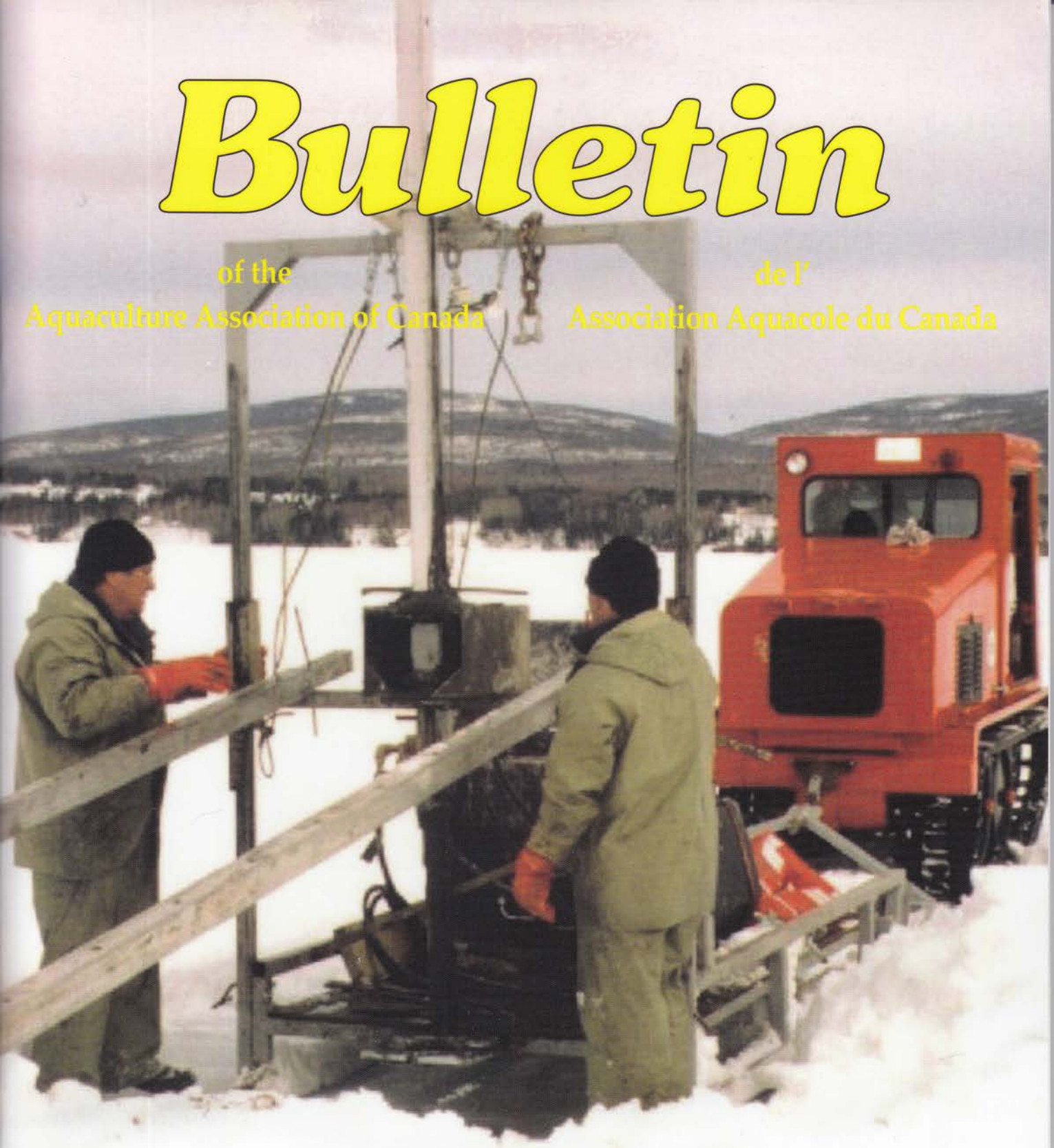
Bulletin

of the
Aquaculture Association of Canada

de l'
Association Aquacole du Canada



Mussel culture
Aquaculture Canada 2000

août/August 2001 (101-2)

Aquaculture Canada 2002

19th annual meeting of the Aquaculture Association of Canada

Co-hosted by the PEI Aquaculture Alliance and the PEI Department of Fisheries, Aquaculture and Environment

"Finding Solutions, Creating Sustainable Wealth"

17-20 September 2002
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Cover: Winter installation of screw anchors used in offshore mussel culture. Screw anchors are drilled into the substrate using a small drill rig and the ice as a platform (John Bonardelli photo).

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Erratum (Bulletin issue 101-1):
AAC apologizes for misspelling the name of the guest editor, Gilles Miron, in the table of contents.

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INNOVATION

The Aquaculture Association of Canada gratefully acknowledges the Canadian Center for Fisheries Innovation (CCFI) for funding this proceedings of the special session on mussel production held at Aquaculture Canada 2000 and providing financial support for the authors to present their papers at the conference.

From the Guest Editor

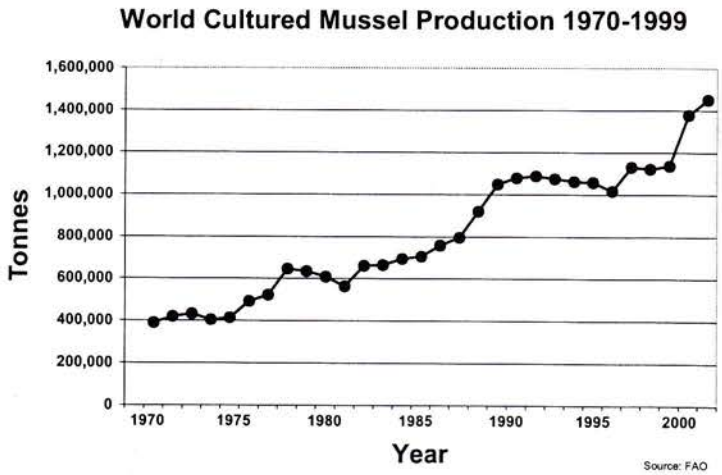
Growth in Mussel Farming —

A special session held at Aquaculture Canada 2000

Global mussel production has been increasing rapidly in recent years, following a period of slow growth in the early 1990s (see figure below). Canadian production figures have increased rapidly as well, averaging in excess of 10% compounded growth annually.

Demand is high for mussels in the Canadian and global marketplace. Mussels are perceived as extremely good value, high quality food items, readily available to the consumer. Recent trends in the North American market have been towards the production of value-added products that can be easily prepared by the consumer, but the demand for fresh mussel products is also on the rise. It is expected that demand will continue to grow in the foreseeable future, which augurs well for the mussel culture industry in Canada and elsewhere. However, this will put increasing pressure on a number of areas central to the sustainable growth of the mussel culture industry, including access to mussel stocks that perform well, access to new growing areas, the need to optimize production in existing growout areas, and continued development of efficient means of keeping the costs of production at competitive levels. These four central themes to expanding mussel production were discussed at a special session convened for this purpose at Aquaculture Canada 2000 in Moncton, New Brunswick. Over 100 people attended the session and participated in the discussions. The following pages contain an abridged proceedings of the session, including articles on development of offshore culture technology (new areas and production cost themes), husbandry effects on mussel genetics and hatchery production (stock performance theme), and sustainable mussel culture (optimizing production theme).

Mytilus edulis cultured in Newfoundland waters



The Canadian Centre for Fisheries Innovation generously sponsored the session providing funds for the speakers to travel to the conference and the printing of this proceedings.

— Cyr Couturier
Marine Institute
Memorial University of Newfoundland

Offshore Mariculture: Logistical Considerations for Socking Mussels and Operating Submerged Longline Structures

John C. Bonardelli and Stéphane Morissette

Offshore longline culture operations are confronted with difficult environmental conditions such as severe storms and winter drift-ice, which limit the number of available work days and leads to periods when the site is inaccessible. But, ultimately, it is the size of the work boat, its working capacity, and the logistical organization that determines the cost of mussel socking operations. In this paper, we examine how modifications to equipment have improved management of offshore mussel production, how various methods have been used to install longlines in series using DGPS technology, and how modifications to socking techniques are required to ensure on-ship safety.

Introduction

One of the greatest challenges facing offshore mariculture is that of moving the operation away from the inshore. The cost of the transition from inshore to offshore is usually underestimated and is much more challenging than generally expected. The principal challenge is adapting equipment to the greater biological production capacity of offshore longlines and the more rugged physical environment.

Offshore mariculture, whether 1 or 10 km from shore, is conducted where wind, waves, and currents act independently or together to reduce access to the site. Access is critical to maintain the production schedule, particularly if the available work window is restricted to 6 months of the year due to fall storms and winter ice. The offshore producer has a greater chance of success if he uses an appropriate longline design, along with equipment that is adapted to the severe environment. The importance of these factors to the success of offshore musssel culture are presently underestimated.

This is an experience-based presentation designed to shed light on the reality of offshore mussel culture. Our objectives are two-fold:

- to identify areas of concern regarding the use of equipment in offshore environments, and
- to present a case for the importance of redefining standard production methods and equipment used for offshore culture.

Autonomy is the Key to Installing Offshore Longlines

There comes a point in the size of an offshore mussel operation when autonomy is the only solution to achieving production objectives. Although there may not be a cost saving in owning a large vessel, there is a substantial logistical benefit from owning, as opposed to renting, especially when weather patterns are unpredictable.

Longline installation

To maximize lease space and reduce entanglement, submerged longlines are 200 m long, anchor to anchor, and are installed along a 2-km track in parallel series separated by a distance equivalent to 1.2 times the water depth. With offshore longline culture, it is important to carefully select the most appropriate type of anchor, time of year installation occurs, and method of installation.[1] It is also critical to determine the predominant current patterns with respect to the wind so that the longlines are properly oriented. The variety of conditions we have experienced at inshore and offshore sites have allowed us to optimize the selection of anchors, vessels and equipment to obtain the best performance from our longline set-up at each type of site.

Depending on substrate type and water depth, the selection of the anchoring system is the key to minimizing the cost of installation and materials, and maximizing longterm stability of offshore longlines. Three

Continuous mussel socking brought to the surface at an offshore site in Chaleur Bay.

types of anchors have been successfully used in depths of > 20 meters: 2-3 tonne concrete blocks, the maritime screw anchor, and the Japanese arm anchor. All these anchor systems are currently in use, but not all sites on the Gaspé peninsula can adopt them or reliably install them.

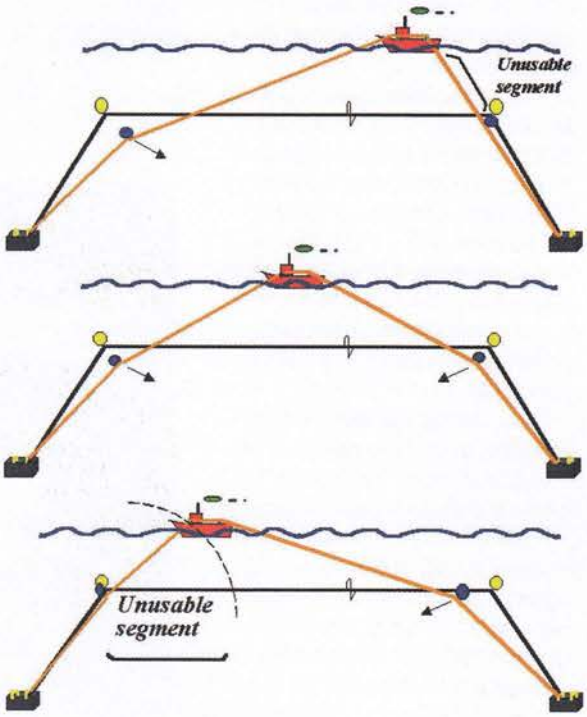
Concrete blocks

Heavy 2-3 tonne blocks are reliable and efficient for most substrates encountered along the coast, from mud bottom to gravel. Gravel substrates require heavier blocks to compensate for the reduced friction compared to that in softer substrates. One of the negative factors in the use of concrete is the 45% loss in mass due to buoyancy; in essence, a 3-tonne block is reduced to 1.7 tonnes of dead weight.

Installation using large vessels

Offshore longline anchors have evolved from the use of steel anchors to the large scale transport and installation of up to 40 concrete blocks per day. Concrete blocks were first installed by contracting the services of a 25-m crab boat or a 50-m Coast Guard vessel. The method is expensive because of the cost of purchasing the blocks and transporting them from the dock to the aquaculture site. When the site is greater than 10 km from shore or the weather window for installation is narrow, there are technical advantages to incurring the extra cost of using a large vessel, including greater deck space, greater number of anchor blocks that can be transported on each trip, and the capability of setting up the longlines on the ship's deck while travelling. Using a large vessel to install longlines requires matching time

Flexibility of submerged longline at surface



Change in geometry of a longline with good structural tension as it is manoeuvered from the surface. The arrows indicate the movement of the corner buoys as the geometry of the longline changes. The length of the unusable segment depends on the depth from the surface.

frames, vessel availability, and the unit cost per longline.

Limitations with large vessels

The per diem rental cost of a large vessel is not that prohibitive unless nature plays against you and safety becomes compromised. It is important to know the site and the seasonal wind conditions. For example, positioning and dropping anchor blocks requires ship speeds below 2 knots, and if the wind picks up or gusts prevent the vessel from maintaining this low speed, both safety and accuracy are affected. If the time slot allotted for installation of the blocks and longlines is fixed or too narrow, problems can develop because although it is possible for larger boats to install up to 40 anchors per day, the mean number installed is only 20.

Back to the monohaul

Because of the large number of anchors to be installed in Chaleur Bay in future years, we needed to become independent of external constraints. We thus purchased a 45-ft monohaul fishing trawler and rearranged the hydraulics and solidified the gunnels for attaching the lines. Haulers were fixed on each side of the cabin to attach each of the 3-tonne blocks on the underside and below the stern, so they could be dragged to the site 10 km away. Longlines are attached to the blocks, which are positioned every 200 m and dropped on site using DGPS (differential global positioning system) coordinates. Although travel speed is reduced from 9 to 4 knots, 3 to 4 return trips can still be accomplished in a day. An additional block can be towed out by another vessel using the same principle.

When the aquaculture boat is working at the extremity of a longline during windy conditions, the anchor block is easily shifted, unless it is well imbedded in soft bottom. That is another good reason for keeping a greater distance between the longlines upon installation in exposed conditions.

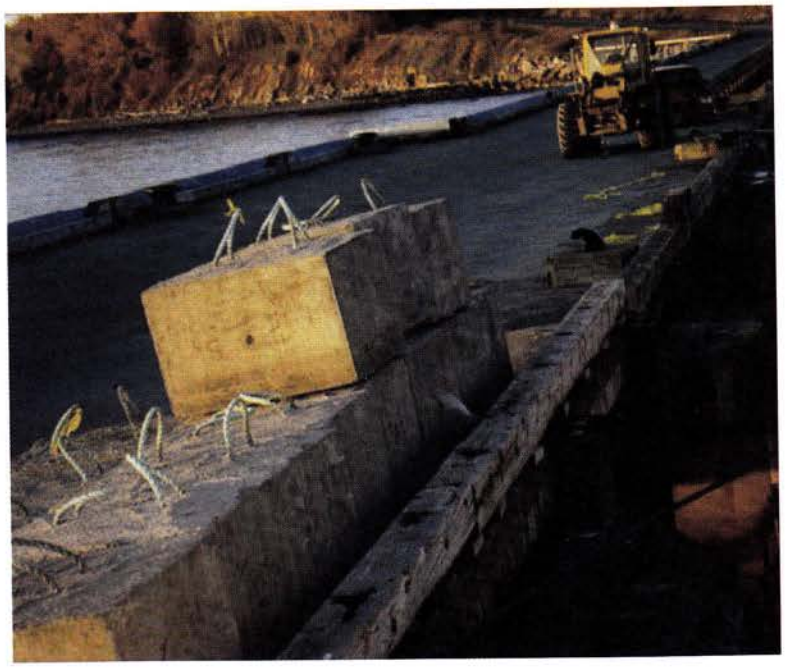
Screw anchor

Advantages

Screw anchors are easily handled and fabricated. They can be drilled through any depth of mud, silt, or sand in any depth of water. They are light weight, inexpensive, and require a drilling rig with minimal hydraulics — all of which can be either dragged across the ice or placed on a boat. Winter installation through the ice has been most effective, because the site can be surveyed using DGPS and snowmobiles, and the lines are easily installed in parallel series. These characteristics allow for maximization of space and efficient team work using 2 crews, with one preparing the holes and the other installing the screw anchors. The lines leading to the corner buoys can be attached from the anchor and left floating below the ice during late winter, when ice formation has ceased. We changed to this technique because it is less costly than the installation of 2- to 3-tonne concrete blocks in summer. A 20-cm disc anchor drilled through 5 m of mud offers very effective stability.

Disadvantages

This technique requires that the drill pipe remain vertical without too much pivotal movement, which is easiest to do on a solid ice platform or a spacious well-anchored boat. The ideal substrate is mud or mud-sand; coarser gravel mixtures and rocks create drilling difficulties. This technique cannot be applied to offshore situations during winter drift-ice conditions and is more difficult to apply in the open ocean, because vessel stability in deep water (22-25 m) is



Concrete anchors (3 tonne) stacked on the wharf in preparation for transfer onto a large open-deck trawler.

Deployment of anchors, buoys and longlines on the ship deck prior to installation at sea.

hard to maintain amidst variable tidal currents and gusty wind conditions.

Japanese arm anchor

Advantages

The Japanese arm anchor consists of a short hollow tube with hinged plates bolted onto the tube. A high-powered pump is required to pump water through the center of the anchor, which blows out the substrate from beneath the tube. The plates fold open as sand settles on them. The vessel is anchored by triangulation or using the wind, and must be very stable so that the pipe anchor is embedded vertically. Compared to the apparent success in the Magdalen Islands and Gaspé Bay with this anchoring system, where silt and mud bottoms predominate, we have had no reliable success with this type of anchor in Chaleur Bay.

Disadvantages

Variable results were obtained in 25 m depth offshore. The sandy substrate contained too much gravel and some larger rocks that prevented the water pressure from sinking the anchor below one meter (to hold 20 tonnes, the optimal depth of the anchor is between 5-6 m). This technique requires investment in hydraulics to pump water, but is comparable to the cost of drilling for the screw anchors.

Performance of Offshore Submerged Longlines

Submerged longlines perform best when they have good structural tension, yet remain flexible. The potential advantage of longlines installed in deeper water (>20 m) is that longer socks (>3 m) can be used to increase production capacity.

However, there are technical and financial consequences of using longer socks and increasing the yield from each longline:

1) Heavier longlines require a larger, more stable vessel and a powerful crane (5+ tonnes) to manoeuvre the lines up onto the starwheels and a pair of heavy duty starwheels to roll along the line.
2) More production per longline translates into a greater requirement for buoyancy and more difficulty maintaining flotation over the winter period if the longlines have to be submerged or if surface buoys must be removed.
3) A greater yield per longline can effectively be translated into fewer numbers of longlines to attain a desired production level. This is useful because it is then possible to gain economies of scale before purchasing additional lines or equipment.

The use of submerged longlines as we have designed them have proven efficient in terms of reliability, ease of access and speed of reflotation in springtime.[1] This efficiency is principally due to their greater tension which facilitates working on the lines using appropriately-designed deck equipment.

Winter installation of screw anchors using a small drill rig and the ice as a platform.

Over-wintering buoyancy

Although greater production capacity is economically advantageous, it is also more difficult to control future buoyancy requirements. Biofouling from second-set and mussel growth are the principal causes for longlines sinking during the winter. It is difficult to prevent the longlines from touching bottom as the biomass increases over the 6-month winter period (the interval between removal of the surface buoys in late October and flotation in May).

Our solution is to increase the number of intermediate 40-cm buoys to 12, which are weighed down with 75-kg concrete blocks, thus allowing an additional safety buoyancy of 375 kg, or 1500 kg wet mass of mussels per longline. This method has proven to be effective for over-wintering 1 km of socked mussels.

Constraints with Submerged Longlines

Access to corner buoys

Longlines submerged below 5 m do not allow easy access to corner buoys. We found the buoys on the market have not been totally reliable and have collapsed or leaked, both at the surface and when submerged.

A technique must be found to efficiently retrieve and replace corner buoys without using SCUBA. Another solution would be to change the angle of the anchor line by increasing the scope from 1.5 to 3 times depth. However, this would increase the tension of the line, reduce flexibility, take up more lease space, and reduce the length of the usable segment. Perhaps engineers could solve this dilemma and devise a simple and reliable method for retrieving the corner buoys.

Visual check of depth of submerged longline and mussel socks using an echo sounder.

Equipment Failures

Just about every piece of essential equipment failed in the last two years of production at sea, including the engine coupling to the hydraulic pump, the crane mounts, the bow thruster motors, the starwheels and most hydraulic components. This was due mainly to the much heavier and more demanding work loads in the exposed environment, but more specifically, to the use of inappropriate components in the hydraulic hoses, galvanized fittings, small starwheel shaft, and weak machinery that was designed according to the standards required for the inshore fishery, but not to those of offshore mariculture. Collapsing buoys and shredding cotton socking created additional problems, but these were solved thanks to some keen suppliers.

Equipment Modifications Improve Efficiency

Production activities at sea consist of manipulating longlines for 4 main operations: (1) maintaining buoyancy, (2) declumping and grading spat, (3) socking (sleeving) activities, and (4) commercial harvest. In all cases, vessels use a 7-tonne crane to position the lines onto the starwheels.

Starwheels

Despite the common availability of starwheels on the market, none have withstood the rigours of working offshore with submerged longlines for more than a year. One of the main problems is the heavy biomass on the longlines and the jarring effect of the boat during wave activity. We have had to enlarge the shaft leading out from the motor, and increase the diameter of the starwheel in order to increase the grip on the mainline.

Bow thrusters

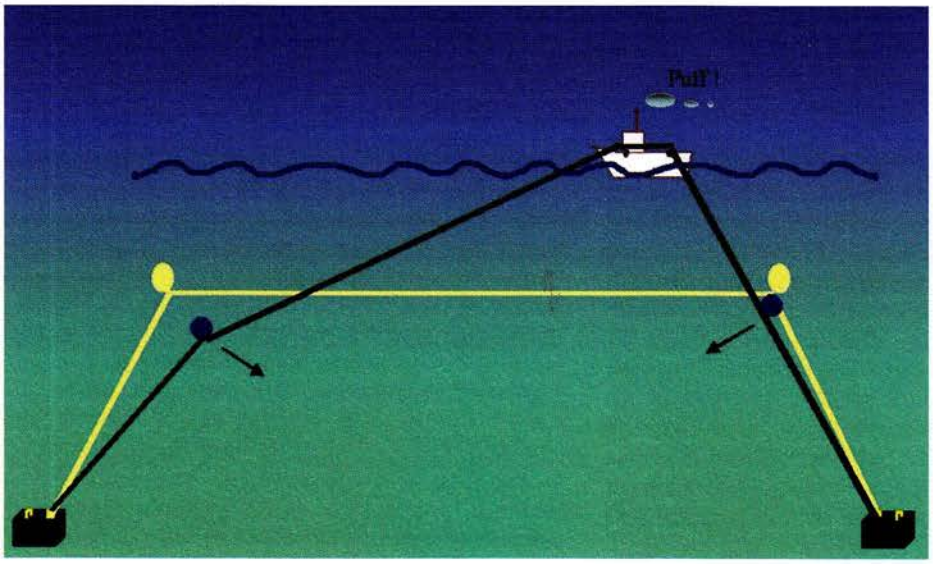
Vessels manipulating the longlines are exposed to mild breezes and sudden gusts, variable tidal currents, and wave activity. The installation of bow thrusters on the vessels have improved manoeuverability and stability of the boat on the longline. This extra expense prolonged the working day under rough conditions.

Modifications to Socking Techniques to Ensure On-Ship Safety

Most socking machines on the market resemble the New Zealand technology, both in height and dimension. However, aquaculture vessels in New Zealand are generally large barges operating within well protected bays. In contrast, space is limited on our boats, so the socking machines stand at least 2 m tall and use smaller spat volumes to save on deck space (the machines must be filled several times each day).

In exposed conditions, any wave action causes the boat to roll. As the spat bag is hoisted nearly 5 m off the deck to be positioned above the hopper of the socking machine, the bag may start swinging and either crash into something or spill its contents onto the deck. This is a serious safety hazard. The most unnerving task is untying the knot in the funnel of the bag. A deckhand must put his arm through the hopper structure and there is a risk of breaking an arm if it is trapped between the bag and the bar of the hopper.

The height of the hopper on the socking machine was lowered to increase safety. A sigh of relief was expressed by deckhands when the hopper



Change in geometry of submerged longline hoisted at the surface.

was modified to stand less than 1.2 m off the ground, and extend in length to 2.5 m, thus allowing 3 bags to be safely positioned and emptied. By stowing this machine to the side of the boat, we were also able to increase the working span of the crane on the deck, which is used to hoist the bags and lift the longline onto the starwheels.

Transfer of product at sea using cranes

One of the challenges in offshore mussel production is the distance from the site to the shore. Round trips are costly and reduce the number of longlines that can be worked in a day. During socking activities, travel is minimized. One boat is occupied harvesting, declumping and grading spat, while the other vessel is continuously socking. Space limitations prevent storing a full day's supply of spat on the boats, so spat bags must be transferred at sea from one vessel to the other. This is sometimes a difficult operation.

Wave conditions are critical in determining the safety of the transfer of the spat bags from boat to boat. Bags can easily start rocking and be snared on the corners of the declumper-grader or the socking machine. By lowering the height of the socking machine on the receiving vessel, and moving it to the side of the vessel, the spat bags are more easily manipulated and transferred. When conditions are too rough, boats move inshore for the transfer operation.

Continuous socking technology and modifications to ice harvesting

As previously noted, mariculture in deeper water provides several advantages, such as the ability to sink lines below fouling or ice levels, or increasing production capacity by attaching longer socks. We have mentioned the added strain on vessels and equipment when the longline production increases, but the effect of biomass must also be considered when harvesting the deep water longlines through the ice.

Using ice as a harvest platform requires the use of several safety procedures, which are strictly enforced by our provincial safety board. Although we may plan to harvest 3 tonnes of mussels from a line, the total biomass can be nearly doubled because of the weight of mud, biofouling, and second set.

Prior to ice harvest, a road is laid out to determine the ice thickness and structural quality. Longlines are located with DGPS and a perpendicular slice about 15 cm wide and 5 m long is cut with a chain saw. The line is hooked with a grapnel and a 45-cm wide slice is cut above and toward the center of the longline that will be harvested. This wider cut makes it easier to pull out 40-cm buoys and the mussels using a hydraulic unit and a hauler mounted on a solid tripod.

Safety considerations include properly anchoring the tripod, and ensuring the ice structure is sufficiently thick to withstand the combined forces at the base of the tripod legs. Every time a strip of ice is cut in a cross-shaped pattern, which is quite typical for ice harvesting, the ice strength is reduced by 75% and the thickness must be all the greater to support the mussels and equipment. Ice capacity charts exist to determine this.

Offshore Site Production Schedule

Accessibility is the limiting factor for successful offshore mussel production. One must determine the number of accessible work weeks. In the Gaspé, we must subtract the 5-month winter drift-ice period (December-April) and most of the month of November due to storms. Several factors have led us to switch to the continuous socking technique in order to schedule production activities in a 6-month window. We wanted to eliminate the peaks and troughs in boat and labour requirements that are required for short periods during the fall socking period. Continuous socking appeared to be the best method to stagger and maximize the use of the equipment and trained employees.

The consequence of this capital intensive socking method is five fold: (a) socking activities can be spread out over the summer and fall (May to October), thus staggering the use of equipment; (b) seed of varying sizes can easily be socked at controlled densities, without fear of trapping seed within plastic mesh; (c) mechanized socking is more efficient and requires no land-based facility; (d) harvesting operations are completely mechanical and continuous, thus eliminating unsafe manipulation of socks by deckhands and; (e) environmentally-friendly, poly rope is re-usable and the cotton socking dissolves naturally, thus eliminating the transport and dumping of discarded material.

We are presently refining the production schedule to avoid second set on socks which must be held over two winters. There is no definite way to set up a farm — the key to success is to understand the biophysical environment so that the selected technology functions most efficiently and safely.

References

1. Bonardelli JC. 1996. Longline shellfish culture in exposed and drift-ice environments. In, Proceedings of the Open Ocean Aquaculture Conference, 8-10 May 1996, Portland, Maine (M Polk, ed). University of New Hampshire Sea Grant College Program.

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Impacts of Aquaculture Practices on Genetic Variability of Blue Mussels (*Mytilus edulis*)

Réjean Tremblay, Bruno Myrand and Jean-Marie Sévigny

Genetic differentiation was detected between *Mytilus edulis* stocks from the Magdalen Islands, particularly between wild and cultured mussels. The genetic differences, as measured from electrophoretic data on multiple loci, are not related to variation in allelic frequencies but to genotype frequencies, particularly the proportion of heterozygous individuals. Important heterozygote deficiencies were observed in suspension-cultured mussels compared to wild mussels collected from sites without aquaculture activities. This observation may have important implications for the local mussel culture industry because of the inverse relationship between heterozygosity and fitness components such as resistance to stress. In this study, we have attempted to identify the causes of the lower heterozygosity observed in cultured mussels. Sampling and electrophoretic analysis of mussel spat collected at various times during commercial sleeving operations did not reveal selection against heterozygotes. Further, environmental conditions at the grow-out site had no effect on mean heterozygosity. The only significant decrease in mean heterozygosity occurred after the mussels had been sleeved and attached to longlines in the fall, with the the major decrease occurring within the first month of transfer to the lagoon. We hypothesize that the heterozygous mussels are more active than the homozygous ones and after sleeving they pass through the mesh of the sleeve more rapidly and are thus more prone to fall-off.

Introduction

There are two stocks of blue mussels (*Mytilus edulis*) in the Magdalen Islands. These stocks show different multilocus heterozygosity (MLH) measured at 7 polymorphic loci. The stock from Amherst Basin (AB) is more heterozygous than that from the House Harbour (HH) and the Great Entry (GE) lagoons with an observed heterozygosity (H_o) of about 0.50 compared to 0.34-0.32, respectively.[1] The stocks also differ in several parameters associated with fitness. Mussels from the AB stock showed a better physiological condition than the GE stock during the most stressful period of the year (first half of August) as indicated by their higher scope for growth, higher O:N ratio, lower ratio of maintenance metabolic rate to total metabolic rate, lower and shorter destabilization of lysosomal membranes, and lower thermosensitivity of metabolism at high temperatures.[2-4] Observations of the oxidative process also suggested a lower level of stress in the mussels from AB stock during August.[5] These results may be related to the inverse relationship between MLH and the metabolic needs of these stocks,[4] and suggest that fitness is higher for the more heterozygous AB stock than for the more homozygous GE stock. Indeed, mussels from the AB stock are much less susceptible to summer mortality than the more homozygous HH and GE mussels.[6] These studies have thus shown that, from an aquaculture perspective, the difference in heterozygosity between stocks may translate into lower performance in a production system. However, the causes of poor performance of the mussels under culture are probably complex and individuals from the same stock may react differently under different culture conditions. Indeed, it has been shown that the mean heterozygosity of suspension-cultured AB mussels transferred to grow-out sites in other lagoons is lower than that of the original spat used for sleeving.[1] Such a decrease in heterozygosity during cultivation suggests that mussel growers may not be gaining the full advantage of the high production potential of the more heterozygous AB mussels. In the present study, we have tried to describe further the relationship between heterozygosity and fitness components as these are relevant to the aquaculture industry.

The aims of this study were (1) to describe the relationship between heterozygosity and fitness using

survival rate, and (2) to identify the causes of the observed decrease in heterozygosity in suspension-cultured mussels.

Materials and Methods

Survival in stressful conditions

This study on the MLH-fitness relationship is based on the comparison between the mean heterozygosity of controls (T_0) and the survivors that had been exposed to one aerobic or one anaerobic stressful condition under controlled laboratory conditions (see methods in Tremblay et al.[1]). Two groups of mussels (50- to 60-mm shell length) from the Amherst Basin were exposed to the stressful conditions: wild mussels and suspension-cultured mussels transferred to the House Harbour lagoon for grow-out.

The aerobic stress was caused by exposure to a high temperature and a low food level in well-oxygenated water. One hundred mussels from each group were introduced to a tank filled with sand-filtered seawater maintained at 26-27°C. Half of the water from the experimental tank was renewed twice daily and no food was added. Oxygenation was provided with air stones. Dissolved oxygen was measured daily before water renewal and was consistently > 90% of saturation. Mussels were glued onto Plexiglass™ cross-pieces with cyanoacrylate gel and distributed randomly to minimize spatial variability in the tank. Mussels from each population were examined twice each day (when the water was renewed) until 50% of the individuals were dead (LT_{50}).

The anaerobic stress was caused by prolonged exposure to air.[7] One hundred mussels from each group were kept out of water in a room maintained at 17-19°C and relative humidity of ~100%. The mussels were placed in alternate positions and examined twice daily until 50% of the individuals were dead (LT_{50}).

Decrease in heterozygosity in suspension-cultured mussels

To understand the causes of the decrease in heterozygosity in suspension-cultured mussels, several analyses (experiments) were performed. First, the mean heterozygosity of mussels was determined at every step of the cultivation process from spat collection until the end of the first year of growth. To carry out these tests, spat were sampled from collectors in October and throughout the commercial culture operation. Samples included mussels that had just passed through the declumper-grader prior to sleeving and sleeved mussels that had fallen into tubs during handling prior to attachment of the sleeves to longlines. In addition, 20 traditional sleeves (10 stocked at normal and 10 at high density) were prepared and the mussels were sampled just before attachment to long lines and then after 2, 7 and 9 months in suspension culture. In another experiment, ten sleeves were prepared at a normal density, and five of the sleeves were placed in vertical mesh cages and suspended on a longline in order to retrieve the mussels that fell from the sleeves. The five other sleeves were suspended on the longline as usual. The comparison of mean heterozygosity of fallen mussels with those still attached to the sleeves provided the opportunity to determine whether more heterozygous individuals are more susceptible to fall-off following the attachment of the sleeves to the longlines. Mussels from the sleeves and those on the bottom of the cages were sampled after 3 and 30 days.

Environmental effects

To examine the possible impact of environmental conditions at the grow-out sites on genetic variability, pieces of collectors were placed in 10 pearl-nets, half of them at the spat collection site in Amherst Basin and the others at the grow-out site in House Harbour lagoon. The mussels in the pearl-nets were sampled in November, June and September.

Effect of using continuous sleeves on changes in heterozygosity

The mean heterozygosity of mussels was also determined in continuous sleeves 1, 7 and 10 months after attachment to longlines. At each sampling, a minimum of 50 mussels were scored at seven loci to determine heterozygosity following the procedure described previously.[1,4]

Results and Discussion

Survival in stressful conditions

There were important differences between the two groups of mussels even though both originated from Amherst Basin. In both types of stressful conditions, the cultured mussels had a much lower survival than the wild mussels (Fig. 1). The deficit in heterozygotes changed sharply among the suspension-cultured survivors when compared to the T_0 controls. The suspension-cultured survivors were systematically more heterozygous than their T_0 controls, and showed the same pattern under anaerobic and aerobic stressful conditions. In contrast, the mean heterozygosity of the AB survivors was always similar to their T_0 controls in both experiments. This study showed a clear relationship between MLH and fitness as estimated by survival in suspension-cultured mussels. Highly dif-

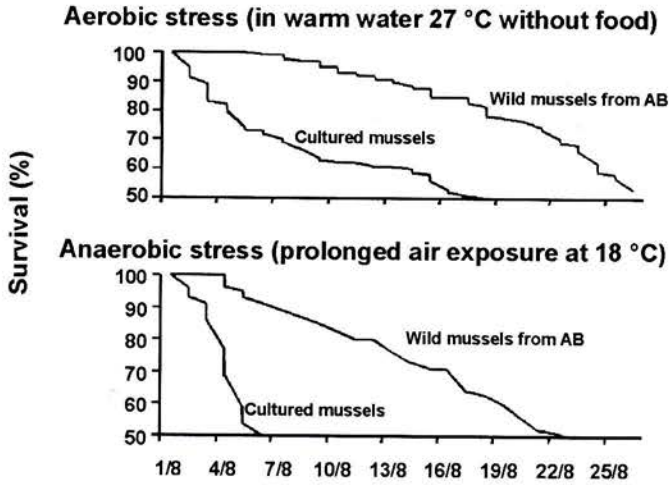

Figure 1. Survival rates of mussels facing aerobic stressful conditions (well-aerated with no food added and temperature > 26.5°C) and anaerobic stressful conditions (prolong immersion at temperature ~ 17-19°C). The initial number of mussels per group and per treatment was 100.

ferent stressful conditions caused an increase in mean hetorozygosity in these suspension-cultured mussels, through a selective mortality of homozygotes. In contrast, there was no selection against the more homozygous individuals and therefore no increase in mean heterozygosity in survivors from Amherst Basin to stressful conditions. The major difference between these two groups was that the suspension-cultured mussels were characterized by a significant heterozygote deficiency and a low observed heterozygosity *Ho* at the onset of the experiments while the wild Amherst Basin mussels had a high *Ho* value and no deficit in heterozygotes. Such a relationship between heterosis and heterozygote deficiency has been suggested in several studies.[8-12] We suggest that it was not possible to detect selection against homozygotes and thus an increase in mean heterozygosity in wild Amherst Basin survivors because of the low initial proportion of more homozygous mussels.

Decrease in heterozygosity in suspension-cultured mussels

The determination of heterozygosity values of mussels at various steps of the commercial sleeving operations did not show any difference in the proportion of heterozygotes among the various steps of the operations. The heterozygosity of spat taken directly from collectors was 2.96 (± 0.11 SE) compared to 2.95 (± 0.18) and 3.13 (± 0.20) in mussels rejected and sorted by the declumper-grader, respectively. The heterozygosity of mussels lost in tubs during handling before the sleeves were fixed to the longline showed no significant differences compared to spat. Thus, there was no modification of heterozygosity prior to attachment to the longline.

The pieces of collectors placed in pearl-nets at the spat collection site and at a grow-out site showed no significant differences in heterozygosity after one year, indicating no environmental effect. These values were not significantly different from the spat value. However, we observed differences in heterozygosity of mussels after the sleeves were attached to longlines, with a greater loss soon after attachment (Fig. 2). In traditional sleeves, a major de-

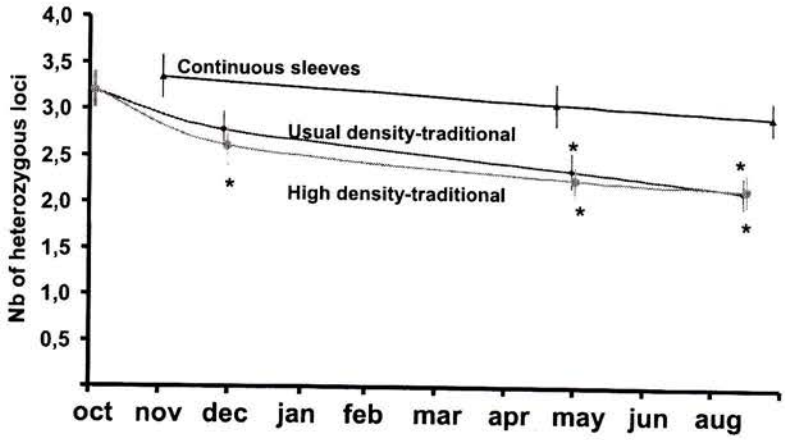

Figure 2. Change in mean heterozygosity of mussels from traditional (at high density and usual density) and continuous sleeves between October 1998 and August 1999.

crease occurred within the first month after attachment to the longline. The decrease was greater on high density sleeves compared to the usual density sleeves. The decrease continues after the first month, but at a lower rate.

Three days after suspension on the longline, mussels on the bottom of the cages showed a lower mean heterozygosity than the spat used for sleeving (Fig. 3). We consider these fallen mussels as passive losses due to handling. After 30 days, only a few mussels were retrieved from the bottom of cages and their heterozygosity was similar to those attached on the sleeves. Therefore, it appears the experimental cages prevented the large fall-offs that occurred in uncaged sleeves because of their stability in the water column. Heterozygosity of mussels from uncaged sleeves was much lower than that of mussels sampled from caged sleeves (limited fall-off). We suggest that more heterozygous spat passes through the mesh more rapidly and thus are more likely to fall-off during the high turbulence that occcurs in the autumn. This hypothesis would explain the low heterozygosity of mussels on traditional sleeves one month after attachment to longlines.

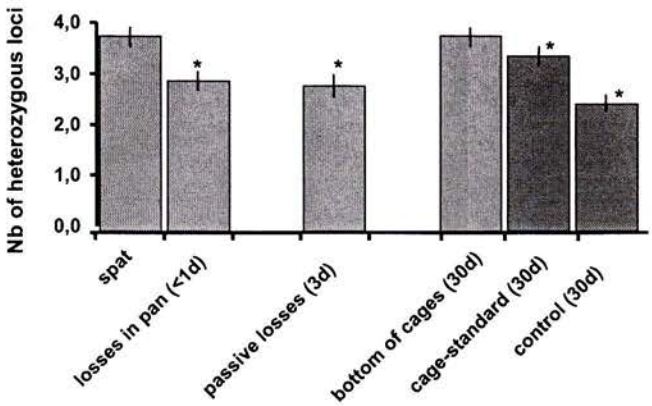

Figure 3. Change in mean heterozygosity related to fall off with standard density sleeves placed in cages and control sleeves without cages. The number of days between the attachment to longline and the sampling is indicated in parentheses.

In contrast to traditional sleeves, it appears that the decrease in mean heterozygosity is lower than in mussels grown in continuous sleeves (Fig. 2). This is possibly because the cotton cloth used for sleeving limits fall-off for a certain period of time (before its degradation) following attachment to longlines. This period of time may be long enough to allow firmer spat attachment to the culture rope and thus limit fall-off.

In conclusion, traditional sleeving may induce losses of the best (more heterozygous) individuals for mussel production. These losses seem to result from fall-off of more active individuals through the mesh of the sleeve. Therefore, any means to limit fall-off, particularly in the first month, should maintain the initial heterozygosity of mussels. Preliminary results indicate that the new continuous sleeving technique which is based on the use of degradable cotton cloth slows down the loss of more heterozygous individuals.

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References

1. Tremblay R, Myrand B, Sévigny J-M. 1998. *J. Shellfish Res.* 17: 1191-1202
2. Tremblay R, Myrand B, Guderley H. 1998. *J. Shellfish Res.* 17: 141-152.
3. Tremblay R, Myrand B, Guderley H. 1998. *Mar. Biol.* 132: 641-648.
4. Tremblay R, Myrand B, Sévigny J-M, Guderley H. 1998. *J. Exp. Mar. Biol. Ecol.* 221: 27-58.
5. Pellerin-Massicotte J. 1997. *J. Rech. Oceanogr.* 22: 91-98.
6. Myrand B, Gaudreault J. 1995. *J. Shellfish Res.* 14: 395-404.
7. Viarengo A, Canesi L, Pertica M, Mancinelli G, Accomando R, Smaal AC, Orunesu M. 1995. *Mar. Environ. Res.* 39: 245-248.
8. Bricelj MV, Krause MK. 1992. *Mar. Biol.* 113: 253-261.
9. Gaffney PM. 1990. *Evolution* 44: 204-210.
10. Houle D. 1989. *Genetics* 123: 789-801.
11. Pogson GH, Zouros E. 1994. *Genetics* 137: 221-231.
12. Zouros E. 1987. *Isozymes Curr. Top. Med. Res.* 15: 255-279.

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Sustainable Mussel Culture: A Millennial Perspective

Carter R. Newell

Growth in the past decade in the supply of and demand for high quality mussels has been fueled by improvements in technology and cooperative approaches to solving problems. This has resulted in opportunities for those involved in mussel spat collection, grow-out and processing. However, integration of other users of the coastal zone, such as commercial fishermen, into mussel aquaculture is required before there will be widespread acceptance of such activities. Selection of culture sites that have the characteristics required for seed collection and grow-out are based on local knowledge and an approach that uses knowledge of oceanography and mussel biology. Over the past 15 years, flow modeling has resulted in advancements in site optimization by controlling stocking densities, site selection for new lease areas, and the prediction of impacts and beneficial interactions with benthic and pelagic ecosystems. Detailed knowledge of the behavior of larval and bysally-drifting mussels, the effects of currents and food concentration on mussel pumping behavior, energy flow diagrams of mussel populations, and studies of food supply and demand within suspended and bottom culture systems has aided in the development of new culture technologies and further growth of the industry. An environmental code of practice, continued modeling efforts, and cooperation with respect to technology transfer within the industry and the scientific community should help launch the mussel industry in North America into the next century with continued sustained growth.

Introduction

For any type of aquaculture to be profitable, four key elements are necessary:

1. The right species must be cultured for a given area. In North America, the edible mussels are *Mytilus edulis, Mytilus trossulus* and *Mytilus galloprovincialis.* Using native species provides the advantage of reducing the cost of spat collection.
2. Growers should choose the right farm environment (either shallow or deep coastal waters, or offshore). For *Mytilus edulis*, maximum temperature should be below 20°C to prevent summer mortalities. It is preferable for the site to be protected from exposure to wave action, ice, and predatory sea ducks. High primary production is desirable, as are low amounts of inorganic silt and clay. Currents should be adequate to supply the mussel farm with sufficient food to match consumption rates, but not so high that the currents interfere with feeding or attachment of the mussels to cultivation ropes or socks.
3. Cost-effective culture techniques are important, and range from bottom culture to longline culture and raft culture. Improvements in culture technology (continuous longline systems, specialized vessels, cranes and conveyors) are key to decreasing the cost of production to make the product competitive.
4. Production of high quality product and effective marketing are important to provide the consumer with mussels that have high meat yields, are of a uniform size, have no byssal threads (debyssed mussels) or breakage, and a long shelf life. These qualities will increase the price of cultivated mussels for both the growers and the processors.

Developing a business growing mussels requires a number of skills. Usually the work on the water involves skills that commercial fishermen already have and can apply to mussel farming. The process of growing mussels involves a range of activities, including seed collection, seeding (attaching mussels to ropes or socks), maintenance of the farm (setting moorings, predator control, thinning), and harvesting.

Often, local knowledge about currents, ice, predators, bottom type, wave conditions, navigation, pollution sources, political climate, and local patterns of fishing activity will be important in ensuring the farm succeeds. In addition, those who are practical in orientation will be more likely to succeed as they will come up with clever ideas on how to make processes run more smoothly, how to increase efficiency, and how to reduce labour costs.

A key element in the development of a new industry such as mussel culture in North America is the willingness of growers to share information with each other. When a bottleneck in cultivation is experienced (e.g., harvesting through the ice), some individuals will inevitably find a solution and if the breakthrough is shared with a group of like-minded growers, the whole industry will benefit. This "shellfish exchange mentality" is the key to rapid industry development and is in sharp contrast to the capitalist concept that ideas should be kept secret to gain competitive advantage. The driving force within the industry should be that there is a huge demand for high quality shellfish, so everyone gains when new developments are shared.

Shellfish farmers become stewards of local water quality because they require pristine areas for shellfish cultivation. In Maine, growers have teamed up with volunteer water quality samplers to help maintain the status of shellfish growing waters and identify pollution sources to be remediated. Certified samplers are involved in collecting nearly 50% of the water samples used in classifying growing areas, which reduces the cost to regulatory agencies and results in the opening of new areas for cultivation.

The role of mussel processors is also critical to the development of the industry. Farmers must be given a fair price for their product, and incentives for increasing yield and meat yield will lead to a better product. Processors need to continually strive to increase the shelf life, reduce breakage, and provide a fair weight to consumers. New regulations with respect to HACCP (hazard analysis and critical control points) help to assure shellfish safety and allow the industry to be pro-active with respect to problem areas. The cost of complying with the new regulations, however, must be absorbed by the industry, which reduces profitability.

Financing and business management are very important aspects in developing mussel aquaculture. While venture capitalists may require 20% interest for high risk investments, low interest loans are important for the farmers and processors to be able to make the necessary investments to develop their farms. While this concept is well understood in Canada, it is still a hard sell in the United States.

Site Selection for Seed Collection and Grow-Out

In order to grow more mussels, the industry needs more sites. Good site selection is a major factor in industry development. Site selection depends on the cultivation phase: areas of good seed collection and areas for good grow-out of mussels should be chosen carefully. Our studies in Maine on seed collection[1,2] demonstrate the importance of hydrodynamics on the concentration of mussel larvae and juveniles (up to 1 mm) that drift using a drifting byssal thread. Areas that are good for seed collection and growth and survival of spat to a size which can be attached to ropes or socks (about 10-35 mm shell length) are not necessarily the best places for grow-out of mussels to market size. In addition, areas with high spat densities (> 100 000 per meter) result in slower growth of the seed mussels than areas with moderate densities (i.e., 10 000 per meter). Where currents provide good vertical mixing, spat will attach to lines over 10 m long, but where currents are slow and there is vertical stratification of the water column, spat may be concentrated in the upper 2 to 3 meters.

Selection of good sites for the grow-out of mussels depends on the type of cultivation. For bottom culture, mean current speeds of 15 to 20 cm/s are necessary to support moderate grow-out densities (i.e., 200-400/m^2)[1,3-5] of mussels in Maine. This is because of the reduction in current speeds near the bottom of the benthic boundary layer, and the tendency of water to become depleted of phytoplankton and detritus in the downstream direction over regions of mussel tissue biomass of 1 kg/m^2. For longline culture, lower currents (5 cm/s) are adequate due to the generally large spacing between the longlines. For raft culture, moderate currents (10-15 cm/s) are necessary to prevent depletion of over 50% of the food to the mussels in the inside of the rafts. Current speeds above 25 cm/s may have a negative effect on mussel growth and attachment to lines in suspension culture, while they may be fine for bottom culture, especially in deep water.[6]

Aquaculture structures such as rafts and longlines, and even mussels seed spread on the bottom, also may affect ambient current speed and direction. In the case of bottom culture, mussel beds extending up to 12 cm off the bottom increase bottom roughness and vertical mixing, improving their food supply. In longlines, large arrays may reduce flow through a site. For rafts, increased flows under and around the rafts generate vertical mixing and complex vortices. Understanding these flow effects aid in developing sites for mussel aquaculture. In addition, ambient hydrodynamics play a large role in the carrying capacity and holding capacity of a site (see next section).

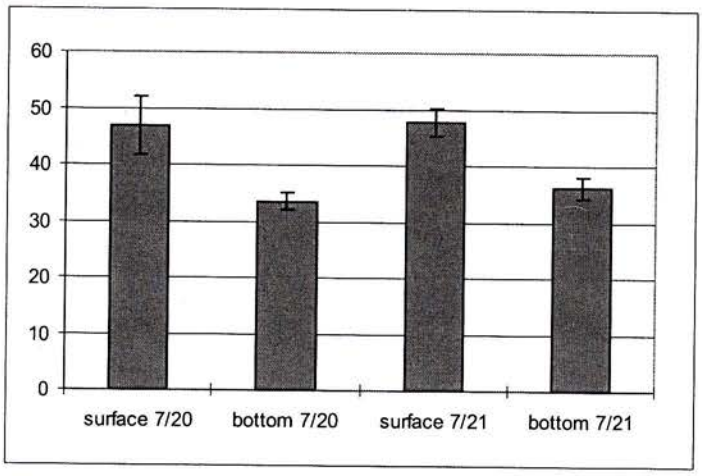


Figure 1. Percent organic seston from surface water and bottom water during marine snow investigations at Roque Island, Maine in a shallow, low current embayment.

Food concentration and quality are also very important aspects of site selection for mussel culture. Studies at our sites in Maine identified over 900 species of phytoplankton, with 95% of the biomass being diatoms. While high levels of chlorophyll a are generally an indicator of a good grow-out site, particulate detritus with a high nitrogen to carbon ratio[4] is also important after seasonal declines in phytoplankton occur. Particulate inorganic matter (PIM) tends to dilute the high quality food for mussels especially in shallow, inshore waters with extensive mudflats. Since mussels have a fixed digestive tract volume, the higher percentage of that volume which is pure phytoplankton, the better the assimilation will be into absorbed organics in the diet. Further offshore in deeper waters, the PIM concentrations decline and food quality of over 90% organic matter in the seston is common. This explains the high meat yields, rapid growth rates and thinner shells of mussels in suspension culture, and points to the possibilities of mussel culture in offshore waters as new technologies are developed.

Recent studies involving researchers from Maine and New Brunswick[7] have also identified a factor that results in slower growth of mussels on the bottom than in suspension culture: *marine snow*. Marine snow is formed, especially in low current areas, when phytoplankton, colloidal carbohydrates, bacteria and inorganic particles stick together in large aggregates, some reaching over 1 cm in length! Our studies showed that these particles form around high tide and settle to the bottom, resulting in a large pulse of particles, mostly composed of PIM, to the bottom. This causes a decrease in food quality for the mussels (Fig. 1,2), and they produce pseudofeces in an attempt to sort the high quality food from the PIM. Nearby in the surface water, mussels suspended from ropes continued to feed at high rates with no pseudofeces. In areas with higher current speeds, vertical mixing supplies mussels with more high quality food and because of the turbulences, marine snow is less likely to form. Therefore, mussels in suspension culture grow better due to higher food quantity and quality.

Holding Capacity

The ICES (International Council for the Exploration of the Sea) working group on the environmental interactions of mariculture (includes fish farms) is a group that meets annually to discuss national production trends, use of chemicals, significant new research results and directions, and development of a program of work related to the ICES Mariculture Committee and Marine Habitat Committee. The working group includes representation from Canada, EU countries, South Africa, and myself from the United States. Originally under the direction of Harald Rosenthal, and more recently Ian Davies of Scotland, the committee discussed the holding capacity of sites (the capability of a particular marine site to

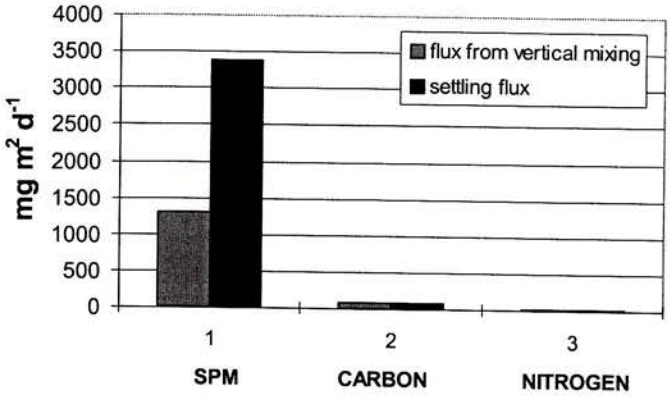


Figure 2. Comparison of the vertical flux of carbon, nitrogen and SPM (suspended particulate matter, mostly inorganic) to the settling flux observed in 24-hour deployments of sediment traps at Roque Island, Maine.

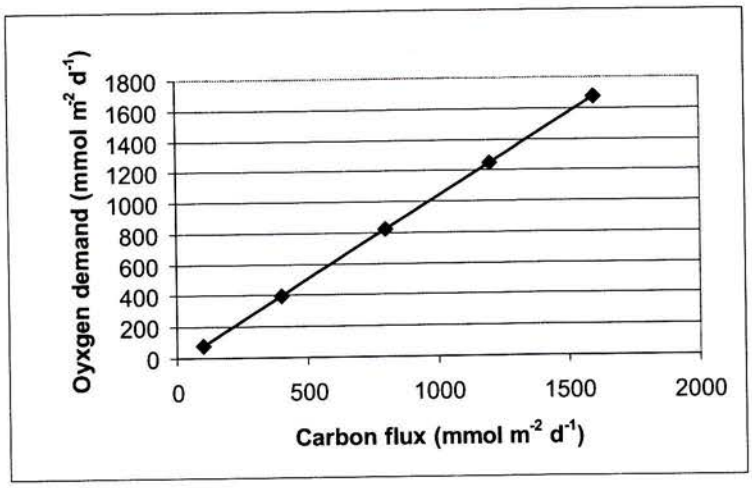


Figure 3. Oxygen demand as a function of organic carbon flux (from Findlay and Watling[7]).

grow fish or shellfish without causing undesirable effects). They recently reviewed the current state of development of predictive 2D and 3D mathematical models of fish farming which integrate environmental physics, husbandry practices and environmental interactions of mariculture. The goal was to balance the organic deposition of biodeposits and fish feed with the ability of the benthic ecosystem to accommodate the waste, thereby ensuring sustainability and also maximizing farm productivity. The stimulation of benthic biomass beneath fish and shellfish farms was observed in moderate and strong current areas but lower current sites could be overloaded with sedimenting organic matter. Findlay and Watling[8] plotted the oxygen demand from the bottom as a function of the organic carbon flux from salmon pens, and compared low and high current sites in Maine with respect to their holding capacity (Fig. 3). The oxygen required for the benthic metabolism to match the net carbon sedimentation at a site was a function of current speed, which diffuses oxygen to the bottom. At minimum 2-hour current speeds of over 5 cm/s, they found adequate oxygen flux for the sites they studied (Fig. 4).

The enhancement of benthic and pelagic biomass around and underneath finfish and shellfish farms is leading to numerous investigations of aquaculture structures such as artificial reefs. Fouling organisms such as kelp, marine polychaetes, sea urchins and hydroids on mussel ropes attract fish grazers and other organisms. Crabs feeding on mussels falling from the ropes may enhance lobster biomass. Sedimented fish feed from salmon pens can attract fish, crabs, sea urchins and benthic bioturbators. Marine worms become a source of food for flounders. In eastern Maine, anglers from over 100 miles away drive to salmon pen sites for good fishing! Nets and mooring lines can form a substrate for attachment of mussel seed, sea scallops and clams.

Since the assimilative capacity of the benthos is a function of oxygen flux, and oxygen flux is a function of current speed, it is useful to consider flow models as a tool in predicting the holding capacity of different sites. Panchang et. al.[9] and Dudley et al.[10] have used flow models such as DUCHESS, SMS and AWATS to provide 50-m resolution flow models that incorporate particulate waste dispersion, rates of resuspension and ambient hydrodynamics into a useful first order diagnostic tool for predicting the holding capacity of different sites.

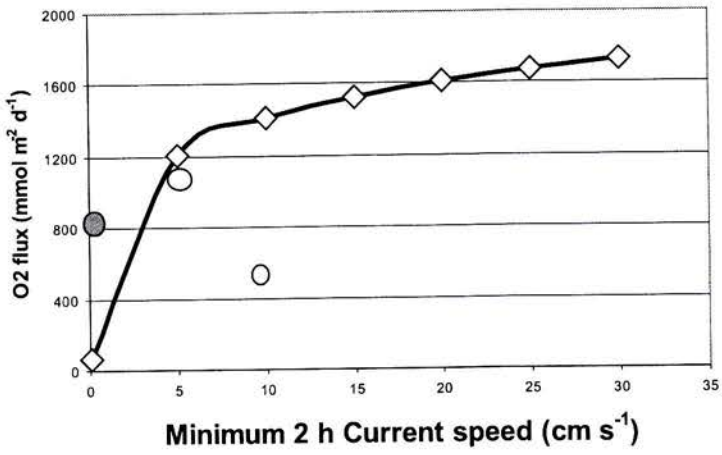


Figure 4. The oxygen required for the benthic metabolism of the net carbon sedimentation as a function of the minimum 2-hour current speed at three sites (from Findlay and Watling[7]). The two white circles to the right of the line were sites that had moderate to strong currents and adequate oxygen flux. The shaded circle to the left (low current site) had inadequate oxygen flux. However, at that site winter wave-induced resuspension and transport off the site resulted in little net carbon sedimentation on an annual basis.[8]

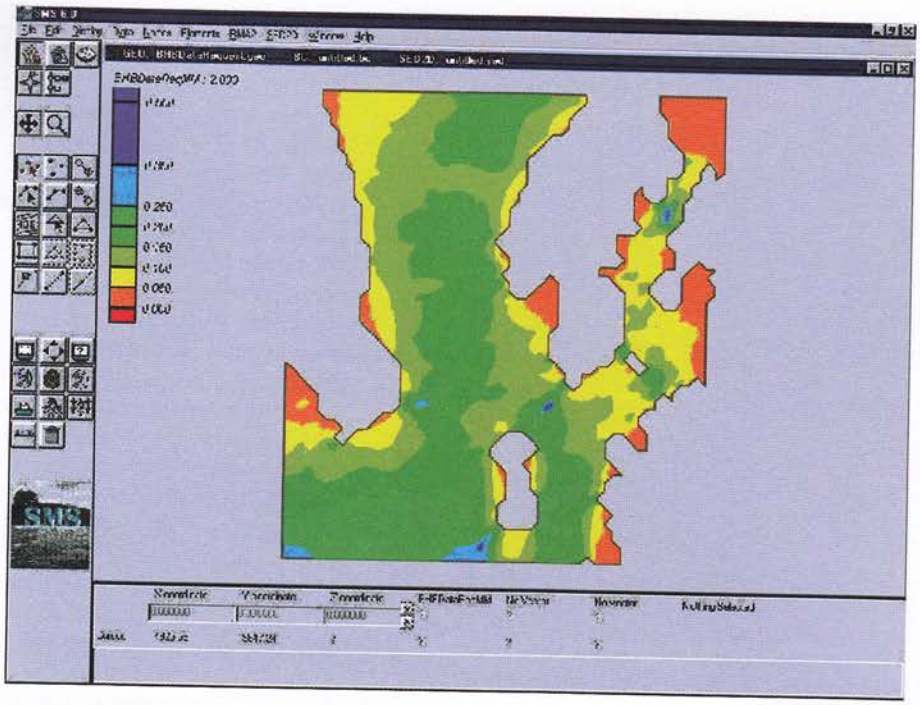


Figure 5. Output of DUCHESS/SMS flow model for mean current speed (in m/s) for a coastal embayment in Maine.[11]

Carrying Capacity

To optimize the harvest yield of market-sized mussels without reducing growth rates at a given site, one can consider the "carrying capacity" of that site. Whether in suspension or on the bottom, at a given time of year mussel biomass may reach a level above which there will be density-dependent growth. Under those circumstances, modelling the relationships among seeding densities, current speeds and food concentration may provide useful results when planning farm management activities. Using the mussel production model MUSMOD,[11] a market-sized mussel of a 4- to 5-gram meat size could be achieved at the Mud Cove site within a year at about 300 mussels/m^2, whereas the same growth rates could be achieved at a density of 600 mussels/m^2 at the Schieffelein site due primarily to higher summer and fall food densities at the latter site.

The carrying capacity of mussel rafts was the subject of a recent study by myself and Dr. John Richardson from

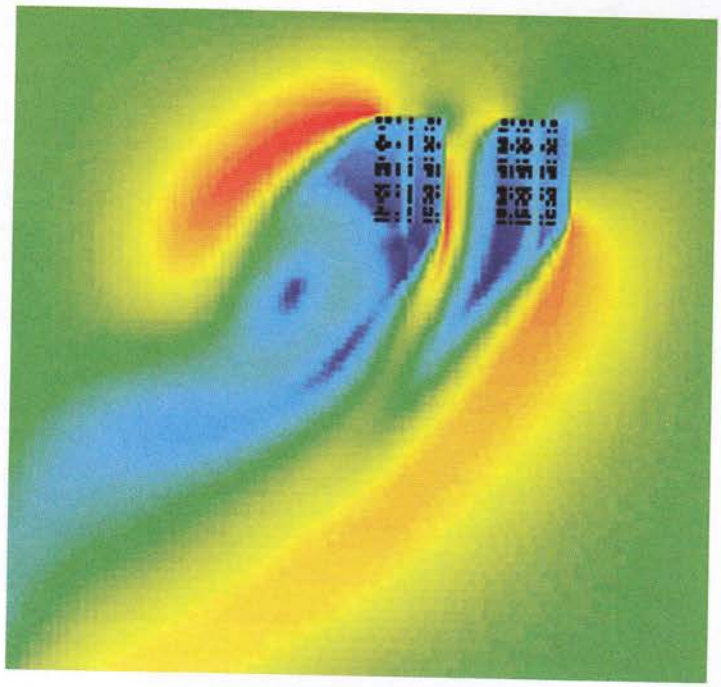


Figure 6. Flow through mussel raft system (colored by speed).

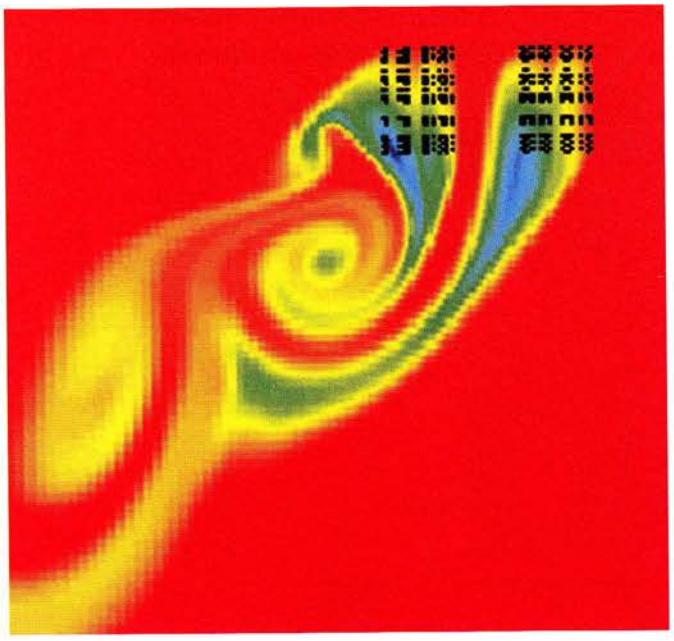


Figure 7. Chlorophyll a (colored by concentration).

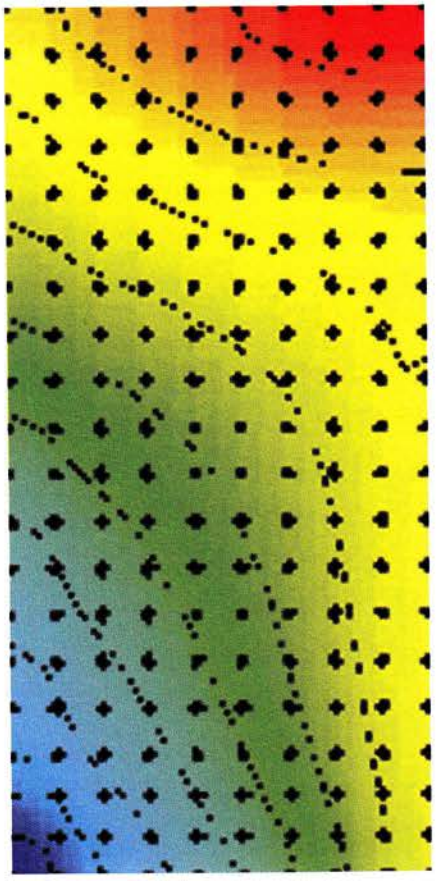


Figure 8. Predicted yield within raft(colored by biomass).

Earth-Tech (Concord, NH) where we investigated the optimization of mussel production through the use of oceanographic and biological models. Using the software FLOW-3D, we utilized 14-m square rafts with 400-500 11-m long droppers for data collection and building the initial 3D flow model. We developed a sampling strategy for current and food particles over horizontal and vertical scales to tune the model with field data. We then provided model simulations to improve raft design and placement at field grow-out sites. Flow fields in the vicinity of the farm were modelled using DUCH-ESS and SMS.[10] In Figure 5, the light green regions represent areas within the study domain that are suitable for mussel raft culture.

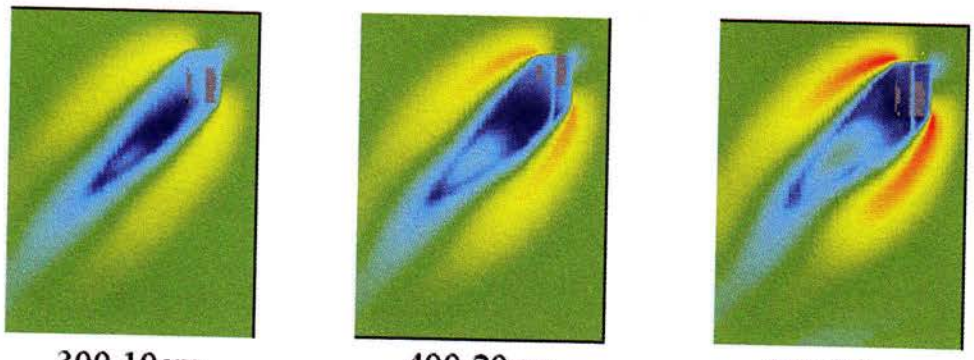
Using data on current velocities, distribution of chlorophyll, POC and PON, we were able to use Flow 3D and estimates of mussel consumption to investigate effects of raft orientation to flow, raft aspect ratio (i.e., 1:1 to 1:4 dimensions), number of ropes and rope diameter, raft size and multiple rafts on the mean flow through each raft and on the food concentration. An example of using FLOW-3D for analyzing current speed is shown in Figure 6, chlorophyll a in Figure 7 and predicted yield in Figure 8.

We were able to investigate quantitative effects of aspects such as the number of ropes and rope diameter in a table comparing mean velocities of the model runs; such data is useful for farmers in managing their lease sites. For example, if ropes are just seeded and 10 cm in diameter, a mean velocity of 6.3 cm/s will be observed through the raft at a density of 500 ropes per raft. However, in order to maintain a flow of over 5 cm/s when the mussel ropes grow to a diameter of 20 cm, they need to be thinned to 300-400 per raft (see below, Fig. 9).

While modelling has its benefits for both investigation of production capacity and for different farm management scenarios, it must be used in concert with field measurements of water velocity and food concentration. Growth data in relation to density within each culture unit and at different locations within the farm site provide valuable data for tuning growth models.

Conclusions

The importance of good husbandry, not only with respect to farm production but also with respect to the environment and other users of the coastal zone has led several areas to develop environmental codes of practice. These will become increasingly important as



300-10cm 400-20cm 500-30cm

Mean Velocity (m/s)

# of Ropes	Rope Diameter (cm) 10	20	30
300	0.076	0.055	0.042
400	0.070	0.050	0.037
500	0.063	0.043	0.030

Figure 9. Effects of number of ropes and rope diameter on mean flow through a Maine mussel raft: results using FLOW-3D.[11]

competition for limited coastal water intensifies. Through continuing integration of aquaculture into integrated coastal zone management, and through efforts to create jobs while maintaining environmental sustainability, we will continue to see growth in the industry. With cooperation and technology transfer within industry, research , government and volunteer sectors, we will see continued reduction in labour costs and increased productivity.

A combined oceanographic and biological modelling approach is important in site selection, yield optimization and predicting the environmental interactions of both shellfish and finfish aquaculture. Sites with moderate currents, adequate water depth and good husbandry can result in adequate dispersion of organic particles, aerobic breakdown in the sediments, and actual enhancement of benthic biomass. Continued modelling efforts and cooperation between the US and Canada (COSAD (Coastal Oceanography for Sustainable Aquaculture Development)) and other regions will help in the choice of good sites for the development and proper management of mussel culture sites. Since shellfish act as a natural control of eutrophication in coastal ecosystems, removing nitrogen from the system when they are harvested and through coupled nitrification/denitrification under aerobic conditions in the sediments, we may actually see the encouragement of mussel and other shellfish farms in the coastal zone as a way of improving coastal water quality!

In summary, there are several ways to maintain and increase sustainable mussel culture into the next century, using new tools that can improve efficiency and reduce the need for a "trial and error" approach to aquaculture development.

I would like to thank the AAC for travel assistance to the conference in Moncton, Dr. John Richardson for his contribution to the FLOW-3D simulations, and Richard Gallant and John Gracey for their contribution to the shellfish exchange mentality.

References

1. Newell CR, Hidu H, McAlice BJ, Podniesinski G, Short F, Kindblom L. 1991. *J. World Aquacul. Soc.* 22:134-152.
2. Newell CR et al., unpublished data.
3. Newell CR, Shumway SE. 1993. In, *Bivalve Filter Feeders in Estuarine and Coastal Ecosystem Processes* (RF Dame, ed.), pp. 85-148. NATO ASI Ser. G Vol 33, Springer-Verlag, Berlin.
4. Newell CR, Campbell DE, Gallagher SM. 1998. *J. Exp. Mar. Biol. Ecol.* 219:143-169.
5. Newell CR. 1999. *Bull. Aquacul. Assoc. Canada* 99:31-38.
6. Newell CR, Wildish DJ, MacDonald BA. 2001. *J. Exp. Mar. Biol. Ecol.* 262:91-111.
7. Newell CR, Robinson SMC, MacDonald B, Pilskaln C, unpublished data.
8. Findlay RH, Watling L. 1997. *Mar. Ecol. Prog. Ser.* 155:147-157.
9. Panchang VG, Cheng G, Newell CR. 1997. *Estuaries* 20:14-41.
10. Dudley RW, Panchang VG, Newell CR. 2000. *Aquaculture* 187:319-349.
11. Campbell DE, Newell CR. 1998. *J. Exp. Mar. Biol. Ecol.* 219:171-204.
12. Newell CR, Richardson J, unpublished data.

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Hatchery Production of Seed: A Future Trend in Mussel Culture?

John Brake, Jeffrey Davidson and Jonathan Davis

Mussel (*Mytilus edulis*) culture in Atlantic Canada utilizes wild seed harvested from spat collection sites. The economics associated with wild-caught seed have proven to be more favourable than with hatchery-produced seed. This is not, however, the case in all areas. In Washington state, seed used for culturing *M. galloprovincialis* is produced in hatcheries. As it becomes increasingly difficult to reliably acquire seed in Atlantic Canada, and the market demands more product, seed requirements may become a larger issue. Will there be a widespread requirement for hatchery-reared seed and, if so, what are the current constraints to production? There are many aspects to consider with this question. The advantages of a hatchery program include the potential for selective breeding programs to produce novel shell patterns, greater control over seed quality, and the ability to produce polyploids for superior growth and sterility. Some of the disadvantages of a hatchery program include the high initial cost, requirement for research to improve the economic feasibility of hatchery methods, and the fact that the infrastructure for wild seed collection currently exists but that for hatchery-reared seed does not. This paper discusses the constraints and merits of using hatchery-produced seed and compares the situation in Atlantic Canada with that in Washington state.

Introduction

The farm rearing of molluscs has, in many cases, spurred refinement of the methods used in seed gathering and production to make culture more profitable and predictable. The North American clam and oyster farming industries have been successful in the profitable use of both wild seed gathering and hatchery seed production. Such endeavours have enabled the expansion of molluscan shellfish farming on local, national, and global levels.

Recent expansion in the mussel culture industry in North America raises the question of the future of mussel seed production. Issues of concern include variable quality and quantity of wild seed, lack of control over the physical and physiological characteristics of wild seed, and the profitability of wild seed collection compared to the alternative of hatchery seed production. This paper introduces some of the major considerations in the hatchery production of mussel seed, including the advantages, disadvantages, constraints, and concerns voiced in the industry in various parts of Canada and the northern United States.

Outline of Mussel Seed Collection

A number of concerns have been expressed by the industry about the collection of wild seed in the northern United States and Canada. Although many of the issues are similar, each geographical area has its own specific culture parameters and thus its own priorities with regards to seed concerns. It can be difficult to compare seed collection/production in different areas because of differences in measuring units and methodology. In some cases, a direct comparison of costs can be made, but in others this remains impossible. The following sections outline seed collection and production in Canada and the northern United States.

Atlantic Provinces and Quebec

Mussel seed collection is similar in the Atlantic Provinces and Quebec. The cultured species is *Mytilus edulis* and all seed is collected from the wild. Seed is generally collected on lines, 2-3 weeks after the mussels have spawned in a particular area. The lines are generally comprised of frayed rope, often recycled from the lobster fishery or from previous years of seed collection. After the mussel seed has reach a size of 10-25 mm on the collector, they are stripped

into 100-lb (45 kg) totes for sale or socking by the leaseholder. Seed of this size are generally sold at a price of $0.20/lb ($0.44/kg), or $20/100-lb tote (amounts expressed in Canadian dollars). There are shortages of seed seasonally, and from site to site on occasion, but in general seed supply is not limiting the production of mussels.

British Columbia

In British Columbia, most mussel seed is produced in hatcheries and little or no wild seed is collected. The cultured species is either *Mytilus edulis* or *M. galloprovincialis* and seed is produced using standard shellfish hatchery techniques.The mussels are spawned, reared in larval tanks until setting, and then grown in upwellers or downwellers using conventional methods. One company, Island Scallops Ltd., sells larvae for remote setting at a price of $150/million. If larger seed are desired, they sell a 3-mm size for $3500/million. In British Columbia, seed supply appears to be more of a limitation to widespread farm development than in Atlantic Canada.

Maine

In Maine, mussel seed is wild caught; there is currently no commercial hatchery production of seed. The cultured species is *Mytilus edulis,* which is grown both on-bottom and in raft culture. Seed constraints appear limiting in the bottom culture of mussels, but only raft culture will be considered here as it is more comparable to the methods used in the other areas mentioned in this paper. Although seed is sold in different units in Maine (i.e., bushels), the numbers in terms of seed cost and size at socking appear to be similar to that in Atlantic Canada. Once again, seed supply does not appear to be the limiting factor in farm development and success of raft culture.

Washington

The situation in Washington is similar to British Columbia in that virtually all mussel seed is produced in hatcheries. The cultured species is primarily *Mytilus galloprovincialis*, which is grown using raft culture techniques. Seed is produced using standard hatchery techniques for spawning and larval culture. Nursery culture uses upwellers and downwellers, as well as nursery rafts. One large company, Taylor Shellfish Ltd., sells mussel seed at a price of $1500/million for a 1-3 mm size.

Seed Collection Concerns

A number of concerns about seed collection have been expressed by the industry in Canada and the northern United States. The following is a short synopsis of the two most serious issues.

Site variability

There appears to be variations in both quality and quantity of wild-caught mussel seed among and within sites. Such variation can lead to what can be thought of as the "socking season shuffle" which occurs when variability in mussel sets causes farmers to either buy from or sell to their neighbouring leaseholders in order for everyone to have enough seed to meet their requirements. In general, it seems to work out from year to year but inevitably some farmers are left without enough seed from time to time.

Lack of control over seed stock

Another concern with respect to wild seed is the lack of control over the seed stock. A farmer has virtually no control over the genetic variables and the associated growth characteristics within a given wild stock. If seed in one lease is genetically superior to that in another lease, the farmers do not start on an equal level. One concern expressed by a Nova Scotia grower was that *Mytilus trossulus*, disliked by many processors as it is assumed to have a more fragile shell, might in fact be spreading within Atlantic Canadian seed stocks. With wild seed collection, growers have no control over the problem.

Disadvantages of Hatchery Production

Hatchery production may be one answer to the problems of variability among sites and control over mussel seed stocks, but it is far from a perfect solution. The following points summarize the industry's major concerns about the disadvantages of producing seed in a hatchery.

Production cost

The major disadvantage of hatchery seed production is the cost of labour and facilities. An estimate given by Taylor Shellfish Ltd. is that up to 90% of the price of seed is simply to cover the cost of production. In many cases hatchery production is not a profitable endeavour, but one that is necessary for making growout profitable. Using this philosophy, large companies such as Taylor Shellfish Ltd. can take a small loss on the hatchery operation in order to produce seed to make its growout operation more profitable.

Need for technology development

The hatchery rearing of mussel seed on a commercial scale is relatively new and in many areas the technology has not yet been developed to make it as profitable as wild collection of seed. There is a need for new technologies and the refinement of current methods in order to optimize profitability. For example, the current socking methods employed in most of Atlantic Canada, where seed is less limiting and costly, are wasteful. Estimates of a 50% loss of seed from socking to final harvest illustrate how efficiency could improve seed utilization and profitability.

Initial financing

One problem with investing in a large-scale mussel hatchery is the fact that mussels are not a high-priced shellfish compared with many other hatchery-reared species. Therefore, the ability to make a profit is often very small. Many investors will not invest in a mussel hatchery unless it has been proven to be cost effective; however, hatcheries cannot be refined to that point until more hatcheries are developed. This limiting circular argument is similar to the classic "chicken before the egg" argument. One possible way to alleviate some of the costs would be to form a cooperative within the industry to share the cost of developing a hatchery so that refinement of techniques can progress to a point where it is profitable.

Price of seed

In practical terms, all of these factors result in a higher price for seed being paid by the grower. Comparison of a hatchery production system versus wild seed collection helps to illustrate the characteristic difference in cost of production between the two systems (Table 1) .

As summarized in Table 1, the cost of labour is much lower for wild seed collection than for a hatchery production system. The additional labour is required for larval rearing and the nursery stages. Value at the time of harvest is therefore smaller for hatchery-produced seed (4-5 times its original cost from the hatchery,[1] due to the required nursery stage after purchase from the hatchery, versus 7-12 times the seed cost from wild sources in Prince Edward Island).[2] In order to make the production of hatchery seed profitable, the processing plant must be able to command a seed price 2-3 times higher than that of wild-collected seed.

Advantages of Hatchery Production

Many possible benefits to the hatchery production of mussel seed have been suggested by some in industry. The following sections summarize the major advantages.

Reliability

After the hatchery becomes established, the quality and quantity of the seed produced becomes more predictable than that obtained from wild seed collection. Such predictability makes forecasting future sales easier, and helps in the business planning of both large and small growers. Reliable seed quality would also allow a grower to make more educated predictions on growth patterns and on the quality of the final product after harvest. The reliability afforded by well-established hatcheries thus makes the business of shellfish aquaculture more predictable and stable.

Obtaining Seed outside the Natural Spawning Season

Seed production is often limited by the natural growth cycle of an animal. Hatcheries allow for manipulation of the biological cycles so that seed can be produced outside of the natural season. This would allow for year-round harvesting of a product of any

Table 1. Summary breakdown of a price comparison between a wild mussel seed collection system and a hatchery mussel seed production system.

	Prince Edward Island Canada	Taylor Shellfish Ltd. Washington, USA
Seed Production	wild seed collection	hatchery production
Labor Cost	low (no nursery stage)	high (for hatchery and nursery stages)
Seed Cost: Sales at Harvest	$20: $150-$250	$6000: $23 000-$27 000 (1 raft unit)
Value at Harvest	7-12 times the seed value at socking	4-5 times the seed value

Table 2. Summary of the major disadvantages and advantages of the hatchery production of mussel seed.

Disadvantages of Hatchery Production of Mussel Seed	Advantages of Hatchery Production of Mussel Seed
High cost of seed production	Reliability of seed production
Need for technology development	Ability to produce seed out of the natural season
Requirement for initial financing	Availability of breeding programs
Increased price of seed for growers	Ability to produce polyploids
	Ability to produce novel products

age during the growout phase of an operation. In this way the ability to obtain seed out of the natural spawning season can also be thought of as a business tool by the aquaculturist, allowing a product to be offered that is not available using wild collected seed.

Breeding programs

Breeding programs are only available by using selected lines that are spawned, crossed, and grown in hatcheries. The mussel industry could benefit from available models for clams and oysters, which may aid in the development of a mussel-breeding program. Such programs are a natural progression in the domestication and optimization of any farm-reared plant or animal species. A breeding program would allow for the selection of more desirable traits within the local mussel population such as fast growth, shell shape, or meat quality.[3] There is general consensus in the industry that as mussel culture matures as an industry, selection for higher quality traits would be very useful in an increasingly competitive market.

Production of polyploids

The production of polyploids, which have become more common in the shellfish aquaculture industry, is only possible through the use of hatcheries. In the case of mussels, sterile triploids could offer higher quality during the spawning period as they are not ripe and do not spawn out as fertile animals do. This would allow for a niche market during and immediately after the spawning period when wild caught (diploid) mussels are of lower quality. Sterile triploids have also shown a record of superior growth[4] compared with their wild counterparts. Hatchery production of mussel seed allows this to be used as an industry value-added tool.

Production of novel products

The use of hatcheries to produce mussel seed would also allow for the development of novel products such as a mussel selected to have rare but desirable traits. An example is the development of the BC Blond™ by Island Scallops Ltd. in British Columbia. They have selected for the blond shell colour sometimes found in mussel populations. They now have a F4 generation of this line of mussel, which was selected from a Prince Edward Island *Mytilus edulis* wild stock. It can be marketed as a trademarked product, allowing for its use as a marketing tool and novel product, separate from other mussel seed.

Concluding Remarks

There is some debate within the mussel industry as to the potential merits and pitfalls of hatchery production of mussel seed. The general consensus, however, is that this is a necessity in some areas, and may become more common in other areas such as the Atlantic Provinces when the technology has been further refined. There are many possible disadvantages and advantages to the hatchery production of mussel seed (summarized in Table 2). In many geographical areas the current economics are not favourable for the hatchery production of seed. However, there is general consensus within the industry that in mussel culture, as with any cultured product, the potential benefits of hatchery production will inevitably make its use more common in the future.

We acknowledge the Canadian Center for Fisheries Innovation for the sponsorship of this session and thank the many industry members who have shared their ideas and opinions with us. We would also like to thank the staff of Taylor Shellfish Farms Ltd., particularly those at the Taylor Resources hatchery in Quilcene, WA, for allowing us to document their hatchery production of mussel seed

References

1. King G, Taylor Shellfish Farms Ltd., personal communication.
2. Gallant R., Prince Edward Island Department of Fisheries and Tourism, personal communication.
3. Matson S, Molluscan Broodstock Program, Oregon State University, personal communication.
4. Go X. 1999. *J. Shellfish Res.* 18(1):266.

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The student endowment fund provides travel support to students presenting papers at AAC's conference. Tax receipts are issued for all donations.

Association News

Awards

The Aquaculture Association of Canada recently honored two scientists, both of whom are longstanding AAC members and former presidents. **Dr. Joseph Brown** of the Ocean Sciences Centre of Memorial University of Newfoundland received the Excellence in Research Award for his research contributions to the culture of marine fish over the past 15 years. **Dr. David Aiken** was given the association's Lifetime Achievement Award for his contributions to AAC (including his role in the formation of AAC, in establishing the association office at the Biological Station in St. Andrews, for reinstating the *Bulletin* and serving as its editor after the original *Bulletin* was turned over to the private sector, and for developing *World Aquaculture* magazine and serving as its editor for 10 years). Both these scientists have been members of AAC since its inception; Dr. Aiken served as president in 1986 and Dr. Brown was president in 1997.

Victoria Chosen as Site of 2003 Aquaculture Canada Conference

Aquaculture Canada 2003 will be held in Victoria, British Columbia, from 30 October to 1 November 2003 at the Victoria Conference Centre and Empress Hotel. Aquaculture Canada 2003 will be held in conjunction with the Pacific Exchange Exhibition and AquaNet III. For information on the conference contact Dr. Shawn Robinson at DFO's Biological Station in St. Andrews (robinsons@mar.dfo-mpo.gc.ca, tel 506 529-5932).

New Staff in AAC Office

Kim Shafer has been running the AAC Office since August, replacing Theresia Fawkes who is on extended leave for health reasons. Kim graduated with a BSc (Marine Biology) from the University of New Brunswick in Saint John in 2000 and then did an internship at the Biological Station in St. Andrews. She worked briefly for AAC in the spring of 2000, assisting with the preparations for Aquaculture Canada 2001, and returned full time in August to assume responsibility for the operation of the office. The AAC office is located at 16 Lobster Lane in Cottage 3 at the Biological Station in St. Andrews.

AAC thanks Leo Muise and the staff of the Nova Scotia Department of Agriculture and Fisheries for so ably handling the local arrangements for Aquaculture Canada 2001.

Registration was handled by Joan Cottell and the people pictured above worked at the registration desk during the conference. Front row (L to R): Michelle Chisholm and Susan Farrant (Malaspina University-College), centre row: Susan Cameron, Yvelle Poirier and Kim Shafer (AAC), back row: Francene Sampson, Joan Cottell and Lorne Dempsey.

Photo by Sheila Ferguson (NSDAF)

Calendar

conferences, workshops, courses and trade shows

• **2nd International Conference on Marine Ornamentals**, 27 November - 1 December 2001, Wyndham Palace Resort, Walt Disney World, Lake Buena Vista, Florida. Information: Dr. James C. Cato, Director, Florida Sea Grant College Program, University of Florida, State University System of Florida, PO Box 110400, Gainesville, FL 32611-0400 (tel 352 392-5870, fax 352 392-5113, e-mail: jcc@gnv.ifas.ufl.edu, website: http://www.ifas.ufl.edu/~conferweb /mo/).

• **52nd Annual Pacific Northwest Fish Culture Conference,** 4-6 December 2001, Doubletree Hotel, Portland, Oregon. The purpose of the conference is to provide hatchery workers with an informal forum to present information related to their work — The art and science of fish culture. Conference proceedings will be available at the meeting. Information: Tracy Cabe (tel 503 872 -5252, fax 503 872-5701, e-mail tracy.a.cabe@state.or.us)

• **Fish International 2002, 8th International Trade Fair for Fish and Seafood,** "The Quality Exhibition" 14-17 February 2002, Bremen Fair Center, Germany. For information, contact MGH by e-mail at info@fishinternational.de or check the website www.fishinternational.com

• **Aquaculture America 2002,** 27-30 January 2002, Town & Country Hotel, San Diego, California. Theme: *Enviro-Friendly Aquaculture for the Americas*. The US National Annual Conference and Exposition of the US Chapter of the World Aquaculture Society, the National Aquaculture Association, and the US Aquaculture Suppliers Association. Contact: World Aquaculture 2002, Conference Manager, 2423 Fallbrook Place, Escondido, CA 92027 USA (tel +1 760 432 4270, fax +1 760 432 4275, e-mail: worldaqua@aol.com).

• **International Boston Seafood Show,** 12-14 March 2002, Hynes Convention Center, Boston, Massachusetts. Information: Diversified Business Communications (tel 207 842-5504, fax 207 842-5505, e-mail food@divcom.com).

• **National Shellfisheries Association 94th Annual Meeting,** 14-18 April 2002, Hilton Mystic Hotel, Mystic, Connecticut. Information: www.shellfish.org. For program information contact Carolyn Friedman at 707 875-2067 (cfriedman @ucdavis.edu).

• **Aquaculture International 2002 and Coldwater Marine Farming Conference,** Scottish Exhibition and Conference Centre, Glasgow, Scotland. Information: Sue Hill, Heighway Events, London (fax +44 20 7831 2509, e-mail sue.hill@informa.com)

• **World Aquaculture 2002,** 23-27 April 2002, Beijing International Conference Centre, China. Annual meetings of the World Aquaculture Society and the China Society of Fisheries. Information: Director of Conferences (tel +1 760 432 4270, fax +1 760 432 4275, e-mail: worldaqua@aol.com).

• **10th International Congress of Parasitology,** 4-10 August 2002, Vancouver Conference and Exhibition Centre. Sponsored by the Canadian Society of Zoologists and the American Society of Parasitologists. Tentative sessions: immunology, molecular biology, morphology and ultrastructure, biochemistry and physiology, systematics and

evolution, ecology and epidemiology. Information: Conference Secretariat, Venue West Conference Services Ltd., #645-375 Water Street, Vancouver, BC (tel 604 681 5226, fax 604 681 2503, e-mail congress@ venuewest. com, website http:// www.venuewest.com).

• **Aquaculture Canada 2002, 19th Annual Meeting of the Aquaculture Association of Canada,** 17-20 September 2002, Delta Prince Edward, Charlottetown, Prince Edward Island. Theme: *Finding Solutions, Creating Sustainable Wealth.* Co-hosted by the PEI Aquaculture Alliance and the PEI Department of Fisheries, Aquaculture and Environment. Information: Cyr Couturier, Marine Institute, Memorial University of Newfoundland (cyr@mi.mun.ca).

• **Aquaculture Pacific Exchange Conference and Exhibition,** 3-4 October 2002, Strathcona Gardens, Campbell River, BC. Consists of a 100-booth trade show and 2-day conference. Produced by Master Promotions Ltd., PO Box 565, Saint John, NB (tel 506 658-0018, fax 506 658-0750, e-mail show@nbnet. nb.ca).

• **Aquaculture Europe 2002,** 16-19 October 2002, Verona, Italy. Organized by the European Aquaculture Society. Theme: *Placing Aquaculture in Rural and Coastal Management.* Workshops: Applied solutions to health management in Mediterranean aquaculture, New technologies for Mediterranean aquaculture, and Certification in aquaculture (HAACP, ISO standards, ecolabelling and organic). Information: European Aquaculture Society (e-mail ae2002@aquaculture.cc, fax 0032 59 32 10 05).

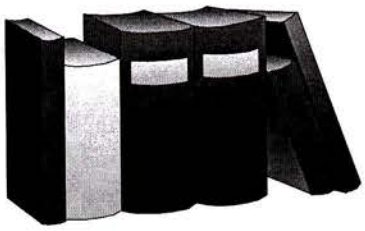
• **Aquaculture America 2003**, February 2003, Commonwealth Convention Center, Louisville, Kentucky. US National Aquaculture Conference and Exposition of the US Chapter of the World Aquaculture Society in conjunction with the National Aquaculture Association and the US Aquaculture Suppliers Association. Information: Director of Conferences (tel +1 760 432 4270, fax +1 760 432 4275, e-mail: worldaqua@ aol.com).

• **World Aquaculture 2003,** 19-23 May 2002, Bahia Convention Center, Salvador, Brazil. Annual meeting of the World Aquaculture Society in conjunction with other associations, industry and government sponsors. Information: Director of Conferences (tel +1 760 432 4270, fax +1 760 432 4275, e-mail: worldaqua@ aol.com).

• **2003 Aquaculture Pacific Exchange Conference and Exhibition,** 30 Oct - 1 Nov 2003, Victoria Conference Centre, Victoria, BC. Consists of a 100-booth trade show and 2-day conference. Produced by Master Promotions Ltd., PO Box 565, Saint John, NB (tel 506 658-0018, fax 506 658-0750, e-mail show@nbnet.nb.ca).

• **Aquaculture 2004**, 29 February - 4 March 2004, Hawaii Convention Center, Honolulu, Hawaii. Triennial meeting of the World Aquaculture Society, the National Shellfisheries Association, and the Fish Culture Section of the American Fisheries Society. Information: Director of Conferences (tel +1 760 432 4270, fax +1 760 432 4275, e-mail: worldaqua@aol.com).

• **2004 Aquaculture Pacific Exchange Conference and Exhibition,** Campbell River, October 2004. Consists of a 100-booth trade show and 2-day conference. Produced by Master Promotions Ltd., PO Box 565, Saint John, NB (tel 506 658-0018, fax 506 658-0750, e-mail show@nbnet.nb.ca).



New Publications

Marketing and Shipping Live Aquatic Products. Proceedings of the Second International Conference on the Marketing and Shipping Live Aquatic Products held in Seattle in 1999. Brian Paust and Allison Rice, editors. ISBN 1-56612-067-5, 320 p. (US$20. For US and Canadian addresses, $35. Overseas). Information on marketing and shipping finfish, shellfish, ornamentals and plants. Forty-two papers written by researchers, managers, fishermen, growers, buyers, wholesalers, shippers and retailers. University of Alaska Sea Grant, P.O. Box 755040, Fairbanks, Alaska (tel 888 789-0090, fax 907 474-6285, website www.uaf.edu/seagrant/bookstore).

Food Intake in Fish, Published November 2001 by Iowa State University Press. Edited by Dominic Houlihan, Thierry Boujard and Malcolm Jobling. 352 p, paperback. ISBN 0-6320- 5576-6, US$128.95. Covers all major aspects of food consumption by fish. Includes in-depth information on foods consumed by fish, techniques for measuring food intake, learning processes in relation to feeding behavior, choices fish make in determining how much they eat, and consequences of consumption of types of food on growth, reproduction, flesh quality, etc. Iowa State University Press (tel 515 292-0140, fax 515 292-3348, website isupress.com).

Migration of Freshwater Fishes, Publication date December 2001. Iowa State University Press, Edited by Martyn Lucas and Etienne Baras. 440 p, hardcover. ISBN 0-6320-5754-8, US$127.95. Provides comprehensive information on the migration of most groups of freshwater fishes. Iowa State University Press (tel 515 292-0140, fax 515 292-3348, website isupress.com).

Practical Genetics for Aquaculture, by Greg Lutz, published November 2001, by Iowa State University Press. 256 p, paperback, ISBN 0-8523-8285-5, US$79.95. Reviews fundamental genetic theory and gives practical examples of applications for genetic improvement. Includes chapters on genetic change for numerous traits and the resultant increased yields and profitability, development and performance of transgenic aquatic organisms, and potential risks to aquatic habitats and populations posed by all forms of genetically improved cultured species. Iowa State University Press (tel 515 292-0140, fax 515 292-3348, website isupress.com).

Biology of Freshwater Crayfish, edited by David M. Holdich, publication date December 2001. Iowa State University Press. 512 p., paperback, ISBN 0-6320-5431-X, US$162.95. Chapters on each genus of commercially important crayfish. Iowa State University Press (tel 515 292-0140, fax 515 292-3348, website isupress.com).

New Species, New Technologies, Abstracts of contributions presented at the international conference Aquaculture Europe 2001 held in Trondheim, Norway in August 2001. EAS Special Publication number 29. 286 p. EUR 69,50 per copy (US$1. = EUR 1,10). European Aquaculture Society (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@aquaculture.cc.

Better Use of Water, Nutrients and Space, Handbook from the International Workshop held in Trondheim, Norway, August 2001, consisting of the contributions and extended abstracts. 62 p. EUR 35,00 per copy (US$1. = EUR 1,10). European Aquaculture Society (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@aquaculture.cc.