

Special Thanks

The scallop aquaculture workshop was generously sponsored by the Department of Fisheries and Oceans — Aquaculture Collaborative Research and Development Program (ACRDP)

Mrs. Caryl A. Parsons designed the 16th IPW workshop logo, which is used throughout these proceedings.



Front cover: Designed by DE Aiken, using the workshop logo and a photograph by Gyda Christophersen of *Pecten maxima* spat.

Back cover: Photograph of the workshop participants by Kelly Bentham, Fisheries and Oceans Canada, Bedford Insitute of Oceanography.

Introduction

The 16th International Pectinid Workshop (IPW) was held in Halifax, Nova Scotia from May 11-18, 2007. This was the second time the IPW was held in Canada and the first time on the east coast of Canada. There were 115 delegates from across Canada and from fourteen other countries all around the world. As part of the IPW, the Department of Fisheries and Oceans (DFO) Aquaculture Collaborative Research and Development Program (ACRDP) sponsored the scallop aquaculture workshop. The Aquaculture Association of Canada (AAC) was also instrumental in providing assistance including logistic support and publishing these proceedings.



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The scallop aquaculture workshop was designed to examine the current status of scallop aquaculture in Canada, highlight current developments on optimising production, examine current challenges and identify research priorities. Selected international speakers were also invited to provide an overview of the status and challenges of scallop aquaculture in other parts of the world. Speakers included scallop growers and researchers from Canada and elsewhere who have been key in addressing some of the challenges of trying to move scallop culture forward. There were fourteen talks given at this special one-day workshop. In addition, there were other technical aquaculture presentations and posters presented during the IPW. These proceedings represent a total of fifteen of these presentations and provide a comprehensive overview of the majority of the Canadian scallop aquaculture production and technology, as well as a broader, global perspective from a number of countries where scallop aquaculture continues to develop. Collectively, these presentations identify research avenues to pursue that can lead to further commercial development of this sector of the aquaculture industry both in Canada and elsewhere.

Lastly, I would like to acknowledge the support of the Maritimes–Gulf DFO ACRDP Committee in providing funding for the workshop (speaker support and the proceedings) and in particular Denise Méthé (regional coordinator). As well, I want to thank the 16th IPW Organizing and Program Committees, the Aquaculture Association of Canada for logistic support (Natalie Hamilton) and producing the proceedings (Susan Waddy) and the support of the AAC Board for their overall support for the workshop.

G. Jay Parsons Chair, 16th IPW



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Halifax, Nova Scotia, Canada 11-18 May 2007

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Small-scale Scallop Farming on Nova Scotia's South Shore

Duncan Bates

The development of scallop aquaculture in eastern Canada has been a long arduous process process that has still not resulted in significant



commercial success. However, the idea is still alive as a handful of resilient operators carry the growth process forward, applying what has been learned from the various pitfalls, attempts, successes and failures of the past twenty or so years.

The presentation on the current state of the industry was done with specific reference to his own farm in Mahone Bay, Nova Scotia. Some topics that were discussed included gear selection/handling/timing, spat collection/supply, invasive pest species, and marketing.

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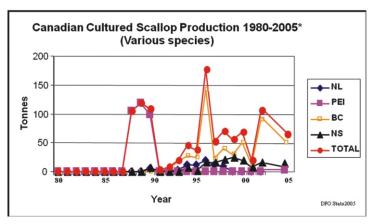
Newfoundland Scallop Farming Experience

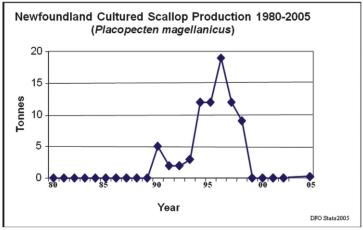
Cyr Couturier

The history of scallop aquaculture in Newfoundland is briefly recounted, including the techniques employed, production levels, and current status and constraints.

Introduction

The island of Newfoundland and its mainland component, Labrador, boast over 17,000 km of pristine, mostly uninhabited coastline. The provincial boundaries range from 47° to 60° N, most of which is within the northern distributional range of the sea scallop, *Placopecten magellanicus*. Sea scallops are found in moderate abundance (0.5 to 1 scallop m²) around the coastal areas of the island portion of the province. However, in the northern portions, beds are far less common and densities are low (< 0.1 scallop m²). The coastal waters are characterised as sub-arctic along the Labrador coast and the northeast portion of the island, includ-





ing annual arctic ice; and northern temperate in climate along the south and west coast of the island, with occasional local ice formation in the winter.

Historical production of farmed scallops in Canada and Newfoundland is shown in Figure 1. Production has been characterised by boom and bust cycles associated with specific events in the history of the industry. In Newfoundland, peak production was 20 tonnes live-weight equivalent in the mid to late 1990s but declined to 0 tonnes by 1999. Production has not resumed to this day.

Figure 1
Canadian and Newfoundland farmed scallop production statistics
[Source: Statistics Canada. Data do not include proprietary information on seabed and suspended culture in the Province of Quebec].

Historical Overview

Efforts to farm scallops commenced as early as the 1960s in Newfoundland and continued for three decades until the end of the 1990s. A chronological outline of milestones in the development of the industry is provided in Table 1. At present, several farms are licensed to produce scallops but none have any animals in the water, due primarily to lack of seed, capital and investor confidence.

Production methods

Production methods were developed to reduce labour and capital costs for each stage of production, from egg to plate. A synopsis of the growing techniques employed is provided in the following paragraphs (the last efforts were abandoned in 2000).

Total cost of production per 90-mm scallop (shell height), from hatchery-produced seed to shucked market meat was in the range of \$0.20 per animal in 2000. Further refinements and cost reductions in seed supply and post-harvest handling were anticipated but never came to fruition due to lack of interest.

Seed supply

Two sources of seed were available to growers, though neither was totally reliable from year to year. The first was wild seed collection employing typical collector arrays of mesh bags filled with various cultch materials (old fishing net,

Table 1
Historical overview of the development of sea scallop culture in Newfoundland and Labrador.
The names of investigators are indicated where applicable.

Date	Milestone					
late 1960s	First spat collection trials undertaken on the south coast of Newfoundland (Evans & Scaplen)					
1975	First larval rearing trials were conducted at Memorial University (Idler et al.)					
late 1970s	Demonstration of biological feasibility of culturing scallops from spat to harvestable size (Naidu)					
1980	First 'commercial' sea scallop farm in the world established in Mortier Bay					
1980s	Spat collection trials conducted at Port-au-Port					
1981-1989	Hatchery and nursery production methods perfected at Memorial University (Dabinett)					
late 1980s	Four commercial scallop farms established					
1992	Patent issued for sea scallop hatchery seed production (Dabinett)					
1992-1994	Spat collection declines to unsustainable levels in Port-au-Port					
1995-2000	Best practices and cost-reduction strategies developed (Couturier & Parsons)					
1996	Commercial sea scallop hatchery built in Belleoram (Dabinett)					
2000	Scallop hatchery closes in Belleoram, as production is inconsistent					
2000	Mass unexplained mortalities at several geographically-isolated sites					
2006	Four licensed farms; no production					

Netron , or other) (Figure 2). The other source was from the purpose-built, commercial sea scallop hatchery at Belleoram, NL, which developed methods to produce 5- to 10-mm seed for approximately \$0.03 per scallop in 2000 (see Figure 2 for photos). Commercial scale trials on remote-setting of eyed sea scallop larvae showed some promise in reducing seed costs by as much as 30 to 35% but were never pursued (Couturier and Parsons, unpublished). The methods developed in the hatchery were state-of-the-art, but issues of capital, lack of buyers, and poor infrastructure meant the hatchery was not commercially sustainable at the time.

Intermediate culture

Intermediate culture from 10 to 50 mm in shell height typically took about one year and was accomplished in either traditional Japanese-style pearl nets or in off-bottom rack and tray systems similar to those developed by the French in the 1970s and enhanced by the Irish and Norwegians in the 1990s (Figure 3). The cost of producing a 50-mm scallop in a rack and tray system is about 50% less than with traditional pearl nets, if one can afford the initial capital investment and find a suitable growing area.

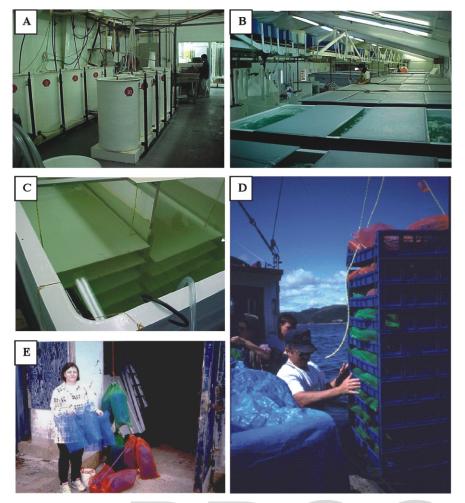


Figure 2
Seed procurement methods
for sea scallops. (A)
broodstock conditioning tanks
(downwelling) at the Belleoram
hatchery, (B) 7,000 L larval
rearing tanks, ©) raceway
panels inserted in larval tanks
at settlement, (D) mesh bag
systems for nursery culture in
the sea (1 to 7 mm), and (E)
spat collection materials
employed for wild seed
collection. [photos A-D courtesy
of Pat Dabinett]

Final growout

Several types of growing equipment were tried, from rack and tray systems, to pearl nets, to suspended mesh bags, and even bottom culture. Time motion analysis trials and cost-benefit calculations showed traditional pearl nets to be competitive, if not superior to most other types of gear for final ongrowing of the sea scallops, particularly if one had access to an experienced workforce and a suitable work platform from which to operate (Parsons et al., unpublished) (Figure 3).

Harvest and marketing

The majority of scallops harvested from farms in Newfoundland were destined for meat or meat and roe-on markets. Local markets began to accept live in-shell "princess" scallops of 60 to 70 mm during the year; however, the short shelf-life of this type of product (2 to 4 days) was a constraint to market development. New products were being investigated at the time commercial production ceased.

Challenges to Future Growth

There is renewed interest in some areas of Newfoundland in experimenting with sea scallop farming. However, the list of constraints facing this industry will need

Figure 3 Various types of intermediate and final growout gear employed for sea scallop cultivation in Newfoundland. A) oyster bag and vinyl-coated mesh, B) rack and tray, C) Savoury cage, D) pearl nets, E) perforated tray, F) final product showing roe-on call. Rack and tray systems (B) were the most cost-effective for intermediate growout, while final ongrowing was most successful with pearl nets (D). [photo F courtesy of Ross Chandler1



to be addressed in order for the industry to be successful. The list includes:

- **Seed supply** There are no commercial sources of seed scallops in Newfoundland at present. Seed suppliers from other provinces do exist but issues related to quality and transfers of seed from one region to another still present a challenge.
- *Capital* A fully commercial sea scallop farm requires a minimum of \$1 million in up-front capital before seeing a return on investment, typically not before year 3 or 4 of the operation. The margins on meats-only appear to be low, probably lower than 10% on the internal rate of return. There is not a lot of patient capital out there.
- **Product type** A product mix of meats, meat and roe, and fresh-frozen in-shell will likely be required to avail of the value-added component. Meats-only compete with the wild harvested products from Asia and North America and the competition is tough! Moreover, serious marketing efforts would be needed, adding costs to any operation.
- *Uncertainty in production* Even today, culturists report massive mortality events in sea scallops grown in suspended culture along the eastern seaboard of North America. Many of the causes of the mortalities are poorly understood, though we have much better information on the optimal growing and husbandry conditions to minimise mortality and enhance growth than was available in the past.

Conclusions

We have learned from over 30 years of trials on sea scallops about what to avoid, so the prognosis for commercial cultivation should be regarded as 'moderate' to 'good'. There is demand for the product which is highly regarded in the market place, but there are major hurdles to be overcome before the industry is truly commercial in Newfoundland and Labrador.

Acknowledgements

The developments in Newfoundland and Labrador have spurred others across Canada and the US to investigate and in some cases undertake commercial sea scallop cultivation. This was due in large part to the pioneering attitude of the Newfoundland industry and university researchers, and all too often their contributions are forgotten. I am grateful to the following Newfoundland 'pioneers' for their efforts in moving the sea scallop industry forward: Sam Naidu, Ron Scaplen, David Idler, John Evans, Terry Mills, Doug and Jennifer Caines, Pat Dabinett, and Marc Lanteigne. In addition, many of our colleagues from off-island have made significant contributions to the development of sea scallop culture in Canada, including Jay Parsons, Mike Dadswell, Thorolf Magnesen, Gyda Christophersen, Neil Bourne, and André Mallet. Their contributions are acknowledged.

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The Scallop Aquaculture Experience in West Arichat, Nova Scotia

Ronald Boudreau and Rodney Fougère

After the collapse of the cod fishery, many fishermen from Nova Scotia still wanted to make a living from harvesting the

oceans. Their first attempt at collecting sea scallop spat was in 1993 off the coast of Cape Breton, Nova Scotia. It took five years to locate an ideal collection site. Since then, Sea Perfect Cultivated Products Ltd., a company based in Arichat, Nova Scotia has been capturing sea scallop spat and selling a high quality spat product (Figure 1). Two thousand spat bags are deployed in Chedabucto Bay every autumn.

Scallop aquaculture has come a long way since the first spat collection, but culture husbandry is still evolving. For example, the scallop spat sorter has greatly improved



Ronald Boudreau

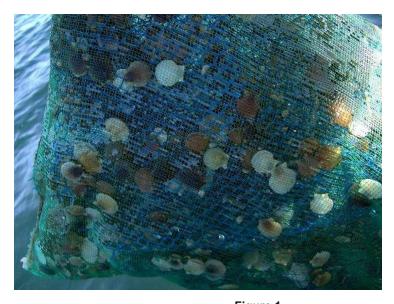


Figure 1
One-year-old scallop
spat in collector bag
deployed in Chedabucto
Bay, Nova Scotia.

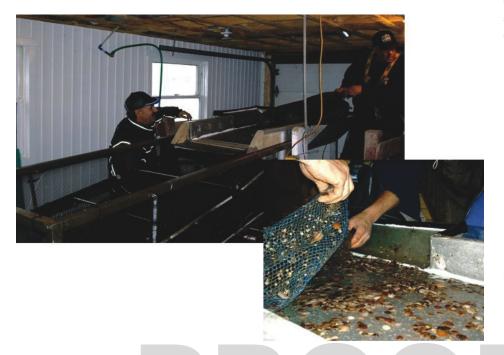


Figure 2 Scallop spat sorter manufactured by Sea Perfect Cultivated Product Ltd.

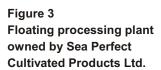
the efficiency of handling large quantities of spat when preparing them for sale (Figure 2).

Demand for spat has been increasing. In 2005, a scallop culture company from St. Pierre and Miquelon, France, purchased most of the company's available spat and expressed a need for up to 15 million spat the following year. So in 2006, 10,000 collectors were deployed to meet their requirements. In 2007, a company from Portland, Maine, USA, purchased a million spat. An aboriginal group from Vancouver, which holds an oyster lease, feels their site is suitable for culturing sea scallops and have expressed an interest in purchasing one million spat. A recent spat request has also been received from China.

Although Sea Perfect Cultivated Products Ltd. has specialised in selling sea scallop spat, the company is also actively seeking and exploring other markets. They have been approached by a shellfish broker to provide whole scallops (> 76 mm) and scallops on the half shell. To meet this demand, they must develop a processing protocol that meets the requirements of the Canadian Food Inspection Agency (CFIA) and obtain a fish processor license. The protocol is being written and changes are being made to the floating plant so that it meets the requirements for certification as a processing plant. Once the work is completed, the company will have the only floating plant in eastern Canada (Figure 3).

Authors

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Innovative Approach Enabled Pecten UPM/MFU Inc. to Transfer Japanese Scallop Culture Technology to New Brunswick

Bruno Frenette

Pecten UPM/MFU Inc. is a nonprofit organization working with three local fishermen's corporations under the management of the Maritime Fishermen's Union. Research and development activities are conducted under scientific permits. In 1997, scallop enhancement activities were initiated (Phase I) and in 2004 a study began on open-water scallop culture (Phase II).

The Japanese are pioneers in scallop enhancement and aquaculture, and their techniques have been adopted by growers in several countries. Pecten UPM/MFU Inc. has been experimenting with Japanese culture techniques on the coast of New Brunswick and found the techniques needed to be modified for local conditions. The dynamics of the open-water environment necessitated changes in the longline structure, especially the anchoring system. The cement anchors used initially (1997–1998) failed to keep the longlines in place during storms and they became seriously tangled. The use of screw anchors was investigated in 1999–2000, but unfortunately they did not meet the requirements either. In 2001, heavy anchors (115 kg) were constructed of old railroad ties. They proved to be very effective and have been in use ever since.

Pecten UPM/MFU Inc. collects scallop spat from the wild using Japanese collector bags containing NetronTM mesh. Comparative studies were conducted to determine the most economical gear. Frayed rope ('fuzzy rope'), which is often used for collecting mussel spat, collected scallop spat as well as the Japanese collector bags. Also, it was discovered that using two pieces of NetronTM mesh in each collector bag was as effective as using three pieces of mesh.

During enhancement activities, collectors were retrieved and cleaned on the boat. Prior to 2005, the contents of the bags were emptied directly into a

Table 1 Type of scallop culture gear investigated and their respective surface growing areas.							
Cage type	Growing surface per unit	Number of replicates per unit	Total growing surface per unit				
Pearl net (4-mm)	0.116 m ²	10	1.16 m ²				
Lantern net (9-mm)	0.196 m ²	10	1.96 m ²				
Suspended cages + Vexar TM bags with 4-mm, or 9-mm-mesh	0.403 m ²	5	2.02 m ²				
Bottom tables + Vexar [™] bags with 4-mm, or 9-mm-mesh	0.403 m ²	8	3.22 m ²				

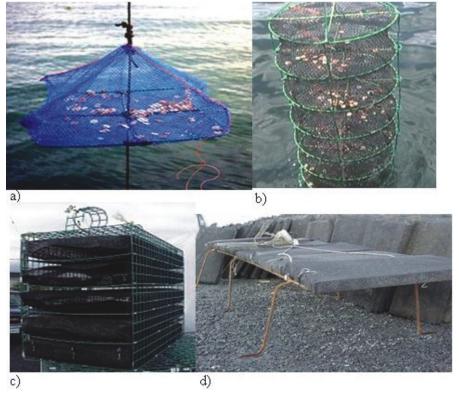


Figure 1
Culture gear that were assessed:
a) Pearl nets, b) Lantern nets,
c) Suspended cages with Vexar™
bags, and d) Bottom tables with
Vexar™ bags.

Figure 2
Pekten lantern net created by
Pecten UPM/MFU Inc.



XacticTM tank (fish tub) supplied with running seawater. The predators (sea star and crabs) were removed and the contents were later shoveled over the selected scallop bed. However, any scallops at the bottom of the fish tub were stressed by the accumulated silt. In 2005, a wire mesh basket was constructed and placed in the tank to contain the spat. The mesh size was small enough to retain the spat but allow the silt to pass through. Since the basket is not as deep as the tank. the silt falls to the bottom of the tank. To seed the scallops, the basket is removed and its contents emptied overboard.

Growth and survival of scallops cultured in various types of gear were monitored (Table 1). The study involved traditional Japanese pearl nets and lantern nets, and two types of gear that held oyster culture bags (VexarTM bags). The VexarTM bags were placed either in suspended cages made with AquameshTM (plastic covered wire mesh) or on bottom tables made with RebarTM (Figure 1).

The bottom tables were not stable and their use was quickly abandoned.

The lantern nets and suspended cages with VexarTM bags were the most effective. While working with these gear types, Pecten UPM/MFU Inc. personnel were inspired to create a new type of suspended gear that was named the Pekten Lantern. It consisted of a series of 10 VexarTM bags linked together with rope and reinforced with AquameshTM (Figure 2). This innovative gear is presently being evaluated and hopefully will contribute to an effective scallop aquaculture operation.

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Scallop Gear Development Project in Prince Edward Island

Ron MacLean

Fishermen interested in diversifying to aquaculture have initiated a project to design innovative cages for the bottom culture of scallops.

Introduction

A group of 41 fishermen from eastern Prince Edward Island (PEI) formed a corporation called 'Northumberland Strait Diversification Sea Scallop Research Group'. Their mission statement is to work with a variety of organisations, government departments, fish harvesters, etc., on research projects and other matters to diversify opportunities for scallop fishermen in eastern Northumberland Strait. The first project they initiated was to develop innovative scallop culture gear.

From 2000 to 2002, New Brunswick scallop fishermen from the Botsford Professional Fishermen's Association (BPFA) experimented with large bottom cages designed and used by scallop fishermen in Hillsburn Basin, Nova Scotia. The BPFA study site was located in the Northumberland Strait, 20 km north of the Confederation Bridge. When the cages were properly placed on the bottom, survival and growth of the scallops were encouraging. Conversely, if the cages were not lowered carefully, they had a tendency to tip over which was detrimental to the scallops. In 2003, BPFA deployed three new cages designed and constructed specifically to prevent this problem. The new designs were more stable, but additional studies are required to determine the ideal design. It was concluded that cages should be constructed so that the last compartment is at least 15 to 20 cm (6 to 8 in) off the bottom and compartments should be spaced 8 to 10 cm (3 to 4 in) apart.

These stable and low maintenance cages greatly interested the scallop fishermen. Many of the fishermen are welders and have the tools to construct cages suitable for their area. They applied for and have received funding to design the ideal bottom cage and to investigate the feasibility of culturing scallops on the east coast of PEI.

Materials and Methods

The first design will be similar to the large cage design utilised by the BPFA. The cage is made with AquameshTM (plastic covered wire mesh) with VexarTM bags (black plastic mesh oyster bags) inserted into the compartments. An angle



Figure 1
Experimental scallop culture bottom cage.



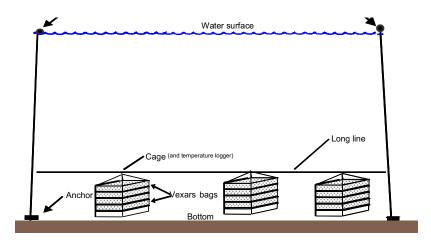


Figure 2
Potential set-up for anchoring the cages.

iron frame will be constructed around the cage to give it additional strength (Figure 1).

The depth of the selected site will be determined and scuba divers will use video cameras to document the bottom type and epifauna.

Sea scallop spat will be purchased in the autumn. If spat must be obtained from outside the region, a request to transfer spat will be sent to the Introduction and Transfer Committee of the Department of Fisheries and

Oceans. The average shell height of the spat will be determined before they are placed in the VexarTM bags. Approximately 200 spat will be put in each bag that is placed in the three "BFPA-type" cages. A temperature recorder will be attached to the cage. Each cage will be placed on the bottom with an anchor.

In the spring and the autumn of the second and third years, scuba divers will use video cameras to document the epifauna on the cages and the habitat near the cages. The cages will be lifted and the scallops examined to determine survival and growth rates. A sample of the scallops will be retained for laboratory measurements, including shell height, shell weight, shell depth, total weight, gonad weight, meat weight, visceral weight, and shell weight. The temperature recorders will be retrieved and the data downloaded. The cages will be cleaned and repaired if necessary, and the temperature recorders will be replaced. The scallops will be returned to the cages and the cages will be returned to the bottom.

After the first year, the fishermen may be inspired to create other designs. If so, they will build additional cages during the summer. Cages must be able to be easily handled on their boats. New design(s) will be sent to a consulting engineer who will review the design to predict the stability and water flow in and around the cage. Three replicates of at least three designs will be built and tested at the selected site.

In the second autumn, additional spat will be purchased for the new cages. If two age-classes (1- and 2-year-olds) are available, six cages of each design will be placed at a selected site: 3 cages with 1-year-old scallops and 3 cages with 2-year-old scallops. To ensure the gear remains in position in the strong currents and wave action in the open sea, the cages must be anchored or tied to a long-line with sturdy anchors (250 lb = 114 kg) (Figure 2).

Under the guidance of a UPEI professor, the environmental impact of the cages will be monitored by a student. Fishermen and divers will assist the student in obtaining samples, environmental data, and video of the cages and study site area.

Discussion

The fishing community has been very interested in this project. Bottom cages provide the potential for culturing scallops in open water and permitting fishermen to continue their regular fishing activity. There is also the possibility that the cages could create their own 'ecosystem' and act as a temporary artificial reef for lobsters and other bottom-dwelling species.

Author

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Pec-Nord's Scallop Farming Activities and Future Challenges

Jean Côté and Paul-Aimé Joncas

Pec-Nord is a scallop aquaculture company that was established on the Lower North Shore of the province of Québec at the end of the 1980s. The first years exclusively involved R&D projects on the sea scallop to gather information on its biology and culture. Even though all the production problems were not solved, in 2001 the company started to sell live sea scallops in the shell and has continued production since then. Today, the greatest effort is dedicated to finding new and innovative ways to market our cultured scallop; the 'Scallop Cévichés' is a result of that approach.



Jean Côté

Background

During a trip to Japan in the mid 1980s, Dr. Paul-Aimé Joncas was impressed by the accomplishments of the Japanese, who are world leaders in scallop fisheries and culturing their native species *Patinopecten yessoensis*. At the time, scallop farming was still in its infancy in Québec and other parts of eastern Canada, whereas scallops have been cultured in Japan since 1930. Dr. Joncas thought aquaculture of the giant scallop, *Placopecten magellanicus*, had similar potential on the Lower North Shore of Québec and he started a small experimental farm. With a name such as 'Anse Scallop' and a history of scallop fishing in the 1960s, the Baie de Jacques-Cartier appeared to be a very suitable site and it was leased for scallop culture. Thus, Pec-Nord—a scallop aquaculture company established on the Lower North Shore of the province of Québec—was born.

The company was initially involved in R&D projects to develop and adapt methods for scallop culture based on the Japanese experience. Key relationships were established with other aquaculture companies, as well as with many researchers from several government institutes and universities. This networking has been an important part of Pec-Nord's success over the years. The first objective of these projects was to ensure a reliable source of spat. We then examined different aspects of the general biology of the giant scallops, such as its reproductive cycle and the success of settlement in different areas of the bay, as well as various methods to

Figure 1 Standard collectors used to collect spat from the wild.





Figure 2
Pearl nets used in the grow-out phase of culturing scallops in suspension culture on long lines.

Figure 3

Adult scallop broodstock used in a broodstock selection program for hatchery-reared spat production.



catch spat in the wild (Figure 1).

As soon as scallop spat were available, other R&D projects examined the different methods to culture them to juvenile size. The traditional pyramidal or conical pearl net was used for intermediate suspension culture and experiments examined the different factors that could affect growth and survival of cultured scallops, such as density, mesh size, or depth of immersion (Figure 2). The possibility of growing scallops by seeding them on the bottom was also examined. We studied factors such as size at seeding, date of seeding, identification of predators and methods to reduce their impact, and suitable sites offering

a better substrate and less potential for dispersion.

In the mid 1990s, Pec-Nord summarised the data collected from each step of the scallop production cycle. We concluded that suspension culture could be achieved successfully in suspended pearl nets with satisfactory growth and survival, and that bottom seeding had potential as a way of growing scallops to a larger size, although survival was more variable. However, one significant problem persisted: spat collection was unpredictable and generally too low to sustain development of a viable scallop farm on the Lower North Shore. In 1995, Pec-Nord addressed the problem by building a hatchery to produce a steady supply of spat in sufficient quantities. Over the last 12 years, the company has been able to increase larval survival and growth, as well as the reliability of production in both

the hatchery and nursery. Also, domestication of the species was started through genetic selection and the development of methods to reduce production costs (Figure 3). The hatchery has produced spat every year, but more research is needed to achieve highly reliable production and sufficient numbers of spat.

Current Approach to Scallop Aquaculture

Today, most of the scallop spat comes from hatchery production but, if needed, Pec-Nord obtains seed through its partnerships with other scallop producers who collect spat in the wild. Hatchery-produced spat, settled on collectors, undergo a nursery stage in a controlled environment or directly in nature. After a period of 3 to 4 months, spat are harvested from collectors and put in pearl nets suspended on long lines submerged at the site. After a year of culture, nets are removed and juvenile scallops size-graded. Although this process is quite labour-intensive, this handling is essential to avoid excessive fouling on the nets, decreased growth and increased mortality. Grow-out of the scallops is continued in suspension culture, using pearl nets or lantern nets, until commercial size (= 50 mm) is attained at the age of 3 years. At this time, if they are not harvested for sale, scallops can be cultured in various structures for their final grow-out. Pearl nets, lantern nets, pocket nets or ear-hanging are all alternatives that can be used. Each one has advantages and problems; the choice will depend on the characteristics of the site (e.g., depth), the equipment and the method used (mechanised or manual) and also the targeted market (muscle meat only, live in the shell). On a smaller experimental scale, bottom culture is also used and scallops are directly seeded on suitable bottoms within the lease.

The Challenge: Marketing Cultured Scallops

Once scallops have reached a marketable size, new challenges, questions and costs arise. There are several possible markets for scallops. The traditional market for wild-caught scallops is as shucked meat, sold either fresh or frozen. Farmed scallops can be sold on that market, but then the aquaculture product is competing directly with the product from the commercial fishery, is vulnerable to price fluctuations and, most importantly, requires a longer period of time to grow scallops to a size to be harvested for meat only. This is a significant constraint since a longer grow-out period means higher capital and labour costs. That is why Pec-Nord is looking at other potential markets and devotes most of its energy to marketing issues. That's where the challenges lie for the future of our young industry.

A first possibility for a new market is one in which larvae, spat or juveniles are sold to other shellfish producers and scientists. This is, however, a small market with unpredictable demand on which no business could survive. The other possibility is the 'innovative'

market, a market that includes selling live scallops in the shell at a smaller size, or to process scallops and sell them on the half-shell or as roe-on scallops (fresh or frozen). Pec-Nord makes the most of this market and since 2001, the company has worked hard to develop a market for live sea scallops. In the last 7 years, we have maintained close relationships with prestigious chefs in several hotels and restaurants and supplied them year-round with scallops at sizes ranging from 50 to 90 mm.

There are advantages to developing this innovative market,

Figure 4

'Scallop Cévichés' is a traditional preparation of marinated raw fish adapted to make an attractive scallop appetizer served in its natural shell.



but at the present time it is more costly than profitable to sell live sea scallops. The live market requires that clients be educated and provided with lots of information on the product. It is also important to develop ways to prepare, cook and taste this product, which is unknown to most people except the chefs. That's why Pec-Nord's mission is 'To reveal the sea and its flavours'. Also, there is a significant problem related to the short shelf life of live sea scallops. Depending on their reproductive cycle, the site where they are cultured, the season they are harvested and the way they are handled, the shelf life can range from only 1 day up to 4 days, a short period of time often spent in shipping and transportation, not in the hands of the end client. While Pec-Nord has set exceptional quality standards to satisfy its many clients, there are still many unanswered questions for which we do not have the answers needed to further improve this product.

In a continuing effort to innovate and market our aquaculture-produced scallops, Pec-Nord has developed over the last 3 years another product, the 'Scallop Cévichés' (Figure 4). We used the concept of the céviché, which is a traditional preparation of marinated raw fish, and adapted it to make attractive scallop appetizers served in their natural shells. In 2007, Pec-Nord's Scallop Cévichés won the second prize of the Novitas contest, an international event held at the Montreal SIAL (Salon International de l'Alimentation) that recognizes the most innovative products offering exceptional nutritive value.

Summary

Pec-Nord, the small company from the 1980s, has grown considerably during the 1990s to become a larger company that has acquired significant knowledge on the sea scallop, its biology and different methods of aquaculture production. Today, the company employs nine full-time and up to 30 seasonal, highly competent workers for the various parts of its development, from management to accounting, and from scallop production to sales and marketing. The sea scallop is the principal shellfish cultured and sold, but the company has evolved and other shellfish such as abalone, American oysters and quahog clams produced in aquaculture in the eastern part of Canada are also distributed to its clients.

The first experiments with scallop farming in Canada were done as early as the 1970s, but scallop aquaculture really started in the early 1990s. Pec-Nord believes that even after all these years of development, scallop aquaculture in Canada is only beginning, far behind other animal production. In a global economy where competition might come from Asia or South America, where production costs are rising and profit diminishing, one can only survive through innovation. Therefore Pec-Nord invests an important part of its resources in R&D, continues to create various partnerships in Canada and around the world, and develops expertise in marketing and selling aquaculture-produced giant scallops as well as other shellfish. Scallop farming remains a very risky, unpredictable venture and to succeed and stay in business, one must be a true believer.

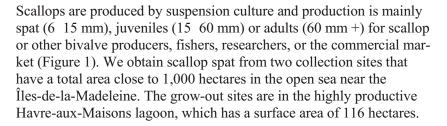
Authors

Paul-Aimé Joncas, MD, the president and founder of Pec-Nord inc., is a medical doctor who has a B.Sc. in engineering and is a businessman involved in several companies. **Jean Côté** M.Sc., is a marine biologist involved in scallop aquaculture for the past 20 years and has been the R&D director of Pec-Nord inc. since 1994. They can be reached at 2800, St-Jean-Baptiste, Suite 230, Québec, QC, Canada G2E 6J5 or by email at info@pec-Nord.com.

Culti-mer inc. — a Brand New Experimental Scallop Production Company!

Mélanie Bourgeois and Sylvain Vigneau

Culti-mer inc., a scallop (*Placopecten magellanicus*) production company created in 2006, is located in Quebec, Canada—specifically in Îles-de-la-Madeleine, a small set of islands in the middle of the Gulf of St. Lawrence. The company is the successor of Pétoncles 2000, a scallop production company that was active in Îles-de-la-Madeleine for 10 years. Culti-mer inc. is comprised of four ex-employees of Pétoncles 2000 who wanted to invest in the continuation of scallop production in the Îles-de-la-Madeleine and save the jobs linked with this activity in the community. We are the only scallop producer on the islands and currently employ more than 20 people.



The production cycle starts with the immersion of spat collector bags three to five weeks after the scallops spawn, which takes place in August. We have a licence to immerse 25,000 collector bags—the bags are compressed for easier transportation and more rapid installation. They are attached to longlines fixed with Japanese anchors to a sandy-bottom site near a protected scallop area. The collector bags are retrieved after nearly one year of immersion. Material is removed from the collector bags using two shaker machines. Afterwards, the scallops are mechanically sorted by a sorting machine coupled with an air-pump conveyor. This machine is very effective; but if there is high mortality in some of the bags of any of the species collected, or there is a high incidence of hydrozoans in or on the collectors, the sorting machine is less effective and sorting must be finished by hand. Spat sorting is done from September to December.

During our first year, we tested a new growing strategy that consisted of retrieving collector bags from July or early August onwards. The resulting small scallops required a short growing period at high density before reaching a minimal shell height of 6 mm. The scallops were placed in pearl-nets installed in the lagoon. After 1-month, the scallops



Mélanie Bourgeois

were retrieved and the nets cleaned. The scallop density in the pearl-nets or in lantern-nets was decreased twice before the shell height reached a desired height of 70 mm for ear-hanging operations (Figure 2). There are four stocks in production on the growing site at the same time.

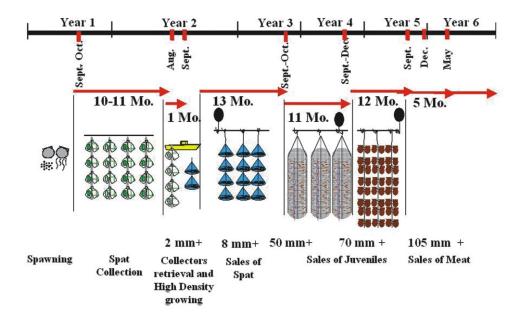
Most of our operations are conducted during the autumn, because the grow-out site is located near a mussel site. If operations were done in the spring, it would result in mussel spat collection (fouling). It is also the reason why we want to use the ear-hanging method for a maximum of 18 months.

Since 2008, we have produced and marketed scallop meat and scallops in the shell (50 100 mm) (princess scallop). New scallop products are also in development for 2009. In the future, we hope to diversify production with another bivalve species.

We also want to be a resource for mariculture development by acting as consultants for companies involved in giant scallop production, and are interested in collaborating on scientific research. Most of our operations are mechanised—fabricating collectors, installing and retrieving collectors, sorting spat, retrieving pearl-nets, retrieving scallops from pearl-nets, and cleaning pearl-nets—but we want to mechanise all operations. Research and development is needed to reach our objectives. Some current projects and those to come, mainly in collaboration with the Centre maricole des Îles-de-la-Madeleine, may help us and other producers address the following priorities:

Figure 1
Giant scallop
production cycle.

PRODUCTION CYCLE



- Optimise the mechanisation of spat sorting;
- Optimise the survival and growth of scallops during the first year;
- Mechanise the sorting and cleaning of juveniles into groups of different shell sizes after growout in pearl-nets, lantern-nets and ear-hanging;
- Utilise lantern-nets for the final growing step before ear-hanging, and mechanise scallop retrieval and sorting;
- Determine the seasonal difference in fouling of scallops grown by ear-hanging and the best time to deploy and harvest the scallops to minimize fouling;
- Utilise a fully-automatic drilling machine;
- Mechanise ear-hanging, cleaning and retrieval;
- Mechanise cleaning and sorting of harvested scallops;
- Optimize scallop winter harvest under ice cover;
- Mechanise shucking.

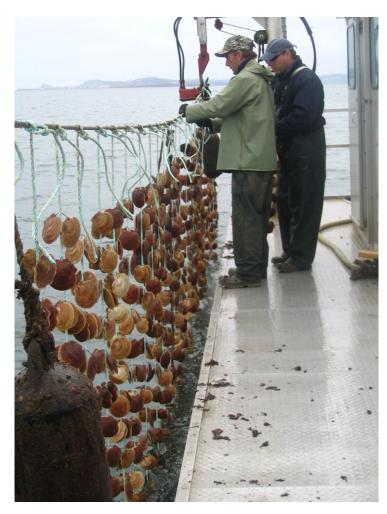


Figure 2 Ear-hanging of scallops.

Authors

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Georges Cliche

Evaluation of Different Parameters to Optimize the Collection Strategy of the Sea Scallop (*Placopecten magellanicus*) in Commercial Operations

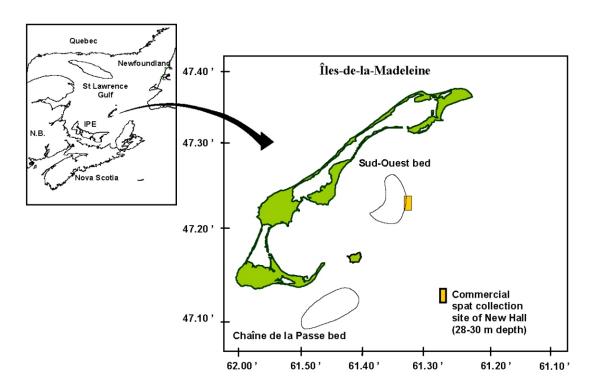
Georges Cliche, Carole Cyr, Denyse Hébert and Mélanie Bourgeois

Fine tuning the commercial strategy for collecting sea scallop spat requires evaluation of the many parameters that could affect the success and cost of acquiring spat. In the framework of commercial collection in Îles-de-la-Madeleine (Québec, Canada), we evaluated some of these factors to determine their effect on the collection of scallops and undesirable species. Compaction of collectors to facilitate transport to collection sites did not affect performance. Success of scallop collection was similar among collectors that contained 2, 3 or 4 sections of Netron substrate, as were collection rates in collectors with new Netron substrate and those with old substrate (whether cleaned or not). However, the use of new Netron resulted in significantly lower numbers of hiatellas (Hiatella arctica). In some years, the very high abundance of this undesirable species greatly slows spat sorting operations. Finally, reducing the number of collectors on the longlines from 960 to 800 did not eliminate the problem of the longlines becoming overloaded and the collectors sinking to the bottom.

Introduction

Fine tuning the strategy used for the collection of sea scallop spat requires evaluating the parameters that affect collection success and cost. In Îles-de-la-Madeleine, scallop spat have been commercially collected since 1995. Many research projects have been undertaken to identify the parameters that affect spat collection. In commercial operations, the aim is to develop a strategy that optimises each step of the operation, including immersion of collectors, checking the longlines, recovery and cleaning of the collectors, etc. In 2005, a research project was initiated that aimed to evaluate some of the parameters that affect the commercial spat collection of the company Pétoncles 2000. Until 2006, this company immersed up to 50,000 collectors annually to ensure an adequate supply of spat. The company wanted to know:

- 1. If the new Netron substrate was more effective than the traditional substrate, and if the old substrate had to be cleaned carefully after the spat had been recovered.
- 2. If compression of collectors to facilitate transport to collection sites affects spat collection.
- 3. If a reduction in the number of collectors attached to each longline, or a



reduction in the quantity of substrate in the collector, could reduce the loss of scallops that occurs if the longline becomes overloaded and sinks to the sea bottom, which often happens about a year after immersion of the collectors.

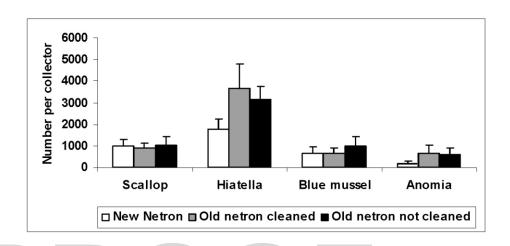
Materials and Methods

This experiment was conducted at the commercial spat collection site of the company Pétoncles 2000 (Figure 1). The collectors were immersed in the autumn of 2005 on

the company's longlines. The depth of water on the site varied between 25 and 30 m. The longlines were deployed 8 m off the bottom and the collectors occupied the portion of the water column ranging from 3 to 8 m from the bottom. The spat collectors were made of 2-mm mesh bags, each filled with 4 tubular Netron sections

Figure 1
Location of the commercial spat
collection site of New Hall (experimental
site) and scallop fishing grounds of
Sud- Ouest and Chaîne de la Passe in
Îles-de- la-Madeleine.

Figure 2
Number of organisms (mean ± s.e.)
found on collectors one year after deployment. Collectors contained new
Netron , old clean Netron or old
Netron that had not been cleaned.



that were 40×80 cm. The experimental longlines supported 800 collectors, but all the other longlines carried 960 collectors. In the experiment that compared the use of old and new Netron $\,$, the old substrate had previously been used in collectors for at least a year. Compaction of collectors was done manually and reduced the collector volume by approximately 80%. The experimental collectors were recovered during the autumn of 2006, cleaned, and analysed individually. Representative samples of scallops and associated species were counted and measured. As it was very important to develop a production strategy that could be used by the industry, a commercial scallop grower was associated with all steps of the experimental project.

Results

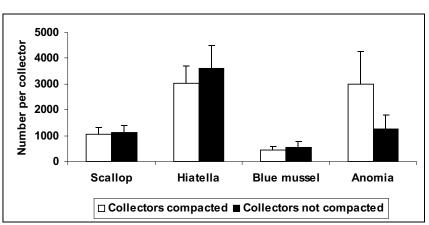
Type of substrate

Collection rates of scallops varied between 902 and 1,053 scallops/collector and did not differ significantly among the three treatments (Figure 2). However, there was a significant difference in the collection of two associated species: hiatella (*Hiatella arctica*) and anomia (*Anomia* spp.). New Netron collected significantly fewer of these species than old Netron whether the substrate had been cleaned or not. With new Netron the numbers of hiatellas and anomies per collector were 1,763 and 161, respectively, compared with 3,687 and 631 with old, cleaned Netron and 3,172 and 594 with old Netron that had not been cleaned. Collection rates of blue mussel (*Mytilus edulis*) and starfish (*Asterias vulgaris*) did not differ among the treatments.

Compaction of collectors

Rates of scallop collection did not differ significantly between collectors that had been compacted (1,040 scallops/collector) and those that were not compacted (1,132 scallops/collector) (Figure 3). Collection rates of hiatellas, blue mussels

Figure 3
Comparison, after one year of deployment, of the number of organisms (mean ± s.e.) found on collectors that had been compacted for transport and collectors that had not been compacted.



and starfishes also did not differ. Collection of *Anomia* spp., however, was significantly lower in collectors that had not been compacted (1,273) than in the compacted collectors (3,000). At the time the study was done, Pétoncles 2000 was already compacting its collectors and our results showed this is a good strategy. Furthermore, even though anomias were more abundant on compacted collectors, it was not really a problem since these organ-

isms are very small and easily eliminated by the mechanical sorting machine.

Quantity of Netron substrate

There was no significant difference between the collection rates of scallops and associated species in collectors with 2, 3 or 4 sections of Netron (Figure 4). The numbers of scallops per collector were 924 ± 279 , 994 ± 301 and $1,146 \pm 312$ scal-

lops, respectively. In the past, 4 sections of Netron were used for each collector. Last year, Culti-mer, a new company involved in scallop culture since 2006, used only 3 sections of substrate per collector. Our results showed this was a good decision and that they could possibly use only 2 sections per collector to further reduce production costs.

Number of collectors on the longlines

It was not possible to conclude if reducing the weight on the longlines by installing only 800 collectors instead of 960 would prevent the longlines from sinking to the sea bottom. Collections rates in the collectors closest to the bottom were comparable on longlines that had 960 and 800 collectors. Observations made by scuba divers shortly before the collectors were recovered showed that each experimental longline had several collectors lying on the bottom. In November 2006, a year after the collectors were deployed, collection rates were not significantly different for collectors that had sunk to the bottom and the ones still suspended in the water column.

Discussion and Conclusions

Type of substrate

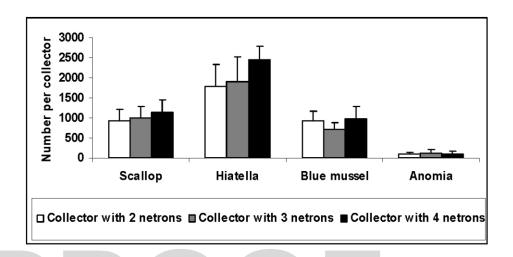
Even if new substrate collects significantly fewer hiatellas and anomias, it does not justify the yearly replacement of all the old substrate, since the retrieval rates of scallops were not any different. However, since an abundance of hiatellas slows down sorting operations markedly, producers could annually replace a part of the old Netron with new Netron to accelerate sorting of a portion of the collectors. The use of substrate that has not been cleaned is an interesting alternative. Since the efficiency of collectors with old substrate was the same, regardless of whether the substrate was clean or not, Culti-mer could eliminate cleaning without reducing the efficiency of collectors and thus realise substantial savings in manpower cost.

Compaction of collectors

Collectors are deployed in the autumn, at a time of the year when the water is often rough. The optimal time period to deploy collectors is relatively short, one to

two weeks. The boat trip to the collection site is one and a half to two hours, so it is very important for scallop growers to bring as many collectors as possible on each trip. Compaction of collectors allows an 80% reduction in volume and permits the growers to immerse up to 10,000 collectors in one day. Since com-

Figure 4
Number of organisms
(mean ± s.e.) found on
collectors, one year after
deployment, that
contained either 2, 3 or 4
sections of Netron



paction did not affect the number of scallops recovered, producers are already using this strategy for their commercial operations.

Quantity of Netron substrate

Surprisingly, collectors with only 2 sections of substrate were as effective as those containing 3 or 4 sections. These results differ from those obtained by Giguère et al. (1) in the Magdalen Islands in 1993. In their study, collectors with 5 or 7 sections of substrate collected significantly more scallops than those with 3 sections of Netron .

By reducing the quantity of substrate, scallop producers reduced collection costs and, in the end, the cost of producing juvenile scallops. Presently, 3 sections of substrate are used in commercial operations and eventually 2 sections could be used.

Number of collectors on the longlines

The results do not allow us to conclude whether a reduction in the number of collectors per longline (from 960 to 800) will prevent the collectors from sinking to the bottom. In this study, the collectors had probably sunk recently and mortality of the scallops in the collectors had not yet occurred. In 2005, collection rates of scallops and other species found in commercial collectors were the lowest they had been in five years. The reduction in the number and weight of organisms, probably meant that the collectors were on the bottom for a shorter period of time, which reduced the mortality. Scuba divers observed large quantities of mussels attached to the ropes and buoys, greatly increasing the weight. This is probably the reason why the longlines with 800 collectors sank to the sea bottom.

Other studies will have to be done, since the loss of scallop spat when collectors are in contact with the bottom for extended periods can be as high as 50% of the spat that were present in the collectors 2 to 3 months before retrieval.

Acknowledgements

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Monitoring Weekly Spat Collection to Predict the Optimal Deployment Period of Sea Scallop (*Placopecten magellanicus*) Collectors

Carole Cyr and Georges Cliche

Studies were carried out between 2003 and 2006 in the Îles-de-la-Madeleine (Québec, Canada) near commercial scallop spat collection sites to evaluate whether monitoring spawning and spat settlement would allow prediction of the optimal period for collector deployment. The goal was to reduce the abundance of undesirable species while maintaining a high collection of scallop spat. The results of weekly monitoring indicated that scallop growers should: i) delay collector deployment if the first peaks in the settlement of hiatellas and mussels occur before the peak settlement of scallops, and ii) extend the deployment season if the weekly collection of scallops is still good. Monitoring the gonadosomatic index (GSI) precisely determined when spawning occurs. In 2005 and 2006, a partial spawning (GSI dropped by 8%) occurred two to three weeks before the complete spawning. Results obtained from weekly collections indicated that the best time to deploy collectors was usually between the fifth and seventh week after initiation of spawning. Weekly monitoring of spat collection and monitoring the gonadosomatic index are the two main tools for determining the optimal period to deploy collectors. Monitoring the cumulative collection of spat on collectors deployed for various lengths of time was used to demonstrate the effect of the deployment period on the quality of the scallop collection.

Introduction

Undesirable organisms such as *Hiatella arctica*, *Mytilus edulis*, *Anomia* spp., *Asterias vulgaris* can settle in scallop collectors. These organisms can slow sea scallop (*Placopecten magellanicus*) growth (competition for food and space) and/or increase mortality (predation and packing). When abundant, these undesirable organisms add extra weight to the longlines, decreasing their buoyancy. In some cases, collectors end up on the sea bottom where they can be damaged by chafing, allowing scallops to escape or be eaten by benthic predators (crabs and sea stars). Also, handling and cleaning of collectors are impeded by the presence of these organisms and labour costs increase. All these constraints reduce the profitability of the aquaculture operations. (1)

Studies were conducted to evaluate if weekly monitoring of the collection of scallops and undesirable species would enable growers to predict the best time to deploy collectors, in order to reduce the incidence of undesirable organisms while maintaining an abundant collection of scallop spat.



Carole Cyr

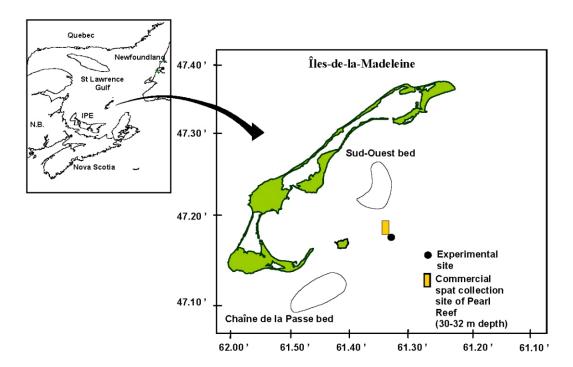


Figure 1
Location of the experimental site used for scallop spat collection, the commercial spat collection site of Pearl Reef, and the scallop fishing grounds of Sud-Ouest and Chaîne de la Passe in Îles-de-la-Madeleine.

Material and Methods

Study area

Experimental studies were conducted between 2003 and 2006 in open waters off the Îles-de-la-Madeleine in the southern Gulf of St. Lawrence (Canada) near the spat collection site used by the scallop growers on Pearl Reef (water depth: 30 to 32 m) (Figure 1).

Scallop spawning

Time of spawning was determined by monitoring the gonadosomatic index (GSI). Weekly samples of 20 adult scallops (length 90 mm) were collected by dredging at a depth of 28 to 30 m, between the end of July and mid-September on the Sud-Ouest bed. GSI was calculated as the percent ratio of the gonad (wet weight) relative to the remaining soft parts (wet weight):

$$GSI = \frac{Gonad (wet weight) \times 100}{Remaining soft parts (wet weight)}$$

Weekly spat collection

Peak recruitment of newly settled scallops and the main undesirable species were estimated using artificial collectors deployed throughout the settlement period. Spat collectors consisted of 2-mm mesh bags filled with four NetronTM sections (40 x 80 cm). They were deployed 2 m above the bottom on the commercial spat collection site of Pearl Reef. The collectors were deployed weekly at three sites for 11 consecutive weeks in 2003 (starting August 19), for eight consecutive weeks in 2004 (starting September 9), for 11 consecutive weeks in 2005 and 2006 (starting September 6). The collectors were immersed for 1 week and were then

retrieved and cleaned individually in the laboratory using a high-pressure water jet. The recovered material retained on a 200-µm-mesh sieve was preserved in 95% ethanol until being analysed. The sea scallops and four undesirable species (3 molluscs: *Mytilus edulis*, *Hiatella arctica*, *Anomia* spp.; and one echinoderm: *Asterias vulgaris*) found in each collector were counted. A random sub-sample of 30 specimens of each species from each collector were measured.

Cumulative spat collection

To characterise how the timing of collector immersion influences spat collection, a series of five tagged collectors was deployed weekly for 6 to 8 consecutive weeks beginning 2 to 3 weeks after spawning began (i.e., on September 15, 2003; September 22, 2004; and September 26, 2005). The collectors were suspended on a longline 2 m above the bottom on Pearl Reef, and were retrieved and cleaned in December. The recovered material was handled, stored and subsequently analysed, as described for the weekly settlement experiment. In 2006, a series of five collectors was deployed the fourth week after partial spawning had begun (i.e., September 15) and retrieved in December to characterise the cumulative collection of spat during the two-month period after deployment. Three other series of 15 collectors were suspended on commercial lines in the fourth (September 15), seventh (October 8) and tenth (November 2) week after the initiation of partial spawning. The collectors were retrieved in the autumn of 2007 to validate if the optimal period of collector deployment, as indicated by the targeted weekly spat monitoring, allowed the best results when the producer retrieved their collectors one year after deployment.

Results

Scallop spawning

GSI monitoring showed that adult scallops initiated complete spawning (scallops completely released their gametes) on the Sud-Ouest bed between August 19 and August 26 in 2003 and between August 30 and September 6 in 2004, 2005, 2006 (Figure 2). In 2005 and 2006, a significant partial spawning occurred about 2 to 3 weeks before the complete spawning.

Figure 2
Gonadosomatic index
(GSI) monitoring (mean ± s.e.) on the Sud-Ouest bed from 2003 to 2006.

Weekly spat collection

In 2003, the scallop settlement period occurred 5 to 9 weeks after spawning began. The peak occurred in the seventh week ($465 \pm 44 \text{ spat/collector}$) in collectors deployed on October 13. The first peak of M. edulis was observed in collectors deployed on August 2. The first peak of H. arctica was obtained in collectors deployed on August 19 and 26 (Table 1).

Settlement was lower in 2004 than in 2003. The main scallop settlement was lim-

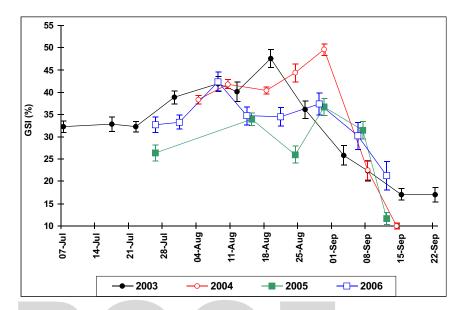


Table 1

Number of postlarvae (mean ± s.e.) per collector deployed (n = 3) at 2 m above the bottom for about 1-week period from 2003 to 2006.

Year	Deployment period	Anomia spp.	Asterias vulgaris	Hiatella arctica	Mytilus edulis	Placopecten magellanicus
2003	Aug 19-26	1 ± 1	2 ± 1	347 ± 202	281 ± 110^{b}	0e
	Aug 26-Sep 2	6 ± 4	4 ± 1	354 ± 104	1148 ± 660^{a}	$3\pm2^{\rm e}$
	Sep 2-8	19 ± 18	2 ± 2	88 ± 34	115 ± 27^{bcd}	0e
	Sep 8-15	47 ± 23	5 ± 2	109 ± 24	104 ± 44^{bcd}	0e
	Sep 15-22	1 ± 1	0	91 ± 32	41 ± 22^{e}	0e
	Sep 22-Oct 1	5 ± 1	26 ± 3	156 ± 35	119 ± 30^{bcd}	5 ± 2 ^e
	Oct 1-7	19 ± 15	6 ± 2	174 ± 20	52 ± 5 ^{de}	46 ± 10^{d}
	Oct 7-13	12 ± 4	1 ± 1	307 ± 29	208 ± 27^{bc}	345 ± 79^{b}
	Oct 13-20	5 ± 2	0.3 ± 0.3	141 ± 26	1014 ± 210^{a}	465 ± 44^a
	Oct 20-29	8 ± 4	0.3 ± 0.3	145 ± 37	218 ± 33^{b}	296 ± 38^b
	Oct 29-Nov 5	2 ± 2	0	114 ± 7	$80 \pm 14^{\text{cde}}$	174 ± 34^{c}
2004	Sep 9-22	0	15 ± 1	14194 ± 408^a	345 ± 30^{a}	3 ± 1 ^d
	Sep 22-29	0	0	853 ± 151^{b}	14 ± 2^{cd}	1 ± 1^d
	Sep 29-Oct 5	1.3 ± 0.3	0	360 ± 56^{cd}	11 ± 4^{de}	14 ± 4^{bc}
	Oct 5-14	0.3 ± 0.3	0	198 ± 29^{de}	62 ± 12^{b}	22 ± 6^{b}
	Oct 14-18	0.3 ± 0.3	0	6 ± 2^{h}	19 ± 2^{cd}	9 ± 4^{c}
	Oct 18-25	2 ± 1	0.3 ± 0.3	65 ± 14^{f}	5 ± 1 ^e	238 ± 34^a
	Oct 25-Nov 1	2 ± 2	1 ± 1	697 ± 207^{bc}	22 ± 5°	307 ± 56^{a}
	Nov 1-9	1 ± 1	2 ± 1	113 ± 18^{ef}	457 ± 24^{a}	338 ± 33^{a}
	Nov 9-18	0	0	16 ± 1^{g}	69 ± 28^{b}	19 ± 2^{bc}
	Nov 18-25	0	0.3 ± 0.3	1.3 ± 0.3^{i}	$10 \pm 1^{\text{cde}}$	1 ± 1^d
2005	Sept 6-13	46 ± 9^a	3 ± 2	373 ± 31^{a}	30 ± 4^{cde}	0^{g}
	Sept 13-19	7 ± 4^{bc}	0	260 ± 76^{ab}	117 ± 35^{ab}	16 ± 6^{ef}
	Sept 19-26	$1 \pm 1^{\text{cde}}$	0	369 ± 68^{a}	39 ± 3^{cd}	11 ± 1^{f}
	Sept 26-Oct 3	4 ± 1^{bc}	0	128 ± 17^{b}	54 ± 11^{bc}	45 ± 6^{cd}
	Oct 3-11	4 ± 2^{bcd}	0	177 ± 92^{b}	164 ± 73 ^a	138 ± 31^{b}
	Oct 11-18	0e	0	9 ± 2^{d}	25 ± 8^{cdef}	30 ± 8^{de}
	Oct 18-25	10 ± 6^{b}	0	217 ± 10^{ab}	12 ± 5^{g}	97 ± 1 ^b
	Oct 25-31	$2 \pm 1^{\text{cde}}$	0	40 ± 8^{c}	9 ± 1 ^g	59 ± 11^{c}
	Oct 31-Nov 9	0.7 ±0.7 ^{de}	0	98 ± 6^{bc}	11 ± 2^{fg}	242 ± 14^{a}
	Nov 09-15	0.3 ± 0.3^{e}	0	10 ± 4^{d}	18 ± 3^{defg}	33 ± 3^d
	Nov 15-21	0e	0	3 ± 1 ^e	$15 \pm 1^{\rm efg}$	10 ± 2^{f}
	Nov 21-28	0.3 ± 0.3^{e}	0	7 ± 2^{de}	24 ± 1^{cdef}	$7 \pm 2^{\mathrm{f}}$
2006	Sept 6-12	1.3 ± 0.3^{e}	1 ± 1	230 ± 65^{b}	37 ± 2^{cd}	0^{d}
2000	Sept 12-21	68 ± 9^a	4 ± 1	1116 ± 350^{a}	490 ± 431^{ab}	0.7 ± 0.3^{d}
	Sept 21-27	2.7 ± 0.3^{d}	2 ± 0	163 ± 37^{b}	165 ± 31^{ab}	2 ± 1 ^{cd}
	Sept 27-Oct 4	40 ± 11^{b}	2 ± 0 2 ± 1	$215 \pm 7^{\text{b}}$	$58 \pm 16^{\text{bcd}}$	16 ± 1^{b}
	Oct 4-9	11 ± 4^{c}	0	46 ± 7^{d}	21 ± 2^{d}	$2 \pm 1^{\text{cd}}$
	Oct 09-16	$0^{\rm f}$	0	82 ± 4^{c}	21 ± 2 22 ± 5^{d}	22 ± 1^{ab}
	Oct 16-23	2 ± 1^{d}	0	14 ± 1^{e}	$26 \pm 2^{\text{cd}}$	53 ± 6^{a}
	Oct 23-Nov 1	0^{f}	0	$7 \pm 1^{\text{f}}$	177 ± 20^{a}	$2 \pm 2^{\text{cd}}$
	Nov 1-6	$0.7 \pm 0.3^{\text{ef}}$	0	3 ± 1^g	2 ± 1^{e}	2 ± 2^{d} 2 ± 2^{d}
	Nov 6-14	0.7 ±0.5 0 ^f	0	$6 \pm 1^{\text{fg}}$	73 ± 12^{abc}	$6\pm3^{\circ}$
	Nov 14-21	0^{f}	0	$4\pm1^{\text{fg}}$	28 ± 11^{cd}	1 ± 0^{d}

^{*} Note: Letters denote means that are significantly different based on a Tukey $post\ hoc$ test.

ited to the period between the seventh and ninth week after spawning began with 238 ± 34 , 307 ± 56 , 338 ± 33 spat/collector in collectors deployed on October 18, October 25 and November 1. The first peaks of mussels and of hiatellas were observed in collectors deployed on September 9 (Table 1).

In 2005, settlement varied greatly with time of deployment and was lower than in 2003 and 2004. The highest abundance of sea scallops was found in collectors deployed on October 31 ($242 \pm 14 \text{ spat/collector}$). The first peak of mussels was observed in collectors deployed on September 13. The first peak of hiatellas was obtained in collectors deployed from September 6 to September 19 (Table 1).

Settlement was even lower in 2006. The first peaks of mussels and hiatellas were observed in collectors deployed on September 12 (Table 1) and scallop collection was highest in collectors deployed on October 16 (53 ± 3 spat/collector).

Cumulative spat collection

The highest cumulative numbers of scallops observed in collectors deployed in September and October and retrieved in December (2 months later) was $5,808 \pm$

Table 2

Number of postlarvae (mean ± s.e.) per collector deployed in 2003, 2004 and 2005 (n = 5).

Collectors were retrieved two months after their deployment. The ratio > 1 is identified by bold characters to ease data examination.

Retrieval date	Deployment date	Anomia spp.	Hiatella arctica	Mytilus edulis	Placopecten magellanicus*	Ratio**
December	Sep 15, 2003	3559 ± 456^{a}	5296 ± 234^{a}	2833 ± 388^a	5074 ± 264^a	0.4
2003	Sep 22, 2003	2099 ± 238^{b}	3697 ± 272^{b}	1336 ± 74^{b}	4244 ± 164^{b}	0.6
	Sep 29, 2003	1735 ± 450^{bc}	$2463 \pm 423^{\circ}$	1481 ± 299^{b}	4284 ± 208^{b}	0.8
	Oct 6, 2003	$1065 \pm 232^{\circ}$	$2118 \pm 235^{\circ}$	1228 ± 165^{bc}	$5808 \pm 334^{\mathrm{a}}$	1.3
	Oct 13, 2003	$376\pm131^{\rm d}$	831 ± 142^{d}	1281 ± 86^{bc}	3693 ± 354^{bc}	1.5
	Oct 20, 2003	$419\pm187^{\rm d}$	950 ± 192^{d}	787 ± 196^{c}	3202 ± 70^{c}	1.5
December	Sep 22, 2004	89 ± 25^a	5280 ± 596^{a}	642 ± 24^{c}	3643 ± 200^{b}	0.6
2004	Sep 28, 2004	88 ± 14^{a}	5164 ± 486^{a}	1781 ± 140^{a}	4588 ± 226^a	0.7
	Oct 5, 2004	48 ± 18^{ab}	4045 ± 281^{b}	1037 ± 119^{b}	$4680 \pm 330^{\rm a}$	0.9
	Oct 14, 2004	32 ± 9^{bc}	$2386 \pm 250^{\circ}$	372 ± 84^{cd}	3664 ± 412^{b}	1.3
	Oct 20, 2004	14 ± 3^{cd}	$2130 \pm 340^{\circ}$	$335\pm102^{\rm d}$	2776 ± 228^{c}	1.1
	Oct 25, 2004	11 ± 7^{d}	1974 ± 175°	441 ± 74 ^{cd}	3174 ± 172^{bc}	1.3
December	Sep 26, 2005	345 ± 21^a	2081 ± 111 ^a	482 ± 97^a	$1148\pm41^{\rm a}$	0.4
2005	Oct 3, 2005	163 ± 24^{b}	1574 ± 106^{ab}	466 ± 67^a	878 ± 66^a	0.4
	Oct 12, 2005	$158\pm21^{\rm b}$	1489 ± 233^{ab}	246 ± 6^{ab}	868 ± 51^a	0.5
	Oct 18, 2005	$370\pm45^{\rm a}$	1233 ± 111^{b}	247 ± 51^{ab}	873 ± 90^a	0.5
	Oct 25, 2005	330 ± 54^a	$798 \pm 63^{\circ}$	100 ± 26^{b}	478 ± 47^{b}	0.5
	Oct 31, 2005	38 ± 4^{c}	$317\pm38^{\rm d}$	139 ± 18^{b}	347 ± 104^{bc}	0.7
	Nov 9, 2005	37 ± 11^{c}	144 ± 11 ^e	118 ± 13^{b}	121 ± 2^{bc}	0.4
	Nov 14, 2005	10 ± 2^{c}	$46 \pm 5^{\mathrm{f}}$	105 ± 8^{b}	$50\pm5^{\rm c}$	0.3

^{*}Note: Letters denote means that are significantly different based on a Tukey post hoc test.

^{**} Ratio = mean number of scallops/total mean number of undesirable species.

334 scallops/collector in 2003 (sixth week after the initiation of complete spawning), $4,680 \pm 330$ in 2004 (fifth week after the initiation of complete spawning), $1,148 \pm 41$ in 2005 (third week after the initiation of complete spawning) and 611 \pm 72 scallops/collector in 2006 (fourth week after the initiation of partial spawning) (Table 2). In 2005, the ratio of scallop abundance to the abundance of undesirable species was not > 1 for any of the deployment dates (Table 2). In 2006, deployed collectors were retrieved only in August 2007 and October 2007.

There was a strong correlation ($r^2 = 0.823$) between the numbers of scallops obtained in the weekly collections and in the cumulative scallop collection after two months of immersion (Figure 3).

Discussion

In Îles-de-la-Madeleine, sea scallop spawning is usually initiated in late August to early September. (3-5) In the past, the growers began deploying commercial collectors about three weeks after the scallops begin to spawn. In autumn, weather conditions are often rough and collector deployment can take one or two weeks. Deploying the collectors between the 3rd and 5th week after the initiation of spawning resulted in large numbers of scallops, but also large quantities of undesirable species like mussels, hiatellas and anomias. When a significant partial scallop spawning occurred 2 to 3 weeks before the complete spawning, as in 2005 and 2006, the collectors were deployed between the fifth and seventh week after the initiation of the partial spawning.

The abundance of mussels and hiatellas observed in the collectors varied from year to year, but the first peak of *M. edulis* and *H. arctica* often occurred in September before the *P. magellanicus* peak. Weekly spat monitoring can be useful for identifying when the peaks occur so that growers can delay collector deployment until after the peaks. However, later peaks of mussels and hiatellas cannot be avoided as they occur in late autumn. The results from weekly spat monitoring indicated that deploying collectors between the fifth and seventh week after initiation of complete spawning or between the seventh and ninth week after initiation of partial spawning, will provide growers with a high number of scallops and reduce the abundance of undesirable species.

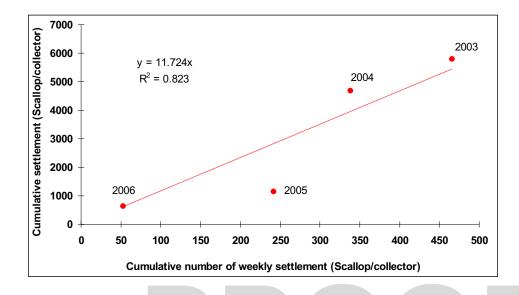


Figure 3
Correlation between cumulative settlement and cumulative number of weekly settlement for years 2003 to 2006.

The collectors retrieved two months after immersion indicated that monitoring the weekly spat collection is a reliable tool for predicting the optimal time for deploying collectors. Based on results from the retrieval of collectors in December 2003 and 2004, it appears the best time to deploy commercial collectors would be six to eight weeks (early to mid-October) after sea scallops begin to spawn. With this strategy, the collection of scallop spat is higher than that of the undesirable species (ration of the abundance of scallop to the abundance of undesirable species was > 1). In 2005, a ratio > 1 was not obtained for any deployment date, probably because a partial spawning occurred two weeks before the complete spawning.

The results showed there was a link between weekly scallop collection and the cumulative collection after two months of immersion. In 2003, the scallop numbers from weekly spat collections were high, and the numbers of scallops obtained in the monitoring of the cumulative spat collection were also high. However, in 2006 the results from weekly and cumulative collection monitoring were both low. Particularly with the scallops, the cumulative numbers obtained from the weekly collections were lower that those obtained from the cumulative collections. Trials have been conducted to evaluate whether this difference could be linked to an inappropriate conditioning of collectors (biofilm). But the results indicate this factor accounted for only part of the difference.

In conclusion, monitoring the weekly spat collection and the gonadosomatic index are two useful tools for predicting the period of collector deployment that will produce a commercially viable number of scallops and reduce the abundance of the undesirable species.

Acknowledgements

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Sophie Gauthier-Clerc

Flow Cytometry as a Tool to Study Immunocompetency in Placopecten magellanicus

Sophie Gauthier-Clerc, Marlène Fortier, Michel Fournier, Jocelyne Pellerin and Michel Lagacé

Haemocytes are the immune cells of bivalves. They are actively involved in immune defence in terms of cellular and humoral immunity. The characterisation of haemocyte subpopulations and the analysis of their specific functions are required to assess the entire immunocompetency of animals in response to environmental factors or bacterial challenge. Classic methods in cytology are time consuming and unsuitable for routine use. Nevertheless, recent publications demonstrate the relevance of flow cytometry to identify haemocyte subpopulations in bivalves as well as some of their properties and functions. We characterised haemocyte subpopulations in *Placopecten* magellanicus with a FACScalibur flow cytometer (Becton-Dickinson, San Diego, CA). We also investigated their relative thiol content and production of reactive oxygen species. This latter property—also called 'respiratory burst'—is required to neutralise pathogens engulfed in cells during phagocytosis. Our analyses clearly discriminated two haemocyte subpopulations on an SCC-FSC density plot in accordance with previous classifications realised in scallops with classic cytological methods. We detected higher NOx and H₂O₂ production in P2 subpopulations in response to cell stimulation with PMA. We also reported a higher thiol content in the P2 subpopulation which may protect cell constituents from the oxidative stress induced by the respiratory burst. These results promote the use of flow cytometry and fluorescent dyes to investigate immunocompetency in Placopecten magellanicus and the development of cell phenotyping to better characterise the properties and function of each haemocyte subpopulation.

Introduction

Placopecten magellanicus is widely distributed in Québec and is of commercial interest. Relatively little is known about scallop immune defence mechanisms. Haemocytes are the immune cells of bivalves, and are actively involved in immune defence in terms of cellular and humoral immunity. Numerous studies have tried to describe subpopulations of haemocytes according to their morphology, cytochemistry and ultrastructure. (1 3) Characterisation of haemocyte sub-populations is also needed to describe their specific function and elucidate their ontogenesis. Recent publications demonstrated the relevance of flow cytometry to identify haemocyte subpopulations in bivalves according to cell size (Forward SCatter) and sub-surface cell complexity (Side SCatter): two to three and more subpopulations have been discriminated by flow cytometry in *Anodonta*

cygnea, (4) Chlamys farreri, (5) Crassostrea gigas, (6) Crassostrea virginica, (7 11) Mya arenaria, (12) Mytilus galloprovincialis, (13,14) Ostrea edulis, (15) Mercenaria mercenaria, (10) and Ruditapes philippinarum. (10) Moreover, haemocyte function (phagocytosis, production of reactive oxygen intermediates) have already been reported using flow cytometry and specific fluorescent dyes in oysters (6 9) or clams. (12,16)

We characterised haemocyte subpopulations with a FACScalibur flow cytometer and analysed the respiration burst function as well as the relative thiol content of each subpopulation. These assays represent the first step to further elucidate the relationship between subpopulation form and function in *P. magellanicus*.

Materials and Methods

Animal and haemolymph collection

Animals were collected from the St. Lawrence estuary 51°28'N, 58°15'W (Québec, Canada). They were maintained at 10° to 12°C in artificial seawater and fed twice a week with *Nanochoropsis* sp. (an autochtonous alga) in the facilities of the Québec City aquarium. Haemolymph was withdrawn from the adductor muscle of individual scallops with a 25-gauge needle attached to a 3-mL syringe, then passed through 80-µm mesh, and stored individually in a tube held on ice to prevent cell clumping until analysis with the flow cytometer.

Flow cytometer analyses

Two kinds of haemocyte parameters were evaluated with a FACScalibur flow cytometer (Becton-Dickinson, San Diego, CA): descriptive parameters and functional ones (reactive oxygen species production). Fluorescence, whether autofluorescence or from fluorescent dyes (DFC, DAF or CMF), was measured by a specific detector FL1 for green dye (500 530 μ m). Analyses were done as described below.

Haemocyte subpopulations

The characterisation of haemocytes was performed on the flow cytometer. The light scattered by the particle indicated their size (FSC, Forward SCatter height) and internal complexity (SSC, Side Scatter height).

Respiratory burst response in haemocytes related to H_2O_2 and NOx production

Respiratory burst activity, represented as the oxidation of DFCH (dichlorofluorescein) to DCF (2.7 dichlorofluorescein) by $\rm H_2O_2$ and DAF-FM to DAF by NOx respectively, was measured as the difference in the mean fluorescence of stimulated and unstimulated cells. Stock solution (5 mM) of DCFDA and DAF-FM (Invitrogen) were prepared in dimethylsulfoxide (DMSO, 99.5% min.). Measurements were performed after 90 minutes of incubation at room temperature with a 50 μ M final concentration for each probe. Stimulated haemocytes were previously incubated with 0.25 μ g

Figure 1
Flow cytometry density plot of
Placopecten magellanicus
haemocytes to characterize
subpopulations according to their
relative size (Forward SCatter =
FSC) and complexity/granularity
(Side SCatter = SSC).

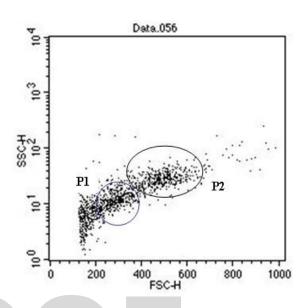


Figure 2

(A) Ratio between the mean fluorescent intensity (as determined by Cell Quest software) in stimulated (with PMA) and non-stimulated control cells due to NOx production and after pre-incubation with NMMA. The letter 'a' is significantly different from b (p 0.05; n = 3) and * indicates a higher mean fluorescence of stimulated cells (p 0.05; n = 3) in comparison to non-stimulated control cells. (B) NOx production in P1 and P2 haemocyte subpopulation measured on a log scale as DAF fluorescence production from oxidised DAF-FM.

1h30

2,5

α

b

1,5

1,0

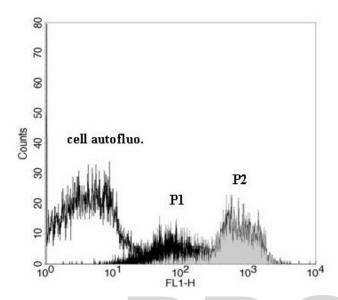
1,0

PMA 0.25

μg.mL-1

1+NMMA

В



mL⁻¹ (final concentration) phorbol myristate acetate (PMA, Sigma). PMA directly stimulates protein kinase C without the requirement to act through a chain of intermediates as would be required for a phagocytosis-induced respiratory burst using zymosan particules. PMA stock solution (1 mg mL⁻¹) was prepared in DMSO.

To further confirm that the oxidation of DCFDH to DFC and DAF-FM to DAF was mediated, respectively, by H_2O_2 and NOx, NMMA (500 μ M final concentration) and W-13 (50 μ M final concentration) were used as inhibitors of NOx and H_2O_2 production, respectively.

Relative thiol content of haemocytes

To assess the relative thiol content of each subpopulation, haemolymph samples were processed individually with the probe 5-chloromethylfluorescein diacetate (CMFDA, Invitrogen). CMFDA is a membrane-permeable, non-fluorescent probe. Immediately after the CMFDA penetrates the

cell, esterase hydrolysis converts it to florescent 5-chloromethyl fluorescein (CMF). Intracellular CMF reacts with thiols on proteins and peptides to form an impermanent, fluorescent, aldehyde-conjugate product (SH-F). The more thiols the cell possesses the higher the cell fluorescence (green fluorescence in arbitrary unit on the FL1). CMFDA stock solution (5 mM) was prepared in DMSO and stored at -20° C just a few days before use. Cells were incubated with 10 mM final concentration for 10 minutes. To insure that fluorescence after CMFDA incubation was only induced by thiols we incubated haemocytes with N-ethyl- maleimine (NEM, Sigma) 100 μM for 30 minutes prior to the addition of CMFDA.

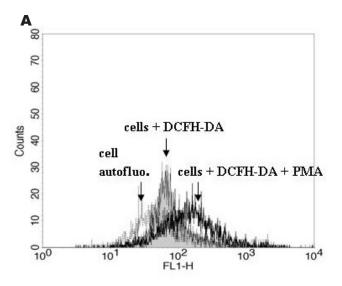
Results

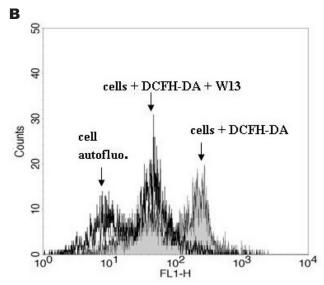
The flow-cytometric analysis clearly discriminated two haemocyte subpopulations on a SCC-FSC density plot (Figure 1) in accordance with previous classifications realised with classic cytological methods. (2)

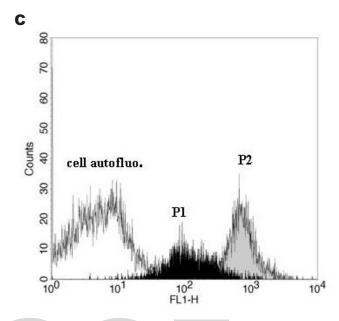
An oxidative burst (H_2O_2 and NOx production) was clearly detected in haemocytes and stimulated by PMA. Graphic representation of the mean fluorescence due to NOx production in stimulated haemocyte in comparison to non-stimulated control cells is represented on Figure 2a. The stimulation resulted in a significantly (p n increased fluorescence in cells and the inhibitory effect of the

pre-incubation with NMMA confirmed the oxidation of DAF-FM by NOx production. Fluorescence of stimulated P1 and P2 subpopulations is superimposed upon each other in Figure 2b showing an approximately two-fold higher fluorescent intensity (as determined by the Cell Quest software) in P2 compared to P1. Moreover (data not shown), PMA did not stimulate NOx production in P1 in comparison to the significant induction in P2 (p 0.05; n = 4). Stimulation of H₂O₂ with PMA is presented in Figure 3a. The fluorescence of unlabelled cells, non-stimulated control cells and PMA-stimulated cells are superimposed upon each other showing an approximately 2-fold increase in mean fluorescent intensity (as determined by Cell Quest software) upon stimulation (log scale). Figure 3b shows that pre-incubation of cells with W13 inhibited the oxidation of DCFH-DA by H₂O₂ and confirmed the specificity of DCFH-DA to be oxidised by H₂O₂. Once more, Figure 3c shows that the P2 subpopulation exhibits higher respiratory burst in comparison to the P1 subpopulation. Mean fluorescence of the stimulated P2 subpopulation, as determined by Cell Quest software, is more that 3-fold higher than fluorescence of P1, although PMA stimulated H₂O₂ production in both subpopulations (p 0.05; n = 3).

Figure 3 (A) H_2O_2 production in haemocytes measured on a log scale as DCF fluorescence from oxidised DCFH-DA by H_2O_2 in stimulated (with PMA) and non-stimulated cells. Results are from one scallop, representative of all tested organisms. (B) Inhibitory effect of W13 on activation of H_2O_2 production in haemocytes stimulated with PMA and reported as DCF fluorescence from oxidised DCFH-DA. ©) H_2O_2 production in P1 and P2 subpopulations measured on a log scale as DCF fluorescence production from oxidised





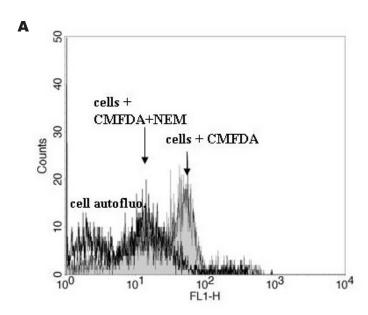


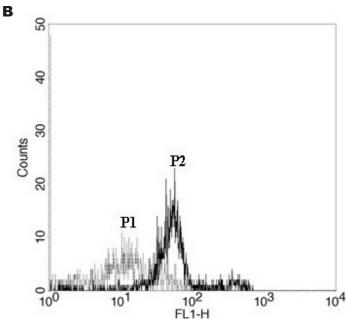
DCFH-DA.

The fluorescent intensities (log scale) reported on Figure 4a demonstrate the efficiency of CMF to react with thiols in haemocytes (as confirmed by the inhibitory effect of NEM). Moreover, thiol content in the P2 subpopulation is approximately five-fold higher (p 0.05; n=3) than in the P1 subpopulation as presented in Figure 4b (log scale).

Figure 4

(A) Fluorescent intensity (on a log scale) of haemocytes incubated with CMFDA in the absence or presence of NEM as reported by CMF fluorescence. (B) Relative thiol content in P1 and P2 subpopulations measured on a log scale as CMF fluorescence.





Discussion

This work represents a first step using flow cytometry to characterise two haemocyte subpopulations in Placopecten magellanicus. In accordance with previous classifications realised in scallop with classic cytological methods, (2) two subpopulations (called P1 and P2) could be discriminated according to the relative size and complexity of cells. Subpopulation properties (thiol content) and function (respiratory burst) tested in our study also showed that the haemocyte subpopulation P2 with a large relative size and high complexity—exhibits a high respiratory burst and has a higher thiol content. This higher thiol content may be a strategy to protect P2 haemocytes from damage potentially induced by reactive oxygen intermediates produced by the respiratory burst. Immunocompetency of P2 seems to be higher than P1 and flow cytometry will be a relevant tool to further investigate immune defence mechanisms of both subpopulations, as well as their efficiency in response to pathogens, environmental parameters or contaminants as already investigated in Crassostrea virginica. (6-9,17,18) A better haemocyte phenotyping (membrane receptors or binding-sites; intracellular components) should also elucidate haemocyte properties, functions and signalling pathways. Then new developments could be proposed in the description of the ontogeny of immune cells.

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Neil Bourne

Scallop Culture in British Columbia: The 20-Year Saga

Neil Bourne and Barbara Bunting

Scallop culture has been under development in British Columbia, Canada, for over two decades. Twelve species of scallop are native to BC, but the Japanese scallop, *Mizuhopecten* (=*Patinopecten*) *yessoensis*, was selected for culture due to its rapid growth rate and large-sized adductor

muscle. Initial culture research was carried out in the 1980s at the Department of Fisheries and Ocean's Pacific Biological Station. Techniques for producing juveniles were developed and Island Scallops Ltd was established in 1989 to commercialize scallop production in BC.

At Island Scallops, early hatchery work focused on producing large numbers of larvae and juveniles (seed), rearing juveniles in onshore nursery facilities, and determining optimum size of seed to transfer to ocean farms and methods to transfer them. In the ocean, Japanese scallop seed proved to be susceptible to disease and high mortalities occurred in some locations. Breeding experiments followed, which led to selection of a disease-resistant strain and a successful cross with the native weathervane scallop (*Patinopecten caurinus*). This strain was marketed as the "Pacific scallop".

Commercial operations are currently concentrated on the east coast of Vancouver Island in the Strait of Georgia. Bottom culture has been tested, but at present all scallop culture in BC is suspended culture. Plans to increase hatchery production, expand farm areas and improve harvesting and processing technology are underway. Key obstacles to further development of the scallop industry are more socioeconomic and regulatory than biological.

Introduction

Thirteen species of pectinids occur in British Columbia (BC) waters but most are small or rare and of interest only to biologists or conchologists. (1,2) Four species are either large or occur in sufficient abundance to elicit enquiries about commercial fisheries: weathervane, *Patinopecten caurinus*; rock, *Crassadoma gigantea*; pink, *Chlamys rubida*; and spiny, *Chlamys hastata*.

Weathervane scallops are large, up to 250 mm shell height, but only small local populations occur in BC and these are too small to support a sustained fishery.

Rock scallops become large and massive and are usually found cemented to rocks. Distribution is erratic and they can only be harvested by diving operations. Attempts at commercial harvest have been made, but have not been economically viable. At present rock scallops can only be harvested in the recreational fishery in BC.

Pink and spiny scallops are small, rarely larger than 75 mm shell height, and occur in small, scattered beds along the BC coast. There is a small drag and dive fishery for both species but annual landings are generally below 100 metric tons (t). Although these fisheries are of local importance, populations of both species are much too small to support a large extensive fishery.

The conclusion from extensive surveys and other work is that scallop resources in BC are insufficient to support a large sustainable commercial fishery. If a scallop industry is to be established in the province with annual landings of 5,000 t or more, it will have to rely on culture operations.

Establishment of a Scallop Culture Industry

At the International Pectinid Workshop in 1991, a report was presented describing the efforts of a company, Island Scallops Ltd., established in BC in 1989 to initiate a scallop culture operation.⁽³⁾ The present paper describes development of the industry in the intervening eighteen years, the current status of the company and the industry, and the future for scallop culture in BC.

Island Scallops is a vertically integrated company with hatchery and nursery facilities capable of producing large quantities of seed (juveniles) used in growout operations that culture juveniles to commercial size. The company also has processing facilities. Located in the Strait of Georgia on the east coast of Vancouver Island, Island Scallops has 125 hectares of deepwater tenures and 250 hectares that can be used for bottom culture. Additional culture areas are held on the west coast of Vancouver Island.

At present Island Scallops is essentially the only company undertaking scallop culture in BC; there are other small operations but their production is insignificant. The company is willing to supply juveniles for other growers and assist with marketing, but to date these efforts have been minor.

Species of Scallop for Culture

An initial decision for Island Scallops was choosing the species of scallop to culture. Commercial operations were based on results of a program undertaken at the Department of Fisheries and Ocean's Pacific Biological Station to investigate the economic potential for scallop culture in BC. This program investigated the potential for culturing four native species: the weathervane, rock, pink and spiny scallops.

Although weathervane scallops are large and have a rapid growth rate, there are only limited populations in BC and broodstock is difficult to obtain. The species also proved extremely difficult to breed in the laboratory and few juveniles were obtained to undertake nursery or growout studies. Because of these factors no further work was undertaken to culture this species.

Considerable work has been done to investigate the potential for culture of rock scallops, particularly in California. Successful breeding was achieved in the laboratory but growth was slow, four years minimum to commercial size. Also, rock scallops assume the shape of the substrate they occupy and for the initial few years tend to be flat with a shallow cup; they only develop a deep cup after three or four years. It was decided they were not suitable for culture in BC.

Pink and spiny scallops have an advantage for culture in BC in that natural seed can be collected. However, they are too slow growing and too small to be cultured economically.

Consequently, the program at the Pacific Biological Station attempted to culture an exotic species, the Japanese scallop, *Mizuhopecten* (=*Patinopecten*) *yessoensis*. This species is very similar to the weathervane scallop and has supported an extensive culture industry in Japan since the 1970s. (6,7) Broodstock was readily available and was imported into BC and spawned under quarantine conditions to reduce the possibility of introducing pests, parasites or diseases. Methods were developed to condition and successfully breed adults, rear juveniles in a nursery system and grow juveniles to adult size. (1)

Island Scallops decided to undertake work only with the Japanese scallop. Subsequent work at the hatchery crossbred Japanese and weathervane scallops and current work at Island Scallops is largely based on offspring of this cross, which is marketed as the "Pacific scallop" (Figure 1).

Development of Commercial Culture Technology

At the start of operations, considerable effort was spent adapting scallop culture technology devised in the Pacific Biological Station's program to a commercial level of operation.

Broodstock is held in the open environment where the major part of conditioning occurs. Animals are brought into the hatchery for final conditioning over a period of three to six weeks. In the first years of operation some broodstock was imported from Japan under quarantine conditions, but now there is complete reliance on locally produced animals. No broodstock has been imported for over ten

years.

Spawning is achieved through thermal stimulation and may involve several animals in a mass spawning or mated pairs. In 2007, 10 billion ferti-

lised eggs were produced in the hatchery. Larvae are reared in 40,000-L tanks with a partial flow-through system. They are cultured at low densities with initial density being about 2 per mL and the final density being at least 1 per mL. There is a complete water exchange two to three times during the larval period. Larvae are fed a mixture of several species of algae including Tahitian Isochrysis galbana, Chaetoceros calcitrans and Thalassiosira pseudonana. Algae are cultured using standard methods either by batch or continuous culture. The larval period is about 18 days at 15 C.

Mature larvae are set on artificial seaweed (cultch) in

Figure 1
Pacific scallop cultured by Island Scallops
reaches 15 cm shell height and 500 g weight.



the nursery system. Considerable effort has been devoted to developing a suitable nursery system to grow spat to a size of 5 to 10 mm shell height in an economically viable manner. Juveniles are fed a mixture of algal species, some of which are the result of blooming species that occur naturally in the seawater. There is a constant exchange of water in the nursery systems.

Juveniles are held in the nursery for various periods of time (minimum of two months) and

moved to the ocean at a variety of sizes. The goal was 30 million juveniles in the ocean in 2007. Timing of transfer of juveniles to the open environment for growout is critical to avoid heavy predation and barnacle sets. Initially, juveniles are placed in pearl nets with a mesh of 1.5 mm and suspended from subsurface longlines submerged at a minimum depth of 10 m below the surface of the water. After a period of about two months they are transferred to pearl nets of 6 to 8 mm mesh to reduce the density (Figure 2). Overcrowding negatively affects growth and survival of scallops in the nets. Growth is variable but scallops may be as large as 5 cm shell height by the first autumn, at which point they are transferred to lantern nets for final growout (Figure 3).

Different methods have been employed to grow juveniles to commercial size; all the methods are essentially variations of techniques developed in Japan. (7) Scattering juveniles directly on the bottom was tried but it is not feasible in BC because of heavy predation





Figure 2
Scallop juveniles after a summer's growth in pearl nets.



by several species of crabs and seastars. Juveniles could be grown to commercial size in cages on the bottom but this method was deemed not economically viable. The only feasible method of scallop growout at present is by suspended culture.

The ear hanging method was tested and in 2005 this technique was used exclusively for commercial growout at Island Scallops. A machine was used to punch holes in the shells and thread lines through the holes. The scallops were attached to lines that were suspended from the subsurface longlines. The machine worked well but overall was still too labour intensive. Scallop mortalities were high and growth was unsatisfactory. As a result, ear hanging has since been abandoned due to high labour costs, heavy fouling, and high mortality.

At present all growout occurs in lantern nets suspended from longlines that are at a minimum depth of 10 m below the surface of the water. The longlines are 100 m in length and spaced 25 to 30 m apart. In most instances there are two lantern nets in a series and they are attached at about 1-m intervals. Density of scallops in the nets is critical. Harvest size of scallops is about 10 cm shell height and this size is achieved in 18 to 24 months from the time of spawning. About 90,000 scallops are harvested per longline and most scallops are marketed whole, primarily to markets in Vancouver. The 2005 year-class produced 3.0 million scallops at an average weight of 5.5 scallops per kg for an estimated production of 550 to 725 t.

Island Scallops is currently the only company producing any significant quantity of scallops in BC. There is considerable interest in scallop culture from other individuals and groups, including First Nations, but to date only experimental culture has been undertaken by these people. Island Scallops is the only source of Pacific scallop seed in BC.

Problems

Scallop culture now appears to be firmly established in BC. Technology has been adapted or developed to culture Pacific scallops to market size in an economically viable manner. The future of the industry appears to be reasonably bright but there are problems that must be dealt with and solved if the industry is to expand and prosper.

Biological

Severe mortalities in any phase of the culture operation can be a major problem and intensive research studies are required to insure this situation is avoided whenever possible. Unfortunately at present in BC there is no dedicated research being undertaken in this field.

To date there have been no major unexplained mortalities during larval culture, although occasional poor growth and survival may occur. The onshore nursery system is critical in scallop culture and periodic heavy mortalities have been experienced there. Some mortalities have been attributed to high water temperatures—water temperatures should be kept below 15 C. This can generally be overcome by controlling the volume of water exchange. Again occasional poor growth and high mortalities may occur.

Water quality has not been a major problem in the hatchery or nursery; Island Scallops is in a clean area and pollution is not a factor. Periodic algal blooms may affect water quality but the incoming seawater is filtered to remove as many impurities as possible.

Severe mortalities have been experienced when juveniles are transferred to the

open environment and during growout. Size of juveniles and timing of outplanting are extremely important. If juveniles are placed out too early they can be coated with heavy sets of barnacles that seriously interfere with growth and survival. In general the larger the juveniles when placed out in the open environment the better the chance for survival. Timing of outplanting is also important to avoid heavy predation by crabs and the flatworm *Pseudostylochus ostreophagus* that was accidentally imported into BC with Pacific oyster (*Crassostrea gigas*) seed from Japan. (8) Island Scallops has developed management practices to mitigate these problems.

Water quality, even at minimal depths of 10 m, is important. A mass mortality of juveniles was experienced in 2003 in several bivalve species in BC and was attributed to a dinoflagellate bloom.

Disease is potentially a problem in all phases of culture. To date it has not been a major factor in either the hatchery or nursery. It has, however, been a factor in growout operations in some areas where mortalities of up to 90% were experienced. These mortalities were due to a protistan (SPX) that was identified as *Perkinsus qugwadi*. ⁽⁹⁻¹¹⁾ This organism is native to BC and is very virulent to Japanese scallops. The serious mortality problem has been managed by growing scallops in areas where the disease does not appear to exist or to be less virulent and also by only culturing scallops derived from a resistant strain and the Japanese–weathervane cross developed by Island Scallops. Growout methods are now well developed and the cost of production is low.

Socioeconomic

Over the years, one of the major challenges facing Island Scallops has been securing sufficient financing. However, in 2005 the company was acquired by Edgewater Foods International Inc, which is listed on the US Over the Counter Bulletin Board Exchange (OTC BB:EDWT), and it now has sufficient funding to undertake current and greatly expanded operations.

There are also serious social problems that must be solved if a large scallop culture industry is to develop. BC has a long coastline—the total extent is about 27,000 km. However, much of the area cannot be used for aquaculture purposes since it is remote and access is only by boat or airplane that makes the logistics of operations prohibitively expensive. Further there are no services in these areas such as accommodation, work force, electricity, fresh water, etc. Consequently most aquaculture operations occur in the southern part of the Province, primarily in the Strait of Georgia where facilities exist and there is also a close proximity to markets. However, this is the area where the major part of the population lives and serious conflicts have arisen among a multitude of users.

There is a strong negative attitude to aquaculture in coastal BC and there is little public support for such operations. Much of this opposition is from people who have cottages or permanent homes in the Strait of Georgia area and wish to maintain a pristine vista for themselves. These people are often well organised, have resources, and are vociferous; any applications for new or expanded operations are met with significant and well-publicised opposition.

In addition, First Nations must be consulted for development within their territory. This can involve several First Nations where sites occur in overlapping territories, compounding the approval process.

Scallop culture is feasible in BC but methods must be found to streamline applications for farm sites so that culture operations can be undertaken with minimal time and expense.

Future

As stated at the 1995 International Pectinid Workshop, (3) the future of scallop culture in BC is bright. Since the 1995 report, considerable progress has been achieved in scallop culture technology. Although some biological problems need to be solved to improve the efficiency of operations, at present a marketable product can be produced within a two-year period. Continued development of new technology will improve the economics of production. The major problem is social. This problem can only be solved with strong support and leadership by both Provincial and Federal governments and continued communication with the public to demonstrate the benefits of aquaculture.

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Scallop Aquaculture in Norway

Thorolf Magnesen

There has been considerable effort in Norway over the past 20 years to develop commercial production of the great scallop *Pecten maximus*. The present scallop production line includes intensive hatchery production of post-larvae, intermediate suspension culture to 3 and 5 cm juveniles, and bottom culture in a fenced area to prevent predation by crabs. Spat preached more than 4 million in 2006, which will sign

in a fenced area to prevent predation by crabs. Spat production reached more than 4 million in 2006, which will significantly increase the development of bottom culture in future years. Despite the political vision in Norway to increase marine aquaculture, and plenty of capital from oil and gas exports, commercialisation of scallop production has been difficult.



Scallop aquaculture should be an attractive commercial activity in Norway. We have natural populations of the great scallop, *Pecten maximus*, and a long coastline with large areas suitable for scallop culture. The development of scallop cultivation started at the University of Bergen (UoB) in 1985 with help from scientists in the United Kingdom and France. The first pilot hatchery, BioMarin AS, was estab-

lished in 1987, but they did not achieve the same success with large-scale production as was obtained on a small laboratory-scale. The facilities were sold, and since 1996 Scalpro AS has run the hatchery. Over the years, several R&D projects have been carried out in close cooperation between UoB, the Institute of Marine Research, and various private companies.

To develop a successful aquaculture industry, control of biological production and use of efficient technology must be backed by adequate financial resources. During the last years, progress has been made in reducing risk and increasing production, which are the first steps toward commercial production. This does not mean that all the production problems have been solved, but significant goals have been reached. Recently, effort has focused on developing stable, predictable spat production in the hatchery and the development of technology to reduce predation in bottom culture.

Developing scallop aquaculture is a high-cost operation. It has been a challenge to raise funding for solving specific R&D problems, but it has been even more difficult for private companies to raise high-risk capi-



Figure 1
Pecten maximus spat.

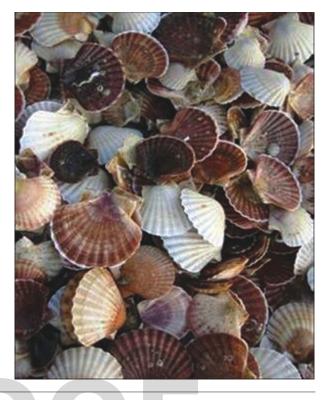




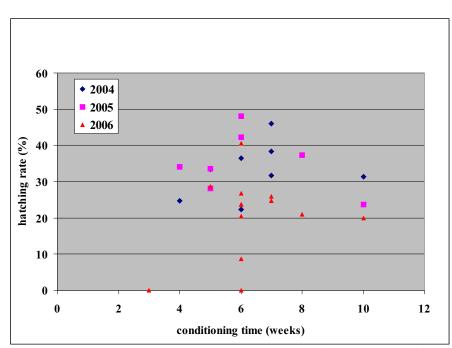
Figure 2

Pecten maximus spawning.

Results

Spat production

Figure 3
Relationship between
hatching rate (%) and the
length of the conditioning
period in the years 2004 to
2006.



tal to cover biomass and operating costs. Aquaculture development is high on the political agenda, but government funding and support for commercialisation is limited and often of only a few years duration. This puts extra pressure on the need for private capital for investment and operating expenses. In some areas there are multi-user conflicts in the coastal zone, limiting access to licenced areas. Several companies, however, are interested in pursuing opportunities and are working hard to succeed. In this paper, the status of Norwegian scallop aquaculture, with a focus on the most important developments during the last several years, is summarised.

Scallop production in Norway includes intensive hatchery production of post-larvae (2 mm), growth to spat in the nursery (10 to 15 mm) (Figure 1), intermediate hanging culture (3 to 5 cm), and sea ranching to market size (>10 cm). Broodstock are conditioned in the hatchery for 4 to 8 weeks before they spawn in the winter and spring (Figure 2), 3 to 6 months prior to the natural spawning season. Each scallop produces about 10 million

eggs, of which approximately 20 to 40% develop into larvae (Figure 3). Broodstock from different locations are used for production, because governmental regulations demand that spat for sea ranching should be produced from scallops of local origin.

Larval rearing has been a particular challenge. (1,4 9) In the early years, high survival was achieved in small-scale batch systems that had a high degree of water filtration. Increased production led to amendments in water treatment, and a change from using batch culture to a continuous flow-through system. (5)

No antibiotics are used and normally 20 to 50% of the larvae survive the larval stage. Average survival in 2004 and 2005 was about 25%, while the yield of ready-to-set larvae was 16 to 18% of D3 larvae. In 2006, a significant increase in both survival and yield was obtained: survival reached 50% and yield of ready-to-set larvae was about 40% of the D3 larvae. Larval settlement takes place in down-welling sieves in flowthrough tanks receiving algae from continuous-flow cultures. The settling rate is normally about 20%. Post-larvae are grown to a size of 2 mm in about 6 weeks before transfer to a land-based outdoor raceway

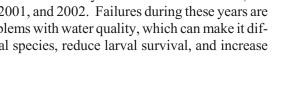
Figure 4 Scallop nursery raceway system.

nursery (Figure 4). Seawater is pumped to the raceways from a depth of 10 m and filtered through a 100-µm drum filter. Spat are held in plastic trays with a fine mesh, and they grow from 2 to 10 mm in 6 to 8 weeks, which is as good as the growth rate in the natural environment. The drum filter efficiently removes mussel, starfish, crab and ascidian larvae, so there is no predation and hardly any biofouling in the raceways. (3)

Spat production increased to about 2.5 million in the period from 1993 to 1998 (Figure 5). Production was fairly stable from 1998 to 2005, except for the years 1997, 2001, and 2002. Failures during these years are thought to be due to problems with water quality, which can make it difficult to grow some algal species, reduce larval survival, and increase

mortality of newlysettled larvae. In 2006, the hatchery produced more than 4 million spat of 10- to 20-mm shell height and two major companies received 2 million spat each.

One particular challenge for the hatchery has been to produce large numbers of spat early in the season. The hatchery has always experienced



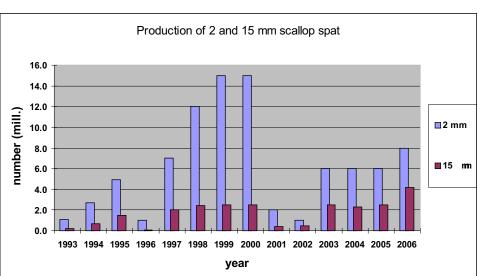


Figure 5 Annual spat production.





Figure 6
Lantern net for grow-out of scallops in suspension culture.

problems with water quality shortly after the collapse of the natural spring algal bloom in March and April. Normally, groups of larvae would be lost at this time of the year, but the problems vary in magnitude between years, and occur independently of whether water is supplied from a depth of 60, 120 or 160 m. The problem in 2006 was less significant and could be due to improved water treatment after installation of a protein skimmer.

Intermediate culture

Spat are transferred from the hatchery to the growers in September and October. (2,10) Initially the growers used plastic trays

suspended from longlines or placed in frames on the bottom for intermediate culture, but now lantern and soft nets are used (Figure 6). The growers use nets with 40 levels that hold about 1,250 scallops. Highpowered washers have been developed for efficient removal of fouling without damaging the juveniles (Figure 7). Two people can clean 200,000 scallops in one day. Occasionally, growers experience high winter mortality of small spat. (11) This has been more pronounced in the southern parts of Norway, where cold, less saline water coming from the Baltic can dominate the coastal current. The negative effect of winter conditions on intermediate culture has been reduced by moving the culture gear deeper in the water column and by aiming to have larger spat in culture the first winter.

Figure 7
Cleaning system for removing fouling from nets.

Figure 8
Juvenile Pecten maximus.

Bottom culture

Juveniles are transferred from intermediate culture to bottom culture the following year (Figure 8). The major method for on-growing scallops in Norway is bottom culture, although trials have been done both with plastic trays and ear-hanging. Originally the idea was to seed 5-cm scallops directly on the bottom. Several experiments, however, have shown that predation from crabs is high on seeded scallops up to this size. Scallops are now being protected from crab predation by various types of enclosures (Figure 9). The first pilot fence was tried in 2002, and in 2005 several 1,000-m long flexible fences were used. The fences are about 1-m high and equipped with floats, heavy weights, and a net along the seabed to prevent crabs from digging under the fence. Scallops are normally seeded in densities from 10 to 15 scallops per m². In the period 2001 to 2003, about 30,000 to 50,000 juveniles were transferred to bottom culture. From 2004 to 2006, the numbers increased to 200,000 to 300,000. The increased availability of spat in 2006 led

to a significant increase in juveniles available for bottom culture in 2007.

Discussion

The long duration of biological and technological development has shown that large-scale spat production is possible. Technology for intermediate culture is highly efficient and bottom culture in enclosures gives high survival. However, further developments in focused areas are necessary for commercial operations. Hatchery production is unstable due to variability in water quality. We have



Figure 9
Underwater flexible net for containing bottom-seeded scallops.



limited knowledge about the optimum density of scallops in bottom culture under different site conditions and on the significance of predation from predators other than crabs, such as larger fish and starfish.

Establishing a scallop aquaculture industry in Norway could be done cooperatively between private enterprises and governmental institutions. Development depends on both biological and technological feasibility, and must be backed by adequate financial support. Producing *Pecten maximus* in culture is characterised by a long production cycle. The national Research Council has been heavily involved in solving specific biological problems, and regional governmental agencies may contribute to financing technological development by private companies. The private companies, however, have a particular challenge to find sufficient funding for scaling-up production, buying spat, and being able to afford to have workers employed for 4 to 5 years before there is return on investment. This financing depends solely on private capital, since bank and governmental loans are not available for these activities due to the high risk and lack of sufficient guarantees.

We do, however, have a vision and so do the politicians. The global market for seafood is good. Norway has plenty of capital from the export of oil and gas, but spending this capital is difficult, due to fear of increasing inflation. Based on progress in production, and new governmental marine funds to support commercialisation of marine species, we are optimistic.

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Settlement of Pecten maximus L. — Effects of the Postlarval Rearing Environment

Gyda Christophersen and Thorolf Magnesen

A challenge in the controlled production of spat for Norwegian scallop culture is to obtain a high and stable rate of settlement that is greater than the current level of 20%. Environmental factors affect the development of postlarvae during the critical early life stages of metamorphosis and settlement. Settlement in tanks with different types of water movement and light conditions was investigated. The postlarvae settled after 2 to 5 weeks. Attachment was affected by water circulation, while light conditions had minor effects. The output was highly variable between larval groups and experiments. Settlement on suspended screens was between 0.1 and 5.7 per cm², similar to the 5 to 10% that settle in downwellers. Final spat yield was < 5% of the larvae transferred to the settlement tanks. Counting the attached

larvae early in the production cycle was not useful for predicting spat yield after nursery growth. Settlement on collector bags in tanks has potential as a viable method, but must be improved to be comparable with settlement on downwelling screens.



Gyda Christophersen

Figure 1

Pecten maximus spat.



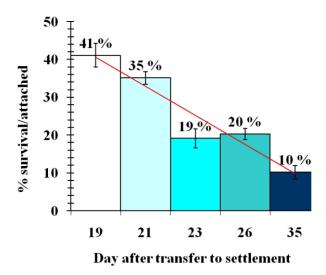


Figure 2
Example of typical settlement values related to the total number of larvae transferred (mean ± se, n = 6 to 9) to downwellers at the Scalpro AS hatchery (data from 1997). The percentages of attached larvae are shown except for day 19 where the result represents a mix of swimming and attached larvae.

Introduction

Successful metamorphosis and settlement are keys to scallop recruitment in nature and for mass production of spat in hatcheries. Temperature, salinity and food supply are environmental factors important for larval and postlarval development. In hatcheries, timing of larval transfer, settlement substrate, rearing tank hydrodynamics and other husbandry procedures that can cause stress may affect the output.

In Norway, scallop (*Pecten maximus*) spat (Figure 1) have been hatchery-produced for nearly 20 years, and for the last 10 years Scalpro AS has produced spat commercially. This company has continuously performed R&D work in collabora-

tion with the University of Bergen and Institute of Marine Research aimed at increasing production. Major efforts have been made to solve problems related to mortality during the larval and postlarval phases. Typically, the output of scallops for nursery growth has been 10 to 20% of the number of larvae transferred to settlement tanks (Figure 2). Great variations in survival have occurred among larval batches, but the implementation of large-scale flow-through systems without prophylactic use of antibacterial agents has led to more stable production of competent larvae. (1,2) However, the settlement ratio has only occasionally exceeded 20 to



Figure 3

Downweller used in the hatchery for spat settlement.

25% of the larvae transferred to the settlement system.

Several experiments to improve settlement of P. maximus in the hatchery have been carried out with the goal of increasing the availability of postlarvae and spat. Traditionally, postlarvae have been allowed to settle on downwelling screens (Figure 3) before transfer to tray culture, but this method is space and labour intensive. Therefore, settlement and nursery growth on collector bags (Figure 4) in large-volume tanks was considered an option to improve output of scallops. Studies used various tank conditions to investigate the effects of water circulation, light, and substrate on settlement.

Methods

Scallops were spawned at the Scalpro AS hatchery. Larvae were reared in circular 3,500-L flow-through tanks with conical bottoms before competent larvae were transferred to square 2,800-L tanks for settlement (Figure 5). Initial density was 1.1 to 1.5 larvae per mL. A temperature of 15°C and full salinity has previously been shown to ensure good postlarval growth and high survival. (3) These factors, and feeding during settlement, were the same in all the studies and were maintained at levels consistent with standard hatchery procedures. Algae were cultured in a SeaSalter continuous-flow system.

We looked at the effects of environmental conditions during growth in settlement tanks by manipulating light condi-



Figure 4
Scallop spat collectors.





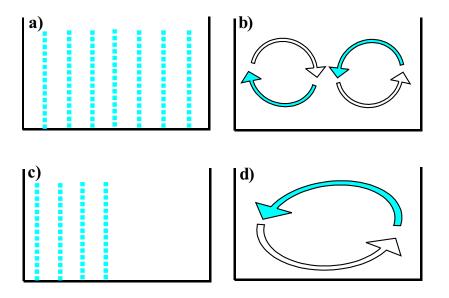
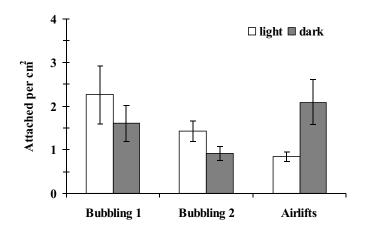


Figure 6
Different types of water movement within settlement tanks created by a) upward air bubbling, b) two airlifts, c) air bubbling in half the tank volume, and d) one airlift.

Figure 7 Settlement on screens in light and dark conditions (mean \pm se, n = 10) after 23 days in tanks with bubbling air (bubbling 1) and after 37 days in tanks with bubbling air (bubbling 2) and airlifts.



tions and water circulation. In some cases, the larvae were given the choice between a light and dark environment (experiment 1 and 2) and, in others, responses to different types of water movement within the tanks were compared (experiments 2 to 4). Dark conditions were created by covering half the tank with a tarpaulin. Water was circulated either with airlifts or by bubbling air upwards from perforated pipes placed on the bottom of the tank. Air bubbling created an evenly distributed water movement pattern, while the airlifts gave an upwelling (suction)-downwelling circula-

tion pattern (Figure 6).

To measure settlement in the tanks, we counted the numbers of attached postlarvae on ten experimental mesh screens (diameter = 32.5 cm) hanging across the tank at a depth of approximately 0.5 m (Figure 5). The intent was to investigate if counts early in production could be used to predict spat yield after nursery growth. Screens were also placed on the tank bottom to see if the settlement on hanging screens was representative of settlement in general. Collector bags were usually placed in the tanks for subsequent transfer to land-based raceway nursery where the final spat yield was estimated after a series of experiments, including the ones reported here. (4)

Results

The number of larvae attached to the screens was counted after 2, 3 (experiment 1) or 5 weeks (experiments 2 to 4). Settlement on suspended screens was between 0.1 and 5.7 per cm². In experiments 3 and 4, settlement varied from 0.1 to 2.6 per cm² on suspended screens and 1.9 and 5.5 per cm² on bottom screens.

In tanks with bubbling air, settlement was higher in light than in dark conditions, while in tanks with two airlifts we found the opposite result (Figure 7). Within each experiment,

the difference between light and dark conditions was not significant.

The effect of type of water movement varied among the experiments. In experiment 2, higher mean attachment was achieved with one airlift placed in each end of the tank than in air bubbling conditions (Figure 8). The difference was not significant after 5 weeks. In experiment 3 and 4, larvae were given the choice between a bubbling and a no bubbling side in one tank, and between a suction and downwelling side created by one airlift in another. In experiment 3, the settlement was higher under airlift than bubbling conditions (Figure 9).

In experiment 4, on the other hand, bubbling conditions provided higher settlement than downwelling (Figure 10). By far the most postlarvae settled on the bottom screens (Figures 9 and 10).

Settlement on collector bags in light and dark conditions showed the opposite result of what was achieved on the mesh screens, and the difference in settlement conditions did not have a significant effect on spat yield after nursery growth. (4) Final spat yield was < 5% on average of the larval number transferred to the settlement tanks.

Discussion and Conclusions

Settlement was highly variable among larval groups and experiments. The highest attached number on the mesh screens (3 to 6 spat per cm²) was equivalent to 5 to 10 % settlement in downwellers. This is much less than the mean of 20% experienced in the hatchery. The counting of newly-settled postlarvae on suspended mesh

screens to predict final spat yield after nursery growth was not a useful method. Differences due to environmental conditions were often inconsistent between observed settlement on screens and the number retrieved from collector bags.

The effect of environmental conditions during settlement seemed to have been negated later in production as the final spat yield was similar regard-

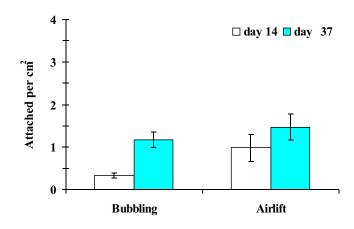
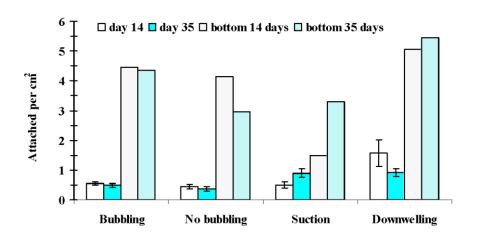


Figure 8
Settlement on screens after 14 and 37
days in tanks where water movement
was created by air bubbling or by two
airlifts (mean ± se, n = 20).

Figure 9
Settlement (mean ± se, n = 10) on
suspended screens after 14 and 35 days
in tanks where water movement options
were air bubbling, no bubbling, or
upwelling (suction) or downwelling
created by airlift. The 'bottom' results
represent the number of spat attached
to one screen placed on the tank bottom
below the suspended screens.



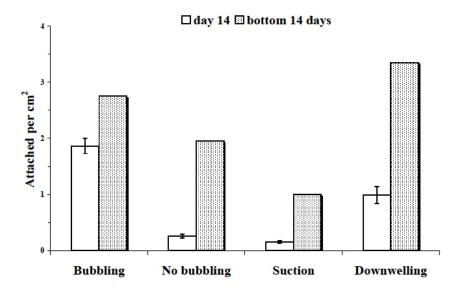


Figure 10
Settlement (mean ± se, n = 10) on suspended screens after 14 days in tanks where water movement options were air bubbling, no bubbling, or upwelling (suction) or downwelling created by airlift.
Bottom results represent the number attached on one screen placed on the tank bottom below the suspended screens.

less of previous treatment. It seemed unnecessary to cover settlement tanks and the effect of changing the type of water circulation was not obvious. Air bubbling ensures the most even water distribution and will therefore be used in the future. Bubbling rate and larval density are other factors that can be further optimised. Later trials have indicated an effect of increased larval density from 1.5 to 3 per mL (60% higher yield) and by using conditioned (old) rather

than new mesh material (30% higher yield). Reducing the intensity of the air bubbling reduced spat yield by more than 50%, illustrating the importance of water movement during settlement.

From our results it is difficult to predict which larvae are capable of undergoing metamorphosis and surviving settlement and what characters are the most important indicators of spat yield in our systems. Use of downwellers is currently the most predictable settlement method. Nevertheless, we believe that settlement on collector bags can be a viable method if the time of transfer and rearing environment is optimised.

Acknowledgements

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Growth and Mortality of the King Scallop (*Pecten maximus*) in Four Coastal Areas of Spain

J. Cano, M. Lozano, F. López, M. J. Campos, L. Díaz, M. Saavedra, J. L. Márquez, M. Marhuenda and C. Lleó

This study examined the growth and mortality of the king scallop (Pecten maximus), using two groups of spat originating from Fuengirola in 2004 and 2005. Research was carried out in four coastal areas: two located in the Atlantic Ocean—Conil de la Frontera (Cádiz, in southwest Spain) and Coruña (Galicia, in northwest Spain)—and the other two in the Mediterranean Sea—Santa Pola (Alicante, in eastern Spain) and Fuengirola (Málaga, in southern Spain). Significant differences were found in growth rates among culture sites, most likely due to the local environmental conditions. The most suitable culture sites were Fuengirola and Lorbé, areas with the highest growth rates in both years. There were differences in the seasonal growth patterns of the scallops grown in the Atlantic and Mediterranean sites: in the Mediterranean, the highest growth rates occurred during the winter-spring period, while in the Atlantic growth was greatest in the spring and summer. In almost all cases, spat mortality due to transport was not significant. In Lorbé and Fuengirola, mortality during grow-out was much higher in one year than the other, whereas in both Conil and Santa Pola mortality was similar in the two years. In all cases, mortality occurred at the end of the grow-out stage when the scallops were very large and covered a high percentage of the culture area.



The king scallop *Pecten maximus* is a high-value species and, although production in Spain is currently at minimal levels, the species is of great commercial interest, making it a perfect target for aquaculture. In the Galicia fishery from 1997 to 2007, landings of king scallops were highly variable, with a minimum catch of 3.3 t in 2001 and a maximum of 183.5 t in 2004 (Fisheries Statistics, Xunta de Galicia 1997–2007). The Mediterranean coast of Andalusia has produced significant yields of this species, although at the present time scallops are not being harvested owing to the presence of ASP and PSP toxins.

Several studies on the growth of king scallops cultured in trays have been conducted on the Spanish coast for the purpose of developing a stable aquaculture strategy for this species. These studies were carried out on the coast of Fuengirola (Málaga, S Spain)^(1,2) and O Grove (Pontevedra, NW Spain).⁽³⁻⁵⁾ A few experiments were also done on the coast of Castellón de la Plana (NE Spain) with *Pecten jacobaeus*⁽⁶⁾—recent genetic reports show these two species are different varieties



Juano Cano



Figure 1 Map of scallop grow-out sites.

of the same species.⁽⁷⁾

The objective of this study was to determine the relative effects of spat origin and culture site on growth and mortality.

Methods

Site

The research was carried out in four coastal areas: two located in the Atlantic Ocean—Conil de la Frontera (Cádiz, in southwest Spain) and Coruña (Galicia, in northwest Spain)—and the other two in the Mediterranean Sea—Santa Pola (Alicante, in eastern

Spain) and Fuengirola (Málaga, in southern Spain) (Figure 1).

Cultivation

Spat used in this research were obtained from wild settlement on collectors moored in Fuengirola in 2004 (group 1) and 2005 (group 2). Group 1 was cultivated from November 2004 to January 2006, and group 2 from November 2005 to January 2007. Group 1 spat transported to Lorbé suffered massive mortality; to replace these spat, a new group of the same age was sent to Lorbé in March 2006.

Specimens were cultivated in oyster culture trays 40 cm in diameter at a density of 20 scallops per tray. The trays were suspended over the seabed at a depth of 10 meters. The height of the scalllops was measured and dead specimens were counted to determine growth and mortality (Figure 2). Growth was estimated using the "isometric" von Bertalanffy growth equation: $L_t = L_{\infty}$ [1-exp(-K(t-t₀))]. L_{∞} = 110 mm was obtained on the basis of observations and bibliographic data.

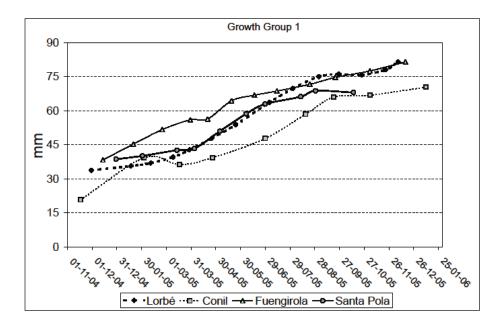
Figure 2
Different stages
in the culture of the king scallop.



Results

Growth

The highest growth rates in both groups were in Lorbé (Table 1). Group 1 grew 47.7 mm in 12 months and had a growth coefficient (K) of 1.08, the highest value of this group. After being transferred in November, the growth rate declined until March, but not significantly 0.01). The (p >growth rate increased significantly from



March until September (p < 0.0001) and decreased in the autumn (Figure 3). In the second year (group 2), the scallops had a growth coefficient of 0.89 and growth began to slow down in July (Figure 4).

Growth at Fuengirola was also high, and there was little difference in growth between the two years (Table 1). After a year of grow-out, scallops in group 1 had increased in size by 43.2 mm (Figure 3), while the scallops in group 2 attained a lower growth value (Figure 4). In both years, the scallops grew quickly during the winter and spring (p < 0.0001); growth tapered off in the summer and autumn, but never came to a complete halt.

The lowest growth occurred in Conil (Table 1). The scallops grew during the spring and summer (p < 0.0001), but the rate decreased during the autumn and there was no growth in the winter (p > 0.1). Scallops in group 1 only measured 20.7 mm when they were placed in the rearing tanks. They then underwent extraordinary growth (18 mm) from November to January (p < 0.0001), and within 14 months had increased in size by 49.7 mm (Figure 3). The growth of the group 2 scallops, however, was low (Figure 4). Except for the initial growth in the spring and summer, they had an extremely low growth rate.

The growth rates recorded in Santa Pola were intermediate compared with growth at the other sites (Table 1). Growth in both groups started to slow in June, continued to decrease during the summer and autumn (p > 0.1), and increased rapidly in the spring (p < 0.0001). The difference in growth between these two groups was due to the inhibition of growth in group 2 when they were held in rearing tanks during the first few months in winter.

Figure 3
Growth of group 1
scallop spat at the four locations.

Mortality

Mortality during transport to culture sites was insignificant, except for group 1 in Lorbé, which experienced 17% mortality (Table 2).

In Lorbé, mortality in scallops detached in 2004 (group 1) reached 35% by July 2006 and 65% in January 2007. Mortality

Table 1 Growth coefficients (k) of two groups of scallops grown in four different areas.						
	Lorbé	Conil	Fuengirola	Santa Pola		
Group 1	1.08	0.74	0.90	0.84		
Group 2	0.89	0.47	0.89	0.75		

Table 2
Spat mortality due to transport and cumulative mortality during the culture period.

			<u> </u>	<u>• </u>
Sites	Group 1		Group 2	
	Transport Mortality (%)	Total Mortality (%)	Transport Mortality (%)	Total Mortality (%)
Lorbé	17	65	1	13
Fuengirola	_	23	_	83
Conil	2	50	1	59
Santa Pola	2	20	1	20

in group 2 was only 13% during the entire trial.

In Fuengirola, group 2 had higher mortality than group 1 (83% and 23%, respectively). In both groups, the highest mortality occurred in November.

Mortality in Conil was 50% in group 1 and 59% in group 2. The lowest mortality (20%) occurred in scallops grown in Santa Pola.

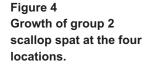
Discussion

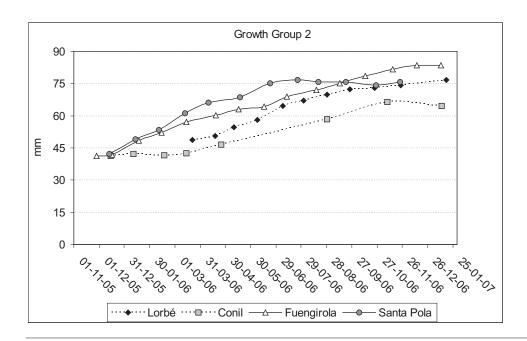
At all sites, growth rates were higher in the first year than in the second. There were also significant differences in growth rates among the culture sites, probably due to local environmental conditions. The most suitable culture sites were Fuengirola and Lorbé.

Seasonal growth patterns differed between the sites in the Atlantic and Mediterranean. The highest growth rates were recorded in the winter and spring in the scallops grown in the Mediterranean areas, and in the spring and summer in the Atlantic sites. These differences are thought to be due to environmental conditions, and suggest that a correlation should be done between growth and the seasonal temperature patterns and/or phytoplankton production, to find out which factors contributed to the differences.

The scallops in Fuengirola and Lorbé attained the commercial size of 80 mm in height in November—after being grown in trays for 12 months after detachment. These growth data were higher than those reported in Fuengirola, although the culture density was greater. (1,2)

The lowest growth rate was in Conil, but this lower rate is similar to the values reported for other areas of Europe, such as Scotland, Norway, France, the Isle of Man⁽¹¹⁾ and Galicia.





Growth in Santa Pola was intermediate compared to the other sites, but was higher than the value reported in Castellón de la Plana, an area near the Mediterranean. ⁽⁶⁾

Mortality varied in intensity among the four sites. There was wide-ranging interannual variation in mortality in Lorbé and Fuengirola, with high mortality (65%) in Lorbé during the first year and during the second year in Fuengirola (83%). In both Conil and Santa Pola, mortality in the two groups of scallops was similar. In all cases, mortality occurred at the end of the grow-out period when the scallops were very large in size and covered more than 33% of the bottom, which is the proportion recommended for the suspended culture of pectinids. (12)

Transport mortality was only significant in Lorbé. During the first year it was 17%, but during the first transport of the second experimental year, it reached almost 100%. It must be remembered that this location is the farthest from the site of origin of the scallop spat.

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Status of Scallop Aquaculture in Brazil

Guilherme S. Rupp

The Atlantic lion's paw scallop, *Nodipecten nodosus*, has been the subject of interest for aquaculture development in Brazil since the early 1990s. Since then, experimental activities have been carried out, and recent developments have permitted the beginning of commercial culture of the native scallop. Currently, scallop production is being done on a small scale in the states of Santa Catarina and Rio de Janeiro, where efforts are being made to promote the development of this new activity.

Introduction

Commercial scallop aquaculture is currently emerging in Brazil based on the Atlantic lion's paw scallop, *Nodipecten nodosus* (Figure 1). Although the first successful attempts to produce scallop spat in the hatchery date from the early 1990s, (1) only recently has spat production attained quantities large enough to encourage development of small-scale commercial operations. Unlike other scallops for which wild spat collection is an abundant source of juveniles, aquaculture activities of *N. nodosus* will have to rely solely on hatchery-produced seed. Therefore the abundance and sustainability of juvenile production are key elements for the development of this new activity.

The Brazilian coastline comprises more than 8,400 km of tropical and subtropi-

Figure 1 Lion's paw scallop, Nodipecten nodosus.



cal waters, in which environmental factors such as temperature variation, food availability patterns, and aggressiveness of fouling organisims differ from most other areas where scallop culture currently takes place in the world. Therefore, local culture strategies must be developed for the successful establishment of scallop aquaculture.

The situation of scallop culture in Brazil has changed since the last review (2) where it was stated that "commercial development of *N. nodosus* culture is imminent". Scallops are now cultured commercially in the states of Santa Catarina and Rio de Janeiro, where there are hatcheries currently producing scallop seed. Recent improvements in the available hatchery facilities in both states permitted a significant increase in seed

production, hence stimulating the development of this activity in both regions.

Santa Catarina State, located in southern Brazil, is recognized as the largest mollusc producer in the country. Oyster (*Crassostrea gigas*) and mussel (*Perna perna*) aquaculture were developed in the 1990s in several coastal fishing communities supported by research and extension activities. These efforts led to a production of about 14,750 tonnes in 2006 which represented 95% of total cultured molluscs in the country, involving nearly 800 growers. Mussels and oyster production reached 11,600 and 3,150 tonnes, respectively. The successful development of commercial mollusc culture in the State created favourable conditions and increasing interest in scallops. Therefore, efforts are now also focusing on the development of scallop aquaculture in order to allow growers to diversify their production with a higher value product.

In Rio de Janeiro, most of the scallop culture activities are located at Ilha Grande Bay, in Angra dos Reis, a region with intense tourism activity and great potential for aquaculture development.

Current Status

Studies to increase seed supply^(4,5) and to identify the influences of depth, culture density, fouling and other environmental factors on different life stages⁽⁶⁻⁹⁾ have recently been carried out in Santa Catarina and, as a result, aquaculture practices suitable for the local environmental conditions were developed and are now being transferred to growers. In Rio de Janeiro, studies have also been carried out.⁽¹⁰⁾

The system commonly used is suspended culture with scallops enclosed in lantern nets. In Santa Catarina, most of the growers are mainly oyster producers who use the same gear for scallops. The leases are typically shallower than 10 m and surface long-lines are used. In Rio de Janeiro, most of the growers focus on scallops only, employing sub-surface long lines in areas usually deeper than 10 m.

In Santa Catarina State, a pilot production of 120,000 seeds was supplied to 50 small growers in 8 municipalities in mid 2006. Results showed that after 9 months of suspension culture (starting with approximately 10- to 15-mm juveniles) scallops attained a mean shell height of about 7 cm with high survival (near 80%) in most appropriate sites, where salinity did not drop below 29 ‰. By the end of the year, about 2 tonnes of whole scallops were commercialised. For 2007, it was estimated that a number above 300,000 seeds were transferred to growers and production surpassed 3 tonnes.

In Rio de Janeiro the hatchery production in 2006 was estimated to be 630,000 juveniles. There are currently 45 mollusc growers with approximately 30 in the region of Angra dos Reis culturing scallops. For 2006, production has been estimated at 15,000 dozen scallops.

A protocol for scallop culture in Santa Catarina is outlined in Figure 2. Broodstock are conditioned to spawn during about 2 weeks in the hatchery and subsequent larval culture takes another 2 weeks. After settlement on monofilament collectors (Netlon®), spat are maintained in a land-based nursery for about 2 weeks. Collectors are then transferred to the sea where they can be held for another 5 to 7 weeks. (6) Depending on the site and season, mean shell heights vary from 0.6 to 1.5 cm at detachment from the collectors. Juveniles are then transferred to small mesh (0.3 or 0.6 mm) lantern nets (intermediate culture), where they display significantly faster growth rates than in pearl-nets (unpublished results.). After approximately 3 to 4 months, scallops reach about 3 to 4 cm shell height and are transferred to 15- or 25-mm mesh lantern nets (grow out). After an-

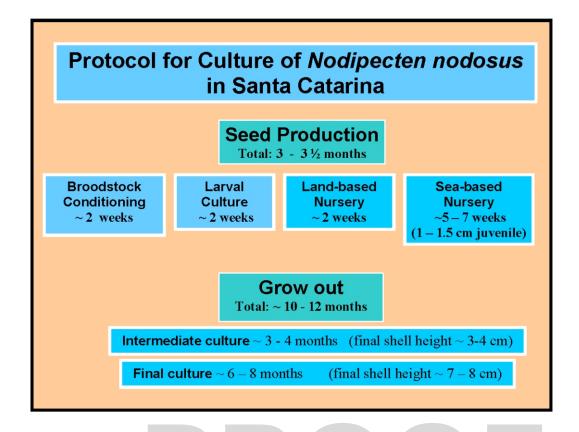
other 6 to 8 months, scallops reach a commercial size (7 to 8 cm), yielding an adductor muscle of 8 to 10 g. Intermediate and grow-out lantern nets are recommended to be changed on a bimonthly basis and densities reduced to maintain approximately 50% coverage of the bottom area, in which production is optimised. So, within 10 to 12 months of intermediate and grow out culture, scallops are ready to be marketed. This protocol varies slightly according to season and specific conditions of the culture sites, where differences in growth rates can be found. In some areas, scallop shells and culture gear are highly colonised by fouling. However, *N. nodosus* seem to be more resistant than other scallop species, showing little mortality, but other negative effects of fouling can be found (e.g., shell deformation and increase in weight of culture devices).

There is a high market potential for scallops in Brazil, but the product is still mainly commercialised as a delicacy in niche markets such as fine restaurants and hotels due to the high price and current small production. Scallops are mainly marketed as whole product, usually fresh and chilled. In Angra dos Reis, whole scallops are shipped to fine restaurants in the larger cities with prices ranging from R\$25 to 34 per dozen (US\$ 12 to \$16 per dozen). In Santa Catarina, whole scallops are locally marketed for approximately R\$30 to \$32 per dozen (US\$ 14 to \$15 per dozen), but also shipped to larger markets.

Figure 2 Lion's paw scallop, Nodipecten nodosus, culture protocols for Santa Catarina.

Conclusions

Seed supply is no longer the bottleneck for the establishment of scallop aquaculture in Brazil. *Nodipecten nodosus* larvae are amenable to hatchery cul-



ture conditions if appropriate practices and conditions are employed. Suitable techniques for nursery culture have been developed and a large number of juveniles are now available for aquaculture. Following the proposed grow-out protocol, commercial-size scallops can be attained in less than 1 year, yielding scallops with an adductor muscle larger than 8 g. Production is still small, compared to other molluscs cultured in Brazil, but as growers become acquainted with scallop culture techniques, and new areas are allocated for aquaculture development, the production will tend to increase. Development of local markets for scallops will depend on an increase of production and subsequent reduction in prices. Commercial culture of scallops is beginning in Brazil and its full potential is about to happen in the near future.

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The Ups and Downs of Scallop Aquaculture Down Under: A Review of the Current Status of Australian Scallop Aquaculture

Peter F. Duncan

An update of recent and current commercial and research activity related to scallop aquaculture in Australia is presented. Of the seven Australian

states and territories with a coastline, four—namely Victoria, Queensland, Tasmania and Western Australia—appear to have some scallop aquaculture activity. However, there are no definitive government statistics on actual scallop production or value from aquaculture. The success, or otherwise, of the major scallop culture initiatives of recent years are presented, with contact details for additional information where available. Overall, some promising initiatives continue which should enable the future development of scallop aquaculture as and when economic, market and regulatory conditions allow.

Introduction

Scallop aquaculture has had a relatively poor record in Australia, despite the presence of several well-established commercial species (*Amusium balloti*, *A. pleuronectes, Mimachlamys australis, Equichlamys bifrons, Pecten fumatus* and related sub-species), well-developed fisheries (8,690 t, worth AU\$25 million in 2006),⁽¹⁾ established domestic and export markets (exports of 1,485 t worth AU\$38.7 million in 2006),⁽¹⁾ clean water and diverse climatic conditions.

The commonly suggested reasons for limited scallop aquaculture development in Australia are those typically reported in other high-cost economy countries and include: high labour and production costs; long growout period of some temperate species; limited wild spat collection and poorly developed hatchery-based alternatives; complex, poorly developed or restrictive local, state or national government aquaculture regulations; and competition with other coastal resource users. In addition, coastal water quality issues appear to be a potentially important factor.

Australian Government statistics⁽¹⁾ indicate that the period 2005/06 recorded no specific scallop aquaculture production, and while scallops are included in the category of 'other mollusc' aquaculture (scallop, tridacnid clam and abalone) (production 532 t, worth AU\$19.76 million in 2006),⁽¹⁾ it appears that very little of this was scallop.

However, declines in fisheries production and the effective closure of traditional grounds over the last two decades due largely to environmental concerns have encouraged efforts to continue the development of scallop aquaculture, with variable success. This paper reports on current scallop aquaculture and research activity in Australia on a state by state basis, with information primarily collected via conversations with key researchers or commercial mollusc aquaculture operators. States and territories with no recent or current scallop aquaculture activity are not specifically included.

Industry Status by State

Victoria

Scallop production in Victoria was traditionally centred on Port Phillip Bay, south of Melbourne; however, in 1997 a dredging closure in the bay effectively ended the fishery. Scallop fishing continues in the eastern Bass Strait and around Lakes Entrance.

Currently, the Victoria State Government has no direct involvement in scallop research, and is not actively promoting either restocking or seabed aquaculture-lease development in the area. However, work by Hickman et al. (2) (available online at www.dpi.vic.gov.au) did report on spat collection and suspended culture trials of the commercial scallop, *Pecten fumatus*, in the Pinnace Channel Aquaculture Fisheries Reserve in Port Phillip Bay.

In relation to potential scallop aquaculture development, the Victorian Government conducted an on-line combinatorial auction for a series of marine aquaculture leases for suspended culture in June 2006. The leases are initially for 21 years, but can be extended for a further 10 years upon payment of a government-determined market-value fee. The auction was conducted over 2 to 3 hours, and used a weighted bidding system to maximise value for the state government. Bidders registered in advance by submitting an expression of interest, and an AU\$5,000 refundable bond.

Seventeen leases ranging in area from 2.5 to 27 hectares were sold. Seven were deep enough for mollusc longline culture: five 18 ha (16 to 18 m deep) and 2 x 27 ha leases (20 to 25 m deep). The average sale price was AU\$3,000 per hectare, which compares anecdotally with similar leases offered recently in New Zealand costing around AU\$20 25,000/ha. The lease conditions in Victoria require site development within 3 years (i.e., at least one longline per hectare); otherwise the lease is cancelled. After 3 years the leases can be sold, although it is believed that the auction attracted genuine aquaculturists, rather than speculators. It is thought that the leases are likely to be initially for *Mytilus edulis* culture, with scallop (*P. fumatus*) culture later. The development of such scallop aquaculture in Port Phillip Bay will initially rely on natural settlement, although hatchery development is proposed.

Access to the auctioned sites began in September 2007 and an additional 14×27 ha leases, with water depths greater than 30 m will be available in the future, probably auctioned under a similar system. The issues of benthic preservation and recovery in Port Philip Bay are still significant concerns and seabed property rights have yet to be addressed, so the government has specifically avoided the options of seabed aquaculture leases and restocking at this time. Further details are available from John Mercer (e-mail: John.Mercer@dpi.vic.gov.au).

In 2002 the Australian Commonwealth Government funded research by Royal Melbourne Institute of Technology (RMIT) University to investigate hatchery

production of *Pecten fumatus* for potential reseeding off Lakes Entrance in eastern Victoria. The hatchery, sited on Bullock Island, utilised bore water sourced from 10 m depth in sandy soil in order to avoid haloclines and toxic algal blooms. Water chemistry constituted 30 to 35 g L⁻¹ salt, but also a high iron content, which was reduced via aeration. However, subsequent freshwater inflow resulted in dilution to approximately 25 g L⁻¹ which proved unsuitable for larval scallops and so had to be supplemented by bay water. A dose-feeding algal system was incorporated into the hatchery to reduce labour costs, but broodstock conditioning was not successful and production was therefore reliant on mature wild-sourced stock. Successful spawning was achieved in June/July 2006, but water quality problems proved insurmountable and the loss of funding resulted in the project being abandoned shortly after. Further details are available from the project leader, A/Prof Brian Leonard (e-mail: brianl@rmit.edu.au).

Queensland

Queensland Sea Scallop (QSS) Ltd. was established in 2002, based in part on the results of a favourable scallop culture feasibility study. The company comprises 24 local share holders, principally scallop fishing and processing interests, and has 6 full-time and 5 casual employees associated with their spat production (hatchery) and seabed ranching operations with *Amusium balloti* in Hervey Bay. The company has two seabed reseeding areas (SRAs), essentially seabed areas leased from the state government, totalling 72 km² which are unique in the Queensland aquaculture industry. These SRAs are primarily experimental pilot-scale sites aimed at proof-of-concept and were established in 2004. Successful trials are expected to result in the development of larger, commercial-scale seabed sites which would be specifically selected for this type of culture operation based on the results of these preliminary studies. An important component of the pilot-scale trials is to monitor and meet environmental impact requirements set by the Queensland Government, since the Hervey Bay area also supports significant eco-tourism and commercial fishing operations.

A major constraint on the aquaculture development of *Amusium balloti* has been the difficulty associated with wild spat collection. (4,5) Significant research into hatchery production of the species established its commercial potential and QSS subsequently developed a dedicated 80,000-L larval-rearing hatchery at Burnett Heads, Queensland in 2004.

The facility has mixed-species algal production capacity of 800 L/week from batch culture and 1,500 L/week via a Bayes-style Continuous Algal Production system. Approximately 500,000, 4-mm spat were produced and seabed seeded in 2004, 3 million in 2005 and 5 million in 2006 (total of 8.5 million since 2004). The first harvest of these hatchery-produced scallops occurred from the seabed sites in 2005. For future commercial-scale operations, it is intended to produce harvestable densities of 1 scallop — on the sites, which are within estimates for wild populations.

In addition to the development of commercial-scale production sites, the company is conducting supporting research, including studies on shell marking of hatchery spat (see below), broodstock maturation and gonad conditioning protocols, egg and larval quality assessment, methods of controlling hatchery bacteria, modelling hydrology within the culture area to better understand algal and larval dispersion around seeding sites, and optimising site selection and avoiding conflicts with other coastal resource users. Further details are available from Rob Dean (e-mail: rpdean@bigpond.com).

Spat-marking project

The identification of hatchery-reared animals is important for gauging the effectiveness of seabed stocking, differentiation from natural settlement and ownership issues, but molecular markers are expensive and require specialised facilities. The Queensland Department of Primary Industries and Fisheries, in collaboration with Western Australia, have recently completed a Fisheries Research and Development Corporation funded project (FRDC project 2005/016, report available from www.frdc.com.au) investigating the application of chemical-dye markers during the early spat phase. Trial markers included oxytetracycline, calcein and alazarin red, all of which have a shell-calcium binding mechanism. Fluorescent bands (Figure 1) are visible under hand-held UV light for the first two chemicals, and under normal light for alazarin red. The most promising appears to be oxytetracycline, due to its binding characteristics and existing approval for aquaculture purposes. Additional aspects of the project, and for future research, include investigating tag longevity, toxicity effects and multiple applications for cohort differentiation. Further details are available from Paul Palmer (e-mail: paul.palmer@dpi.gld.gov.au).

Tasmania

Tasmania has had perhaps the longest history of scallop aquaculture in Australia, ⁽⁹⁾ and probably remains the most diverse state for mollusc culture in general. It has several hatcheries producing bivalve mollusc spat, one of which, Shellfish Culture Ltd., is the only Australian commercial supplier of hatchery-cultivated

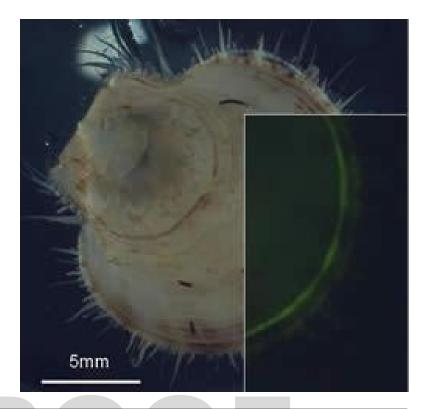


Figure 1

Amusium balloti spat showing fluorescent ring caused by exposure to oxytetracycline as a means of identifying hatchery-produced scallops.

scallop (*Pecten fumatus*) spat. However, it is not currently (2007) producing scallop spat, since their main scallop customer is now focussed on mussel (*M. edulis*) culture. The hatchery is currently producing mainly oyster (*Crassostrea gigas*) spat, although also *M. edulis* and abalone (*Haliotis rubra*). Further details are available from Richard Pugh (e-mail: info@shellfishculture.com.au).

Current information indicates that there is only one active scallop aquaculture operation in Tasmania, based in Great Bay at Bruny Island, adjacent to D'Entrecasteaux Channel. The operation is based on wild spat collection and produces 3 species: *Pecten fumatus* (the commercial scallop), *Equichlamys bifrons* (the Queen scallop) and *Mimachlamys asperrima* (the doughboy scallop). The farm has three 5-ha growout sites, based mainly on suspended pearl nets, then lantern net techniques, although ear hanging and bottom culture are also utilised. Product is sold live in both local and domestic markets, although there is no available information on either production volume or value.

Reliance on wild spat collection is always a potentially limiting factor in scallop aquaculture and hatchery development for this operation is possible in the future, although at least two existing hatcheries in Tasmania have the capacity for scallop spat production (see above).

Western Australia

Western Australia (WA), in common with Queensland, also has a significant trawl fishery based on the saucer scallop Amusium balloti. Although clearly related to the Queensland species, recent molecular genetic studies indicate that the WA scallop should be recognised as a distinct subspecies, perhaps unsurprising given the discontinuous and large geographic distance between the populations. (10) Coincidentally, similar seabed ranching projects began in both states at the same time, and some collaborations were developed. The WA operation (West Coast Scallops Pty. Ltd.) established a hatchery site at Geraldton to support their offshore seabed seeding sites at the Abrolhos Islands. Although successful in producing 12 million spat for seeding in 2003, hatchery production was not consistent, largely due to external factors. Parent broodstock nutritional status appears to be a critical factor in variable larval quantity and quality, with success in hatchery larval production also reflected in good natural recruitment. This appears to be an area of potential research for both states. Additionally, however, water quality problems at the hatchery site in Geraldton, potentially caused by local harbour dredging operations (WA Parliament Hansard, 17th August, 2004) may also have been a factor in variable larval production.

The hatchery and seabed culture operations of West Coast Scallops Pty. Ltd. ceased activity in November 2003 and the hatchery has now closed, with the seabed culture leases at the Abrolhos Islands likely to lapse.

Further details of the WA operation, including research related to hatchery techniques, spat transport and deployment methods have been reported in an FRDC project (FRDC 2002/048 *Enhancement of Saucer Scallops (Amusium balloti) in Western Australia*). Importantly, this research project highlighted the need for an effective marking method to enable differentiation of seeded hatchery-reared scallops from wild recruitment, which led to support for the subsequently developed marking project detailed above. Further details are available from Rick Scoones (e-mail: rscoones@bigpond.net.au).

Other states and territories

No scallop aquaculture production or significant research activity is reported

from New South Wales, South Australia or the Northern Territory at this time (2007).

Conclusions

Scallop aquaculture remains a very small-scale industry in Australia, with several attempts at significant commercial operations being ultimately unsuccessful. However, knowledge gained from these efforts, and the continued development of new production concepts, locations and species, may result in niche industries becoming established. For example, seabed ranching is still ongoing, and, with the continued contraction of commercial fishing throughout much of Australian coastal waters, may ultimately prove to be the most suitable option for large-scale culture operations in this country.

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