence experiment. There was no significant drop in growth or quality in the large/old sea urchin trials. Senescence does not appear to be a major concern with these animals.

Further Research Requirements

- The characteristics of wild stocks of both sea urchins and kelps are inadequately known. Use of either kelp or sea urchins for commercial aquaculture requires proper stock assessment to determine acceptable harvest practices
- Knowledge of the chemistry of sea urchin digestion and assimilation is necessary to determine the specific dietary components responsible for

- producing the necessary gonad yield and quality.
- Cost-effective artificial feeds must be developed before sea urchin aquaculture has any hope of growing. Feeds must recognize the unique physiology and biology of these animals.
- Sea urchin ecology and behavior require more study, to improve effectiveness and uniformity of feeding in large populations, and to improve cage or tank designs.

This project would have been impossible without the support and encouragement of the Canadian Centre for Fisheries Innovation and the Government of Newfoundland, Department of Fisheries and Aquaculture. Randy Batten and Paul James provided conscientious technical assistance. Green Seafoods of Winterton provided invaluable industrial advice. Mike Parsons and Reuben Samms deserve special gratitude for keeping the aquarium system functioning during frigid winter storms and power outages.

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Culturing the purple sea urchin, Paracentrotus lividus, in a recirculation system

Jean-Louis Blin (1)

A land-based culture system for the purple sea urchin, Paracentrotus lividus, has been under development in Lower Normandy, France, since the late 1980s. The project involves producing juveniles in a hatchery and rearing them to commercial size. Various aspects of sea urchin culture have been studied, but this report focuses on only two areas: larval development and gonad quality. The hatchery production of juveniles is fairly well understood, but it is still necessary to optimize the number of larvae that metamorphose. Using two species of phytoplankton, Hymenomonas elongata and Pleurochrysis cartere, at a density of 10 000 cells per larva, 80% of the larvae were competent to metamorphose. It is also important to control the rate of metamorphosis. The use of Corallina sp. and seawater that was in contact with adults resulted in 80 to 90% of the larvae metamorphosing one day after induction. Gonad quality is of critical importance as it is the main objective of sea urchin production. It is important that gonad development is synchronized, that the gonad index is 10%, and that the gonads have good texture and flavor and are not mature (ripe). We tested different ways of producing such gonads. First the sea urchins were starved to bring the gonads to a similar level of development. Then, maturation (ripening) was inhibited by holding the sea urchins at low temperatures. The sea urchins accumulated reserves when fed compounds such as maize that were rich in carbohydrates. Seaweeds were added to the diet to improve flavor. By controlling most of the important points of the recirculation system, a good quality gonad was obtained and the production of commercial sea urchins required only 2 or 3 years instead of the 5 to 7 years required in nature.

Introduction

The team working on this sea urchin culture project is comprised of 1) the laboratory of Prof. Jangoux, Free University of Brussels, that specializes in echinoderms and is conducting fundamental studies on sea urchins, 2) the limited liability company Echinoxe that is developing the commercial aspects of the project, and 3) the Syndicat Mixte d'Equipement du Littoral (SMEL), a public organization responsible for the marine economic development of the "La Manche" area. SMEL is in charge of the hatchery and gonad enhancement project at its experimental centre.

Human activity along the coast of "La Manche" is very important and tourism, fishing and aquaculture all compete for space. The only remaining opportunities for aquaculture in this area are in land-based systems and, economically, the only alternative is the use of recirculation systems. Such systems limit risk linked to loss of environmental equilibrium or to depredation caused by other parties.

The species chosen for culture is the purple sea urchin, *Paracentrotus lividus*. It is a common sea urchin distributed along the western coast of Europe, from Ireland to the Mediterranean Sea. It is found on exposed rocky substrates, from the subtidal to a depth of a few tens of meters.

So far, the hatchery phase is the best controlled step in the culture of sea urchins. The 400 000 individuals needed to produce 10 t of sea urchins/year can be easily raised. On-growing is carried out with an original technique using controlled physico-chemical and biological parameters. Research was carried out to control the following parameters in the recirculation system: dissolved nitrogenous compounds, dissolved inorganic carbon, calcification of sea urchins, gaseous exchange between sea urchins and the surrounding water and live seaweed as a source of food. Currently, a water renewal rate of 20%/day is sufficient.

Several biological parameters have been studied as well, including the effect of temperature on growth rate, optimization of feeding, size distribution, competition between individuals, mortality rates, and quality of gonads.

Results obtained thus far suggest that a recirculation system is feasible for sea urchin culture. However, more validation studies are required and the final results are not expected until 1998. In this paper, we will only focus on some of the results obtained at the hatchery level, including gonad enhancement and the feeding and settlement of larvae.

The Recirculation System

The technique we use to raise sea urchins is a land-based recirculation system that reduces the requirement of "new" seawater and allows for the control of important parameters such as temperature and dissolved oxygen. Only 20%

of the sea water is replaced daily. The standard rearing structure is composed of raceways built above a seawater storage tank (Fig. 1). Each raceway is inclined and a pump brings the seawater from the storage tank to the top of the first raceway where it descends by gravity through the raceways, thereby inducing a current. The temperature is controlled by a heat exchanger in the storage tank. In each raceway, there is just enough seawater to cover the animals, allowing exchange between the air and the water. Further oxygenation occurs as the water falls between each raceway.

The object of this technique for rearing sea urchins is to reduce the time required to obtain commercial-sized sea urchins of 40 mm. In nature, animals take 5 to 7 years to reach a size of 40 mm due mainly to reduced growth in winter when water temperature averages 8°C. With our system, water temperature is constant and elevated (18-20°C) enabling us to produce sea urchins in 2 or 3 years. As well, this system allows us to condition the broodstock and produce juveniles throughout the year and not just during the natural reproductive period in the summer.

Hatchery

It is relatively easy to produce juveniles in large quantities. Broodstock are conditioned and are induced to spawn artificially using injections of KCl. Two days after fertilization, the characteristic pluteus larvae of echinoderms, which has 4 arms, is obtained. The larvae are

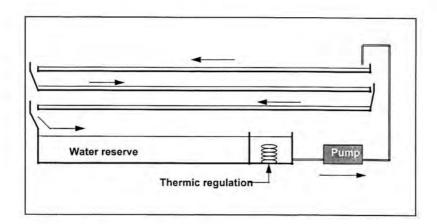


Figure 1. Diagram of the standard rearing structure.

transferred into tanks at the optimal density and fed after the third day with cultured microalgae. Larval rearing is complete when the larvae are competent to metamorphose — at approximately 20 days at 20°C. At this stage, the sea urchins have 8 arms and an echinoid rudiment on their side. (2)

To optimize the rearing of the larvae, we carried out larval feeding experiments with the objective of obtaining a large number of com-

petent larvae after 3 weeks. For feeding, we tested 6 species of phytoplankton, which were given separately: Pavlova lutheri, Tetraselmis suecica, Phaeodactylum sp., Isochrysis galbana, Hymenomonas elongata and Pleurochrysis cartere. With H. elongata and P. cartere, 80% competent larvae were obtained (Fig. 2). Subsequently, however, we used P. cartere as H. elongata is very difficult to rear in large volumes. We also tried using a mixture of dif-

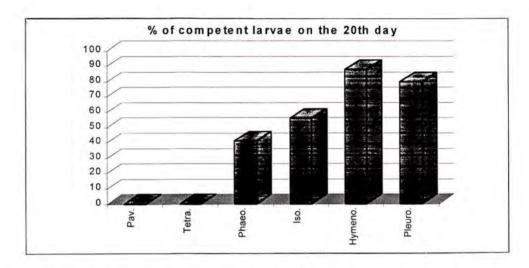


Figure 2. Percent competent larvae on day 20 when fed single microalgal diets (Pav = Pavlova lutheri, Tetra = Tetraselmis suecica, Phaeo = Phaeodactylum sp., Iso = Isochrysis galbana, Hymeno = Hymenomonas elongata, and Pleuro = Pleurochrysis cartere).

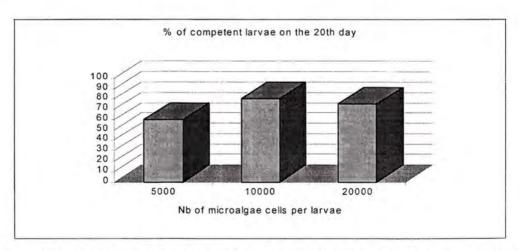


Figure 3. Percent competent larvae on day 20 when fed different concentrations of microalgae (# cells / larva).

ferent species, and focused on the four that gave good results: *H. elongata* or *P. cartere* were mixed with either *Phaeodactylum* sp. or *I. galbana*. In either case, the mixture did not give better results than with *H. elongata* or *P. cartere* used alone.

Studies were done to determine the optimal quantity of algal cells for rearing sea urchin larvae (Fig. 3). We obtained 80% competent larvae when they were provided with 10 000 algal cells per larva.

It is important to control the timing of metamorphosis as competent larvae do not settle synchronously. (3) If metamorphosis is not induced, some larvae settle as early as day 15 and some a month later. Thus we tested different methods of inducing metamorphosis, including using GABA which can induce metamorphosis in abalone larvae, (4) seawater that was in contact with adults, and *Corallina* sp., a red calcareous macroalgae found in nature near the juvenile recruitment area. The best results were obtained with *Corallina* sp. and seawater in contact with adults (Fig. 4). The control larvae were held without an inducer.

When the larvae were competent to metamorphose, they were placed into a shallow box lined with mesh and transferred to a growth structure. One week after settlement, the digestive tube becomes functional and juveniles can eat. At first they were fed with a green seaweed, *En*-

teromorpha sp., then after 2 to 3 months they were fed the red seaweed *Palmaria palmata*, and lastly they were fed the brown kelp *Laminaria digitata*. When the juveniles were large enough, they were released into the growth structure.

Control of Gonad Quality

To obtain a high quality product, the gonad must not be over ripe; otherwise the gametes leak out and the result is not appetizing, especially with male gonads. On the other hand, the gonads must be large enough. The gonad index (GI = fresh gonad/fresh body weight in %) must be greater than 10%. Above a GI of 10%, the product is very good. However, under our initial rearing conditions (elevated temperature, darkness), we obtained heterogeneous results that were not satisfactory. The rearing conditions resulted in a good growth rate of the gonad but inadequate quality. Because of the elevated temperature, most animals were mature (ripe) and because of the darkness gonadal development was heterogenous. It was thus necessary to produce sea urchins with gonads of more homogenous quality.

In nature, the development of gonads is closely linked to temperature and day length. (5) From the end of summer to the end of spring, gonad indices increase. The sudden decrease in

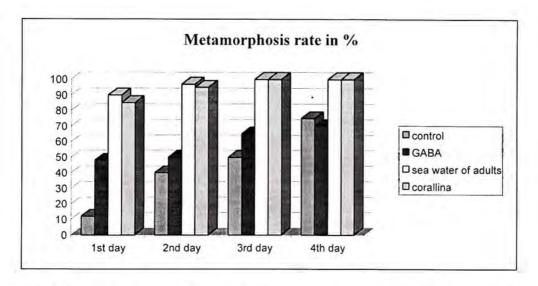


Figure 4. Rate of metamorphosis (%) when competent larvae were induced with GABA, seawater which contained adults, or *Corallina* sp. (the control contained no inducer).

gonad indices in the summer coincides with spawning. During the increase in the gonad index, the biochemical content changes. This phenomenon can be schematically shown (Fig. 5). In the autumn, the beginning of the increase in the gonad index is due to the accumulation of carbohydrate reserves. At this time, temperature and day length decrease. In spring with the increase of temperature and day length, the remaining reserves are used to make gametes.

To assess gonad quality, the maturity index is determined from histological preparations. Byrne⁽⁵⁾ has defined 6 stages of gonad development:

1 Recovery stage extensions of nutritive phagocytes are present;

2 Growing stage gametogenesis starts using reserves;

3 Premature stage some gametes are mature;

4 Mature stage gonad is full of mature gametes;

5 Postspawn stage some, but not all, of the gametes have been ejected;

6 Spent stage gonad is totally empty.

The desired stages are the first three stages, particularly the third stage because it corresponds to the best commercial product. In Figure 6, we have pooled observations from different experiments to determine the relationship between gonad index and maturation stage.

Stages after the premature stage (#3) are not of interest because at these stages the gonads are mature or totally empty (GI < 10%). On the other hand, the most interesting stage is the premature one in which all GIs are above 10% and the gonads are not totally full of gametes but contain reserves. The first and the second stages are potentially interesting because of the reserves, but only if GIs are above 10%. To obtain these stages, we tried to vary several parameters such as temperature, day length and food quality.

In addition to temperature and photoperiod, food quality can be a determining factor in the accumulation of reserve material. (6) We obtained stage 1 to 3 gonads by using the following procedure. Sea urchins were first grown to the desired size independent of gonad quality. Then, in order to produce sea urchins with a uniform gonad they were starved(7) which standardized the stage of gonad development. We then blocked their maturation by holding the sea urchins at low temperatures. Finally, we increased their storage reserves by feeding the sea urchins with compounds rich in carbohydrates such as maize (carbohydrates represent 80% of dry weight). A GI greater than 10% was obtained but the composition of the feed had to

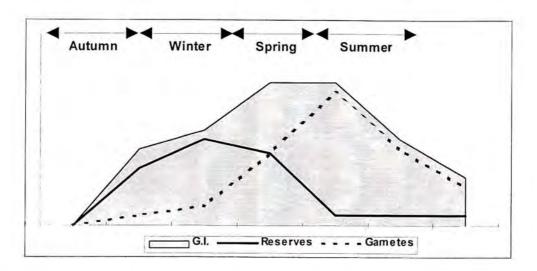


Figure 5: Schematic view of the seasonal development of the gonad.

be changed because of the undesirable flavor of the gonads of sea urchins only fed with maize. This was solved by feeding the animals with a mixture of seaweed and maize.

Conclusion

It seems that it is possible to culture sea urchins in a recirculation system. This technique enabled us to produce commercial-sized animals 2 to 3 years after fertilization. To obtain a good quality product we conditioned sea urchins at the end of the on-growing period with rearing conditions that favor gonad growth over development. This step, which is vital in the commercialization of sea urchins, is now controlled.

Experiments we have carried out so far have enabled us to understand and control the physico-chemical parameters linked to the recirculation system. We are now studying the impact of grading or not grading sea urchins during on-growing. The last point to examine will be the economics of this technique of culturing sea urchins. So far, the data we have accumulated make us optimistic in stating that the recirculation system is probably a good technique for raising invertebrates.

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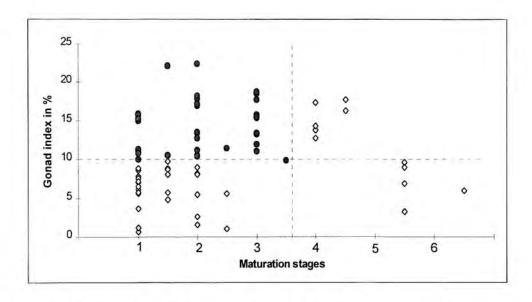


Figure 6: Gonad index (%) at maturation stages 1-6. See text for description of stages.

Enhancing roe of the green sea urchin using an artificial food source

S. M. C. Robinson (1) and L. Colborne (2)

As the industry on the green sea urchin, Strongylocentrotus droebachiensis, continues to expand, there is growing interest in increasing the value of the harvested animals. Therefore, a project was initiated to investigate the feasibility of enhancing the roe in sea urchins using artificial food and hanging-culture methods. Sea urchins were exposed to one of five dietary treatments: 3 artificial diets based on terrestrial food sources, an algal diet of Laminaria longicruris, and a starvation control. The roe content, survival and other characteristics of the sea urchins were measured at 4-wk intervals from December 1995 to February 1996. The artificial diet based on carrots and cabbage gave the best gonad growth (roe content increased from a mean of 4.3% whole body weight to 9.8%) over the 12-wk period. L. longicruris produced an intermediate response (roe content increased from a mean of 4.3% whole body weight to 7.9%), while the roe content of starved animals remained basically unchanged. Color, taste and texture of the gonads were all reported as "good" by an experienced local processor. Mortality in the cages was low.

Background

The high demand of the Japanese sushi market for the product "uni" (the gonads, or roe, of sea urchins) has largely been responsible for encouraging the development of fisheries for sea urchins around the world, in both the northern and southern hemispheres and the Atlantic and Pacific Oceans. The animals have primarily been harvested by local community fishers and the roe is either processed locally or the whole, live sea urchin is shipped, via air, to Japan for processing. For the green sea urchin, Strongylocentrotus droebachiensis, the minimum roe content demanded by the market is generally 12% of the body weight of the whole animal, but this may vary depending on market demand and the availability of local processing.

The sea urchin fishery in southwestern New Brunswick in the Bay of Fundy initially developed as an additional source of product for the industry based in the United States. According to personal accounts by fishers, there were sporadic landings (1-2 t) on Campobello Island in the 1950s and 1960s just before the Christmas season, but the industry did not really develop

until 1987. The majority of the harvesting effort has used drags, although the number of diving-based operations has increased recently. Landings have risen steadily from 47 t in 1987 to 1,446 t in 1995. The landed value during this period increased from less than \$100,000 to almost \$3 million.

Unfortunately, the quantity of roe in the sea urchins in this fishery is marginal. During the January to April period of 1994 and 1995, the mean roe percentage ranged between 7 and 12% in sea urchins obtained near Grand Manan and between 10 and 15% for sea urchins from waters off mainland areas. Mean prices for these sea urchins have ranged between \$1.90 and \$2.25 per kilogram (\$0.85 to \$1.00/lb), while those harvested on the Atlantic coast of Nova Scotia have regularly been sold by harvesters for \$4.50 to \$6.70 per kilogram (\$2.00 to \$3.00/lb).

Biological surveys of the stocks in the Bay of Fundy have indicated that sea urchins from the mainland coast are generally much smaller than those from Grand Manan. (3) Ageing studies have shown that most of the legal-size sea urchins (greater than 50 mm test diameter) are 10

years of age or older and are relatively slow growing. (4)

The sea urchin industry in southwestern New Brunswick is dominated by external market forces, as production is minute compared to the world supply of sea urchins. For example, the sea urchin fishery in Maine is an order of magnitude larger than the one in New Brunswick. Therefore, it is important to obtain the maximum value from the product that is harvested if the local industry is to grow to its maximum potential. One option is to undertake value-added processing in local processing plants. Another is to improve the product being harvested using supplementary feeding, a process known as "product enhancement".

Roe Enhancement

Several studies that examined the potential of feeding sea urchins to boost their roe content(5-8) indicated that captive sea urchins can be fed with various algal species and that significant increases in gonad growth can take place, although there are differences in the effectiveness of each algal species. In most cases, kelp (Laminaria sp.) was the best choice of food for enhancing gonad growth. Other studies investigating the potential use of artificial diets(9-11) have been effective at producing a significant increase in the size of the gonads. Artificial diets may hold promise for the future, particularly for operations requiring large amounts of food on a regular basis or those that have problems harvesting wild kelp. Harvesting problems may arise from a shortage of kelp due to unsuitable habitat for growth of kelp or social pressures from other industries that have a stake in the kelp beds. For example, there is an established relationship between kelp beds (L. longicruris) and the American lobster (Homarus americanus) where the juveniles and adults utilize the kelp beds as refuge habitat.(12) This would make the wide-scale harvesting of kelp beds difficult in several locations in the Canadian Maritimes because of the importance of the lobster fishery to the local economy.

Therefore, in view of the possibility of enhancing the quality of roe of the slow growing sea urchins from the southwestern New Brunswick area, we initiated a study to test the feasibility of doing this on a commercial basis. Our objectives were: 1) to set up an experimental system to enhance the roe quality of legal-size

sea urchins, and 2) to develop an artificial diet that could replace kelp as a food source for contained sea urchins.

Methods

The sea urchin roe enhancement project was conducted at the St. Andrews Biological Station of the Department of Fisheries and Oceans in conjunction with the private company Green Gold Sea Ranch. The feeding trials were done in Brandy Cove, a small cove located in the St. Croix River estuary in front of the Biological Station.

Adult green sea urchins were collected by divers from the face of the Biological Station wharf during the week of November 5, 1995, at depths ranging from 5-10 m. A dense population of sea urchins was present and little algal growth on the wharf or pilings was observed. The collected sea urchins were taken to the surface where those with test diameters ranging between 40 and 60 mm were selected for the study. The sorted sea urchins were weighed using a spring scale and divided into 15 groups, each weighing 10 kg (~160 sea urchins). The groups of sea urchins were placed into individual cages and secured to a buoyed longline.

Each end of the longline was anchored with a one tonne cement block connected to the longline backbone by large mooring buoys (Fig. 1). Smaller buoys were used to compensate for the load placed on the longline and to regulate the amount of submersion affecting the longline. The sea urchin cages were constructed of plastic-coated lobster wire (mesh size was 3.6 cm square). The dimensions of each cage were 1.2 x 0.6 x 0.3 m and a 0.9 m partition was employed to divide the cage lengthwise to increase internal surface area to 2.3 m² and increase cage stability. The suspended cages were 3 to 10 m off the seafloor depending on tidal fluctuations.

Five feeding treatments of three replicates each were used in the experiment. Three artificial diets were compared to a kelp control (*Laminaria longicruris*) and a starvation control. Ingredients of the artificial diets are shown in Table 1.

Carrots were used in the diets because of their high carotene content, which might contribute to the development of the desirable orange-yellow color of the sea urchin gonads. Cabbage or potatoes were utilized to supplement the low total essential amino acid content of the carrots. These vegetables contain approximately 1% protein, versus the 5-6% found in most macroalgae, so soybean and poultry meal were used to increase the protein content of the feed formulations. Guar gum was used as a binder and soybean lecithin was incorporated because some of its components have been identified as a feeding stimulant. (13) A commercial grinder

and tumble mixer were used to shred the vegetables and combine the ingredients. The final product had the consistency of thick oatmeal. It was packed into steel trays by hand and tied into the cages receiving the artificial diets.

The sea urchins were fed about once every two weeks throughout the 3-month period. Food rations were calculated based on 5% of sea urchin weight per day and then increased by

Table 1. Components of the artificial sea urchin diets A, B and C. Details on proportions are proprietary. (2)

Diet A	Diet B	Diet C
Carrots, raw	Carrots, raw	Carrots, raw
Cabbage, raw	Cabbage, raw	Potato, raw
Soy meal	Poultry meal	Soy meal
Guar gum	Guar gum	Guar gum
Potato starch	Potato starch	Potato starch
Soybean lecithin	Soybean lecithin	Soybean lecithin
Sea water	Sea water	Sea water

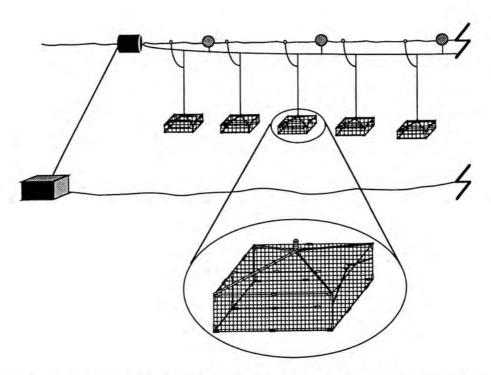


Figure 1. Illustration of the long-line set-up (a) and the wire mesh cages (b) for the hanging culture experiment in Brandy Cove.

25% to allow for some of the food being lost due to water currents, etc. All cages were briefly hauled to the surface once a week to monitor feeding progress.

Thirty animals were sampled from each cage at week 0 (November 29/95), week 4 (December 29/95), week 8 (January 27/96) and week 12 (February 25/96). In addition, a sample of the sea urchins from the Biological Station wharf was taken at each sampling period. After measuring the test of the sea urchins, all animals were weighed to the nearest 0.001 g. The tests of the sea urchins were cracked on the aboral surface and inverted for ten minutes to allow the coelomic fluid to drain. Animals were then reweighed. Using a roe scoop and tweezers, the gonads were removed and placed into preweighed and labelled aluminium dishes. The gonads were weighed and evaluated for qualitative characteristics (sex and color), and the sex was determined. The gonads were then placed into a drying oven at 85°C for a minimum of 48 hours and re-weighed to determine water content.

Results

After some initial mortality in the cages due to harvesting and handling effects, the survival of sea urchins in the prepared-diet cages was over 90%. Sea urchins maintained on *Laminaria longicruris* and the unfed control group showed 90% survival. The feed consumption rate was difficult to accurately estimate as the strong tidal currents in Brandy Cove washed away a portion of the artificial food and the *L. longicruris*. Approximately 10 kilograms of feed were placed in each cage every two weeks throughout the enhancement trial and there was generally less than 1 kg of food remaining after each two-week feeding cycle.

The mean wet gonad weight increased over time in all treatments, including the controls (Fig 2a). There was no significant difference in mean wet gonad weight between the starvation control and the wild population from the wharf (t-test, P>0.05). Diet A produced the most rapid gonad growth, increasing from a mean of 2.3 to 5.3 g in 8 weeks. There was little change from the samples taken at 8 and 12 weeks for most of the treatments except for the two artificial diets B and C, which showed significant increases in weight (ANOVA, P<0.05).

The mean dry gonad weights showed a different pattern than that observed for wet gonad weights (Fig. 2b). While the mean dry gonad weights of the wild population and starvation controls remained constant throughout the duration of the study (t-test, P>0.05), the various dietary treatments each produced different patterns of gonad change. The mean gonad weight of the sea urchins fed the L. longicruris diet increased to a peak at 8 weeks, after which the mean weight decreased. The gonad weight of sea urchins on diet A peaked after 4 weeks, stayed constant from week 4 to 8 and then decreased to week 12. The gonads of those on diet B increased to week 4, had a slight decrease to week 8 and then increased to week 12. Those on diet C had gonads that increased consistently from the start of the project to week 12.

Analysis of the water content of the gonads indicated that all treatments consistently increased over the course of the study from approximately 77% in November to 84% in February (Fig. 2c).

The whole weight gonad index increased over the course of the study for all groups (Fig. 2d). Diet A produced the most rapid and largest increase in mean gonad index from 4.3% at week 0 to 9.8% by week 12 (t-test, P<0.05). The starved control and the wild population from the wharf were essentially identical and produced the lowest increase in the gonad index from 4.3% at week 0 to 4.9% at week 12. The difference was not significant (t-test, P>0.05).

The drained weight gonad index showed the same patterns as the whole weight gonad index for all dietary treatments throughout the study (Fig. 2e). Diet A produced the largest mean drained weight gonad index, increasing from 6.7 to 14.4% after 12 weeks, while the unfed group produced the least, increasing from 6.7 to 8.7% after 12 weeks. Both of these gains were significant (P<0.05).

Although the mean values of the drained weight gonad index for all food treatments increased over time, the distribution pattern of the values in each treatment did not remain constant over the course of the study. For example, the distribution pattern of drained weight gonad index values for the starved control remained essentially the same from week 0 to week 12, although there were a few individuals that had a high index at the end of the study (Fig. 3). However, the distribution pattern of the index changed from a relatively compact one at week

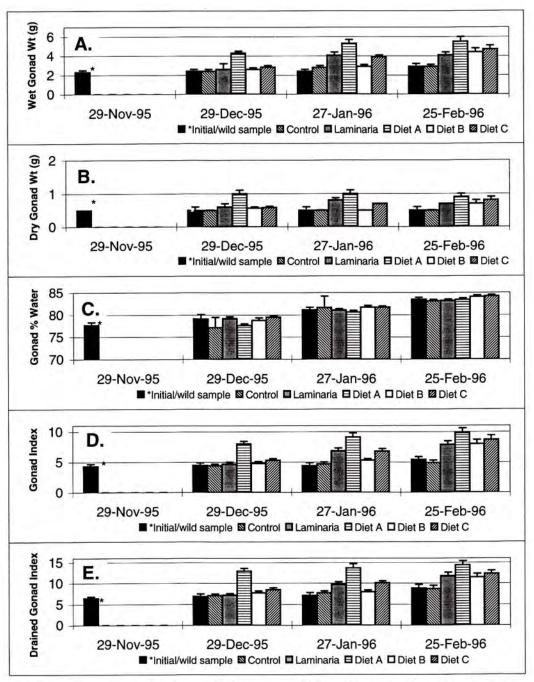


Figure 2. Mean values for five variables measured from the sea urchins fed the dietary treatments at four sampling periods: a) wet weight of the gonads, b) dry weight of the gonads, c) percentage of water in the gonad, d) standard gonad index of the sea urchins (wet weight of gonad/whole weight of sea urchin) x 100), and e) drained gonad index of the sea urchins (wet weight of gonad/drained weight of sea urchin after cracking the test) x 100). The initial/wild samples were animals harvested from the Biological Station wharf. Error bars represent ± one standard error.

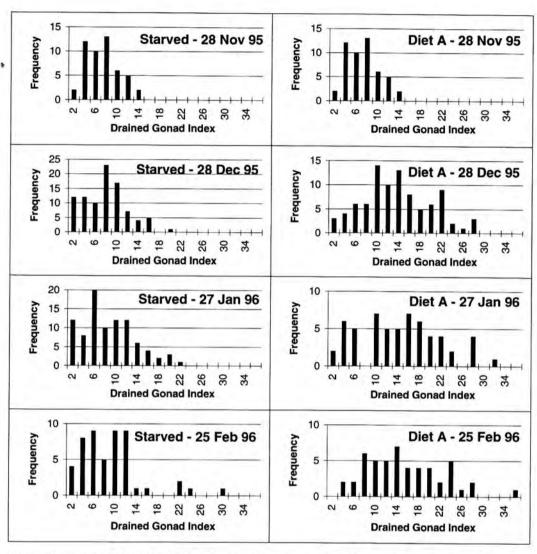


Figure 3. Distribution of the values for the drained gonad index at the four sampling periods during the study for the starved control sample and diet A.

0 with diet A to a much broader one by week 12. Some of the animals achieved a drained gonad index of 36%, but there were others that remained at 4%. This broadening of the distributions was common in all fed treatments.

Discussion

This study confirmed the basic results from other studies that the gonads (or roe) from sea urchins can be enhanced in a relatively short period by using abundant, high quality food. This study also demonstrated that sea urchins can be held in suspended cages from a longline system for periods of up to 12 weeks and that they can be successfully enhanced on a diet comprised of land-based agricultural crops. In addition, we demonstrated that an artificial diet was superior to feeding the sea urchins their preferred local diet of the kelp, Laminaria

longicruris, for periods up to 12 weeks. The roe that was produced in this study, based on a subjective analysis in early February by a local sea urchin processor, was satisfactory for the market and was comparable to what was currently being harvested by the wild fishery.

Gonad wet weights increased over time, but an analysis of dry gonad weight and the percent water data indicated that the increase in water content of the gonad during this time of year was partially masking the actual wet weight gain of the gonad. In sea urchins fed diet A, the mean dry gonad weight data showed that much of the weight gain occurred during the first 4 weeks. Other diets had different patterns of development. Therefore, it is important to quantify the water content of a sample before comparisons are made between treatments within a study or with other studies.

The changes in the distribution patterns of the drained weight gonad index in the various fed treatments was unexpected (Fig. 3). It may have been caused by sub-lethal handling effects on the sea urchins during the collection process, that resulted in some animals not growing, or there may have been differences in the feeding behaviors of the animals in the cages. Whatever the reason, this effect would be undesirable to prospective farmers as they would be striving to produce the highest quality product with the lowest variance. More research is required on this aspect to understand the mechanism behind this phenomenon and reduce it.

Although this study provided promising results for the possibilities of sea urchin enhancement, it also identified other areas that require refinement. Further studies should be done with the artificial diets at different times of the year when water temperatures are warmer and the animals are actively building their energy reserves. It is also possible that the artificial diets may lack some essential ingredients for long-term maintenance of sea urchins. More work needs to be done on refining the diet as well as the delivery mechanisms for the food to the sea urchins.

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Conditioning green sea urchins in tanks: the effect of semi-moist diets on gonad quality

Simona Motnikar, (1) Piotr Bryl (2) and Julie Boyer (2)

Several studies were conducted between 1991 and 1994 on the green sea urchin (Strongylocentrotus droebachiensis) fed with semi-moist diets and dried algae (Laminaria longicruris). Four- to five-week conditioning studies tested various diets for their ability to increase the gonadosomatic index (GI) to 10% or more, the minimum acceptable to the market. Diets composed of algae, wheat gluten, and starch, and enriched with minerals, were formulated in the form of semi-moist, rubbery, sinking granules that were water resistant for up to 48 hours. The diets were well accepted by the sea urchins. Trials were carried out in a flow-through system using local seasonal water temperature and photoperiod. Gonads were evaluated and compared to commercial specifications in terms of the gonadosomatic index, appearance, color and taste. Furthermore, the diets and gonads were analysed for their chemical, amino acid and carotenoid composition at the beginning and at the end of the studies. Diets containing calcium, magnesium and vitamin C produced a positive effect, while the addition of fish oil did not improve gonad development. A preliminary study with a diet containing carotenoids did not result in an increase in gonad carotenoid content. Conditioning during the months of July to October produced the best results, suggesting that sea urchins need a period of recuperation following spawning. The best diets resulted in 100% of sea urchins with a GI greater than 10-12%. We did not, however, manage to obtain a high percentage of gonads with acceptable color (bright yellow or orange). The gonads of sea urchins that had adequate color, and were fed the most promising semi-moist diets, presented sensory attributes, including taste, that were greatly appreciated by a panel of Japanese experts.

Introduction

The recent interest in the exploitation of the green sea urchin (Strongylocentrotus droebachiensis) has shown a need to establish clear criteria for evaluating market-bound product, to develop techniques for enhancing gonad quality, and to develop a high-performance diet for sea urchin conditioning. A supply of a consistently high quality product would go a long way towards the establishment of an industry based on the exploitation of sea urchins in Québec. The value of sea urchin gonads is directly related to their size, color and appearance. Varying among Japanese buyers, the minimum gonadosomatic index (GI) acceptable on the mar-

ket is between 10 and 12%.⁽³⁾ Furthermore, Kato⁽⁴⁾ and Ward⁽⁵⁾ indicate that the preferred gonad color is a bright yellow or orange.

The exploitation and direct marketing of a freshly harvested product are hampered by variations in sea urchin density, size and gonad development around the Gaspé peninsula. Gonad quality (GI and color) varies with geographic location, as well as season. A high percentage of commercial-size urchins (≥50 mm in diameter) have gonads that are too small for the Japanese market. Of those, few are of acceptable color. It has been noted as well that chemical composition of the gonads varies with season and that the water content is lower than in those harvested in Japan. (6)

Table 1. Composition of	experimental diets.
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Ingredients	D1-92	D2-92	D3-92
Hydrolysed algae (%)	44.0	44.0	41.5
Wheat gluten (%)	22.0	20.0	21.0
Modified starch (National 1215) (%)	30.0	28.0	29.0
Calcium phosphate (CaHPO4) (%)	-	2.0	2.0
Calcium carbonate (CaC03) (%)	-	2.0	2.0
Calcium sulfate (CaSO4) (%)	2.0	2.0	2.0
Vitamins (Salmon VIT-C-1326) (%)	1.3	1.3	1.3
Choline chloride (%)	0.7	0.7	0.7
Vitamin C (%)	-	- Te	0.5
Total	100.00	100.0	100.0

From May to July, the primary fishing season, the GI of the sea urchins varies between 2 and 5%. (7,8) The gonads reach commercial size and their color improves during the winter months. Spawning in April or May causes a rapid decrease in the gonadosomatic index as well as the quality of the color. (6) It is therefore evident that in Ouébec the climate poses serious logistic problems for the establishment of a sea urchin fishery due to ice cover in the winter and difficult fishing conditions in late autumn and early spring, when the quality of sea urchins peaks. To circumvent the problem of limited access to the harvesting grounds while the quality of the product is high, it appears to be possible to condition sea urchins harvested during the summer and autumn to obtain gonads that will meet market requirements.

Early studies have shown that it is possible to enhance the gonads by feeding the sea urchins an appropriate diet. (9) Laminaria longicruris produces the best growth and it has been suggested that the green sea urchin prefers this algae. (10) A Japanese specialist (11) suggested that a diet of L. longicruris could be supplemented with straw or fish by-products. However, an algal-based diet is preferred as it maintains the desired taste of the gonads. Preliminary studies conducted in September 1991 showed that a diet of straw, wheat by-products, or algae was not completely satisfactory. Gonadal development required a period of 111 days, which is too long for commercial production. (12) In addition, high mortality of sea urchins fed straw (33%) or a diet composed of algae and wheat (43%) suggested that the addition of essential minerals and vitamins might benefit survival and gonad development. We wanted to test this hypothesis by developing a semi-moist diet enhanced with vitamins and minerals and studying its effect on the gonad enhancement of sea urchins.

Materials and Methods

Preliminary tests carried out prior to 1991 served to define and perfect diet composition and the conditioning technique. For all subsequent studies, di-

ets were formulated with ingredients listed in Table 1 according to the method described by Bryl and Renaud. (13) All the diets were prepared in advance of the start of each study and kept at -30°C until used. They were given to the sea urchins in the form of rubbery, sinking pellets about 1 cm in diameter, during conditioning trials that varied between 28 and 35 days. The studies were carried out at different times of the year, which helped to determine the optimal periods for conditioning sea urchins.

The sea urchins used were collected by divers in the areas of Percé and Pointe St. Pierre (Gaspésie). Those selected had a minimum test diameter between 45 and 50 mm and appeared healthy and undamaged. They were distributed randomly into 0.5 x 0.4 x 0.2 m covered plastic perforated baskets and acclimated to the tanks for 5 to 7 days prior to the start of each study. For all studies, the density of sea urchins varied between 40 and 50 g/L of seawater.

During the four years of studies, two types of tanks were used. The 1991-1993 studies were carried out in fiberglass-coated wooden tanks, compartmentalized into sections, each containing a volume of 0.06 m³ of seawater. Each section contained one plastic perforated basket with sea urchins. The 1994 study was carried out in rectangular wood and fiberglass tanks with a capacity of 0.6 m³ of seawater. Each of these tanks contained 10 of the plastic perforated baskets.

Natural seawater at local seasonal temperature was supplied to all tanks and the flow rate was adjusted to ensure an hourly exchange. The studies were carried out under natural photoperiod cycles. Water quality in the tanks was

monitored daily and mortalities were noted. The tanks were cleaned, mortalities were removed and sea urchins were fed 3 times per week, at a rate of 1% of total body weight per day.

Various analyses such as the gonadosomatic index (GI), the weight of the sea urchins, gonad color, which was measured on the Munsell scale, (14) the total composition, the mineral content, and the amino acid content of the gonads were determined according to the methods described in Motnikar et al. (3) In 1993, for the study dealing with pigments, an analysis of the carotenoid content in the diets and in the sea urchin gonads was performed. The preliminary results from these studies are reported here. The final report, with complete data analysis, will be published later.

Results and Discussion

In 1991-92, a semi-moist diet composed of algae, wheat, vitamins and starch was developed. Conditioning in January produced inconclusive results, since water temperatures below 6°C slowed sea urchin activity. The conditioning trial was repeated in August 1992 for a 32-day period. Calcium was added to one of the diets (D2-92) in order to more closely reflect the

basic mineral requirements of the sea urchins, since according to LeGall(15) calcium is an essential element in their physiological processes. indispensable in spine and tooth regeneration as well as in the overall growth process. This diet appears to produce a marked improvement in the GI (initial: 3.1 ± 1.4 (n=24), final: 10.9 ± 2.8 (n=14)). Furthermore, Tacon(16) notes that a lack of vitamin C reduces growth and survival in shrimp. Therefore, in the next series of studies. to further reduce mortality and augment the GI, 0.5% (D3-92) and 1.0% (D4-92) vitamin C were added to the diet D2-92. Both new diets produced similar results. During the October 1992 35-day study, the diet D3-92 was retained as the most promising (initial GI: 6.4±2.3 (n=30), final GI: 12.5±2.6 (n=15)) as the mortality was lower (2.8%) compared to the mortality of the group fed with D4-92 (11.0%).

Analysis of chemical composition of the gonads fed with algae and those fed with the basic semi-moist calcium and vitamin C enriched diets showed that after 35 days of conditioning, the percentage moisture of the gonads increased by about 2% for the group fed with algae and by about 5% for the group fed with semi-moist diets. A slight decrease (4 to 7%), was noted in the lipid content of gonads from groups fed with

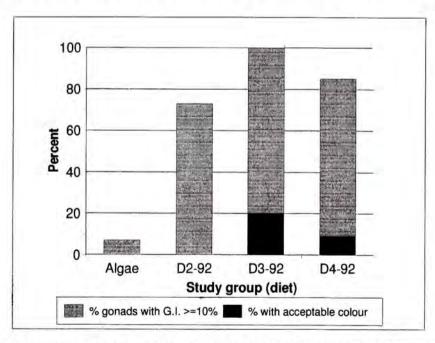


Figure 1. Percentage of commercial-size (GI \geq 10 %) sea urchin gonads and the proportion of those having an acceptable color, according to market preference. The October 1992 study lasted for 35 days.

Table 2. Total carotenoid content in the gonads of sea urchins conditioned with semi-moist diets enriched with carotenoids.

Study Group	Carotenoid Content (µg/g)	Gonadosomatic Index (%)
Start of study	136	6.2 ± 2.0^{a}
D1-93: D3-92 + Apocarotenoic ester	120	7.9 ± 2.6
D2-93: D3-92 + Astaxanthine	97	10.2 ± 3.2
D3-93: D3-92 + Canthaxanthine	83	9.7 ± 4.1
Basic diet: D3-92	79	11.7 ± 4.1
Starvation group	122	4.7 ± 3.4
Algae	76	4.5 ± 3.3
Wild Urchins	85	2.8 ± 1.8

a mean ± standard deviation

Length of study = 28 days (May to June, 1993)

semi-moist diets while the group fed with algae had a decrease of 3%. Glycogen content seemed to increase (4 to 8%) in the gonads of sea urchins fed with semi-moist diets, as compared to the group fed with algae which had an increase of 2%. There was little difference noted between initial and final values for the protein composition. In general, between the three semi-moist diets, there was very little difference in water

content, lipid, glycogen and protein composition of the gonads at the end of the study.

Color acceptability between groups of sea urchins fed algae and semi-moist diets was compared at the beginning and at the end of the October 1992 study. The best performing diet, D3-92, showed

that although 100% of the gonads sampled had a GI≥10%, only 20% of the gonads were the color preferred by consumers (Fig. 1). This led to a series of trials in 1993 to enhance the color of gonads through conditioning. A diet of algae, the semi-moist diet D3-92, as well as three diets containing D3-92 and one each of apocarotenoic ester (0.1g/100g) canthaxanthin (0.1g/100g) and astaxanthin (0.1g/100g) were used. Analysis of the total carotenoid content was carried out for the diets

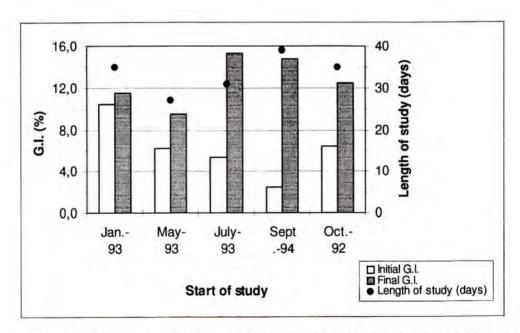


Figure 2. Gonadal enhancement (mean GI) of sea urchins fed with the diet D3-92 during various studies between 1992 and 1994.

as well as the gonads at the start and the end of the study. No direct relationship seemed to exist between the carotenoid content of the diets and that of the gonads at the end of the study. Furthermore, the total carotenoid content of the gonads did not appear to be correlated with the gonadosomatic index (Table 2). It appears that these particular pigments do not produce the desired result and further research into alternate pigments is required.

A final series of studies was carried out in 1993, in which the basic diet D3-92 was enhanced with 2.0% (D4-93) or 4.0% magnesium (D5-93). Finally, fish oil was added to the basic diet (D6-93) to determine the effect as compared to the algae and the basic diet D3-92. Preliminary results again seemed to indicate that the sea urchins fed with the semi-moist diets had gonads of a higher GI than those fed a diet of algae (final GI: 6.8 ± 0.9) (n=30). However, little difference was noted between the gonads of sea urchins fed with semi-moist diets with different concentrations of Mg and fish oil. The initial GI of 5.4 ± 1.1 (n=30) was augmented with the diet D4-93 to 16.7 ± 0.3 (n=20) and with the diet D5-93 to 13.3 ± 0.4 (n=20). The final GI of the sea urchins conditioned with the diet D6-93 was 14.9 ± 0.4 (n=20).

It appeared that in the Gaspé area, the optimal period for gonad enhancement was between July and October. The sea urchins seemed to require a period of recuperation following spawning in April or May. The May study in 1993 supported this suggestion, as the GIs at the end of the study were inferior to those obtained in studies done between July and November (Fig. 2).

In 1994, gonads selected for optimum size (GI ≥10%) and color, which were produced by a period of conditioning with the semi-moist diets D4-94 and D5-94, were presented to a panel of Japanese chefs familiar with sea urchin gonads. They determined that the gonads had an agreeable odor and texture. Taste seemed to be directly related to color and the panel had a preference for orange gonads. They found the taste pleasing, which was encouraging, as the semimoist diets seem to produce gonads that have similar characteristics to the wild product.

Conclusions

These studies showed that it was possible to increase the gonadosomatic index of sea urchin gonads to more than 10% following a period of

conditioning of 30 to 35 days between the months of July and November. Various semimoist diets enhanced with vitamin C and minerals produced good results. It was, however, not possible to obtain this objective by feeding the sea urchins only with the algae Laminaria longicruris. In taking factors such as mortality and gonadosomatic index into account, the diet containing 6% salts and 0.5% vitamin C (D3-92) seemed to be the most promising. Furthermore, the addition of the pigments apocarotenoic ester, canthaxanthin, and astaxanthin to the diet did not increase the percentage of gonads having the optimal color (yellow or bright orange). However, sea urchins fed with a semi-moist diet and having the best color and sensory attributes (taste, appearance and texture) were highly appreciated by a panel of Japanese connoisseurs.

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- Centre technologique des produits aquatiques. Direction de l'Innovation et des Technologies, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, 96 Montée Sandy Beach, C.P. 1070, Gaspé, QC Canada GOC 1R0
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Roe enhancement in the red sea urchin, Strongylocentrotus franciscanus, fed the bull kelp, Nereocystis luetkeana

Dominique Bureau, (1,2) Alan Campbell (3) and E. Brian Hartwick(1)

Experiments were conducted to investigate the enhancement of roe in the red sea urchin. Sea urchins were collected from a site of high sea urchin density near Tofino, British Columbia, and fed fresh or frozen bull kelp, Nereocystis luetkeana, in laboratory aquaria. Adult sea urchins fed fresh kelp for 54 d increased their gonad index (gonad weight/total weight X 100) significantly from 5.5 to 10.3%, but roe color and texture remained the same. Individuals (70-100 TD) fed frozen N. luetkeana for 152 d showed a significant increase in gonad index from 6.5 to 22.1%. Gonad index of the wild population collected at the end of the experiment (5.5%) was lower than that of the laboratory-reared sea urchins. Roe color improved while texture did not change for sea urchins from the laboratory compared to those of similar size from the field. Red sea urchins (15-26 mm TD and 47-56 mm TD) fed frozen kelp for 152 days, showed increases in gonad indices from 0.04 to 12.4% and from 4.2 to 20.9%, respectively. Final gonad indices of laboratory-reared sea urchins in each size class were higher than that of wild sea urchins. Feeding fresh or frozen N. luetkeana to red sea urchins increased gonad growth compared to that of field-sampled red sea urchins over the same time period. Collecting and holding red sea urchins in feed lots or large tanks for several months could be a way to enhance roe yield and color quality, especially for populations from high density areas with poor food availability.

Introduction

The red sea urchin, Strongylocentrotus franciscanus, is the largest and most abundant species of sea urchins found in British Columbia. (4) The purple, S. purpuratus, and green, S. droebachiensis, sea urchins are also found in shallow rocky habitats throughout BC. The commercial dive fishery for S. franciscanus started in the early 1970s, (5) rapidly expanded in the 1980s and then expansion slowed down in the early 1990s with the introduction of quota systems. (7) Despite the decreased landings in recent years, the demand for sea urchin roe is increasing. (7,8) With the decreased roe availability, there is increased interest for sea urchin culture.

The roe quality of sea urchins is often low in wild populations. (6,9) However, several studies

have shown that roe (gonad) size and quality of sea urchins can be improved by holding sea urchins in various enclosures and providing them with ample, good quality food. (9-13) Collecting wild sea urchins with poor roe quality and feeding them for several months could be a profitable short-term aquaculture method to improve roe yield and quality. The bull kelp, Nereocystis luetkeana, is the preferred food of red sea urchins on the Washington State coast and the alga that provides the best somatic and gonadal growth rates. (10) Although the annual N. luetkeana is abundant throughout BC during May to November, the supply during late autumn and winter could be limiting to sea urchin culture projects. The kelp Laminaria spp. was frozen to ensure food supply in abalone farms in Japan. (14) Freezing the bull kelp

also might ensure year round supply of this high quality food.

The objective of the present study was to investigate the potential for roe enhancement in red sea urchins fed fresh or frozen N. luetkeana.

Materials and Methods

Red sea urchins were collected on two occasions from a high density sea urchin population (25 sea urchins/m2) site off Vargas Island near Tofino. The site had low food availability and sea urchins had poor gonad quality. A preliminary experiment was conducted from September 23 to November 16, 1993. Ten sea urchins. 95 to 115 mm in test diameter (TD) were held in individual aquaria at the Pacific Biological Station, Nanaimo, BC, and supplied with flowing unfiltered aerated seawater at ambient temperature. The sea urchins were fed fresh N. luetkeana blades ad libitum every 4 to 5 d. Feeding rates were measured as the wet weight of N. luetkeana ingested per sea urchin wet weight. The difference between the weight of the kelp (air-dried for 5 min) before adding it to a tank and after 4 to 5 d was used to calculate the

feeding rates. A sample of sea urchins (n=25) was dissected before the experiment to determine initial roe quality (i.e., gonad index, roe color and roe texture). Gonad index was measured as the ratio of gonad weight to total wet sea urchin weight X 100. Gonad color and texture were each rated on a scale from 1 to 3 with 1 being good quality, i.e., yellow or firm gonads, and 3 being poor quality, i.e., brown or flimsy gonads. The experimental sea urchins were dissected after a 54-d feeding period and roe quality was determined the same way.

Two similar experiments followed, with red sea urchins of three size classes fed frozen rather than fresh *N. luetkeana*. The second experiment was conducted from October 31, 1993, to April 1, 1994, (152 d) with 70-100 mm TD sea urchins (Size 3 (S3)). The third experiment was run from November 16, 1993, to April 17, 1994, (152 d) with 15-26 mm TD (S1) and 47-56 mm TD sea urchins (S2). In the latter two experiments, sea urchins were held in tanks supplied with flowing unfiltered aerated seawater at ambient temperature (8-9°C) and fed frozen *N. luetkeana* blades ad libitum every 4-5 d. About 150 kg of *N. luetkeana* blades were harvested in

October, 1993, and kept in a -20°C freezer to ensure food supply for the entire experiment. The experimental sea urchins (S1 n=58, S2 n=30, S3 n=27) were dissected after a 152-d feeding period and roe quality was determined. For each size class, a sample of wild sea urchins was also dissected at the start of the experiment (S1 n=26, S2 n=11, S3 n=20) and at the end of the experiment (S1 n=37, S2 n=16, S3 n=30) to determine roe quality.

Differences between samples were compared using two sample t tests as-

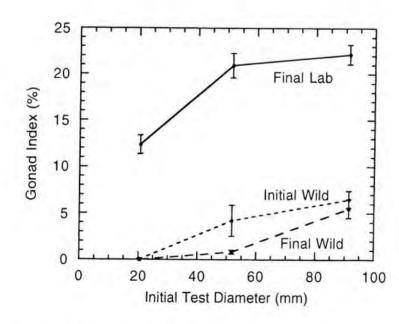


Figure 1. Gonad index of wild red sea urchins (mean \pm 2 SE) initially (initial wild) and after a 152-d period (final wild) and of red sea urchins fed frozen *Nereocystis luetkeana* in the laboratory (final lab) for 152 d, in relation to mean initial test diameter for each size class.

suming unequal variances. Gonad index data were arcsine transformed prior to analysis.

Results

For the first experiment, the gonad index of 95-115 mm TD red sea urchins fed fresh *N. luetkeana* for 54 d increased significantly (p<0.001) from 5.5 to 10.3%. Roe color improved slightly (p=0.068), but roe texture remained the same (p=0.617). Feeding rate averaged 3.0% body weight per day (minimum 0.7%, maximum 6.1%).

For the second and third experiments, where sea urchins were fed frozen N. luetkeana for 152 d, the gonad index of sea urchins in each of the three size classes increased significantly and the gonad index was higher in laboratory-reared sea urchins than in wild sea urchins at the end of the experiment (Fig. 1). In 15-26 mm TD sea urchins, the gonad index increased from 0.04 to 12.4% (p<0.0001) in laboratory animals, whereas the gonad index of wild sea urchins of equivalent size at the end of the experiment was 0.01%, lower than that of laboratory sea urchins (p<0.0001). In 47-56 mm TD sea urchins, the gonad index increased from 4.2 to 20.9% (p<0.0001) and the gonad index of wild sea urchins at the end of the experiment (0.8%) was lower than that of laboratory sea urchins (p<0.0001). Sea urchins 70-100 mm TD showed an increase in gonad index from 6.5 to 22.1% (p<0.0001) and the final gonad index of laboratory sea urchins was higher than that of wild sea urchins (5.5%) at the end of the experiment (p<0.0001). In 15-26 mm TD sea urchins, both field samples had practically no gonads so determination of roe color and texture was not possible. For 47-56 mm TD sea urchins, roe color, which was good in both field samples, did not change (Table 1). Texture, however, was better in laboratory sea urchins than in sea urchins of both field samples (p<0.0001). In 70-100 mm TD sea urchins, roe color of laboratory sea urchins was better than that of both field samples (p<0.0001) but roe texture did not change (p>0.2).

Comparison of the initial and final samples of wild sea urchins for each size class showed that gonad index, roe color and texture did not change during the 152-d period (p>0.05) except for the gonad index in 47-56 mm TD sea urchins which decreased from 4.2 to 0.8% (p<0.0001).

Discussion

The gonad index of 95-115 mm TD red sea urchins fed fresh N. luetkeana nearly doubled in the 54-d feeding period. Although roe color did not improve significantly, it did start improving, suggesting that a longer feeding period might enhance not only roe size but also roe color. No field samples were available to compare the final roe condition of laboratory reared sea urchins to that of wild sea urchins. However, a sample of wild sea urchins dissected 33 d after the start of the experiment had a gonad index of 6.5% and poorer roe color than that of the laboratory reared sea urchins at the end of the experiment. Therefore, the improvement in roe quality in laboratory sea urchins was probably not paralleled in the wild. The average feeding rate of 3.0% is slightly lower than the 5% reported by Cuthbert et al. (9) for S. droebachiensis fed Laminaria digitata.

Table 1. Roe color and texture (mean \pm SE) of red sea urchins of 3 size classes, at the beginning and after 152 d of feeding on frozen *Nereocystis luetkeana* in the laboratory (final laboratory) and for wild sea urchins at the end of the experiment (final wild). N/A = Not available because the sea urchins in the sample had no gonads.

Size Class (mm TD)	Initial	Final Wild	Final Laboratory
Ame Ames (see		Color	
15-26	N/A	N/A	1.00 ± 0.00
45-56	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
70-100	2.35 ± 0.17	1.90 ± 0.18	1.07 ± 0.07
		Texture	
15-26	N/A	N/A	2.47 ± 0.08
45-56	2.73 ± 0.20	3.00 ± 0.00	1.93 ± 0.07
70-100	2.10 ± 0.12	2.30 ± 0.14	2.07 ± 0.12

The gonad index of 70-100 mm TD and 47-56 mm TD sea urchins fed frozen N. luetkeana for 152 d increased by about 15% to reach final values of over 20% and for smaller sea urchins. the gonad index increased by about 12%. The lower increase in gonad index of the smaller sea urchins was probably due to investing relatively more energy into somatic growth and less energy in gonadal growth than mature sea urchins. Size at first reproduction in red sea urchins is about 50 mm TD.(4) Both larger size classes (S2 and S3) therefore, consisted of mature sea urchins while the smaller size class (S1) contained juvenile sea urchins. In the smaller size class, the mean TD increased by 68%, from 20.5 to 34.5 mm. In the second size class, the mean TD increased from 51.7 to 59.3 mm, i.e., a 15% increase, and the mean TD did not change significantly over the experiment in the larger size class. Since there was considerable somatic growth in the smaller size class (S1), there is a possibility that the increase in gonad index was in part due to their larger size compared to field samples. However, the field samples of 47-56 mm TD sea urchins, which were larger than the mean final size of laboratory-reared sea urchins in the smaller size class, had a lower gonad index than that of the smaller laboratory reared sea urchins. The increase in gonad index was therefore more likely due to better feeding conditions than to larger size. The possibility of producing roe in small, fast-growing red sea urchins might prove to be a good aquaculture option for hatchery-reared animals.

The gonad index of wild 47-56 mm TD sea urchins was lower at the end of the experiment than at the start, possibly due to spawning of the wild sea urchins. No evidence of spawning was seen in the laboratory. Spawning might not have been induced under laboratory conditions; however, if sea urchins were held in pens, the possibility of spawning might be higher. Although we think the results obtained here were due to feeding, future research will need to look at optimal time of year and duration of feeding to produce the best quality roe.

Along with the increase in gonad index, for each size class, either roe color or roe texture improved compared to both initial and final samples of wild sea urchins. The improvements in roe quality in the laboratory were not paralleled in the wild. Frozen *N. luetkeana* appeared to have a good nutritive value to sea urchins. Freezing large amounts of *N. luetkeana* during

the autumn might be an effective way to ensure a year round supply of high quality, preferred food for sea urchins.

Roe enhancement has also been achieved in S. droebachiensis. The gonad index of green sea urchins held in boxes anchored at the surface in Portugal Cove, Newfoundland, and provided with ample L. digitata for food, increased from 2.2 to 19.7% in 2 mo.(11) In the laboratory, the gonad index of green sea urchins fed Fucus edentatus increased from 2.2% to 15.5% in 3.5 mo.(11) Cuthbert et al.(9) also showed that green sea urchin roe can be enhanced to commercial yield and quality. The gonad index of green sea urchins held in tanks and fed L. digitata increased from 3.7 to 19.0% in 10 wk and to 30.0% in 25 wk. (9) When green sea urchins were held in cages on the sea floor at 10 m depth, gonad index increased from 5.6% to 22.0% after 10 wk and to 27.5% after 25 wk of feeding on L. digitata. (9) The values obtained here for adult red sea urchins, i.e., an increase in gonad index from 6.5 to 22.0% in about 22 wk, suggest that the red sea urchin could also be a good candidate for roe enhancement.

The lack of fresh N. luetkeana during the second and third experiments made it impossible to compare the value of frozen versus fresh kelp as food for sea urchins. However, freezing or drying has no apparent effect on the food value of Laminaria spp. (14) Furthermore, the significant improvements in gonad indices in all three size classes fed on frozen kelp suggest that freezing does not deteriorate the quality of the alga as food for sea urchins, although freezing must cause some degree of nutrient lost. Feeding fresh or frozen N. luetkeana over a few months to red sea urchins held in pens or tanks might therefore be an effective way to increase gonad indices as well as roe color and/or texture. especially in sea urchins coming from high density areas with poor feeding conditions. However, harvesting kelp is labor intensive and expensive(15,16) and freezing involves electricity costs so this option requires a cost/benefit evaluation for each situation. Furthermore, feeding macroalgae is labor intensive and does not lend itself to mechanization.(15) In abalone farms in Japan, artificial feeds are preferred to frozen macroalgae because they are cheaper, easier to store, allow mechanization of feeding, and produce better growth rates.(15)

de Jong-Westman et al.(17) studied roe enhancement in green sea urchins fed one of 7

artificial diets or dried N. luetkeana over a 9-mo period. Sea urchins fed high protein diets (20% dry weight) or kelp showed greater increases in gonad indices than sea urchins fed low protein (10% dry weight) diets.(17) Over the 9-mo period, the gonad indices increased to 23-31%, depending on the diet used.(17) Artificial diets have also been used to test roe enhancement in S. franciscanus. McBride et al. (12) found that N. luetkeana produced higher gonad indices than artificial feeds. Pearse et al. (16) noted gonad indices 2-3 times higher in sea urchins fed artificial feeds compared to those fed kelp. However, the roe color of sea urchins fed the artificial diet was not optimal.(16) An alternative to feeding either kelp or artificial diets to sea urchins is to provide them with a mix of kelp and artificial food. S. droebachiensis fed artificial feed with kelp consumed less food and increased their mass faster than sea urchins fed artificial feed only. (18)

Sea Urchin Culture in British Columbia

Initial interest in sea urchin culture is being shown by several groups in British Columbia, although there are no commercial sea urchin culture operations at present. Most of the interest is for roe enhancement, especially in green sea urchins since their roe is generally worth more than that of red sea urchins. In 1994, the ex-vessel value of green sea urchin roe was \$6.45/kg,(19) and for red sea urchin roe was \$1.35/kg.(8) The red sea urchin harvesters may be interested in culturing red sea urchins in the future. Some attempts have been made to test roe enhancement in green sea urchins held in fish aquaculture nets but survival rates were poor. An experimental project to investigate roe enhancement in green sea urchins fed artificial diets or kelps was recently approved by government agencies and is set to start shortly in British Columbia.

Sea urchin roe enhancement efforts in British Columbia might be influenced by existing regulations or by conflict with other industries. High costs are associated with holding sea urchins in tanks, but leases are required for pens. The present minimum harvest size for the red sea urchin fishery is 100 mm TD⁽⁷⁾ and roe enhancement operations would probably have to respect this size limit. If roe enhancement was to be done using kelp as food, a kelp harvesting license would be required and harvesting kelp

might conflict with the valuable herring spawn on kelp fishery as well as decrease kelp availability for wild sea urchins.

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Prepared food coupled with manipulation of photoperiod yield an out-of-season crop for the green sea urchin

Charles W. Walker and Michael P. Lesser (1)

Two problems facing the sea urchin fishing industry are poor roe quality and short fishing season. We have coupled enhancement of gonadal growth of poorly fed sea urchins utilizing prepared food with photoperiodic manipulation of the gametogenic cycle to produce an out-of-season crop which could be used to exploit a lucrative end of summer market now supplied by Chile.

Introduction

The fishery for the green sea urchin (Strongylocentrotus droebachiensis) has rapidly grown to become the second largest in the northeastern United States behind lobsters. Overfishing has drastically depleted once abundant natural populations. Two other problems affect the commercial industry. One of these is poor roe quality in a large percentage of the sea urchins harvested, leading to a lower than maximum price. Another is the short period when roe quality is high. There is a window of time from September until April when sea urchins have firm, ripe gonads. If sea urchins in a land-based aquaculture facility could be fed a prepared food and could be induced to ripen again after February, then the period of availability of highest quality roe could be expanded, greatly increasing the market potential for Gulf of Maine sea urchin roe. We have coupled: 1) enhancement of gonadal growth of poorly fed sea urchins utilizing prepared food with 2) photoperiodic manipulation of the gametogenic cycle to produce an out-of-season crop which could be used to exploit a lucrative end of summer market now supplied by Chile.

Methods

Collection of sea urchins

Approximately 150 sea urchins were collected by SCUBA at a depth of 10 m in March 1995, from the Isles of Shoals off the coast of New Hampshire (42°59.29'N, 70°37.01'W). The sea urchins were returned to the University of New Hampshire Coastal Marine Laboratory and maintained at ambient environmental temperature and salinity in flowing sea water holding tanks until used in the experiment described below.

Food and feeding

The food is a pelletized, non-dissolving, artificial diet for sea urchins containing defined animal and algal components. It has been under development for over 10 years ⁽²⁾ by Dr. John Lawrence (Department of Biology, University of South Florida) and Dr. Addison L. Lawrence (Texas A&M Shrimp Mariculture). It is FDA and USDA approved.

Photoperiod experiments

Throughout the experimental period (beginning March 9, 1995, and ending September 30, 1995), two identical tanks (each 61 x 61 x 61 cm) were equipped with fluorescent lights (General Electric F40D Daylight) that were controlled by astronomic time switches (R.W. Cramer and Co., Type SY Model SOL) and supplied with flowing sea water at ambient environmental temperature and salinity. Approximately 65 sea urchins were placed in each tank and used to determine the effect of feeding the prepared diet ad libitum in combination with the

application of premature September photoperiod on the timing of the reproductive season, compared to natural populations. Sea urchins with a minimum size of 30 mm test diameter were used for this study to insure that they were all reproductively mature. (3) Before and during the experiments, all laboratory animals were fed the commercially prepared food ad libitum (=3-5 pellets/sea urchin every 3-5 days). For all feedings, the pelletized food was dropped directly on the spines of experimental sea urchins to ensure contact with, and subsequent consumption of the food. On March 9, 1995, lights were set for an ambient photoperiod corresponding to a July 1, 1995, calendar date (using sunrise and sunset values in the 1995 Farmers' Almanac) and were therefore 4 months ahead of the local ambient photoperiod.

Monthly sampling of sea urchins

Monthly samples (March through September) of randomly chosen animals from each of 2 identically treated experimental tanks were collected. Field samples of 10-20 animals each

were collected as controls in June, August and September.

Sea urchin morphometrics

During each sampling, vernier calipers were used to assess changes in body size (= somatic growth) of animals in the experimental tanks by measuring the maximum height and width of each sea urchin to the nearest tenth of a millimeter.

Gonad index

Monthly samples from the experimental tanks and natural populations were analyzed to assess the percentage of gonadal weight compared to the weight of somatic tissue. The total wet weight of the sea urchin and the separate wet weight of the gonads were used to calculate the gonad index (GI) as an assessment of roe production and quality. It is essential to include this index in order to determine if a marketable product has been produced. The simplest approach is to take the blotted weight wet of the

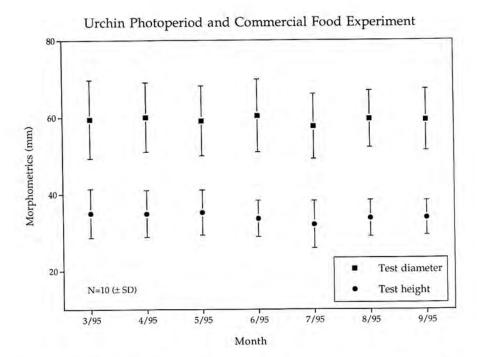


Figure 1. Monthly measurements of test height and width (N=10 \pm SD) during the experimental period. No significant effect of time was detected using a one-way ANOVA (P> 0.05).

whole sea urchin and the wet weight of the extracted gonads and apply the formula: GI = gonad wet weight/whole sea urchin weight wet X 100. Changes in the size of the test and gonad index were evaluated using a one-factor (fixed effect of time) analysis of variance (ANOVA) at a significance level of 5%. Gonad indices were arcsin-transformed before analysis and reported as backtransformed values. No unequal variances were detected with the Fmax test and where significant treatment effects did occur, the Student-Neuman-Keuls (SNK) multiple comparison test was applied at the 5% significance level to identify individual differences among sampling times. (4,5) Additionally, the color quality of the roe was measured using a sea urchin quality control card distributed by the Department of Marine Resources, Maine.

Histology

Portions of whole gonads were fixed with Bouin's fluid, rinsed in distilled water and dehydrated in an ethanol series. Embedding followed in Paraplast (56-60°C) and 8 µm sections were prepared. These were mounted on slides and stained with Mallory's Phosphotungstic Acid Hematoxylin (PTAH). (6) The gametogenic condition of each sea urchin was evaluated and assigned a stage based on a modification of the system used for the European sea urchin, *Paracentrotus lividus* by Byrne. (7) Images of each gonad (experimental and field controls) were recorded on TMAX 100 film using a Zeiss Axiophot microscope.

Preliminary Results and Discussion

Morphometric analysis of experimental animals showed no significant differences in test height or diameter (Fig. 1) between sampling times (ANOVA, P>0.05). A steady increase in the gonad index was observed for experimental animals fed the artificial food and exposed to a 4-month advance in photoperiod (Fig. 2). A significant effect of time on gonad index was detected for experimental animals (ANOVA, P=0.001). Experimental animals from the first

Urchin Photoperiod and Commercial Food Experiment

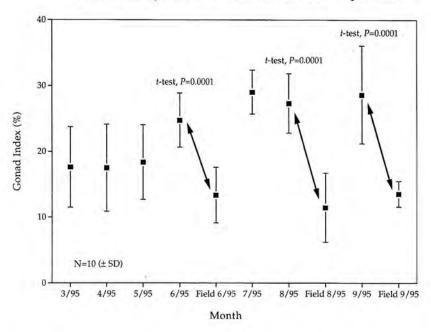


Figure 2. Monthly measurements of gonadal index for out-of-phase photoperiod induced animals. A significant effect of time was detected by ANOVA (P<0.05). Field and laboratory collections for the same month were significantly different (t-test, P<0.0001).

3 months showed mean gonadal indices of approximately 18% (Fig. 2) that were statistically indistinguishable from each other (SNK, P>0.05), while field animals at this time had gonad indices of 3-10% (data not shown). This higher index was maintained until animals were experimentally exposed to the autumn photoperiod cue. Beginning with collections dated 6/95 (Fig. 2 [=10/95 photoperiod]) gonadal indices of experimental animals increased to 25% or greater and were statistically different than previous collections (SNK, P>0.05). Experimental animals collected in June, August, and September were directly compared to simultaneous field collections. The gonad indices of experimental animals for these three months were significantly greater (Fig. 2 [Student's t test, P=0.001 for all months]) when compared to animals collected in the field that had not yet been exposed to the autumn photoperiod cue to initiate gametogenesis.

Histological analysis of photoperiod treated animals indicated that spermatogonia undergo rapid proliferation and that normal spermatogenesis follows 4 months earlier than in the natural environment. Oogonia also proliferate 4 months early, but resulting primary oocytes undergo minimal vitellogenesis. Increase in the size of testes was ultimately based on the accumulation of normal, functional spermatozoa. Increase in the size of ovaries was based on the continued growth of nutritive phagocytes.

The abundance of sea urchins with low roe content has stimulated interest by several groups in New England and Canada to enhance sea urchin gonadal growth. In one approach, sea urchins would be brought into contained environments (for example a marine laboratory or an aquaculture facility) and fed kelp to increase their roe content before sale. An important concern with most of these projects is that they require the harvesting of substantial amounts of kelp, which has raised concerns in areas of Maine because kelp beds are believed to be good habitat for juvenile lobsters. (8) Preliminary efforts at using kelp in Maine indicate that such a practice might have a detrimental effect on juvenile lobster habitat. (9) Alternatively, a prepared diet of known and consistent nutrient content could be developed and utilized in such projects. The resulting enhancement of roe content would greatly increase the value of substandard sea urchins prior to sale.

Crops of sea urchins are of greatest value around Japanese holidays such as New Years (January 3-6) and the Emperor's birthday (December 23). After January, as the sea urchins prepare to spawn, the gonads become thinwalled and deteriorate, quickly reducing their value in the Japanese market. Our studies showed that sea urchins can be induced to ripen again after January. This result suggests that the period of availability of highest quality roe could be expanded, greatly increasing the market potential for Gulf of Maine sea urchin roe. Such markets are currently supplied by fisheries in other parts of the world where sea urchin roe are of highest quality at different times of the year.

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Gonad and somatic production of Strongylocentrotus droebachiensis fed manufactured feeds

T. S. Klinger, (1) J. M. Lawrence (2) and A. L. Lawrence (3)

Strongylocentrotus droebachiensis were maintained from January to March, the period prior to the major annual spawn, and from June to September, after the major spawn, and fed ad libitum on two feeds manufactured from grains, soy, and fish meal. One feed contained kelp meal. Individuals consumed significantly (p ≤ 0.05) more feed and had significantly greater rates of increase in mass in the post-spawning period $(0.53 \pm 0.03 \text{ g/ind/d})$ and $0.24 \pm 0.06 \text{ g/ind/d}$, respectively) than during the pre-spawning period (0.16 \pm 0.01 g/ind/d and 0.12 \pm 0.01g/ind/d, respectively). Significantly less feed with kelp $(0.33 \pm 0.02 \text{ g/ind/d})$ than feed with no kelp $(0.40 \pm 0.03 \text{ g/ind/d})$ was consumed. Feed with kelp supported significantly greater rates of increase in mass than feed with no kelp $(0.21 \pm 0.05\%/d$ and $0.13 \pm 0.04\%/d$, respectively). With feeding during the post-spawning period, gonad indices increased to levels comparable to those of pre-spawning individuals (ca. 20%), but did not differ with feed type. Gonad indices were high for individuals collected in January and did not increase significantly with feeding. Gut indices increased markedly with feeding, to ca. 6-7%, but did not differ with feed type or season. Either feed was suitable for maintaining sea urchins in mariculture and promoting gonad production. However, neither feed promotes significant whole-animal growth.

Introduction

Availability of appropriate feeds is essential to mariculture. Little information exists on manufactured feeds suitable for sea urchin mariculture, or about the nutritional implications of seasonal changes associated with the annual reproductive cycle of sea urchins. (4) Small scale studies of feeds prepared from fish meal and soy meal have shown that sea urchins will readily consume preparations with the appropriate form(5) and will grow and produce gut and gonadal tissue. (6-8) Nutritionally adequate manufactured sea urchin feeds composed of readily available grain, soy, and fish meals are currently under development. The present study compares feeding, gonad and gut production, and wholeanimal growth of Strongylocentrotus droebachiensis fed two extruded feeds during both the

winter pre-spawning and summer post-spawning periods.

Methods

g, 47±2 mm H.D.; mean±1 SEM) were collected in June 1994 and January 1995 from Isle au Haut, Maine (44° 5′ N, 68° 37′ W). Individuals were maintained in the laboratory in individual 800-mL plastic containers with mesh tops. Each container was suspended in a sea water system and supplied recirculating sea water (salinity 34‰, temperature 6-8°C) at a rate of 402 ±21 (mean±1 SEM) mL per min through a tube. Lighting was maintained on a 12 hr light–12 hr dark cycle. Individuals were allowed to adjust to laboratory conditions and clear their guts for 5 days, and were then fed one of two manufactured extruded feeds (Table 1) for 8 weeks dur-

Table 1. Composition (%) of manufactured feeds.

Constituent	Feed without kelp	Feed with kelp	
Corn meal	36.5	32.0	
Wheat meal	36.4	27.3	
Kelp meal	0.0	14.0	
Soybean meal	11.1	11.1	
Fish meal	10.0	12.0	
Calcium carbonate	1.7	0.0	
Sodium biphosphate	1.1	< 0.1	
Potassium phosphate	0.0	1.3	
Phospholipid	1.0	1.0	
Fish oil	0.7	0.2	
Sodium chloride	0.6	0.0	
Cholesterol	0.3	0.3	
Trace vitamin and mineral mix	0.2	0.2	
Antioxidant	0.2	0.2	
Vitamin C	0.1	0.1	
Roxanthin	< 0.1	< 0.1	

ing the winter pre-spawning period and for 12 weeks during the summer post-spawning period. Individuals were proffered a surfeit of fresh feed three times per week and allowed to feed ad libitum. Feces and uneaten feed were removed and containers were rinsed at each feeding. Feeding rates, masses, and horizontal diameters were measured weekly. Feeding rates were estimated by comparing the mass of the uneaten food to the mass of ration proffered. Production of gut and gonadal tissues were estimated by comparing gut and gonadal indices ([wet weight of the gut or gonadal tissues ÷ wet weight of the intact individual] x 100%) at the time of collection to those at the end of the periods of feeding. Feeding rates, rates of change in mass and diameter, and gut and gonad indices were compared using analyses of variance (ANOVAs) utilizing the SYSTATTM statistical package.

Results

Both the feed with and the feed without kelp were readily consumed by Strongylocentrotus droebachiensis (Table 2). Feeding rates did not vary significantly (p > 0.05) over the time course of feeding, but did differ significantly between feed types and seasons. Significantly less of the

kelp-containing feed was consumed. Feeding rates were significantly lower during the pre-spawning than the postspawning period. Both feeds promoted high levels of production of gonadal and gut tissues. At the ends of the periods of feeding, gonad and gut indices did not differ significantly between individuals fed either feed or between seasons. Whole animal growth rates were low with either feed. Increases in mass were significantly higher on the kelp containing feed and during the summer post-spawning period. Similarly, horizontal diameters increased marginally for individuals fed kelpcontaining feed, but not for individuals fed feed that did not contain kelp.

Discussion

Feeding rates of Strongylocentrotus droebachiensis on extruded feeds were lower than those reported for feeds prepared with a binder. (6) However, all ani-

mals fed on each ration proffered and feeding rate showed no variation over the time course of feeding. Observed levels of production indicated that individuals consumed sufficient quantities of the very dense feeds to be well nourished. Either feed was acceptable to S. droebachiensis. Although more of the feed without kelp was consumed, the difference in consumption was small. Production of gonadal tissue was high for both feeds. Indices of ca. 20% are comparable to peak gonad production reported for natural populations of S. droebachiensis(9) The lack of increase in gonad indices in individuals fed during the winter pre-spawning period probably was a result of the already high gonad indices at the time of collection. Individuals were well nourished at the time of collection and further feeding could not increase gonad indices beyond a physiological maximum. High levels of production of gut tissues indicate that either feed will support the establishment of substantial short-term nutrient stores, (10) even during the pre-spawning period when nutrient allocation can be diverted from gut to gonad production.(11) Rates of increase in mass were not dramatic on either feed. However, whole-organismal growth of large sea urchins is slow. The observed increases in mass without concomitant increases in test diameter

Table 2. Feeding and production of *Strongylocentrotus droebachiensis* fed manufactured extruded feeds during the winter pre-spawning (January to March) and summer post-spawning (June to September) periods of the reproductive cycle. (Values are means ± 1 SEM; N in parentheses.)

Measure of Feeding and Production	Winter Pre-spawning Period			Summer Post-spawning Period			
	Initial	Feed without kelp	Feed with kelp	Initial	Feed without kelp	Feed with kelp	
Feeding rate (g wet weight/ind/d)		0.14 ± 0.01 (142)	0.18 ± 0.02 (135)		0.63 ± 0.04 (170)	0.44 ± 0.03 (179)	
Gonad index (%)	17.1 ± 6.7 (9)	19.6 ± 3.9 (17)	19.8 ± 4.7 (17)	4.9 ± 3.4 (15)	23.1 ± 2.6 (13)	21.9 ± 4.5 (15)	
Gut index (%)	4.9 ± 0.8 (9)	6.5 ± 1.3 (17)	6.0 ± 1.2 (17)	2.6 ± 1.4 (15)	7.1 ± 1.0 (13)	7.0 ± 0.8 (15)	
Change in mass (%/d)		0.14 ± 0.02 (18)	0.10 ± 0.02 (17)		0.13 ± 0.07 (16)	0.35 ± 0.10 (15)	
Change in horizontal diameter (%/d)		0.07 ± 0.03 (18)	0.03 ± 0.01 (17)		-0.29 ± 0.43 (16)	0.70 ± 0.26 (15)	

suggests that these feeds increase the densities of tissues, but that some qualitative element necessary for the production of the test was lacking. Greater increase in mass during the summer post-spawning period was probably a result of greater consumption during this period. but may also reflect allocation of nutrients to somatic production.(12) Increases in mass and in diameter were small, but consistent, for individuals feed kelp containing feed, suggesting that kelp provides some qualitative element necessary for growth (see de Jong-Westman et al.(13)). Either feed, as they are now formulated, is sufficient for maintenance of S. droebachiensis and for promoting production of the gonadal and gut tissues. However, qualitative changes in the formulation of these extruded feeds will be necessary before they will also support rapid whole-animal growth.

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Gonad conditioning and wild stock enhancement of the purple sea urchin Paracentrotus lividus on the west coast of Ireland

Evelyn Moylan(1)

The recent decline in the sea urchin fishery in Ireland has prompted investigations into artificial breeding and collection of wild spat. Gonad enhancement trials are underway on the unexploited populations of the west coast of Ireland. The condition of the sea urchins is poor throughout the main fishing season, and therefore this and similar populations have been ignored by the fishery. Onshore conditioning units comprised are in operation and experiments are currently being conducted where sea urchins are stocked at densities of 300 per tray (1 x 3 x 0.1 m) and fed a natural diet consisting primarily of *Laminaria digitata*.

Introduction

The purple sea urchin *Paracentrotus lividus* is distributed throughout northern Europe, and as far south in the Atlantic as the Moroccan coast of Africa. Their northern limit seems to be determined by a requirement for a minimum sea temperature of 8°C in February.⁽²⁾

Purple sea urchins are commonly found along the west coast of Ireland inhabiting intertidal rock pools or in aggregations in the sublittoral. Market size is greater than 50 mm. Ripe ovaries are orange, while the testes are cream or yellow.

There have been exports of *P. lividus* to the French markets from the southwest coast of Ireland since 1948.⁽³⁾ As a result of the decline in the French fishery in the early 1970s, the Irish fishery soared with over 350 t recorded landings into Irish ports in 1976. However, not all landings are documented and harvesting is still unregulated. Fishing is mainly carried out by divers and fishermen working intertidal rock pools. The fishery, which stretches along the southwest and west coast of Ireland, has been overexploited and has now collapsed completely with only 9.7 t landed in 1995 (Fig. 1).

The green sea urchin, Psammechinus miliaris, is common along the entire Atlantic coast, from the Trondhjem Fjord along the Scandinavian coast to the Baltic and North Sea, and from Iceland to Morocco and the Azores. It grows to

a maximum size of 50 mm, and market size is 40 mm. The breeding season is in the early summer months, and gonads are light cream to grey in colour. There is no commercial fishery for *P. miliaris* in Ireland, and although it is fished on the Brittany coast of France, stocks are few and poorly documented.

Management of the commercial sea urchin fisheries is non existent in Irish waters as no laws have been established aimed at controlling and regulating existing fisheries of natural sea urchin stocks. Limitation in size to 50 mm, dictated by the French market, appears to be the only control at present. Areas of former exploitation have been denuded of all sizes of sea urchins and recruitment back into these areas is very slow (pers. obs.).

Seed Collection

Natural seed collection appears to be a costeffective seed source to supplement recruitment of wild stocks. This could be done in conjunction with stock management programmes, enhancing the number of seed recruiting and thus increasing the survival rate of settling seed using nursery facilities.

Taighde Mara teo initiated its collection programme in 1989 on the Island of Inis Oirr, the smallest of the three Aran Islands. These form a broken escarpment running from the Burren

region of County Clare across the mouth of Galway Bay, on the west coast of Ireland.

Inis Oirr, located 8 km from the Clare coast, is composed of limestone rock and is surrounded by intertidal and subtidal populations of P. lividus. The main bed of intertidal sea urchins is on the northeast side of the island. The sea urchins here reach market size of 50 mm+ and are found in Lithothamnion sp. encrusted rock pools burrowing into the limestone rock. The main population of subtidal sea urchins is found on the southwest side of the island. Here the sea urchins are market size or greater; however, roe content is poor, and food availability at the site is low as the sea bed is a limestone rock bank. Local divers and fishermen have been managing the beds, moving sea urchins to more productive sites north of the island to improve gonad condition. This form of management is not uncommon on the west coast of Ireland; however, loss of sea urchins is great as they are usually moved in the summer months when the weather is more favorable for working. Due to the large population of purple sea urchins around the island, the feasibility of an intensive seed collection programme seemed to be a real possibility. Collectors, based on the Japanese system, were constructed using three square plates of corrugated PVC, 30 cm on a side, which were separated by 1-inch (2.5 cm) wavin piping, and attached intermittently to a subtidal longline system. The collector ropes were initially placed at different

sites around the island and recruitment was highest above the sea urchin bed that housed the main subtidal population.

The cycle of installation and retrieval was tested over a 3-yr period, varying from a fortnightly installation to a 15-wk installation. The juvenile sea urchins were 0.35 to 3.5 mm in test diameter when the collectors were removed from the water column. Settlement appeared to take place in low numbers throughout the summer, with maximum recruitment taking place in the second half of August. No settlement was observed on plates that were two weeks or less in the water column and it appeared that aging of the collector unit was necessary to induce metamorphosis of juvenile sea urchins, i.e., the formation of a bacterial and diatom film on the collector units. Bacterial films have been implicated in the settlement of other larvae. (4)

Grow-out Trials

Grow-out trials were initiated in a low-cost nursery system constructed in a prefabricated building. The system was comprised of fibreglass tanks into which the collectors were suspended. A constant water supply was maintained and nutrients were added to the tanks on a daily basis to enhance the diatom growth on the collector plates. Sea urchins were harvested from the collectors as soon as they were visible and they were placed into upwelling columns.

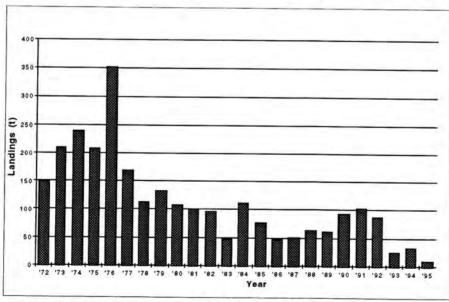


Figure 1. Quantities of sea urchins landed from 1972 to 1995 in Ireland.

Recruitment was about 36 sea urchins per collector, giving 7,500 sea urchins in total. These ranged in size from 450 um to 4.0 mm, and after a period of growth it appeared that two species, Psammechinus miliaris and Paracentrotus lividus, were recruiting on the collector plates. Over 90% of sea urchins recruited on the collectors were lost the first two months in the nursery. This was attributed to the large number of iuvenile starfish (Asterias rubens) in the size range 2 to 10 mm observed over that period. Sea urchins were removed from the collectors at approximately 1 mm or greater. They were transferred into downwelling systems and further investigation revealed that over 95% of those successfully harvested were Psammechinus miliaris. Within two years, 10% of these animals were 30 mm and by the following year over 28% had reached market size of 40 mm with the remaining exceeding 25 mm.

The overall aim of this collection project was to provide a sufficient number of sea urchins to prove its viability as a mariculture candidate, however, recruitment numbers versus cost needs to be closely examined.

Cost of Seed Collection

The cost of mooring, maintaining and construction of the collectors used in this study was estimated at IR£5 (\$7.50) per collector. The collectors can be re-used for several years, therefore costs for the second year of deployment was determined at IR£1.50 (\$2.25) per collector. Using these cost estimates for the first year of operation, it would be necessary to collect between 280 and 350 seed per collector to match French seed prices (French farmers purchase 2 mm P. lividus seed at a price of 140 francs per 1000 animals or 1.5-1.75 pence (1 cent) per animal(5)) and 500 seed per collector would be necessary to compete with Irish hatchery produced seed (The Shellfish Research Laboratory at Carna plans to sell urchin seed at 0.25 p/mm or 1 penny for a 4 mm animal(6)).

However, in year two and subsequent years of operation costs would be greatly reduced. In these subsequent years, 85 to 100 seed per collector would be required to compete with French prices and 150 seed to match Irish seed prices. Recruitment over the 2-year study fell short of competitive levels. However, results from previous years yielded an average of 70 sea urchins per collector and a maximum of 200

was recorded on one collector. This would meet seed requirements to successfully compete with French hatchery prices. Similar trials were conducted in Killary Harbour, also on the west coast of Ireland, and these proved to be more feasible with recruitment in excess of 200 individuals per collector.⁽⁷⁾

Conditioning

During the summer of 1995, Taighde Mara teo initiated trials on the conditioning of wild populations of *P. lividus* for market using a conditioning unit that was installed in the prefabricated building on Inis Oirr. The objective of the trial was to remove sea urchins with low roe content from their natural habitat, which were market-size or greater, and to improve the gonad quality by manipulating temperature and feeding.

Two recirculation systems were put into operation. Each unit, comprised of 4 trays measuring 1 x 3 x 0.1 m, were stacked two high and two wide over an underlying reservoir unit. One unit was operated using ambient water and the second unit had water heated to 2°C above ambient. Water was pumped from the reservoir to each of the trays and the overflow returned to the reservoir at the opposite end of the tank, thereby allowing the detritus, etc. to collect at the end opposite to the pump. The continuous flow cleaned the trays and cast spines and detritus were washed into the underlying reservoir, which was cleaned daily.

Sea urchins were introduced to the unit in July 1995 and were stocked in the trays at a density of 300/tray. Previous trials had shown that densities in excess of 300/tray resulted in mortalities due to the carnivorous practices of the sea urchins. After the initial control period, in which the sea urchins were given time to acclimate to their new conditions, a sample of thirty sea urchins were taken haphazardly from the trays. A gonad condition index was calculated and compared to the gonad condition of the wild population. Over the 10-mo trial period, this process was repeated on 5 occasions. Initially there was no difference in water temperature in either of the two holding systems as a constant ambient temperature of 15°C was maintained. However, over the winter period the temperature in the heated water system was maintained at 1.5 to 2°C higher than ambient at all times. Sea urchins were fed a diet of 1 kg of Laminaria

digitata per tray/day and were held in continuous darkness. Ensuring a constant temperature within the conditioning units proved to be very difficult as the temperature of the building itself could not be controlled. Results of the recently completed trial showed that throughout most of the monitoring period, the sea urchins held in the heated conditioning unit had a higher gonad condition index than the sea urchins in the ambient conditioning unit or the natural populations on the shore (Fig. 2). However, the gonads of the shore population continued to grow, whereas the gonads of both the heated and ambient conditioned animals decreased. The exact reason for this has yet to be determined. A gonadosomatic index of >20% was the desired size required for sale. At no time during this trial did any of the sea urchin populations achieve this level.

The conditioning units are presently being upgraded by the addition of two extra holding trays and the reservoir unit is being insulated to ensure better temperature control.

It is proposed that conditioning trials will be conducted over a 10- to 12-week period. At the end of each period animals will be replaced by a fresh population from the wild. Gonad analysis will be carried out once a month.

The following investigations will take place:

a) The effectiveness of different diets will be tested to improve the gonadal quality of the sea urchins and thereby increase their market value.

- b) The effect of temperature manipulation on gonadal development.
- c) The time it takes for unconditioned animals to obtain market quality.
- d) Whether gonad enhancement to market quality can be achieved outside the natural reproductive season.

Finally, Taighde Mara teo's overall aim is to develop techniques that can be used to return productivity to the once fertile sea urchin beds, which have been denuded, and to develop a resource management programme to prevent such destruction of our natural resources, as was common in the 1970s and early 1980s, from taking place again. Although Taighde Mara provides the expertise, these projects are community based and their success is dependent on the co-operation of local fishermen and co-operatives.

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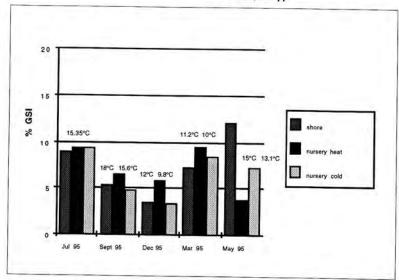


Figure 2. Gonad somatic index of Paracentrous lividus on the west coast of Ireland.

Developing markets for feed lot sea urchins

R. Whitaker, (1) W. Quinlan, (2) C. Daley (2) and J. Parsons (3)

Defining the requirements of the Japanese market for sea urchins is difficult as there is considerable variation among areas and companies. This presents the sea urchin producer with a conundrum that is not easily solved. This paper addresses the factors that contribute to the variability in market requirements, the issues affecting economic viability, and the application of developing technology, including the use of aquaculture feed lots, to resolve the critical issues.

Introduction

This paper provides suggestions and approaches to developing markets for sea urchins conditioned in feed lots. The perspective presented resulted from a trip to Japan to visit two sea urchin processing plants, one in the Tokyo area and one in Hokkaido. Also included in the trip was a meeting with another buyer, visits to the seafood auction markets in Tokyo and Sapporo, and tour of a fisheries research institute.

Japanese Market

We were advised that the development of the Japanese sea urchin industry resulted from the desire to reduce the number of wild sea urchins that graze and destroy the highly valued seaweed beds used for nori. It is possible that current taste preferences for sea urchin roe ("uni") are related to the natural diet of Japanese sea urchins, as some of the characteristics of uni depend on feed type. It is our understanding that the most highly favored sea urchins have grazed on Laminaria japonica. Given that Japan is the principal market for Canadian sea urchins, the following remarks apply to that market.

As is well known, Japanese seafood markets are complex and multi-layered. The normal route for sale of seafood to Japan is through specialised companies, many of which buy raw product or semi-processed product for further processing and/or repacking. Subsequently, the product is sold directly to retailers, through

auction houses or various other routes established by the buyer. Since it is virtually impossible to enter the market at higher levels in the market chain, our focus is on the primary level. Buying practices vary with the buyer and supplier. Pricing of sea urchins generally varies throughout the season; however, one of the buyers indicated that he would be prepared to develop a stable price contract with the supplier if he was satisfied with all aspects of the relationship. In general, Japanese companies like to establish long-term relationships based on strong elements of trust, mutual respect, and reliable product quality.

Market demand for sea urchins varies with season, the end-user and the location of the buyer. Demand for offshore product is highest from about September until April. Local supplies are more or less sufficient between April and September and are generally preferred. Retail price varies and is determined by supply, demand associated with certain festivals, perceived quality perferences, and packaging. Given these complexities, it is important that companies work closely with a Japanese buyer to develop their market for feed lot sea urchins. It is evident that the development of feed lot culture provides an opportunity for producers to ship product of uniform yield and quality, steadily and reliably to buyers throughout the period

of demand and to schedule production to take

advantage of the high demand during festive

seasons.

The two sea urchin buyers we visited have different approaches to the market. One buys only live sea urchins, either directly or indirectly through North American subsidiaries, the other buys only semi-processed or market-ready product. Part of the reason for the latter preference is location, as the company is situated in Tokyo and has a waste disposal problem.

Experimental Feed Lot Culture and Processing

To date, experimental grow-out of sea urchins results in wide ranges in yield. The yield can apparently be manipulated by controlling temperature and feeding rates. The buyer of live sea urchins indicated that the most desirable sea urchins yield 10-12% uni; yields of less than 10% result in high labor and overhead costs, while yields of more than 12% are felt to be indicative of a lower quality product in freshly harvested wild sea urchins (apparently related to texture). The other buyer had an open mind on yield and was very interested in the potential of higher yield. Work under progress at Guigné International Ltd. (Paradise, Newfoundland) on a non-invasive device for measuring the roe content of live sea urchins may provide a useful assessment tool for both live harvesters and feed lot operators.

Color preferences vary with the market and no clear pattern emerged. What is clear is that roe in finished packs and, to some extent, semi-finished packs for repackaging, should be of uniform color and size. Texture must be fairly firm; milkiness is undesirable. Flavor preference is for local Japanese product that has fed on specific seaweeds.

Our own green sea urchin is quite similar to the Japanese sea urchin. Comparison tasting and testing could be carried out by importing live Japanese sea urchins. However, great care would be required in handling and isolation techniques to ensure the Japanese sea urchin is is unable to reproduce and does not introduce new shellfish diseases to the region.

Treatment of roe varies with the producer. Some use only salt water at approximately ocean strength (3.5%), others use both salt water and alum treatments. Since these are buyer specific preferences, the method of treatment has to be developed with the buyer's technicians. The process witnessed in one plant used several changes of chilled salt water as the product was

progressively cleaned. The product stayed in the same mesh basket through this process but was moved from tank to tank as it became progressively cleaner. It is assumed, given the length of time in the brine, that the product would contain close to 3.5% salt at the end of the process. However, this should be determined from the finished product in order to establish standards for quality control purposes.

Final packing was done in a "clean" room that was entered through an air lock in which high velocity air removed loose particles from individuals passing through. Face masks, mobcaps and lab coats were worn. The packers sorted and packed roe into various sizes and styles of packs ranging from 15 to 250 g. Broken roe tended to be packed underneath. The top layers were neatly packed in rows like orange slices. Uniform color and size in a pack were critical. Many of the packages were traditional wooden trays. However, more extensive use is being made of plastic trays and some of these are loose packs. Gift packages such as those in the form of small model boats are also sold and these sometimes include other types of seafood.

Shipping containers are readily available for live and semi-processed sea urchins. The masters are styrofoam. We observed finished product packed in small plastic (125 g) containers and semi-finished product in tray layers. These are packed with gel packs. Given the high cost of air shipment there is a clear advantage in shipping semi-finished or finished product rather than live sea urchins. However, finished and semi-finished product has a limited shelf life.

Sea urchin roe is almost a fresh product, not withstanding the use of low strength brine. It may be expected that bacterial spoilage, various forms of autolysis and normal biochemical processes will continue after processing and that several days elapse between harvest and consumption. A day will be lost during processing. packing, and delivery to the airport, a day in air shipment from the east coast of Canada to Japan, at least a day in local transport and repacking, and at least a further day to retail and end sale, for a minimum elapsed time of four days. More time may elapse prior to consumption. This provides little insurance against deterioration in quality. To maintain quality, it is recommended that processing be done at reduced temperatures, and include:

1. Pre-cooling the live sea urchins;

2. Using chilled brine/alum baths;

3. Pre-cooling all packaging;

4. Maintaining cool plant temperatures;

Chilling the trays or small packs in a cool room prior to mastering;

Maintaining the masters in a cool room prior to shipping.

By strictly following these procedures the shipper should be able to add a few days to the shelf life, has the potential to earn a higher price because of the quality, and has provided insurance against losses due to shipping or other delays.

All three buyers indicated that they are eager to work closely and cooperatively with companies and researchers involved in the development of sea urchin feed lots. All companies would send technicians to Canada to assist with evaluation of product quality and to show companies how to process the product to their requirements. If this is successful and the participants are comfortable with each other, long-term relationships will develop.

Recommendations

Groups involved in the development of feed lot technology should work closely with companies that have market knowledge and that are likely to invest in the technology. Such partners should develop close working relationships with buyers and arrange to have the buyer's technicians work with them on site periodically to understand the product and process preferences so that they are better able to meet the requirements. Groups should undertake comparison quality testing between live Japanese sea urchins and local sea urchins. The latter should be a regular part of quality assessor training to maintain personnel competency. (This might be conducted on a group basis in consort with Department of Fisheries and Oceans inspection personnel to work towards uniformity). Last, but not least, groups should visit the Japanese partner companies to attain a better understanding of company philosophy, processing methods, marketing and consumer preferences.

Notes

- 1. Box 67, Site C, Portugal Cove, NF, Canada A0A 3K0
- Quinlan Brothers Ltd., Box 40, Bay De-Verde, NF, Canada A0A 1E0
- Newfound Foods Inc., Unit 129, 38 Pearson Street, St. John's, NF, Canada A1A 3R1

Sea urchin gonad enhancement: preliminary economic feasibility analysis

Brian Burke (1)

The Canadian Centre for Fisheries Innovation, in cooperation with the Newfoundland Department of Fisheries and Aquaculture, has sponsored two years of research on sea urchin gonad enhancement at Memorial University of Newfoundland. This paper addresses the potential economic viability of sea urchin farming, based on information obtained from these two years of study and costing and market information from the existing industry. An economic model was prepared to evaluate both on-land tank farming and bottom culture. The results from this preliminary analysis demonstrate the impact of sales price, roe yield, growth rates, raw material costs, processing costs, and other factors on potential economic viability. Sea urchin gonad enhancement has the potential to be economically viable, especially if premium prices can be obtained for the consistent, high quality product available through controlled farming.

Introduction

The Canadian Centre for Fisheries Innovation (CCFI) has sponsored a number of research projects over the past five years in an effort to assist the development of the fledgling sea urchin (Stronglyocentrotus droebachiensis) industry in Newfoundland. These projects have considered various facets of harvesting and processing for the wild harvest of sea urchins. Over the past two years, CCFI, in collaboration with the Newfoundland Department of Fisheries and Aquaculture, has sponsored research aimed at assessing the potential for sea urchin gonad enhancement using locally available kelp resources. (2,3) This research was conducted at Memorial University of Newfoundland's Bonne Bay Biology Field Station. The principal researchers in this project were Dr. Robert Hooper of Memorial University's Biology Department and Mr. Thomas McKeever of the Fisheries and Marine Institute of Memorial University's Centre for Aquaculture and Seafood Development.

The wild sea urchin harvest in Newfoundland has generally been plagued by low yields and variable quality. In addition, harvest by diving during the peak season, November and December, can be treacherous so the wild supply is often sporadic. The prospects of providing a product with consistent yield and quality on a consistent basis provided the impetus for research on sea urchin gonad enhancement.

Results of the two years of research, undertaken in both controlled on-land tanks and in bottom placed cages, have demonstrated that low yield sea urchins fed a diet of kelp, *Laminaria digitata* or *L. longricuris*, will rapidly increase their gonad size and quality to commercial levels (10%). Additional research has focused on the impact of ration size, season, sea urchin size, stocking density and other factors.

Methodology

A simple pro-forma financial model was developed based on a five-year period and providing Net Present Value (NPV) and Internal Rate of Return (IRR) calculations. Scenarios were considered based on the use of either bottom culture or land-based tank/raceway culture and with the final product sold as either live sea urchins or processed roe. Sensitivity analysis was performed to determine the impact of variables including: feed costs, feeding rations, desired roe yield, stocking densities and processing costs.

Assumptions

As with any economic/financial model, the accuracy of the results is based solely on the quality of the assumptions used in the analysis. In the case of sea urchin farming there are no established operations in Canada at present. As such, the primary sources of information used for the economic analysis were three CCFIsponsored reports: Sea Urchin Feeding and Ranching Experiments,(2) Sea Urchin Aquaculture- Phase II (3) and Project Report: Sea Urchin Business Development. (4) Additional information was obtained through contact with private sector companies currently involved in sea urchin harvesting and processing and companies considering an involvement in sea urchin farming. The following paragraphs outline the primary assumptions used in the economic analysis of sea urchin gonad enhancement.

Sales price

The primary market for sea urchin roe is Japan where an auction system determines price on a daily basis. Wide price variations are a normal occurrence, with fluctuations determined by product quality and seasonal and daily supply/demand variations. The primary goal of a sea urchin farming operation would be to produce a product of consistent quality and yield and to provide the market with a stable supply of such product. It would be expected that such positive sales attributes would enable the farmer to obtain a premium, i.e., above average price.

For the following analysis, the 1993 average

annual import price for Canadian sea urchin roe was used to provide a comparative baseline price. The average price for fresh/chilled roe was \$38.67/kg (\$17.54/lb) while the average price for live sea urchins was \$8.87/kg (\$4.02/lb).⁽⁵⁾

Variable costs

Raw material — sea urchins. Newfoundland sea urchin processors have been paying harvesters \$0.30 to \$0.60 per pound (\$0.66 to \$1.32 per kilogram) for live sea urchins, depending on the roe yield and quality. For a sea urchin farming operation, low yield and quality sea urchins would be purchased for gonad enhancement and quality improvement. These sea urchins would be harvested from May to September, outside the more dangerous autumn/winter season and as such a purchase price of \$0.30/lb (\$0.66 per kg) is assumed.

Raw material — feed (kelp). Research has demonstrated that sea urchins have a poor food conversion ratio when fed natural kelp products. (2,3) As such, the cost of feed and the amount of feed required to enhance the sea urchin gonad to the desired yield are important factors in determining the potential economic viability of sea urchin farming. Kelp costs may range from a low of \$0.08/lb to a high of between \$0.15 and \$0.30/lb (\$0.18 to \$0.66/kg). Feed consumption varies with feeding ration and desired roe yield (Fig. 1). Feeding sea urchins to satiation (100% ration) on Laminaria digitata, the amount of feed consumed, as expressed in pounds of feed per pound of sea urchin (or kg of feed per kg of

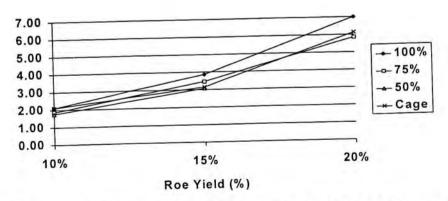


Figure 1. Feed consumption patterns. Feed consumption (kg food/kg of sea urchins or lb food/lb of sea urchins) at varying yields.

sea urchin), varies from 2.10 to reach a 10% roe yield, to 3.85 to reach a 15% roe yield, to 7.00 to reach a 20% roe yield. Reducing the feed ration results in a reduction in feed consumption to reach a desired yield. To reach a 10% yield consumption varies from 2.10 lb/lb (or kg/kg) at 100% ration, to 1.86 at 75% ration to 1.75 at 50% ration. Although total consumption to reach a desired yield is lower at reduced rations, it will also take a longer time to reach the desired yield under these reduced rations.

Labor. The labor required for sea urchin farming, whether land-based or bottom culture, is not intensive. Primary labor requirements will be required during the setup of the operation, for raw material collection, and for subsequent harvesting and processing. Day to day operations involving feeding and maintenance are not labor intensive. As a result, one full-time and one part-time person will be required for a landbased operation (2,000 m² growing area) and two full-time personnel, with diving capabilities, will be required for a 10,000 m² (100 m x 100 m) bottom culture operation.

Processing. Processing costs were derived from an analysis of processing costs presented by Haytor.⁽⁴⁾

The cost of processing of live sea urchins totaled \$3.02 per pound (\$6.64 per kilogram), including labor, packaging, ground and air transport, plant overhead and selling expenses.

The cost of processing roe included the ex-

penses required for processing live sea urchins and additional expenses related to processing labor and additives. Because labor inputs required to open a sea urchin are equivalent regardless of the sea urchin's roe yield, the processing cost per pound of roe will vary with the yield. Processing costs range from \$15.04/lb (\$33.09/kg) of roe for 10% yield, to \$12.77/lb (\$28.09/kg) of roe for 15% yield, to \$10.50/lb (\$23.10/kg) of roe for 20% yield.

Fixed costs

Land-based and bottom culture operations have different requirements in terms of their fixed overhead costs and the costs for supplies and consumables. Based on discussions with the private sector, the fixed costs have been estimated at \$5,000/month for bottom culture and \$6,000/month for tank culture.

Capital costs

Potential capital costs for developing a sea urchin farming business will vary depending on the type and size of farm and the amount of existing infrastructure and equipment that can be used on the project. For bottom culture it is assumed that the operator, possibly an existing harvester, will have available a boat and the required diving and harvesting gear. Landbased culture will be assumed to make use of an

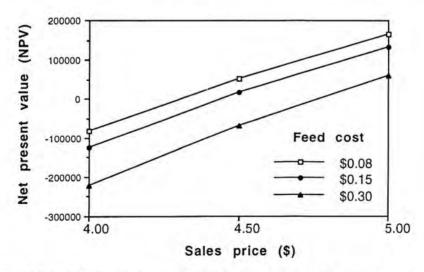


Figure 2. Land-based, live sea urchin sales: sensitivity to feed costs (in dollars per lb; multiply by 2.2 for dollars per kg). Net present value (NPV) as impacted by sales price and feed costs.

existing under-utilized fish plant or lobster holding facility with an adequate water supply. The size of operation assumed for bottom culture is 10,000 m² or a 100 m by 100 m area of the bottom. A land-based operation is assumed to have 2,000 m² of usable surface area for sea urchin culture. The total cash outlay for capital items for either a bottom or land-based operation is assumed to be in the \$20,000-\$50,000 cost range.

Other Assumptions

Stocking density

Preliminary experiments have been performed on potential stocking densities for sea urchins. (2) In tanks, a stocking density of 5 kg/m² has been achieved with minimal mortality. The land-based raceway system used in France has achieved stocking densities of 10 kg/m². (6) Given the space limitations imposed by land-based culture, maximizing stocking densities without negatively impacting on growth or mortality is an important consideration. Bottom culture experiments have been undertaken at stocking densities up to 2.5 kg/m².

Mortality rate

With careful harvesting, handling and proper stocking densities, mortality rates can be minimized. In the research by Hooper et al. (2,3) most mortalities occurred soon after harvest and handling. Total mortalities were low and did not exceed 0.5% in total.

Operating season

An analysis of seasonal growth patterns by Hooper et al. (3) has demonstrated that the best operating season for a sea urchin farming operation would be from post-spawning (May) to December. Collection of new sea urchins for farming would be halted in September, prior to the normal wild harvest season.

Results

Using the assumptions outlined above, a financial analysis was completed for bottom and land-based culture selling either live sea urchins or processed roe.

Land-based culture. Scenarios were run for a land-based culture operation with 2,000 m² of working surface area. At a stocking density of 5 kg/m² such a facility could hold a maximum inventory of 10,000 kg of live sea urchins. The capital cost used in the analysis was \$35,000.

Figure 2 illustrates the financial sensitivity to changes in feed costs. This figure portrays the Net Present Value (at a cost of capital of 10%) at various sales prices and feed costs. Feed costs have a significant impact on viability as the break-even price required (NPV = 0) increases from \$4.28/lb at \$0.08/lb of feed (\$9.42/kg at \$0.18/kg of feed), to \$4.42/lb at \$0.15/lb of feed (\$9.72/kg at \$0.33/kg of feed), to \$4.74/lb at \$0.30/lb of feed (\$10.43/kg at \$0.66/kg of feed). Therefore for every \$0.01 increase in feed costs, the sales price required for break-even increases by approximately \$0.02.

Sensitivity to changes in feeding ration is illustrated in Figure 3. This analysis demonstrates that the break-even sales price increases

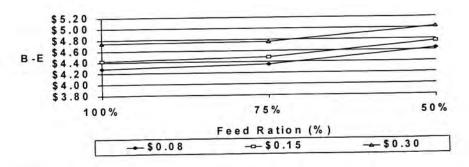


Figure 3. Land-based, live sea urchin sales: sensitivity to feed rations. Break-even sales price (\$ per lb; multiply by 2.2 for \$ per kg) influenced by feeding rations.

with reduced feeding rations. Although feed costs are less at lower rations, the costs related to the increased time to reach the desired yield at the lower rations more than offsets these savings. Dropping from a 100% to 75% feeding ration results in only a marginal increase in break-even values. Therefore, if the quantity of feed supply is of concern it may be wise to use a 75% ration.

Figure 4 illustrates that when holding sea urchins to obtain higher roe yields, a higher breakeven price will be required, from \$4.48/lb at 10% yield, to \$5.42/lb at 15% yield, to \$6.52/lb at 20% yield (\$9.86/kg at 10% yield, to \$11.92/kg at 15% yield, to \$14.34/kg at 20% yield). Providing a live product of higher yield

may be able to attain higher prices but this can only be confirmed through market testing.

In general, under the various scenarios illustrated the land-based farming of sea urchins would have to achieve a 10-20% premium price for live sea urchin sales over the baseline average price.

Bottom culture. Similar scenarios were run for a bottom culture operation with 10,000 m² of growing area. At a maximum stocking density of 2.5 kg/m², such an operation could hold 25,000 kg of inventory at a time. The capital costs for this operation were estimated at \$25,000.

Results of this analysis show similar trends to land-based culture. However, in general the

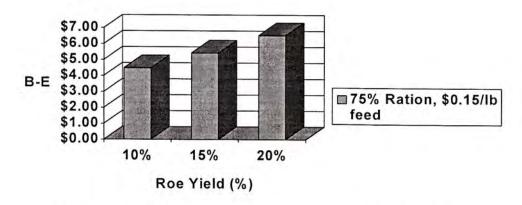


Figure 4. Land-based live sea urchin sales: sensitivity to roe yields. Break-even price at varying roe yields.

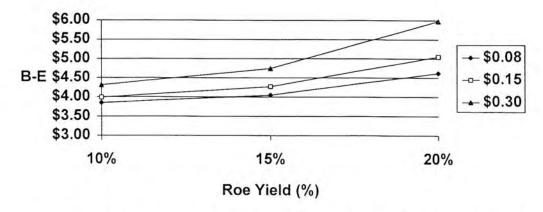


Figure 5. Bottom culture, live sea urchin sales: sensitivity to roe yields and feed costs (\$ per lb; multiply by 2.2 for \$ per kg). Break-even price as influenced by roe yield and feed costs.

break-even costs for bottom culture are lower and, as shown in Figure 5, a farmed sea urchin with 10% roe could potentially be sold at or near the 1993 baseline price and the business could achieve a break-even position.

Processed roe sales

Figure 6 illustrates the break-even price for processed roe, at \$0.15/lb (\$0.33/kg) feed cost and 75% ration, for both land-based and bottom culture. In both cases the break-even price is slightly reduced at higher roe yields, due to the fact that processing costs (in \$/lb of roe) are lower for higher yield sea urchins. For both the land-based and bottom culture operations, break-even prices are significantly above the base-line price of \$17.54/lb (\$38.56/kg) (20-50% higher). The difference in break-even prices between the land-based and bottom culture operations is due to the higher scale economies achievable with bottom culture. However, if it is possible to use land-based culture at a higher stocking density, such as the 10 kg/m2 achieved in France, the break-even values for both land-based and bottom culture are comparable.

Conclusions and Recommendations

The preceding analysis demonstrates that roe enhancement may have significant potential, especially if a premium, above average price can be obtained for the product. From this analysis, bottom culture appears to be more viable than land-based culture but this is a reflection of economies of scale and does not consider the higher risks, such as premature spawning, greater yield variation, and lower control related

to bottom culture.

Sensitivity analysis has shown that economic viability is sensitive to feed costs and consumption (food conversion ratios). Therefore, additional research is required on the optimization of feeds and rations, whether natural or artificial. Further research is also required on the optimization of stocking densities, especially for land-based operations.

Results of this preliminary analysis are largely based on laboratory-scale research. As such, pilot-scale trials with private sector partners are required for both land-based and bottom culture to strengthen the assumptions and further refine the economic analysis. Such pilot-scale studies must be combined with ongoing controlled experiments on feeds, stocking densities, etc.

Through technology transfer and national and international cooperation and research, the potential exists for the development of a new industry based on sea urchin gonad enhancement.

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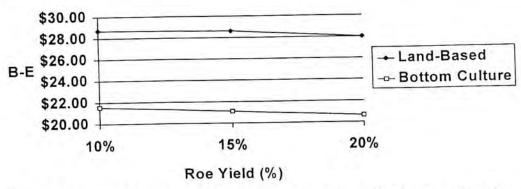


Figure 6. Processed roe sales: land-based and bottom culture. Break-even price (\$/lb) as influenced by roe yield (%).

Sustainable development of the green sea urchin

John C. Bonardelli (1)

The green sea urchin is a highly prized species on Asian markets and could represent a source of supplementary income for Ouebec fishermen and processors. Preparing sea urchins for market through storage in land-based tanks, by conditioning with natural or artificial algal diets, or by culturing and re-seeding, are alternatives that should be carefully considered for their potential impact on the sustainable development of the industry. During the workshop "The Sustainable Development of the Green Sea Urchin" held 27-28 March, 1996, at Grande Rivière, Quebec, fisheries, aquaculture, and processing professionals together with potential promoters, reviewed progress to date and focused on the obstacles to be overcome if a sustainable industry is to be developed. With the objective of promoting regional development and initiating the establishment and expansion of competitive and profitable companies, information on green sea urchin biology, distribution, harvesting, conservation, conditioning, processing, quality and marketing was discussed. Workshop sessions informed participants of ways of managing and conserving the sea urchin resource with a view to sustainable development. A resumé of the key elements in each of the topics discussed is briefly presented in this paper.

Introduction

There is a growing interest in under-utilized species, such as the green sea urchin, that may provide an additional source of revenue for fishermen. The renewed interest in the sea urchin resource is understandable in light of its high demand on Asian markets. However, several constraints prevent further development of the fishery. Representatives from a multi-disciplinary field of specialists in fisheries and aquaculture from the federal Department of Fisheries and Oceans (DFO), Quebec Ministry of Agriculture, Fisheries and Food (MAPAQ), Regional Development Council, and Centre Spécialisé des Pêches training college came together at a workshop with invited stakeholders to analyse the sea urchin sector and identify obstacles that need to be overcome to ensure its sustainable development. The objectives of the workshop

 Establish a sustainable development strategy within fishing regions with a view to establishing competitive and profitable companies;

- Invite stakeholders to contribute to a common vision of development;
- Inform participants on how to manage and conserve stocks;
- Relay the state of knowledge to stakeholders on topics of concern, including:
 - Biology and harvest of the sea urchin resource,
 - Preparation for market and associated costs.
 - Product processing and commercialization.

The following summary is based on discussions of presentations and from the plenary sessions for each of the topics covered.

Sea Urchin Biology and Harvest of the Resource

A total of 62 exploratory sea urchin harvesting permits were allocated in 1995 to lobster fisher-

men around the Gaspésie peninsula, despite the fact that the only allowable harvesting method is by scuba diving. Because fishermen do not generally have the required practical and safety training, the financial resources to initiate this fishery, or the training to harvest safely by scuba under drift-ice conditions, it is difficult to grasp how the development of this new sector will be undertaken in a co-ordinated manner.

Efforts should be made to understand the population structure of the sea urchins and to quantify the resource in different localities before large-scale exploitation occurs.

Distribution and biological characteristics

There is an abundant supply of sea urchins in depths of up to 5 meters. Densities are as high as 200/m², but there is considerable variability between sites. Studies have shown that small sea urchins hide in crevices in sub-optimal conditions waiting to replace the larger individuals that monopolize the food resources.

Habitat and the exploitable biomass

Sea urchins are generally very abundant along the Gulf St. Lawrence coast, but the consensus is that a conservative approach should be taken to harvesting in order to avoid the problem of overfishing that has occurred in California, Washington and Maine. To maintain a sustainable fishery, the harvest technique should protect the biomass of new recruits that are abundant along the coast. In this way the reduction in densities resulting from harvesting should increase gonadal growth and the quality of larger sea urchins.

Licensing and fishing exploitation

One of the principal queries from fishermen was related to situations in which harvested sea urchins would be transferred to delimited management zones to increase the gonad index (GI) — How could an individual fisherman ensure exclusive access to the transferred sea urchins within his permit?

Further, the winter period is when the best quality gonads are obtained, but access to the harvest sites is difficult due to drift-ice. A better alternative would be to harvest in the summer and autumn and condition the sea urchins. But there are presently no facilities available for this.

The Department of Fisheries and Oceans sea urchin management plan is based on the control of fishing effort through harvesting by scuba diving, and not by the implementation of a quota system. However, there are few safety and training measures in place, creating a situation that is potentially hazardous for harvesters. The advantage of harvesting by scuba diving is that one can select for animal size as well as gonad quality. It is a rapid and efficient method of harvest, but safety measures require a crew of three people (one in the boat and two in the water). In regard to the attribution of licenses, there is the question of whether a license should be issued by zone, bay, region, fishermen's group, or co-operative.

Preparation for Market and Associated Costs

The quality of sea urchin gonads is optimal from the months of November to April, just prior to spawning, when it is difficult if not impossible to harvest due to drift-ice. Furthermore, and not insignificantly, most of the processing plants in Quebec are closed during the winter months. The solution to the dilemma of low gonad yield in summer and autumn would be to condition sea urchins and enhance gonad mass by holding the sea urchins in sea cages or land-based tanks and using a comprehensive feeding program to increase the quality and flavor of the gonads so that the required yield to suit the market niche is obtained.

Storing and transportation

The main concern related to storage and transportation was the lack of available standards to be used at sea and on land to maintain the quality of the sea urchins (e.g., How much ice should be used to preserve the freshness of the product during transport?).

Enhancement at sea or in land-based tanks?

When conditioning of sea urchin gonads was discussed, the principal concerns were the cost to enhance growth and gonad quality in sea urchins held on the sea-bottom and what infrastructures are required to condition sea urchins

on land. It was felt that studies to evaluate costs of food for conditioning sea urchins should be applicable to commercial-scale operations, and the development of experimental protocols should include more collaboration with private industry to ensure studies are directed at commercial applications.

From the discussions, there did not appear to be any special permits required to condition or enhance sea urchins on land. However, a processor does require a MAPAQ processing permit for other species and an aquaculture permit is required by fishermen conditioning sea urchins at sea within a designated area.

Decisional flow-charts

Market opportunities vary dramatically from season to season related to the quality and texture of sea urchin roe. Critical periods where decisions are required to either harvest, process or enhance sea urchins can be identified (Fig. 1). The flow of product thus depends on the "choice of opportunity" at the time of market. The price being paid for sea urchins will also be a principal parameter in determining whether

the product goes directly to processing, to enhancement installations at sea or on land, is rejected in the processing stage, or is directed toward value-added processing (Fig. 2). In either case, a structured communications network between fishermen and processors is required so that the objectives of marketing a high yield and high quality product are met.

Food preferences and effect of semi-moist diets on roe quality

Results of on-going experiments comparing the effects of algal diets and artificial feeds suggest that additional effort is required to achieve the ideal diet. In this respect, data enabling the estimation of the cost of feed for commercial-scale projects using the different production strategies were unavailable. At the workshop in Grande-Rivière, it seemed there was little understanding of the factors that control the onset of gametogenesis. Such knowledge is required to condition sea urchins throughout the year. However, this subject was subsequently covered in detail at the annual meeting of the Aquaculture Association of Can-

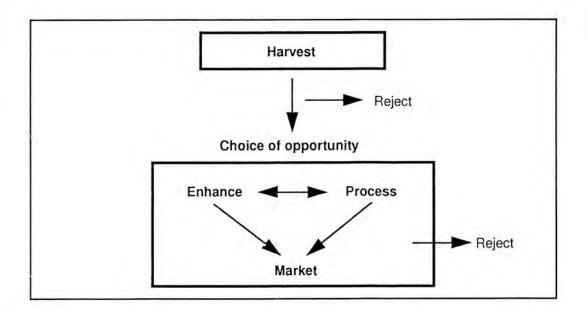


Figure 1. Decisional flow chart for the product movement of green sea urchins. A variety of opportunities exist for the processor as techniques are refined to enhance gonad quality on a seasonal basis.

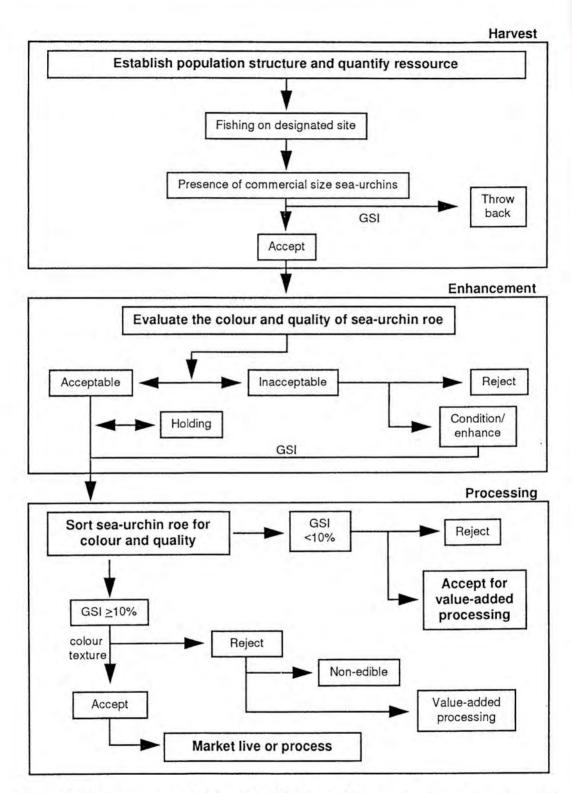


Figure 2. Product movement decisional flow chart for the harvest, enhancement and processing of sea urchin roe (GSI: gonadosomatic index).

ada in June 1996 (reported in this proceedings). It appears clear that advances in the control of gametogenesis are transferable from France and the United States, and that future work should address the fine details of how the reproductive state of sea urchins affects feeding and what the nutritional requirements are in the various stages of gamete development.

Product Processing and Commercialization

Processing methods

The fact that processing sea urchins is simple and requires little investment on the part of processors is in itself a clear indication that the problems in developing a sea urchin industry are located on the supply side. Processing does require trained staff and high quality standards. Although the dollar value of sea urchins is mostly a function of gonad quality, the impact of product handling on quality and price, from the moment of harvest to that of processing and shipping to the doorstep of the market, seems to have been overlooked.

Regulations affecting the market

Contrary to many species, the rules affecting sea urchins are simple and supple. An export permit is required by DFO along with a quality control program using measures such as the Hazard Analysis Critical Control Point (HACCP) procedures. Since there is still much confusion in the marketplace regarding the supply of quality roe, there is a need to co-ordinate harvesting at sea and conditioning of sea urchins to maintain a supply of quality roe for the marketplace.

Marketing and profitability

The confusion in the market is largely based upon the lack of a structured marketing network with a long-term vision that fishermen and processors can use to develop a sustainable development plan. The value of sea urchins is based not only on gonadal yield, but also on color and quality. Therefore more effort is required to

determine strategies to obtain the highest quality product.

Many chefs, restaurant owners and market specialists consider that it is time to put more effort into targeting local restaurants and markets, as alternatives to exporting sea urchins. They feel the product should be available on menus locally, regionally and nationally. For example, seafood restaurants could start promoting the product by incorporating sea urchin roe into sauces for fish dishes, and using roe as a base for soups, or as an hors-d'oeuvre served on toast.

Industry viewpoints on profitability

Consensus was obtained that there is no interest in fishing sea urchins with baited traps, because only hungry sea urchins enter traps. Such animals are of poor quality and are difficult to enhance.

There was a plea for continued support to build a common approach and a structured development strategy to harvest or produce quality roe outside of the winter months, when gonadal yield is normally high but the sea urchins are not accessible. It was understood by all participants that harvest, enhancement, processing and marketing activities are closely linked and that a coordinated effort to manage these aspects will contribute to the sustainable development of the fishery while providing the best product (Fig. 2).

Conclusion and Consensus

Stakeholders at the workshop in Grande-Rivière agreed there is a need to: 1) establish a common plan of action that ensures a sustainable level of harvesting; 2) form working groups to solve problems associated with each aspect of this new fishery; and 3) determine the associated costs of all the steps involved in developing the industry.

Notes

 MAPAQ, Direction de l'Innovation et des Technologies, 96 Montée Sandy Beach, CP 1070, Gaspé, QC Canada G0C 1R0.

Aging and growth of the green sea urchin

S. M. C. Robinson (1) and A. D. MacIntyre (2)

If an industry based on enhancement of the gonad ("roe") is to develop on wild-harvested sea urchins, it will be important to understand the age structure and growth profiles of the targeted animals. It is possible that older animals do not grow as quickly as younger ones of the same size. Populations of sea urchins in the southwestern New Brunswick portion of the Bay of Fundy have been sampled since 1994 and results of aging work, based on the number of rings found in the coronal test plates and the rotules (components of Aristotle's lantern), indicate the animals are older than previously thought. Ages have been validated using a tetracycline marking technique and an elemental ratio technique using a microprobe.

Background

The test (or shell) of sea urchins is formed from a series of interlocking plates composed of calcium carbonate. There are four different plate types: a series of five genital plates on the dorsal surface, five double columns of coronal plates (ambulacral and inter-ambulacral) and five ocular plates on the ventral side. (3) Animals increase the size of their test through a combination of growth in size of the plates and by periodically adding new coronal plates. Each of the plates is fenestrated with a series of channels known as the trabecular network. As the plates grow in temperate zone animals, changes in the organisation of the trabecular network form a concentric ring pattern in each plate and other hard body parts, such as the spines and Aristotle's lantern, corresponding to the growth rate of the animals.(3) Several studies have used these ring patterns to age sea urchins. (4-6)

The green sea urchin, Strongylocentrotus droebachiensis, is very adaptable in its response to the environmental conditions it encounters. When food resources are high, the sea urchin is capable of relatively rapid growth rates and much of its excess energy, above basic metabolic requirements, is stored in the nutritive vacuoles in the gonads. (7) It can also exist for long periods in barren-ground situations with low food resources, resulting in small, old animals with very little excess energy stored in the gonads. (8,9)

Over the last nine years, a harvest industry for the green sea urchin has developed in the southwestern New Brunswick portion of the Bay of Fundy. The sea urchins are harvested for their gonads (sometimes called roe or uni) using divers or boats towing special sea urchin trawls. The sea urchins are either shipped whole to Japan or are processed locally. Landings have risen consistently in an exponential fashion from 47 t in 1987 to 1,446 t in 1994. However, compared to other fishing areas, the quality of the roe has been mediocre (as measured by the size of roe relative to the body weight) and there is a growing interest in the possibility of enhancing the roe of captive wild sea urchins using supplementary feeding. If a culture-type industry, based on enhancement of the roe, is to develop on wild-harvested animals, it may be important to understand the age structure and previous growth profiles of the animals targeted for enhancement, as it is possible that older animals do not grow as quickly as younger ones of the same size.

Therefore, our objective was to determine the age structure and estimate the growth rate of the wild populations of sea urchins in southwestern New Brunswick.

Research Surveys

One of the traditional methods used to investigate the age structure of animals in a population is to examine the size-frequency distribu-

tion for distinct modes that may represent age classes. A spooling transect was deployed from shore at the low tide mark at several locations (Fig. 1) in the study area by two divers. (10) Each diver swam one side of the spooled transect line and counted the number of sea urchins occurring within 1 m of the transect line and noted their relative size. Data on the number of sea urchins encountered, depth, bottom type and the relative size of the sea urchins were tabulated every 10 m (i.e., the divers estimated two 10 m² plots every 10 m). At the end of the transect (150 m or a water depth of 22 m) samples of sea urchins were collected along the transect at four locations to determine size frequencies of the population at that site.

Results from the surveys indicated there were relatively few distinct modes in the size-frequency age structure from any site (Fig. 2). However, there was a difference in the size distributions between the two areas with Grand Manan waters having much larger sea urchins.

Although pooling the data for Grand Manan and Deer Island and Campobello from the transects can tend to obscure some of the size modes in a frequency distribution, there were few clear modes in any of the individual transect frequencies. With the relatively uniform shape of these size-frequency distributions, it became apparent that other techniques would be required to determine the growth and age characteristics of the sea urchin populations.

Derivation and Validation of Growth Rings

Although studies have indicated there may be internal rings in the coronal test plates of the sea urchin which may be seen once the plate has been cleaned, our observations with a dissecting microscope, using either reflected or transmitted light on untreated plates, revealed no such structure until we further processed the plates. Using the Jensen technique, (11) both sides of the

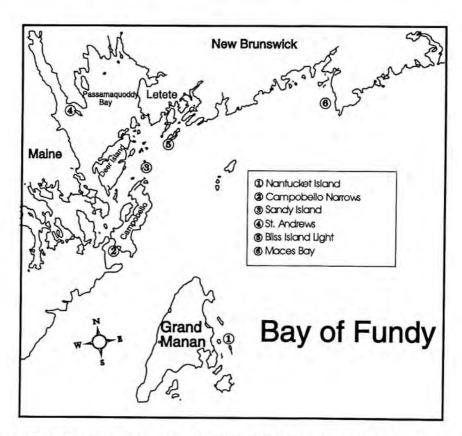


Figure 1. Map of locations of sea urchin collection sites for age studies in the southwestern New Brunswick area of the Bay of Fundy.

plates were wet sanded to one half the original thickness with 600 grit wet-dry sandpaper, lightly charred using an alcohol lamp, and then wetted with a xylene substitute (HistoclearTM) to enhance viewing of the internal rings. Initially, the inter-ambulacral plates were used, but because new plates of this type are added periodically as the sea urchin grows, we decided to concentrate on the genital plates to age the animals as these were assured of being the oldest plates on the sea urchin. We also investigated the structures in the internal feeding apparatus known as "Aristotle's lantern". The same technique to reveal the internal growth lines was used on the jaw elements (demi-pyramids) and barbell-shaped structures known as the rotules.

The technique for highlighting the rings in the plates, jaw elements and rotules of the sea urchins worked very well. The alcohol lamp was found to be superior to a bunsen burner as the heat was substantially less and the charring process could be more closely controlled. We found that the rings in the structures would disappear if they were over-heated, implying that the rings are composed of organic material and were being ashed. The use of the HistoclearTM substantially improved the visibility of

the rings by penetrating the plate and making it more translucent. The genital plates were smaller, more porous and more susceptible to ashing than the inter-ambulacral plates or the rotules. All plates and rotules showed the same patterns of rings throughout, suggesting they were all responding to the same external stimuli.

To test the hypothesis that the rings from the test plates and the rotules were annual in periodicity, we validated the rings using two techniques:

1) An aqueous solution of the antibiotic, oxytetracycline (10 mg/mL) was injected into the peritoneal cavity of 50 sea urchins through the oral membrane using a hypodermic needle. The injected sea urchins ranged in size from 25 to 58 mm in diameter with a mean of approximately 42 mm. The oxytetracycline became incorporated in the test and created a ring in the test plates which served as a time mark that could be revealed as a glowing yellow ring under short-wave ultraviolet light. After injection, the sea urchins were placed in a cage and fed to satiation with the kelp, Laminaria longicruris, for 14 months.

Injection with oxytetracycline stained the tests dramatically as seen with long-wave ultraviolet

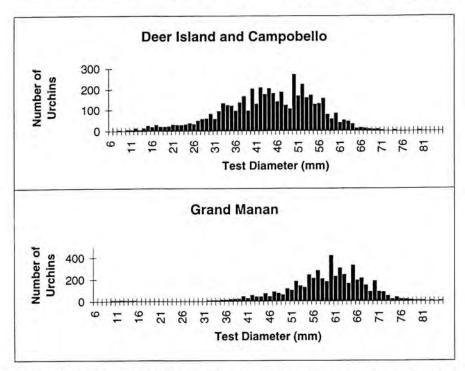


Figure 2. Size-frequency distributions of sea urchins in water off Campobello Island and Deer Island and off Grand Manan.

light (black light or miner's light). The inside of the test was bright yellow under ultraviolet illumination and initially the tetracycline could be seen in the ends of the tube feet and in the teeth on the exterior of the animal. Microscopic analysis of the plates in the tests with short-wave ultraviolet light and reflected white light after 14 months indicated there was a dark and white growth zone between the tetracycline line and the edge of the test plates. This confirmed the annual nature of the lines in the plates as the sea urchins would have experienced one slow and fast growth period during the previous year.

2) Certain elements are incorporated into the test at different rates based on external water temperatures. (12) Therefore, to look at the pattern of elemental isotopes in the test, sectioned genital plates, ambulacral plates and rotules taken from wild sea urchins collected off the wharf of

the St. Andrews Biological Station were embedded in epoxy resin, sectioned and polished before being analysed for elemental composition along a transect using an X-ray microprobe attached to a scanning electron microscope at the Biology Department of the University of New Brunswick in Fredericton. The growth lines on the plates or rotules were then measured with a dissecting microscope attached to an image analysis system (OptimasTM) to determine where they were in relation to the microprobe samples.

The locations on the genital plate analysed with the microprobe showed distinct differences among the different areas as the Ca:Mg ratios fluctuated between approximately 12.8 for the dark areas and 14.3 for the light areas. There was a repeating pattern of values and the replicability among samples in any of the loca-

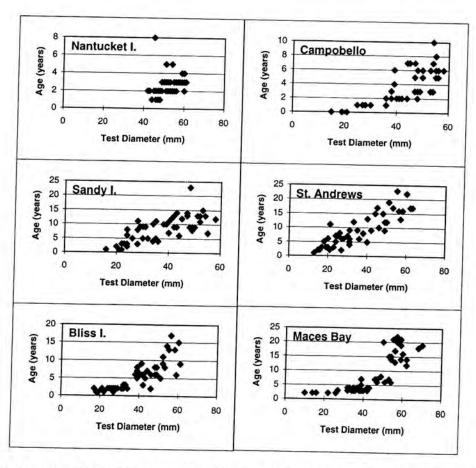


Figure 3. Test diameter versus age, based on test plate rings from six study sites in the southwestern New Brunswick area.

tions was good. Overall, the repeating pattern of the chemical elements and the correlation with the light and dark areas of the test indicated that the patterns observed were likely based on an annual cycle. Thus, we should be able to age sea urchins based on the internal shell lines.

Sea Urchin Ages in the Field

The ages of sea urchins in the various locations were found to differ markedly and several areas contained sea urchins approaching 25 years in age (Fig. 3). Nantucket Island on Grand Manan had the youngest and fastest growing sea urchins as most of the legal-size sea urchins (51 mm) were between 2 and 4 years of age. Campobello Narrows also exhibited relatively young sea urchins with good growth rates; most of the 51-mm sea urchins were between 2 and 7 years in age. In contrast, both the Sandy Island site and the St. Andrews harbour site had older sea urchins that ranged in age up to 24 years; 51-mm animals were approximately 10 to 15 years old. The difference between the two former sites and the two latter sites was the level of fishing activity and the degree of exposure. Nantucket Island and Campobello Narrows have received some of the heaviest fishing effort over the last 8 years while Sandy Island and St. Andrews harbour have had the least, according to reports from the fishing industry. Bliss Island and Maces B ay were more intermediate in value for both ages and growth, although there are a few older sea urchins in Maces Bay (a 51-mm sea urchin at these sites was approximately 7 to 8 years in age).

Discussion and Conclusions

This study has demonstrated that growth rings in the test of the green sea urchin can easily be revealed and that the lines appear to have an annual periodicity. Wild populations of sea urchins throughout the southwestern New Brunswick area differ in their size and age distributions and in some areas could be up to 25 years old. There was a great deal of variation in the age at a particular size, suggesting the animals were limited in their growth potential, probably through lack of food. For example, a 20-mm sea urchin could be between 2 and 10 years old while a 50-mm sea urchin could range from 4 to almost 25 years. Therefore, size was a poor indicator of age. This explains why the size-fre-

quency distributions were not particularly helpful in separating year-classes.

These results have a direct bearing on the concept of enhancement of sea urchins. While some locations have very poor growth, there are others that seem to have fast growing sea urchins. Some of the difference between the sites may be due to fishing activity reducing the densities of larger sea urchins. The results suggest that if sufficient food is available, then the sea urchins are capable of responding to the increased resources. However, the initial goal in enhancement is not necessarily growth of the sea urchin, but simply fattening of the gonads of legal-size animals. If there is any reproductive senescence in older animals, it may not be economically feasible to target large, old animals. Instead, the younger, more actively growing animals may be more desirable. Further research should address this issue.

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Out-of-season maturation of echinoid broodstock in fixed light regimes

N. T. Hagen

Green sea urchin, Strongylocentrotus droebachiensis, broodstock was exposed to treatments of either continuous light or continuous darkness. The experimental animals were individually marked with PIT (passive induced transponder) tags and maintained (mean residence time about 8 months) in laboratory tanks supplied with fresh kelp, Laminaria hyperborea and L. digitata. The experiment was terminated in August, at the antipodal point of the climax of the natural annual maturation cycle of the species. Histological examination of the gonads demonstrated that the proportion of mature individuals was significantly higher in the dark treatment than in a natural control population that was sampled at the same time (G-test, P < 0.05). However, the proportion of mature individuals in the continuous light treatment was not significantly different from the control population (G-test, P > 0.05). The sex ratio of mature individuals was significantly skewed towards males (G-test, P< 0.01), although the overall sex ratio for experimental and control populations was approximately 1:1. The proportion of mature males was 60% in darkness,

22% in continuous light, and 25% in the control population; whereas the proportion of mature females was 15% in darkness, 15% in continuous light, and 0% in the control population. These results suggest that darkness stimulates out-of-season production of mature males, but has no detectable effect on females. Nevertheless, a small proportion of mature females can be obtained by maintaining broodstock on an abundant diet of fresh kelp. The practical implication for broodstock management is that a large number of females are required to ensure a reliable out-of-season supply of mature individuals. In August, both laboratory populations had already attained large gonads, comparable to those typically found at the optimal harvest time 3-4 months later, in natural kelp-resident populations. The practical implication for future echinoculture operations is that continuous light may ensure optimal quality by impeding unwanted maturation of males.

Department of Fisheries and Natural Science, Bodø College, N-8002 Bodø, Norway

Research directions and management options for sea urchin culture in Nova Scotia

Bruce G. Hatcher (1,2) and Annamarie I. Hatcher (1,3)

We summarize the biological, ecological and cultural characteristics that are critical to the formation of a policy leading to sustainable exploitation and aquaculture of green sea urchins, *Strongylocentrotus droebachiensis*, and identify areas where strategic and applied research would be beneficial.

Introduction

The green sea urchin, Strongylocentrotus droebachiensis, forms the only commercially viable stocks of sea urchin on Canada's east coast, and there has been interest in harvesting them at least since the early 1970s. The solid and growing market for their high-quality gonads, the recent boom and collapse of sea urchin fishing in Maine, and the recent collapse of the east coast ground fisheries has caused Atlantic Canadian fishermen and scientists to look again at sea urchins as a sustainable resource. It is timely to re-examine the wealth of information collected on this species and the options for culture exercised for related species elsewhere. We here summarize the biological, ecological and cultural characteristics that are critical to the formation of a policy leading to sustainable exploitation and aquaculture, and identify areas where strategic and applied research would be beneficial.

Biology of Strongylocentrotus droebachiensis

The green sea urchin is a robust and versatile echinoid which has been well-studied, and for which there is a proven market for roe and a growing commercial fishery in several regions such as British Columbia, Maine, New Brunswick and Newfoundland. This species is distributed in the Pacific from the Aleutian Islands to

Oregon and in the Atlantic from Greenland to Cape Cod. (4) Natural populations are highly susceptible to economic overfishing. (5,6) The fishery in Nova Scotia is small and disorganized at present. There is considerable room for the development and implementation of both capture and culture technologies in exploiting this underutilized marine resource in a sustainable manner. There is also a potential for overexploitation and collapse.

The complex life cycle and flexible behavioral adaptations of sea urchins afford numerous control modes for the enhancement of stocks and production. The most viable options in the current ecological and economic climate of Nova Scotia are:

- Sea Ranching transplantation of adults from poor to good habitat for growth;
- Feed Lots addition of improved food to natural or captive populations;
- Reproductive Manipulation alteration of temporal patterns of gonad growth.

While a great deal of research has been conducted on the basic biology and ecology of sea urchins, directed research into the enhancement options listed above is scarce. The relevant programs currently underway are based in:

- Japan other Strongylocentrotus spp. all options have been explored since the 1970s.
- California other Strongylocentrotus spp.
 — feed lots operated since 1992.

- Maine S. droebachiensis sea ranching since 1993; reproductive manipulation planned.
- Newfoundland S. droebachiensis feed lots since 1993.
- New Brunswick S. droebachiensis feed lots planned.

Of these active or proposed programs of research, only those in Maine are being conducted in the public domain, such that the knowledge is directly transferable to the situation in Nova Scotia.

Movement and Dispersion in Natural Populations

The movement, dispersion and aggregation of sea urchins are spatially and temporally variable behavioural responses to food availability and predation, modified by seabed topography, water movement and temperature. When moving, the green sea urchin travels at rates up to 12.5 cm/h (average 2 cm/h), but may remain stationary for months if foods (or predators) are abundant. (7,8) Sea urchins can chemosense food and predators upstream at distances of several meters, and move towards or away from the stimulus to enhance growth and survival. (9) The presence of abundant food can overcome the avoidance of predators, and cause sea urchins to form and remain in very dense (100s per square meter) feeding aggregations. (10) Strong tidal currents do not prevent the formation of such aggregations, but strong wave action can physically disperse sea urchins, and move algal foods in such a way as to prevent sea urchins from feeding effectively. Based on the results of most studies to date, it is likely that adult green sea urchins would remain within aggregations and distances realistic for harvest on natural sea beds or feed lots where high quality food is maintained in fixed position. This prediction must be tested throughout the year in specific habitats chosen for sea urchin enhancement.

Growth

The growth of sea urchin somatic and gonadal tissues are the result of the complex interaction among several factors: age, size, feeding behavior, reproductive stage, food availability and quality, and the physical environment. At harvestable size in natural populations, food availability appears to be the dominant influence on

growth. Sea urchins can survive on almost anything (including dissolved organic compounds), but maximum growth is achieved on the highly preferred diet of large brown algae (kelps), augmented with small amounts of animal tissue.(11,12) Test growth rates of as much as 2 mm/month (24 mm/yr) are possible on preferred diets, which is 2 to 5 times the rates typically achieved on poorer, natural diets. (13,14) After an initial fast (logarithmic) growth phase as juveniles (1.1 to 1.3%/day increase in size), growth slows to a slower (linear) phase as adults (0.3 to 0.5 %/day). (7,15) While somatic growth rates decrease with age, the growth of gonad tissue as a proportion of total energy allocation increases with age. Thus, the green sea urchin will reach an optimal balance of size and gonad production between the ages of 4 and 6 years. (12) Enhancement of diet quantity and quality have produced improved tissue and gonad growth within 1 to 5 months (with growth rates of up to 3.4%/day, and 2- to 3-fold increases in gonad mass over the long term. (14,16)

The effect of diet on gonad quality is less well understood, but the presence of plant pigments and protein is known to influence the color and texture, as well as the mass of gonad. There exists considerable opportunity to fine-tune diets comprised of abundant natural foods to the specific needs of local populations and conditions, with the goal of optimizing gonad, rather than somatic growth. Artificial diets should not be necessary, given the abundant natural food resources in coastal Nova Scotia, but the incorporation of additives to improve gonad quality and perhaps the timing of production is an option which should be explored experimentally.

Feeding and Nutrition

Feeding by sea urchins is closely related to aggregation behavior in that it depends on both food supply and predator avoidance, modified by the local environment. When adequate food is delivered in the form of drifting algae, sea urchins can live and grow in small cryptic aggregations in topographically-complex habitats, relatively safe from predators. If large algae are only available attached to the seabed (kelp beds), and the threat of predation is limited, then sea urchins may form extremely dense feeding aggregations (grazing fronts or "feed lines") of over 250 sea urchins/m².(10) As long as food remains abundant, sea urchins can survive well

at such high densities without serious increases in mortality, although there are no data available for the density-dependence of growth at surplus food levels. In situations where food is superabundant and sea urchins can feed ad libitum (as would be the case in a well-managed feed lot), adult green sea urchins consume kelp at rates of 0. 3 to 3.4 g (fresh weight)/sea urchin/day.(17,18) The feeding rate increases with sea urchin size (5-fold increase from 30 to 70 mm test diameter) and temperature (ca. 2-fold increase from 1°C to 12°C), but also changes with season, in concert with the reproductive cycle (2- to 3-fold increase from winter to spring, despite steady low temperatures). Although the available data allow estimation of kelp food supply rates to feed lots (average of 1.5 g (fresh weight)/50 mm sea urchin/day), locale and season-specific rates must be determined for each case to optimize economics. Experimental trials are also required to determine cost-effective stocking densities and food supply methods (i.e., cut or whole, fresh or pelletized).

Reproduction

Sea urchin reproduction is a well-studied sequence of interrelated events which are controlled both by internal (endogenous) and external (environmental) factors. The gonads are a composite of both sex cells and storage cells. The latter accumulate the nutrients required for the expensive process of producing eggs and sperm and constitute the bulk of the gonad mass in the early stages of gonad growth. The quantity and quality of the stored nutrients (and thus of the resulting gametes and entire gonad for market) are directly related to the food consumed by the sea urchin during the extended process of gonad growth. This stage begins shortly after spawning (between February and May) in green sea urchins of 2.5 to 3 years old. (15) Spawning in this species of sea urchin is triggered by a chemical released by phytoplankton in the spring bloom. (18) The rate and timing of the storage phase of gonad development is thus strongly influenced by the environment, and growth of other tissues slows during this period as most of the assimilated food goes to the gonad. The initiation of the next stage of reproduction (the development of eggs or sperm) is triggered by internal chemicals, but is also influenced by temperature, daylength, and food. It is possible to alter the timing of this stage of reproduction

(and hence, perhaps the whole seasonality of gonad development) in the laboratory by manipulating these factors (e.g., daylength) or by administering hormones. (20,21) The scaling-up of such manipulations to commercial operations has tremendous potential because populations of out-of-phase sea urchins with ripe gonads could be available for harvest all year, rather than only during a 3-4 month period. There are, however, significant impediments to commercial application of these reproductive technologies. Research on reproductive manipulation is urgently required for the development of sea urchin aquaculture.

Mortality

Mortality of sea urchins due to predation, parasitism, pathogenic disease, pollution and poor handling is the major cause of unprofitability in production enhancement operations. Few natural predators have the potential to significantly deplete enhanced green sea urchin populations in Nova Scotian waters. (22) An amoebic infection which caused mass mortalities of natural populations along the Atlantic coast of Nova Scotia in the early 1980s has the potential to completely destroy culture operations in shallow waters during periods of warm sea temperatures. (23) The source of the pathogen is unknown, and no accurate predictions of the recurrence of the disease are available, although they appear to be correlated with warm water incursions onto the Scotian Shelf. Methods of prevention or treatment suitable for commercial populations have not been developed.

Large aggregations of sea urchins and their foods in protected coastal areas used for production enhancement are susceptible to mass mortalities and reduced growth as a result of reductions in water quality. Lowered salinity, reduced oxygen concentration, and perhaps toxic phytoplankton blooms are the most likely threats. Site selection, handling practice and environmental monitoring requires sound management decisions based on locale-specific research in order to minimize damage to the enhanced populations, as well as the surrounding habitat.

Further Directions

The management of green sea urchin production has received little consideration by scien-

tists or policy-makers in Nova Scotia until recently. The capture fishery has been slow to develop in the province in part because the federal regulatory agency has invested little in research, and has inhibited initiative by limiting access to the resource by entrepreneurs with a non-selective license lottery. Landings in the 1993-94 season were less than 100 metric tons (ca. \$100,000), with only a few of the 53 licensees actively fishing (the remainder of the licenses were held in speculation). In the 1995-1996 season, there were 60 licensees fishing and about 1000 metric tons were landed in Nova Scotia. Active licenses comprised just over 50% of the total.

Aquaculture of the species has recently received attention in Newfoundland, where a private company is experimenting with feedlot technologies, encouraged by the provincial government. Similar activities are reportedly underway in New Brunswick, although no written accounts of current activity are available. Aquaculture is a provincial government responsibility in Nova Scotia. The production enhancement methods appropriate to sea urchins often fall somewhere between the capture-culture extremes, and thus span the federal-provincial jurisdictions, further complicating the development of effective production management. There exists a fine opportunity to develop a sea urchin industry in Nova Scotia, which is desperately needed by the beleaguered coastal communities of the province. In this paper we have pointed out the initial directions to follow. Funding for directed research and a plan to allow equitable access to the resource are top priorities.

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- Present address: Caricom Fisheries and Resources Assessment Unit, Tyrell St., Kingstown, St. Vincent and the Grenadines, West Indies

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Calendar

Aquaculture Trondheim '97 and AquaNor, 10-16 August 1997, Trondheim, Norway, EAS Conference and AquaNor, the world's largest aquaculture trade exhibition. Theme: Cultivation of cold water species: production, technology and diversification. A workshop on selections, operation and management of recirculation systems for aquaculture is scheduled to run in conjunction with the conference. Information: EAS, Slijkensesteenweg 4, B-8400 Oostende, Belgium (tel +32 59 32 38 59, fax +32 59 32 10 05; e-mail eas@unicall.be).

Annual Meeting of the American Fisheries Society, 24-28 August 1997, Monterey, California. Theme: *Interfaces*. Meeting will highlight the interconnectiveness of various disciplines, environments, culture, and nations involved with fisheries and aquatic environments. Information: Paul Brouha or Betsy Fritz, AFS, 5410 Grosvenor Lane, Suite 110, Bethesda, Maryland 20814 (tel 301 897-8616).

British Trout Farming Conference, 3-5 September 1997, Sparsholt College, Winchester, England. Topics: oxygenation, implications of exotic fish imports, European Database, feed alternatives, residues legislation, disease legislation and inspection procedures, PKD research in the USA, etc. Information: Shaun Leonard, Dept. Fish, Game & Wild-life, Sparsholt College, Winchester, Hampshire S021 2NF UK (tel 01962-797266, fax 01962-776587).

Practical Short Course on Aquaculture Feed Preparation, Nutrition and Feed Management, 7-12 September 1997, College Station, Texas, USA. A 1-wk course taught by Texas A&M University staff, industry representatives and consultants. Program covers information on designing new feed mills and selecting conveying, drying, grinding, conditioning and feed

mixing equipment. Current practices are reviewed and practical preparation of sinking and floating feeds demonstrated on 4 types of extruders using various shaping dies. For more information, programs and application forms, contact: Dr. M.N. Riaz, Food Protein R&D Center, Texas A&M University, College Station, Texas 77843-2476 (tel 409 845-2741; fax 409 845-2722; E-mail mnriaz@ tamu. edu).

First International Symposium on Stock Enhancement and Sea Ranching, 8-11 September 1997. The World Aquaculture Society Working Group on Stock Enhancement is involved in the planning of this meeting. Special Sessions: Theoretical basis for stock enhancement, Methods/factors influencing success, Measuring success, Impacts of stock enhancement, Management of enhanced stocks, Case studies. Contact PUSH, Bontelabo 2, N-5003 Bergen, Norway (fax +47 55 317395; E-mail borthen@telepost.no; internet: http:/www.imr. no/sear/ hav97.Html). Convener: E. Moksness, Institute of Marine Research, Fldevigen Marine Research Station, N-4817 His, Norway (fax +47 37 05 90 01).

Workshop on Market Access for Seafood, 15-16 September 1997, Toronto. Follow-up to the International Conference on Fish Inspection and Quality Control held in Washington D.C. in May 1996. The meeting is sponsored by the Fisheries Council of Canada, the National Fisheries Institute of the United States, the Canadian Fisg Inspection Agency and others. Information: Fisheries Council of Canada, #806-141 Laurier Avenue West, Ottawa, Ontario K1p 5J3 (fax 613 238-3542).

III International Symposium on Nutritional Strategies and Management of Aquaculture Waste (NSMAW), 2-4 October 1997, Via Real,

Portugal. Sessions: Eutrophication process in fresh and salt waters; Diet formulation and control of solid and soluble wastes; Voluntary feed intake and minimization of feed waste; Feeding systems; Modelling of waste production; Biotechnology to improve feed utilization: Other sources of pollution in aquaculture operations; Waste removal systems in fish farm effluents; Waste management and environmental regulations; Economics in fish farming: interrelationships of price, production and waste. Secretariat: A. Fontaínhas Fernandes, Universidade de Trás-os-Montes e Alto Douro, Apartado 202, 5001 Vila Real Codex, Portugal (tel: 351-59-320230; Fax 351-59-320480; E-mail fontain@utad.pt).

Japanese Society of Fish Pathology, International Symposium on Diseases in Marine Aquaculture, 3-5 October 1997, Hiroshima. Sessions will consist of presentations on viral, bacterial, fungal, protozoan, parasitic and non-infectious diseases of fish and shellfish. Deadline for abstracts: 30 May. Information: Dr. K. Muroga, Faculty Applied Biological Science, Hiroshima University, Kagamiyama 1-4-4, Higashi-hoshima, 739 Japan (tel +824 24 7977; fax +824 22 7059).

3rd International Abalone Symposium, 5-11 October 1997, Monterey, California, USA. Aquaculture, biotechnology, ecology, fisheries management, morphometrics, nutrition, life history, biology. Information: C. Ashley, California Sea Grant, 9500 Gilman Drive, La Jolla, CA USA 92093 (fax 619 534 2231; E-mail cashley@ucsd. edu).

ISTA IV/Aquaculture Engineering Society Annual Meeting (4th International Symposium on Tilapia in Aquaculture) hosted by the Florida Aquaculture Association, 9-12 November 1997. Extensive technical program with special emphasis on commercial production of tilapia and the latest innovations in production system technology; engineering sessions, industry trade show, and tours of production, research and training facilities. Information: Kevin Fitzsimmons, University of Arizona,

2601 E. Airport Drive, Tucson, Arizona 85706 (tel 502 741-1990; fax 520 573-0852; E-mail KevFitz@ag.arizona.edu).

PESCAL (Latin American Fishing and Seafood Exposition), 2-4 December 1997, Centro Costa Saiguero, Buenos Aires, Argentina. Trade exposition and congress serving Latin America's commercial fishing, seafood processing and aquaculture industries. Information: Diversified Expositions, P.O. Box 7437, Portland, Maine USA 04112 (tel 207 842-5500; fax 207 842-5503).

Aquaculture '98, 15-19 February 1998, Las Vegas, USA. International triennial conference and exposition of the World Aquaculture Society, the National Shellfisheries Association and the Fish Culture Section of the American Fisheries Society. Abstracts due 31 July 1997. Contact: Conference Manager, 21710 7th Place West, Bothell, WA 98021 USA (tel 425 485-6682; fax 425 483-6319; e-mail worldaqua @ aol. com).

3rd International Symposium on Aquatic Animal Health, 30 August – 3 September 1998, Renaissance Harborplace Hotel, Baltimore, Maryland, USA. Four days of scientific session, including plenary lectures and contributed oral and poster presentations. Symposium office: Division of Comparative Medicine, Johns Hopkins University School of Medicine, 720 Rutland Avenue, Baltimore MD USA 21205 (tel 410 955-3273; fax 410 550 5068; E-mail wellfish@welchlink.welch. jhu.edu).

Aquaculture Canada '98, 15th annual meeting of the Aquaculture Association of Canada, 31 May-3 June 1998, Delta Hotel, St. John's, Newfoundland. Theme — *Research: An Investment in the Our Future.* Hosted by the Newfoundland Aquaculture Industry Association. Special sessions, technical sessions, trade show and industry tours. Information: Dr. J. Parsons, Aquaculture Unit, Fisheries & Marine Institute, Memorial University, P.O. Box 4920, St. John's, Newfoundland A1C 5R3 (tel 709 778-0307; fax 709 778-0535; E-mail jparsons@gill.ifint.nf. ca).

New Publications and Websites

Controlling the Sex of Salmonids, by G. Feist, C.B. Schreck and A.J. Gharrett. Oregon Sea Grant Publication No. ORESU-H-96-001. Manual is designed to be used by aquaculturists, provides instructions on how to produce all-female, all-male, and sterile populations of fish using a variety of methods. It also includes methods for the storage of eggs and sperm. Oregon Sea Grant Communications, Oregon State University, 402 Kerr Administration Building, Corvallis, Oregon USA 97331. Cost US\$4. per copy plus postage (US orders: \$1.25; Canadian postage: \$1.50; Foreign postage \$3.00).

Ascot International Fish Database has a web site on the Internet that describes the fish database and provides a registration form for producers to enter their respective species. The database was orginally established to provide a registry of tropical fish producers. Because of the reponse received, the database has become a registry of commercial fisheries as well, including food fish, ornamentals and aquatic species in all categories from all environments. Data collected are made available to aquaculture interests and agencies throughout the world. The registry has made it possible for otherwise unknown producers to find a market while improving contacts with other producers. Internet address is http://www.mosquito.com/

International Directory of Fish Technology Institutes. FAO has published a third edition of its International Directory of Fish Technology Institutes. The most noticeable changes reflect the changing political climate of the world and the advancement of communication technology in recent years. Long existing but previously not recorded institutes now emerge onto the world

stage; cable and telex addresses are becoming obsolete and are being replaced by the faster and more efficient fax and e-mail. The Directory is published as FAO Fisheries technical Paper No. 152 Rev. 2 (1997). Proceedings of the Second International Conference on Fish Inspection and Quality Control held in Washington in May 1996 are available in a 800-page book published by Technomic Publications — Fish Inspection, Quality Control and HACCP: A Global Focus. Cost is US\$149.00 plus postage from the National Fisheries Institute, Washington, D.C., USA (tel 703 524-8880; fax 703 524-4619).

A second, updated and enlarged edition of ISO 9000 Quality Managements Systems: Guidelines for Enterprises in Developing Countries was recently published by the International Trade Center (ITC) and the International Organization for Standardisation (ISO). The book is available in English, French or Spanish. Information: Mr. Enrique Sierra, Senior Adviser on Export Quality Management, International Trade Center, UNCTAD/WTO, Palais des Nations, 1211 Geneva 10, Switzerland, Tel: (41-22) 730-0111, Fax: (41-22) 733-4439, Email: itcreg@intracen.org.

Principles od Salmonid Culture, edited by W. Pennell and B.A. Barton. Provides a synthesis of the biology and culture of salmonid fishes. The important practices in salmonid culture as well as the theory behind them is described. Volume will be of interest to students, researchers, fisheries biologists and managers as well as practicing aquaculturists. Elsevier Science, 1996, 1042 pp, hardbound. US\$225. Elsevier Science, P.O. Box 945, New York, NY 10159-0945 USA (tel 212 633-3730; fax 212 633-3680).

AAC Special Publication No. 3

Aquaculture Career and Training Directory

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