



# ***Bulletin***

of the  
**Aquaculture Association of Canada**

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**Association Aquacole du Canada**

**103-3, December 2003**

**Offshore Aquaculture  
Commercialization of New Species**



# **Proceedings of Special Sessions on Offshore Aquaculture and Alternate Species held at Aquaculture Canada<sup>OM</sup>**

**Victoria, BC, 30-31 October 2003**

Craig Clarke, guest editor

## **Offshore Aquaculture**

There is increasing interest in moving the aquaculture industry offshore as a possible solution to a shortage of suitable sites in coastal areas. Due to the high cost of coastal land, conflicts with other users, and concerns about pollution of inshore areas, it is becoming increasingly difficult to obtain new tenures for aquaculture facilities in many regions. However, in order for the aquaculture industry to move offshore there are a number of legal, engineering and biological issues to be resolved.

Speakers from across Canada and the United States were brought to Victoria to provide perspectives on jurisdiction and regulatory issues, as well as recent research, demonstration and development on engineered systems for culturing marine finfish and shellfish species in exposed oceanic environments.

I would like to thank Chris Bridger for his assistance in organising and co-chairing the session.

### **Session Organising Committee:**

Craig Clarke (e-mail: [ClarkeC@pac.dfo-mpo.gc.ca](mailto:ClarkeC@pac.dfo-mpo.gc.ca))

Chris Bridger (e-mail: [chris@naia.ca](mailto:chris@naia.ca))

## **Progress in Commercialization of Alternate Species**

In recent years, there has been a growth in research effort directed at cultivation of new candidate species with a view to diversifying the aquaculture industry in Canada. This session was intended to review the progress and current constraints for several species that are moving beyond the stage of laboratory research into commercial development. The session was made possible by financial support from the Newfoundland Department of Fisheries and Aquaculture. With this support, speakers from both the Atlantic and Pacific coasts of Canada came to Victoria to share their knowledge on the status of commercial production of geoduck, halibut, cod, haddock and sablefish.

I would like to thank Dr. Chris Pearce for his assistance with organising and co-chairing the session.

### **Session Organising Committee:**

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**Front cover:** Wild-caught cod being transferred from a seasonal grow-out cage into a sorting cage in Ship Cove, Little Hearts Ease Inlet in Trinity Bay, Newfoundland. The photograph was taken in July 2001 during trials to determine whether the use of size-sorting grates to ensure fish stocked in a cage were of a similar size would improve growth rates. [C. I. Hendry photo]



# Contents

Proceedings of the Special Sessions on Offshore Aquaculture and  
Progress in Commercialization of New Species  
held at Aquaculture Canada<sup>OM</sup> in Victoria, BC, October 2003

Craig Clarke, guest editor

Introduction . . . . .	1
Review of the "The Eel" by F.-W. Tensch <i>R.H. Peterson</i> . . . . .	59

## Offshore Aquaculture

A system design for surface-based open ocean aquaculture operations <i>C. J. Bridger and C. A. Gauley</i> . . . . .	4
Design, operation and economics of submerged longline mussel culture in the open ocean <i>Richard Langan and Forbes Horton</i> . . . . .	11
An open ocean aquaculture system for submerged operations in New England <i>David W. Frederickson, Michael D. Chambers, Judson C. DeCrew, Brett Fullerton, M. Robinson Swift, Glen Rice and Barbaros Celikkol</i> . . . . .	22
Offshore aquaculture in Canadian waters: Legal issues and challenges <i>Gloria Chao</i> . . . . .	32

## Progress in the Commercialization of New Species

Cod grow-out in Newfoundland: History and future considerations <i>Christopher I. Hendry</i> . . . . .	40
Creating a culture-based system of management for the geoduck clam industry in British Columbia <i>Eric Gant</i> . . . . .	47
Progress in commercialization of sablefish ( <i>Anoplopoma fimbria</i> ) farming <i>Gidon Minkoff and Craig Clarke</i> . . . . .	53





## A System Design for Surface-based Open Ocean Aquaculture Operations

C. J. Bridger and C. A. Goudey

Offshore aquaculture—operating out of the sight of land—has the logistic requirements of nearshore operations plus those associated with the higher energy of the offshore site and increased distance from shore. The Gulf of Mexico Offshore Aquaculture Consortium (OAC) has been confronted with these challenges and has developed a suite of components to manage offshore aquaculture systems. This report presents a system design that integrates the developed components and meets the logistic requirements of offshore aquaculture. Emergency preparedness that ensures survival of farm capital and fish stock while maintaining system integrity and worker safety in the event of a tropical front is discussed. Finally, long-distance communication and monitoring of the farm is explored for situations with decreased human presence and during severe storms.

**“Offshore aquaculture . . . has the logistic requirements of nearshore operations plus those associated with the higher energy of the offshore site and increased distance from shore.”**

### Introduction

The United States is confronted with a seafood trade deficit approaching US\$9 billion annually. Some research investment has been made to offset this trade imbalance through domestic aquaculture production following creation of a Department of Commerce Aquaculture Policy (signed August 10, 1999) “to create sustainable economic opportunities in aquaculture in a manner that is environmentally sound and consistent with applicable laws and policy.” Recognizing a presently overburdened coast with numerous user-conflicts and substantial anthropogenic sources of pollution, this investment has been directed towards developing aquaculture technologies for the open ocean, including areas out of the sight of land within the US Exclusive Economic Zone.

The Gulf of Mexico is the seventh largest marine area in the world and can be considered a very productive eutrophic sea. It has been described as the ‘fertile fisheries crescent’.<sup>(1)</sup> This productivity could potentially increase the assimilative capacity of the water, thereby reducing the environmental impacts associated with aquaculture effluents from offshore farms.

Acquiring a site with water depth in excess of 25 m, to avoid hurricane damage to cages, is desirable and may require locating the operation as far as 40 km from land. Further, some areas of the Gulf of Mexico are prone to seasonal hypoxia associated with thermally-stratified water during late summer that do not experience turnover in the absence of tropical fronts. Although the hypoxic layer is generally restricted to the lower one-third of the water column, large cages or submerged operations may be impacted. The nepheloid layer developed from re-suspension of fine sea-floor sediment generated from bottom turbulence is also common. Little is known of the effect of this layer on the health of fish or its seasonal extent in much of the Gulf of Mexico.

It is unlikely that hurricanes can be avoided completely in the northern Gulf of



Mexico. However, it may be possible to decrease their impact on aquaculture ventures by sinking cages during storms. With this strategy comes the risk of exposing fish to sediment re-suspension that may irritate the gills, create secondary bacterial infections, and result in mass mortality and economic loss to the operation.

Finally, much of the Gulf of Mexico has long supported both commercial and recreational fishing. User conflicts must be carefully considered and dealt with to ensure success of an open ocean aquaculture industry. All of these issues limit the number of appropriate sites for aquaculture in the Gulf of Mexico to some degree.

The OAC chose a site approximately 40 km off the coast of Mississippi in federal waters (29° 58.649'N, 88° 36.297'W) that had a water depth of 26 m. The research operation was adjacent to a ChevronTexaco manned gas production platform which minimized conflicts with fishing and shipping activities while providing continuous surveillance of the cage to monitor for vandalism and storm damage.

The challenges OAC researchers face include the severity of the offshore environment, which compromises both worker safety and structural integrity; the distance from shore, which limits work days, increases operating costs, and requires innovative mechanization; and economic viability. The individual components that have been developed to mitigate these challenges have been described previously.<sup>(2-4)</sup> However, the components have not yet been combined into a coherent system design. To this end, we will describe the system design envisioned for effective and safe farm management within the Gulf of Mexico and other potential regions requiring development of distant aquaculture sites.

### **System Components**

Developing an open ocean aquaculture sector, in the absence of nearshore operations, allowed innovation that might otherwise have been stifled by attempts to adapt existing operations to exposed high-energy locations. Offshore aquaculture requires innovative technologies to support operations, maintain cages on station during extreme weather conditions, allow appropriate levels of feeding, provide long-distance communication in the absence of cellular phone coverage, and provide carefully planned levels of response to emergency situations.

#### ***Aquaculture Support Vessel***

Increased capital investment and operating costs associated with open ocean aquaculture will rely on economies of scale for feasibility. Economies of scale demand increased feed inputs to large stocks of fish during grow-out. Daily transport of feed and other supplies might prove uneconomical due to cost of transportation. In addition, daily visits could introduce an unacceptable risk due to the unpredictability of offshore conditions.

A more reasonable approach to manage open ocean aquaculture operations involves establishing a permanent support structure near the cages that can handle feed requirements and other daily operational logistics. Indeed, previous visions of offshore aquaculture in the Gulf of Mexico placed operations adjacent to oil and gas platforms that would serve as support structures to mitigate logistic challenges.<sup>(5)</sup> However, this approach has numerous constraints, including the operation of both sectors simultaneously; the requirement to establish an Abandonment Bond to address removal of a decommissioned platform (estimated at a couple of million dollars); and inappropriate design and location of existing platforms for aquaculture operations.



**“... risks increase with distance from shore and greater exposure of an aquaculture site to natural elements.”**

An alternative approach involves the design and deployment of a purpose-built Aquaculture Support Vessel (ASV). Design criteria for the expected capabilities of such a vessel should include:

- Cage fleet communications and control,
- Mooring system installation and removal,
- Cage installation, towing, maintenance, and repair,
- Fish stocking, sorting, harvesting, and transport,
- Feed hopper re-supply,
- Fish health monitoring and treatment,
- Environmental monitoring including benthic sampling,
- Diver and ROV support.

In conjunction with Good Streak Marine (Slidell, LA), a lift-boat concept was designed to service offshore cages and be the focal point for a permitted offshore aquaculture site.<sup>(2)</sup> Within the current design, the lift-boat has a total usable deck space of 500 m<sup>2</sup> and four hydraulic legs appropriate for water 26 m deep. The size of the platform and the length of the legs can be adjusted according to site specifics.

The regular operational mode would see the lift-boat jacked up from the water surface, perhaps to a 7-m height, to provide a stable working platform. Further design requirements include a helicopter pad, sufficient living space for workers, adequate feed storage, maintenance and office space, a fish health and environmental monitoring laboratory, and a crane capable of lowering and raising farm work boats and feed.

#### ***Single-Point Mooring***

Most objects are anchored in the open ocean using single-point moorings (SPM). The obvious advantages of using a SPM in aquaculture operations include:

- Decreased complexity associated with requiring precise adjustment of multiple anchors in typical grid mooring systems.
- Predictable location of loads that allow appropriate engineering of the mooring to ensure survival during storms.
- Decreased costs associated with a single mooring line compared to multiple lines.
- Decreased maintenance requirements with a single mooring line.
- Improved accessibility to the cage or cage array regardless of weather direction.
- Allowance for advanced production planning and cage arrangements for stocks that require high oxygen levels and faster water flow compared to other cage stocks.
- Decreased environmental impacts compared to a cage system fixed spatially within a multi-anchor system. The SPM allows the cage system to wander within a watch circle of a diameter dependent on the length of mooring line.
- Reduced bottom area required for the mooring system, thereby decreasing costs associated with leasing space, especially in deep-water areas that require an expansive bottom area for multi-anchor mooring systems.
- Decrease in the potential impacts on and entanglement with marine mammals in the vicinity of aquaculture sites by having fewer lines present in the water column associated with the farm mooring system.

The design of the SPM system evolved over time (Fig. 1).<sup>(3)</sup> Redundancy of the more vulnerable components is provided by a second set of bridles that are longer

than the primary set of bridles. The redundant bridles, and their attachment points, experience no load unless the primary bridles are severed or disconnected. The final configuration was tested on numerous occasions in the Gulf of Mexico, including during two tropical storms and two hurricanes. The system provided trouble-free performance prior to cage removal during the summer of 2003.

### **Robofeeder**

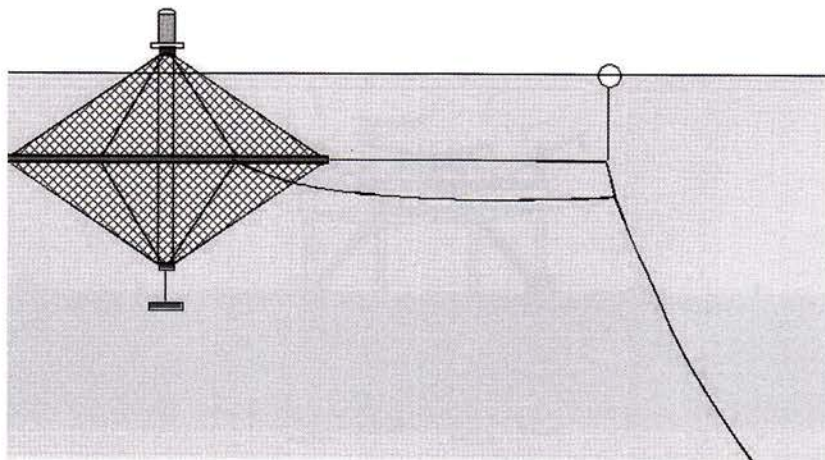
Feeding fish in any aquaculture venture is arguably the most important task to ensure profitability. Offshore aquaculture ventures are unlike nearshore operations located within the confines of protected bays and fjords where rough seas are episodic. Relying on daily site visits for feeding ensures the fish are not fed continually and jeopardizes the safety of farm workers when conditions are unfavorable. Offshore aquaculture must rely on mechanization and automation for many of the day-to-day operations. Feeding is one such important task and without cost-effective, reliable, unmanned feeding systems, open ocean aquaculture is commercially impractical. To this end, an innovative approach to unmanned feeding—the Robofeeder—has been developed by the Center for Fisheries Engineering Research at the Massachusetts Institute of Technology (MIT) in cooperation with Ocean Spar Technologies for use on the OAC's 600 m<sup>3</sup> Sea Station™ submersible cage.<sup>(4)</sup>

The Robofeeder is an on-cage pellet storage and dispensing system with a 225-kg capacity. Employing electronic control and pneumatic actuation, the system relies on gravity to dispense feed. The on-board timer dispenses controlled amounts of pelleted feed up to 24 times per day. Robofeeder is relatively trouble free since its one battery and one air tank are expected to last at least three months. The silo is designed to specifically fit on top of the Sea Station™ work platform.

Feed is dispensed via a pneumatic-controlled gate-valve that opens to a 5-cm Y-fitting. From this fitting, sinking pellets fall through tubes into the cage. All electronic components are housed in an on-board Pelican case. If neutral or floating pellets are used, the dispensing tubes are provided with a flow of seawater to propel the pellets into the cage.

Though not employed by the OAC, Robofeeder can be operated in a submerged mode by pressurizing the hopper and dispensing passages equal to the ambient depth. The water level in this “diving bell” approach is automatically maintained by sensors; however, air consumption is significantly greater. Having a multi-day

**Figure 1**  
Illustration of the OAC single-point mooring system showing the position of the shorter primary bridles 1.5-m above the longer, redundant set of bridles and their respective connection points on the cage rim.





feed storage capacity eliminates the need for daily visits to the site.

### Integration of System Components

There is no doubt that risks increase with distance from shore and greater exposure of the site to natural elements. Economic, environmental, and management risks might best be avoided through a systems approach that integrates the numerous components of farm infrastructure and management into a holistic design. It is precisely this approach that has been adopted by the OAC for developing an off-shore aquaculture system by evaluating farm components—cages, moorings, nets, feeders, service and logistics support, applicable regulations, economic inputs, and market outputs—and taking into consideration the interactions of these components to create the system. All the components described have been designed while maintaining a vision for an operating offshore farm and how best to service cages in a safe and efficient manner.

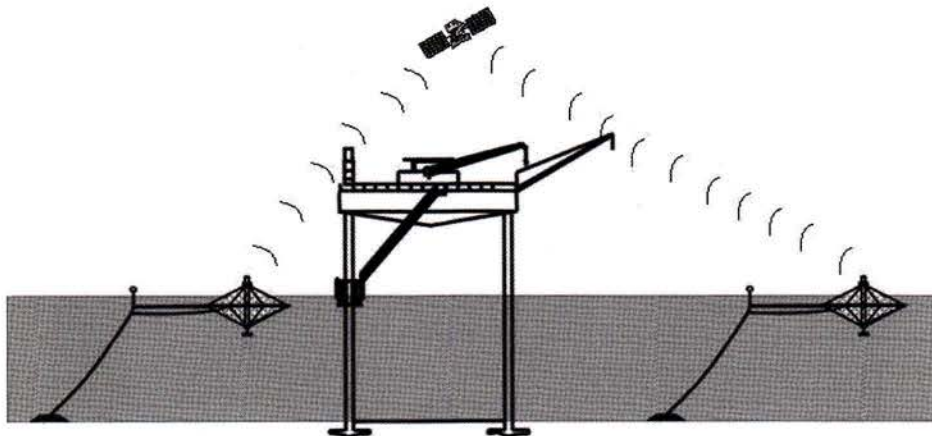
Under normal operation cages would be positioned at the surface and necessary farm chores would be completed when sea conditions allow (Fig. 2). An essential chore will be to maintain adequate feed levels in the Robofeeder hoppers to cover extended periods of inclement weather. Operators would be urged to use the Robofeeder at all times to prevent feed from becoming rancid if left in the feeder for a long period of time.

The lift-boat would serve as the central point of operations for the farm, which might service cages both within its immediate vicinity and some distance from the lift-boat. Feed would be stored in air-conditioned sections of the hull. Cages near the structure might have feed replenished directly through a hose running between the lift-boat and Robofeeder during calm conditions. Alternately, feed could be transferred to work boats that ferry feed to each Robofeeder as necessary.

In severe storm or hurricane conditions, workers would sink the cages prior to either raising the lift-boat legs and moving to shore or, preferably, keeping the lift-boat in operational mode and being evacuated by helicopter. The single-point moorings are independent of the lift-boat (illustrated in Figure 3) and the cages can be ballasted with water to facilitate sinking.

Cages submerged in this fashion also require active de-ballasting to again bring them to the surface. The OAC has overcome this issue by designing the single-point mooring with excess reserve buoyancy in its surface float that does not

**Figure 2**  
Normal operational  
configuration of the  
aquaculture support  
vessel, cage,  
single-point mooring,  
feeder, and mooring  
monitor.



allow automatic submergence of the cage. Instead, the cage is maintained just at the water surface in a state of least resistance. As storms approach and wind-driven currents increase, the cage/mooring system will be pulled underwater by the added tension in the mooring line. Its depth will therefore depend on the intensity of the storm.

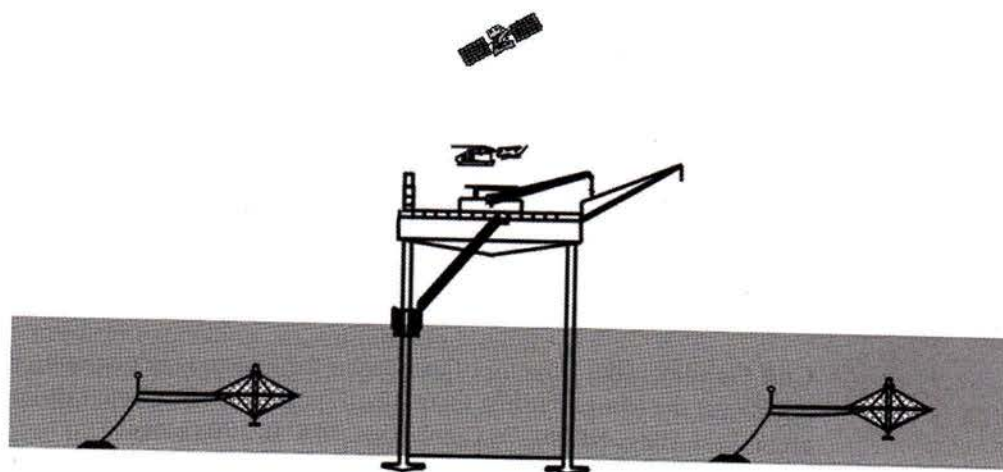
As the storm subsides the cage reappears at the surface in the same position as it was prior to the storm. This configuration allows immediate communication and monitoring of the cage systems after the storm passes rather than relying upon return of staff to the site which might not occur for a few days following the storm.

Lack of, or decreased, human presence, particularly for cages some distance from the lift-boat or following severe storm events, will require a substantial change in the mindset of both owners and managers of offshore aquaculture ventures. These individuals will need to rely more on technology to communicate with the farm particularly during storms. Indeed, as Muir<sup>(6)</sup> points out "a major challenge for future systems may be to overcome the psychological dependence on human-based management, allowing greater reliance to be placed on automatic monitoring, control and management systems."

To this end, the OAC partnered with Brightwaters Instrument Corporation (Brightwaters, NY) to develop a remote monitoring and communication system for offshore cages. The basis for this system is a GPS/ARGOS mooring monitor that checks the cage position at a user-defined time interval and compares determined positions with a defined 'watch circle' of where the cage should be located (e.g., the cage position could be checked every 30 min (Fig. 2)). An alarm will be activated that e-mails those involved of cage positions should the determined and defined positions not correspond after three successive position fixes. The instrument also possesses a depth sensor that will notify operators when a cage is sinking, potentially due to structural failure or excess biofouling. An additional data port could be used to monitor feed levels within the hopper and provide an alarm should levels fall below the threshold needed to meet daily feeding requirements.

The mooring monitor is invaluable during hurricane conditions. A cage would be expected to submerge during hurricanes if deployed on a single-point mooring in the least resistance configuration described above. During hurricanes, the lift-boat would likely be evacuated for worker safety. While submerged, no communication with the cage would be possible through satellite systems. However, once the cage resurfaces an e-mail message would be expected as the mooring

**Figure 3**  
Submerged position of the cages and evacuation of the farm operators during severe storms.





monitor again locates its position and communicates with the operators. Feeding would continue following the hurricane with food maintained in the hopper.

## Conclusions

Developing innovative technologies to mitigate offshore aquaculture logistics in the absence of a system design strategy would be remiss. Without effective and safe integration of all components, the entire system would likely be too inefficient to support economically-feasible aquaculture in the open ocean environment. Operating within the Gulf of Mexico, the Offshore Aquaculture Consortium has developed numerous individual components—a lift-boat Aquaculture Support Vessel, a single-point mooring, an autonomous feeder, and a cage/mooring monitor—that, in combination, meet the demands of foreseeable issues associated with operating a farm in a distant and harsh environment. Open ocean aquaculture operations can now be considered through use of these engineering innovations.

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# Design, Operation and Economics of Submerged Longline Mussel Culture in the Open Ocean

**Richard Langan and Forbes Horton**



Richard Langan

Mussel aquaculture industries worldwide are facing constraints on expansion in protected, nearshore embayments where conditions are favorable for raft and surface-referenced longline culture. In some areas, the carrying capacity of embayments has been exceeded, while in others, degraded water quality, user conflicts, and resistance by shorefront owners have limited opportunities for growth. One solution is to develop mussel culture in the open ocean where space is available. The University of New Hampshire has established a demonstration site 10 km from shore in the waters of the Gulf of Maine, USA. Water depth at the site is 52 m, which is fully exposed and can experience wave heights of 9 m during severe storms. Two longlines, each 130 m in length, with the horizontal headline submerged 12 m below the surface, were installed in 1999. A fishing vessel was equipped to tend the longlines. Gear and technology used in surface-referenced longline culture were modified for use in the ocean environment, and several types of buoys, grow-out ropes, and socking materials and methods were evaluated. The project has developed operational protocols and production strategies and demonstrated that excellent growth and production can be achieved in the open sea. Seven seed cohorts of blue mussels have been grown to market size with an average production cycle of 13 mo from spat settlement to a size of 55-mm shell height. Yield at market size has ranged from 7.5 to 12 kg/m of mussel rope, depending on seeding density. Product quality and meat yield have been consistently high, with cooked meat weights ranging from 42% to nearly 60% of whole cooked weight. An economic analysis concluded that high quality mussels could be produced at a cost of US\$0.55/kg, indicating a high potential for profitability.

## Introduction

Over the past 20 yr, aquaculture's contribution to global seafood production has increased steadily, and now accounts for more than a third of all seafood consumed. At the same time, capture fisheries have continued to decline, signaling an even greater need for expanding aquaculture production.

A challenge for the United States, which already lags well behind other countries in aquaculture production, is to determine where aquaculture development will take place. Inshore waters and protected embayments where conditions are most favorable for traditional operations are in great demand for other uses such



**"In locations where adverse sea conditions or drift ice occur, submerged longlines are the only option."**

as recreation and fishing, and are highly scrutinized by regulators and the public due to aesthetic concerns. Many in the industry have recognized the need for exploring the offshore environment; however, the challenges are considerable and current profit margins slim, leaving minimal resources for exploratory research and development. The industry needs solid information on the opportunities and risks before making the move.

In order to fill the critical void between basic aquaculture research and the establishment of a healthy commercial industry, the University of New Hampshire initiated the Open Ocean Aquaculture Demonstration project in 1998. The overall goal of the project is to stimulate the further development of environmentally responsible commercial aquaculture in New England, thereby increasing seafood production, creating new employment opportunities, and contributing to economic and community development. The project has made significant progress in developing engineering solutions for offshore installations, husbandry methods for several native cold-water species of finfish and shellfish, and operational methodologies for offshore farms. The shellfish component of the project was designed around the concept that inshore commercial fishermen and local fishing cooperatives would be the eventual participants in commercial development of offshore shellfish culture, and that existing fishing vessels and the cooperatives' infrastructure for processing and distribution could be adapted for shellfish production.

Suspension culture of mussels has been practiced for many years and now takes place in over 15 countries. It is well established and highly productive in many parts of the world, including Spain, New Zealand, China and Canada. While bottom culture is practiced in some locations such as the Netherlands, Scandinavia, and the USA (Maine), suspension culture, because of superior product quality, accelerated growth, and opportunities for mechanization, has emerged as the leading method of production.<sup>(1)</sup> Techniques and materials used for suspension culture vary somewhat from place to place; however, in general, methodology consists of suspending mussel ropes or "droppers" from either rafts or longlines.<sup>(2)</sup> Raft culture was pioneered in Spain and from there became established in Scotland and more recently in Maine.<sup>(3)</sup> While rafts can be highly productive, they are suitable for use only in very protected embayments. Longline technology, which was developed in Japan, consists of either surface or submerged longlines, held in place with anchors and supported by buoys or floats. As with raft culture, surface longlines are suitable for use in protected areas.<sup>(2)</sup> In locations where adverse sea conditions or drift ice occur, submerged longlines are the only option. Submerged longlines are used primarily in locations where winter ice would impact buoys and lines (e.g., Canada). It is only in recent years that there has been interest in applying the technology to exposed offshore locations.<sup>(4)</sup>

Unlike most well-established molluscan shellfish aquaculture sectors, the mussel industry relies almost entirely on wild-caught seed. While seed availability is seen as a possible impediment to expansion of green-lipped mussel (*Perna canaliculus*) culture in New Zealand,<sup>(1)</sup> no such shortage is anticipated for mytilid species in North America. Blue mussel (*Mytilus edulis*) larvae are abundant in coastal locations from spring through fall, and are planktonic dominants at certain time of the year.<sup>(5)</sup> Spawning commences when water temperatures reach 10°C, so spawning time varies throughout the range.<sup>(6)</sup> In some locations, spawning and settlement can occur over an extended period (e.g., in New Hampshire from May through October<sup>(5)</sup>) and peak activity is highly variable from year to year. The larval period can last from 3 to 8 weeks, depending on environmental conditions.<sup>(7)</sup> Most culture operations in North America rely on a single seed col-



lection period, generally during the peak settlement period in June or July.<sup>(3)</sup> Many different types of ropes are deployed to capture larvae, and though there is anecdotal information on the performance of different types of materials, timing and location of deployment appear to be the most important factors.<sup>(3,8)</sup> Seed mussels are left on the collection ropes until they reach a shell height of 15 to 25 mm. They are then removed from the lines, graded to size, and either sluiced into mesh tubes or "socks" or bound to ropes with a biodegradable mesh cotton sleeve using either the Spanish or New Zealand method. Socks or ropes are then attached to the horizontal head rope of the longline.<sup>(1,3)</sup> Grow-out time to market size can be highly variable, and while temperature and salinity may be factors, within a range of temperatures between 5° and 16° C and salinity > 25 ppt, food quantity and quality are the most important.<sup>(3,6)</sup> Growout to minimum market size (55 mm) from 20 mm seed can range from 8 to 18 months depending on location.<sup>(4,9)</sup> The growth rates reported for the Gulf of Maine generally range from 2 to 5 mm/month averaged over all seasons.<sup>(3)</sup> In locations with rapid seed development and good growth rates at growout locations, it is possible to go from seed settlement to market size in 12 to 14 months.<sup>(9)</sup>

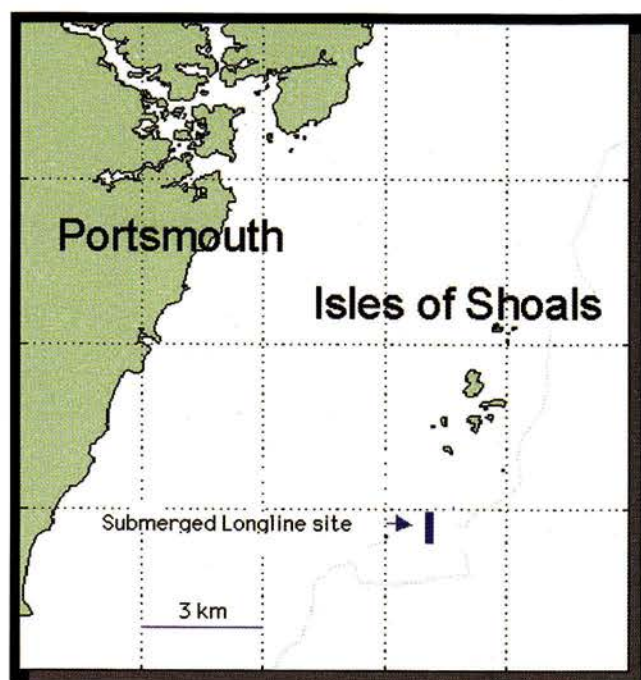
While environmental conditions (e.g., temperature and salinity) in continental shelf waters of the western Gulf of Maine are ideal for mussel culture, no commercial offshore farms have been established, likely due to the lack of technology suitable for fully exposed waters, and the anticipated risk and expense of operating offshore. The purpose of this project was to evaluate system designs, equipment, materials, biological performance and production of mussels in open ocean environments, and to provide prospective entrepreneurs with information on the technologies, operational methods and economic data needed to establish commercial enterprises.

## Methods

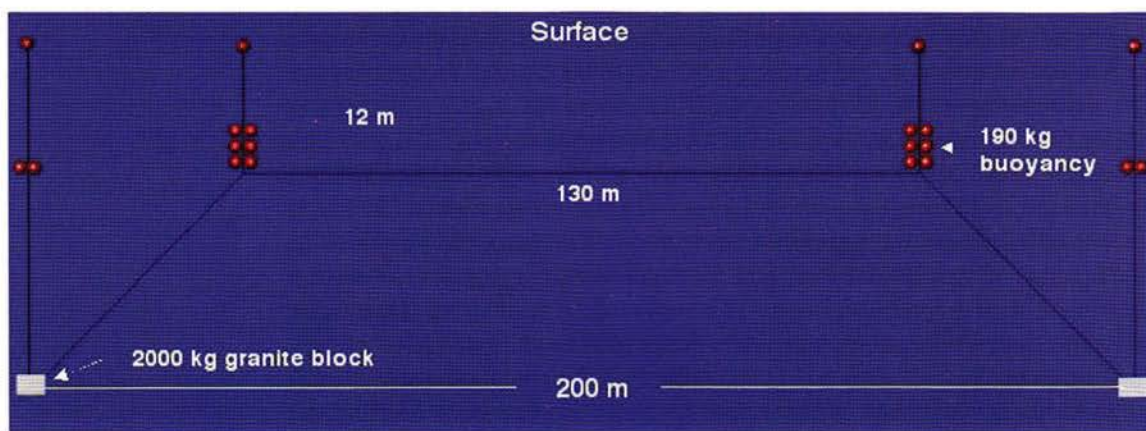
### Site selection and permitting

Site assessment surveys were conducted off the coast of New Hampshire over a period of a year (1997-1998). A broad area was initially surveyed in waters 45 to 60 m deep and ranging from 7 to 12 km from the mainland coast. The surveys gathered data on bathymetry, bottom substrate, benthic community, current direction and velocity, and vertical profiles of water column conditions including temperature, salinity, turbidity, chlorophyll *a* concentration, and dissolved oxygen. The data indicated that conditions were favorable for mussel culture,<sup>(10)</sup> though chlorophyll concentrations were in general lower (< 1 to 5 µg/L) than in inshore waters where mussel culture takes place in Maine and Atlantic Canada.<sup>(3)</sup> Following discussion and negotiation with federal and state regulatory agencies, commercial and recreational fishermen, and the shipping industry, a final site was selected (Fig. 1). Permit applications were submitted and permits granted in 1999.

**Figure 1**  
Map showing the location of the submerged longline installation 10 km off the New Hampshire coast in the western Gulf of Maine.







**Figure 2**  
A schematic of a submerged longline showing dimensions and depth of deployment.

#### **Seed collection**

Seed collection began in 1998 at a protected nearshore location in Portsmouth. Several types of rope were used, including natural fiber (sisal), 3-stranded and braided polypropylene, and polydacron lobster warp. Five-meter lengths of ropes were deployed from a surface raft, and larval settlement was monitored over a 3-month period. During the first year of growout (1999), seed settlement was observed on the longline that was deployed at a depth of approximately 12 m. Seed collection was initiated at the offshore site in 2000. Polydacron lobster warp and subsequently “chopped” polypropylene and “netcord” were deployed from the offshore longlines in late May-early June and in September 2000, 2001, and 2002.

#### **Longline design and deployment**

The initial longline installation consisted of two lines in series anchored by three 3.2-tonne mooring blocks. Buoyancy was achieved with 92-cm diameter steel corner floats, each providing 150 kg of buoyancy. Polysteel rope (2.75 cm) was used for anchor lines and headlines. The distance between moorings was 200 m and a headline length between corner floats of 130 m, resulting in a submerged depth for the headline of 12 m (Fig. 2). As mussels increased in weight, additional buoyancy was added to the submerged longline to maintain proper depth. Submersible plastic buoys from several manufacturers were attached to the longline using short lengths of braided nylon twine. Each buoy type was evaluated for performance at depth.

**Figure 3**  
The custom designed and fabricated hydraulic starwheel mounted on the starboard side of the vessel.



#### **Vessel conversion and tending operations**

A typical nearshore fishing vessel (13 m LOA) was con-



**Figure 4**

**A sluicing table is used to fill mesh socking with mussel seed.**

verted for use in mussel culture. A custom-designed hydraulic starwheel (Fig. 3), an aft idler wheel purchased from a Canadian company, and a stationary boom for vertical lifting were installed on the vessel.

#### ***Mussel socking and growout***

Seed mussels were socked using either a sluicing table and tubular mesh socks (in 1999 and 2000) or an automated socking machine that employs a rope core and biodegradable cotton sleeve (beginning in 2001) (Fig. 4, 5). Mussels socked in the tubular mesh were first graded to size and socked in discrete "dropper" lengths of approximately 12 m. Seed socked using the rope core method and cotton sleeve method were graded to size and attached to the headline in continuous lengths of up to 600 m per longline, with the pattern consisting of alternating short (3 m) and long (25 m) loops (Fig. 6). Several different types of core rope were evaluated for ease of use with the automated socking machine and qualitatively for the strength of byssal attachment. Socking densities ranged from 500 to 1000 seed/m and growth rates at different densities were evaluated. Growth (shell height) was measured approximately monthly by taking four to five 0.3 m samples of sock or core rope at varying depths from randomly selected socks/ropes. All mussels were measured to the nearest millimeter. Meat yield of the samples was calculated using the formula: cooked meat weight/whole cooked weight. In all, 7 seed cohorts were deployed between June 1999 and May 2003 and length of time to market size, as well as final meat yield at harvest, was determined for each cohort.

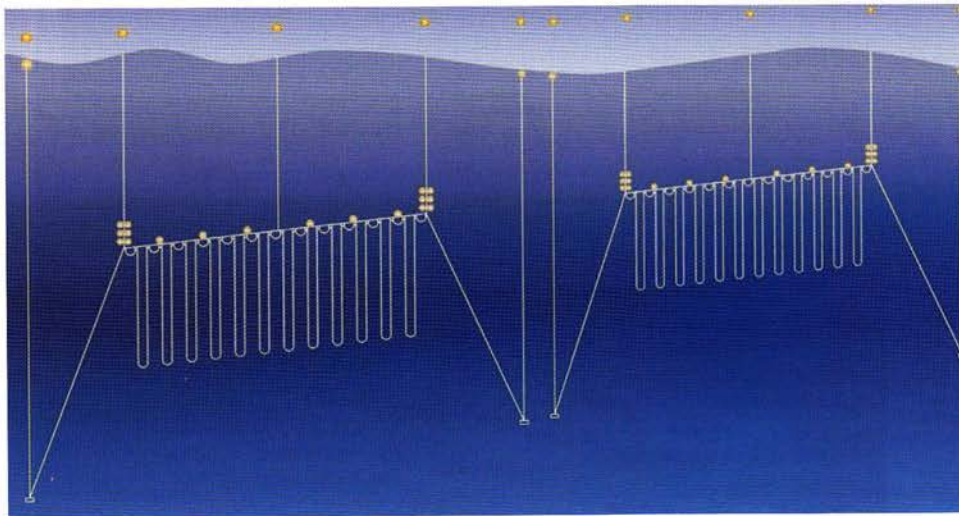


**Figure 5**

**Mussel seed, bound to a core rope with cotton sleeving as it comes off the top of the wheel of the automatic socking machine.**







**Figure 6**  
A schematic of the looping pattern used for growout using continuous socking with core rope and cotton sleeving (not to scale).

processed by hand. Mussels were marketed to local restaurants and seafood retailers under the trade name "Isles of Shoals Supremes". A product quality survey was developed and distributed to restaurant chefs and to customers at retail shops.

#### **Economic assessment**

An economic assessment and business plan were developed by a contractor to determine the economics of farm size, options for business ownership, production costs and potential profitability.

#### **Technology transfer**

A series of meetings were held in New Hampshire and Maine to inform fishermen about business opportunities for offshore mussel culture. The meetings were followed by hands-on demonstrations at the offshore site and additional meetings with fishing cooperatives and individual fishermen to identify offshore sites and

#### **Harvesting, processing and marketing**

Harvesting was accomplished with a custom-designed mechanical harvester that consisted of a slide, a hopper, and a hydraulically driven hauler (Fig. 7). Large quantities of harvested mussels (> 1 tonne) were sent to commercial facilities for processing and smaller quantities (up to 75 kg) were processed by hand.

to assist with the development of federal and state permit applications for commercial enterprises.

#### **Results**

##### **Seed collection**

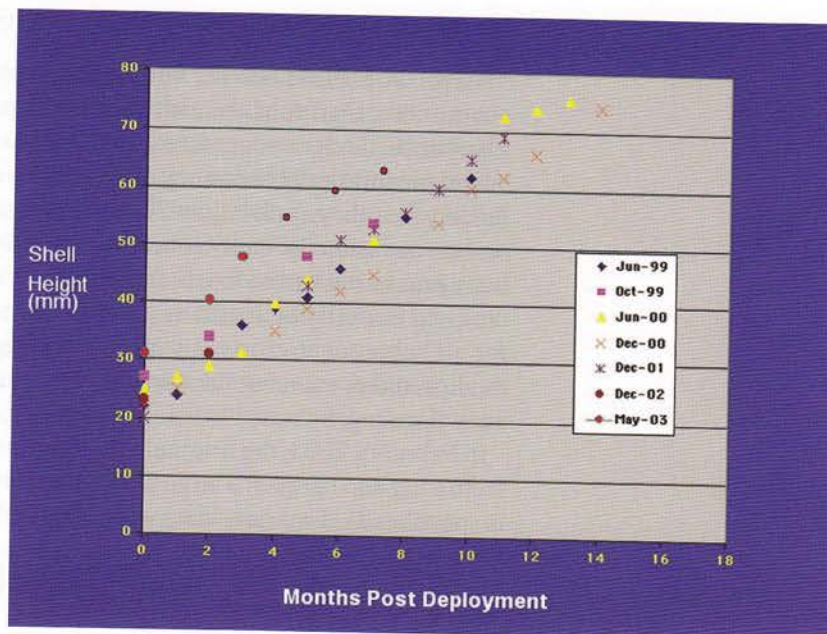
Commercial quantities of seed were collected from inshore locations and from the offshore longlines in the late spring and early summer and again in the fall. Annual variation in the density of settlement was observed, with

**Figure 7**  
Harvesting mussels with the custom designed mechanical harvesting machine.





both spring and fall peaks differing by as much as 30 d. Average density for all years was approximately 2,000 seed/m by the time the seed grew to a shell height of 25 mm. The 25-mm size was reached at an average over all years of 5 months post-set. At the inshore sites, all rope types caught mussel seed except the natural fiber rope which became heavily fouled with filamentous algae within a week of deployment. Best results were achieved with polydacron lobster warp that had been used for lobster fishing for several seasons. Similar results were observed at the offshore location, with the "netcord" material exhibiting the poorest and the lobster warp the best performance. Seed settlement at the offshore site was best between 12 and 17 m, and thinned out quickly beyond that depth. Virtually no seed was collected deeper than 20 m. Fouling by the hydroid *Tubularia* sp. hampered seed collection and subsequent growth and sorting for growout.



**Figure 8**  
Growth rates of seven cohorts of mussel seed deployed for growout since 1999.

**Figure 9**  
Market sized mussels produced at the offshore site.





### ***Longline design and deployment***

All ropes, anchors, corner buoys, and lines were in very good condition after 4 years of use; therefore, the estimated life expectancy of the materials was 7-10 yr. The one difficulty encountered was with the submersible plastic floats that were added for additional buoyancy during grow-out. Buoys from three manufacturers failed when they sank below 20 m, causing the longline to sink even deeper and on two occasions actually touch bottom. A 40-cm diameter rotationally molded buoy purchased from a fourth manufacturer was tested in 2002; it maintained volume and integrity at depths as great as 50 m. These buoys were used exclusively for all subsequent growout cycles, resulting in more reliable depth stability for the line and decreasing the number of maintenance trips to the site to add buoyancy during growout.

In February 2003, the original longline was destroyed when either a safety cable from a tug and barge or a large mid-water trawler fouled the installation (the cause is speculated). Two new lines were installed in March 2003. These differed from the original in that each line was moored separately with two granite blocks (2 tonnes each), rather than 3 concrete blocks for two lines. One additional change in design was that the 92-cm steel corner floats on one of the lines were replaced by a cluster of six 40-cm plastic buoys.

### ***Vessel conversion and tending operations***

The conversion vessel performed well under most conditions; however, the direction of the wind, waves, and currents were nearly as critical a factor as the wave height and wind speed. Line tending was difficult at wind speeds greater than 35 km/h and wave heights greater than 2 m, particularly in beam winds and seas. In addition, the vessel had difficulty safely tending a line fully loaded (> 5 tonnes) with market-sized mussels in marginal sea conditions.

### ***Mussel socking and growout***

Mesh socking lacked the strength needed for droppers of the length used (12 m) and virtually all socks from the 1999 deployment broke as mussels reached market size. In 2000, lengths of 5-mm braided nylon twine were run through the mesh sock during seeding operations to provide greater strength. This worked to some degree; however, the use of mesh socking was abandoned after the purchase of the automated socking machine. Beginning in 2001, the rope core and cotton sleeve method was used for growout. Though no scientifically valid data were gathered on rope performance, qualitative assessment indicated that the New Zealand "loop" and "Christmas tree" ropes were the preferred materials in terms of handling, ease and efficiency of socking, and strength of byssal attachment.

Growth rates for all seed cohorts were remarkably similar, regardless of initial seed size or season of deployment. Mussels grew an average of 4 mm per month, reaching minimum market size (55 mm) after 8 to 9 months on the longline (Fig. 8). Seeding density up to 900/m did not affect growth rates. At higher densities, growth was slightly slower, but yield was higher. Optimal density was determined to be 750 mussels/m, which resulted in a yield of 9 kg/m of rope, and a total yield of 5.4 tonnes per line (Fig. 9). Meat yields ranged from 42% to nearly 60%, with the lowest percentages recorded in post-spawning mussels.

### ***Harvesting, processing and marketing***

Mussels were removed from the growout ropes quickly and efficiently using the mechanical harvester, and very few mussels were damaged during harvesting operations. Some difficulties were encountered in guiding the mussel-laden ropes onto the overboard slide when tidal currents and wind direction affected vessel positioning on the line. Processing at commercial facilities resulted in a substantial breakage ranging from 29% to 40% of individual lots. The two processors that were used deal almost exclusively with bottom cultured or wild mussels that have substantially thicker shells. Therefore their handling methods and processing machinery resulted in unacceptable product loss.

The consumer response to the ocean-grown mussels was very positive, with most respondents indicating their preference to "Isles of Shoals Supremes" over all other products.

### ***Economic assessment***

An economic assessment was conducted by the Marine Policy Center at Woods Hole Oceanographic Institution. Their published findings used cost and production data from the UNH offshore demonstration project.<sup>(11)</sup> They examined a number of scenarios and determined that a farm with 100 longlines can produce up to 600 t per year, and deliver unprocessed mussels dockside at a cost of US\$0.55/kg. Based on the current market, this assessment indicates that offshore operations can be profitable if they are developed at the proper scale.

### ***Technology transfer***

Technology transfer efforts resulted in applications for two commercial startup operations that were submitted in late 2003. It is anticipated that permits will be granted in the spring of 2004.

### ***Conclusion***

Over the past four years, the project has demonstrated the operational and economic feasibility of growing high quality mussels in offshore waters. Convincing and repeatable data on the production cycle has been compiled, and important information on optimal materials, equipment, and operational methodologies has been provided to potential entrepreneurs. It has been demonstrated that converted fishing vessels can be used in offshore culture operations, providing an alternative business opportunity for local and regional capture fishermen. The applications for two commercial farm sites that were submitted in late 2003 are affirmation of the value of applied research, technology development and demonstration to commercial development.

Despite optimism that commercial startups will be successful using the methods developed through this project, it is anticipated that issues (such as invasive fouling organisms) that can affect production may arise in the future, as they have in other aquaculture sectors. It is also likely that while converted fishing vessels may be successfully used in a nascent industry, continued evolution will include larger specialized vessels and a higher degree of mechanism, similar to what has occurred in the New Zealand mussel industry.

**"Over the past four years, the project has demonstrated the operational and economic feasibility of growing high quality mussels in offshore waters. "**



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**Mr. Forbes Horton** is a 2002 graduate of the University of New Hampshire where he majored in marine and freshwater biology. He has been involved in the UNH offshore mussel project since 1999, and has lent his considerable skills in mechanical design, welding, metal fabrication, and seamanship to the project. He is also at the Cooperative Institute for New England Mariculture and Fisheries in Durham, New Hampshire.

# An Open Ocean Aquaculture System for Submerged Operations in New England

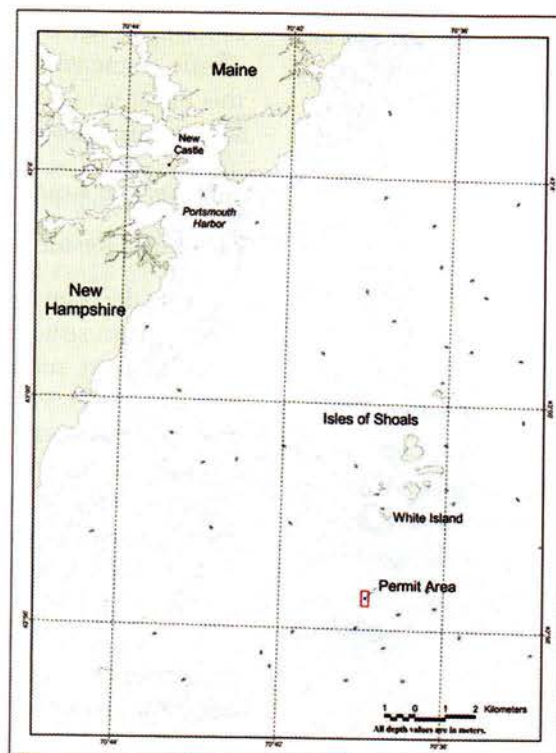
David W. Fredriksson, Michael D. Chambers,  
Judson C. DeCew, Brett Fullerton, M. Robinson Swift,  
Glen Rice and Barbaros Celikkol

The open ocean conditions off the coast of New England present unique challenges as the coastal marine aquaculture industry considers moving into exposed locations. Many of these challenges are being investigated by researchers involved in the Open Ocean Aquaculture project at the University of New Hampshire. The investigation of nearly "commercial-scale" operations was initiated in July 2003 when a four-cage, submerged grid mooring system was deployed in 52 m of water approximately 10 km from the New England coast. Deployed in the grid are three submersible *Sea Station*<sup>TM</sup> cages being used to contain Atlantic halibut, haddock and Atlantic cod. The cages are kept in the submerged configuration since 9 m seas and icing can occur at the site. Distance from the shore, energetic sea-states and submerged operations make consistent feeding difficult. Since existing feeding technologies are geared to the inshore aquaculture industry, two automated, experimental feeding systems were developed and are deployed at the site.

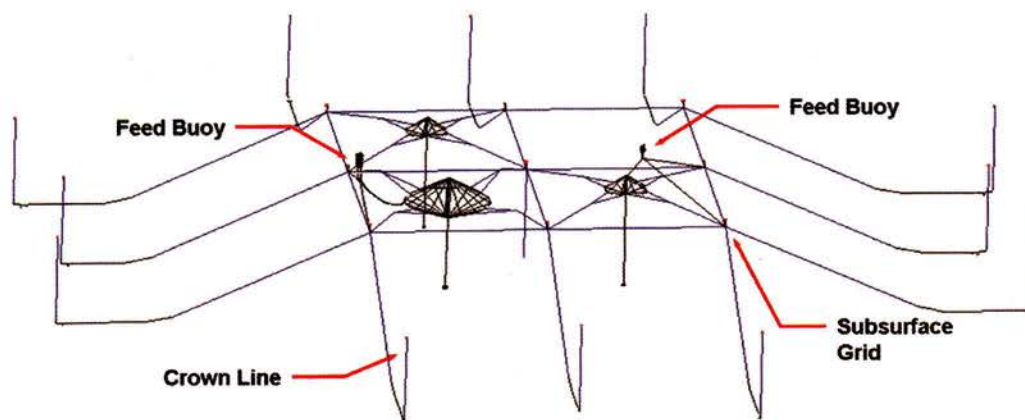
## Introduction

As environmental and utilization issues put pressure on existing nearshore aquaculture facilities, the need to move operations into more exposed sites is becoming necessary. The technologies required to perform economic open ocean aquaculture, however, are still in the process of being developed. The University of New Hampshire (UNH) operates a 12.4 hectare, open ocean aquaculture site in 52 m of water, approximately 10 km from the New Hampshire coast in the USA (Fig. 1). The site is permitted to perform research related to the operational, engineering, biological and environmental aspects of open ocean aquaculture. Specification for equipment suitable for the site is difficult because of the harsh environmental conditions. The most extreme storms come from the northeast where significant wave heights have been measured to be on the order of 8 m with maximum waves possibly approaching 13 m.<sup>(1)</sup> Cold temperatures and high winds that occur during the

Figure 1  
Location of the Open  
Ocean Aquaculture re-  
search site off the New  
Hampshire Coast.







**Figure 2**

Three submersible cages are deployed within the four-cage grid mooring with two feed buoys. Crown lines are attached to the anchors to adjust the mooring if needed.

winter months often create freezing spray that covers surface gear with ice. Current velocities can be substantial, with magnitudes often exceeding 50 cm/s. Research performed in the past few years, however, has shown that equipment can survive at this location during extreme conditions.<sup>(2)</sup>

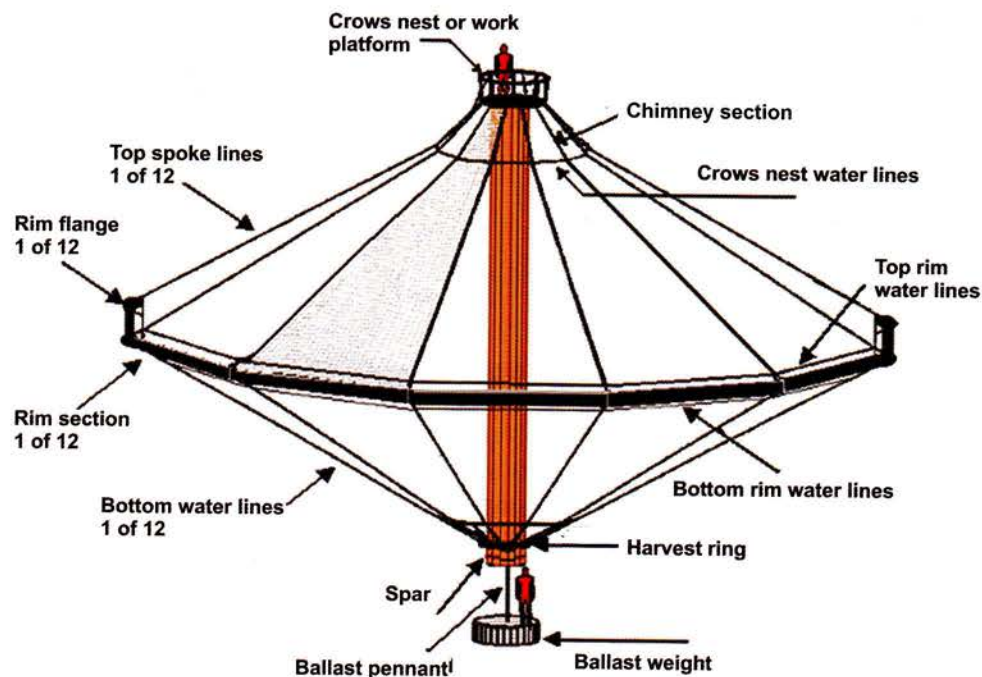
A four-cage grid mooring deployed at the site is being used to hold three, submersible *Sea Station*<sup>TM</sup> fish cages and two feed buoys (Fig. 2). Atlantic halibut (*Hippoglossus hippoglossus*), haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*) are being raised separately in each of the three cages. Many of the operations are being performed below the surface (the top of the cages are at a depth of approximately 10 m). Distance from the shore, energetic sea-states and submerged operations make consistent feeding difficult. Since existing feeding technologies were developed for the inshore aquaculture industry, new feeding systems are being designed and deployed.<sup>(3,4)</sup> These feeding mechanisms generate their own power and are controlled remotely so the fish can be fed in the submerged cages without having personnel at the site. The mooring systems used with each of the feed buoys are uniquely designed with elastic elements that connect into the four-cage grid mooring. The objective of this paper is to describe the equipment deployed and the species being raised to investigate open ocean aquaculture where exposed, cold water conditions exist.

## Submerged Aquaculture Equipment

### Fish Containment Structures

One of the primary components necessary for open ocean aquaculture is the fish containment structure. Since energetic wave conditions and icing are typical in New England, submerged containment systems are being used. Three were purchased from Net Systems, Inc. located in Bainbridge, Washington State, USA. Two of the cages consist of the 600 m<sup>3</sup>, *Sea Station*<sup>TM</sup> (SS600) deployed as part of a previous phase of this project.<sup>(5-7)</sup> The third cage consists of the 3000 m<sup>3</sup> *Sea Station*<sup>TM</sup> (SS3000) purchased in July 2003. The SS600 cages are constructed around a central spar approximately 9 m long and a rim with a nominal diameter of 15 m, held together with spoke lines. The rim is made of eight, 6.2 m sections of steel pipe. One of the SS600 cages incorporates a ballast weight assembly attached to the bottom of the spar consisting of a 25 m line connected to a 1.1 tonne clump weight. Attached to the clump weight is 16 m of chain that extends to the bottom and drags on the ocean floor. The other SS600 cage uses a single 2 tonne weight. The SS3000 cage has a similar construction except the spar is approxi-



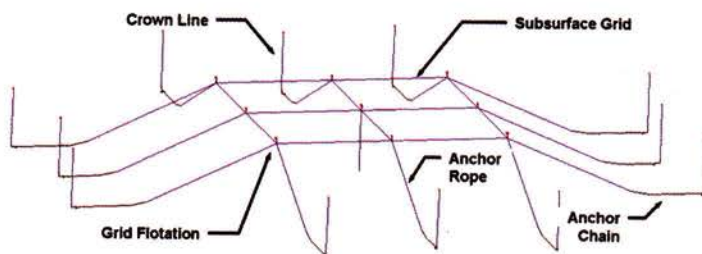


**Figure 3**  
A schematic of the general configuration of the SS3000 cage. The SS600 is similar except the spar is shorter and the rim is constructed with eight sections.

mately 15 m long and the rim is made of twelve 6.63 m sections of steel pipe with a nominal diameter of 25 m. The ballast weight assembly attached to the bottom of the spar consists of a 6 tonne clump weight. In each of the cages, a chamber in the spar permits ballasting, allowing the cage to be either at the surface or submerged. Component details can be found in Fredriksson et al.<sup>(8)</sup> and Kurgan<sup>(9)</sup> for the SS600 and SS3000 cages, respectively, or from the manufacturer. The general components of the SS3000 are shown on Figure 3.

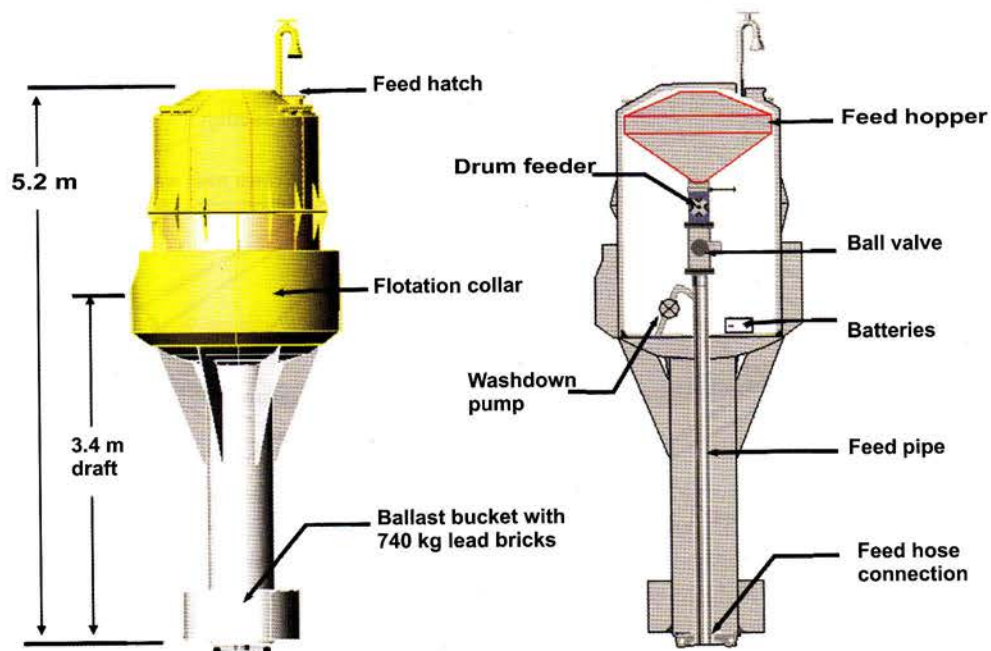
#### Mooring System Concept

The mooring system was also designed to facilitate submerged aquaculture. It incorporates a four-cage grid that is located approximately 15 m below the surface (Fig. 4). Four sets of bridle lines connect the cages to the submerged grid (not shown on Fig. 4). The grid openings allow the cages to be submerged and are anchored to the bottom using 12 anchor legs each incorporating co-polymer rope



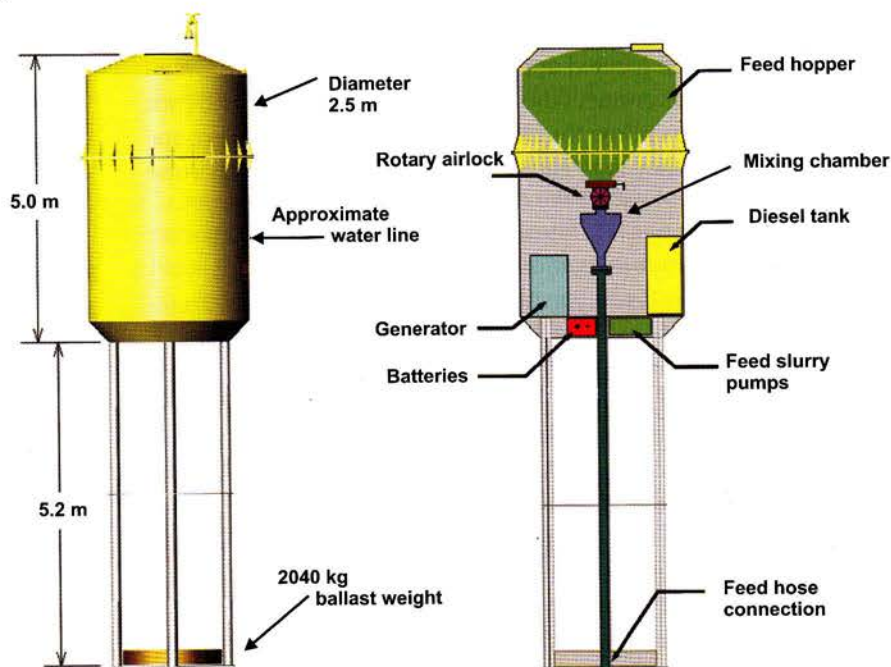
**Figure 4**  
An isometric view of the submerged four-cage grid system. It consists of eight corner anchor legs, four side anchor legs, one center anchor line and 12 grid lines.





**Figure 5**  
A schematic of external features of the 227-kg feed buoy (left). A cross-section of buoy showing the internal feeding mechanisms (right).

**Figure 6**  
Schematics of external (left) and internal (right) components of the 907 kg feed buoy.



and a chain catenary. Tension in the system is maintained using grid flotation at the nine nodal locations. Due to the 12 anchor design, flotation elements at the corners are larger than those at the grid sides to accommodate the weight of chain for two anchor legs. Design details are provided in Fredriksson et al.<sup>(10)</sup> During the deployment process, the anchors were set using crown lines to form the required geometry, which submerges the flotation elements down to the desired depth and



lifts chain up off the bottom. The chain catenary in the anchor legs provides necessary compliance to the system. This effectively pretensions all of the grid mooring gear, which is an important consideration to minimize marine mammal entanglement. The mooring concept also employs large diameter ropes (44 to 52 mm), which also helps to prevent entanglement.

#### **Quarter-Ton Feed Buoy**

To feed the fish in the cages, automated feed systems were developed since the equipment is not available in the United States. The first system was designed for a 227 kg (quarter-ton) capacity to supply feed to one of the SS600 submerged cages.<sup>(4)</sup> It consists of a surface buoy, moorings attached to the submerged grid, a feed transfer hose, feed dispensing machinery, and telemetry/control components. The buoy is taut-moored above the cage by compliant members to provide flexible response to tides and waves. The buoy operates remotely at the site using automated feed dispensing, power supply, control and communication systems.

The major dimensions and the arrangement plan of the hopper, batteries, pumps and other internal systems of the 227 kg feed buoy are shown on Figure 5. The main body consists of a 1.5 meter diameter aluminum cylinder based on a previous design described by Rice et al.<sup>(3)</sup> A 0.6 m diameter cylinder extends downward and supports a 1 m diameter "bucket" at the base filled with lead ballast. Reserve buoyancy is provided in the form of a 20 cm thick Surlon foam flotation collar. The center of gravity is well below the center of buoyancy. The resulting metacentric height provides a substantial reserve righting moment. Extra buoyancy and righting moment were viewed as essential for safety of maintenance personnel as well as buoy survival in severe storms, icing conditions or loss of watertight integrity.

Feed pellets are loaded into the buoy through the top hatch and stored in the hopper shown in Figure 5. A rotary drum valve is used to meter out the desired amount of pellets for each feeding. The feed pellets drop through an open ball valve into a small chamber with water, where a pump forces the mixture down through the hose to the cage. These components are powered by both solar and wind energy. Two 60 watt solar panels provide electricity during clear, sunny days and a wind generator provides power during moderate wind. The power systems charge two 24 volt, 105 amp-hour battery banks.

A CF-1 microcontroller with a load distribution panel controls the systems inside the buoy. The system was designed to allow the microcontroller to monitor all of the voltages and currents that control the feeding operation. The controller is also interfaced with two spread-spectrum radio systems to allow for land-based remote control and data acquisition. The first of these systems contains two 900 MHz serial (RS-232) radios that allow for direct monitoring and control of the CF-1. The system was designed and programmed to allow for land-based upgrading of the control programs/feed schedules without having to be at the site. The second radio system consists of a set of 2.4 GHz radios used for live video monitoring from two cameras strategically placed within the fish cage to view feeding behavior.

The 227 kg feed buoy mooring system connects to the four-cage grid using two compliant tether assemblies and an elastic feed hose connected to the top of the cage. Each tether assembly consists of a pair of 2.5 cm diameter elastomeric members (connected in parallel) and a single, 89 kN capacity braided nylon rope. Since 9 m waves and a 3 m tidal range can occur at the site, the feed buoy mooring components were designed to remain taut with the buoy at the level of low tide in

the trough of the wave, yet be within the operational elastic limits of the hose and tether while the buoy is at the high tide, wave crest level.

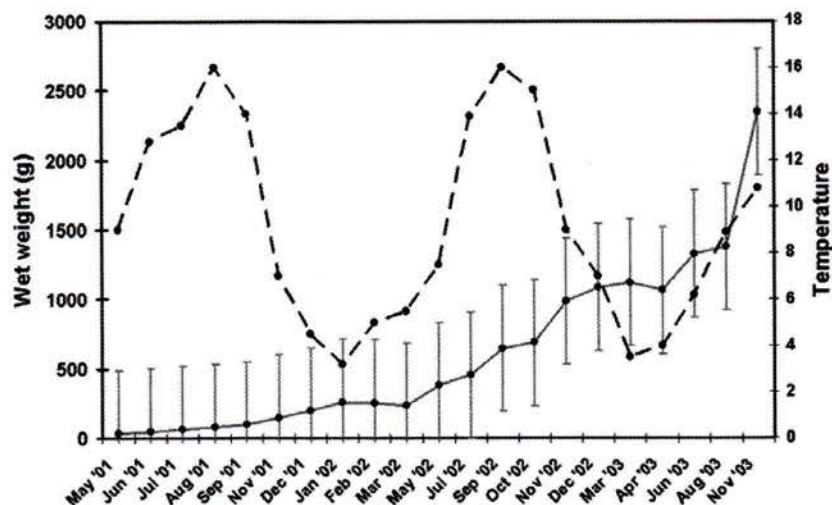
#### One-Ton Feed Buoy

Another prototype feed buoy is deployed at the site to feed the fish in the SS3000 cage. This system is similar in design and operation as the 227 kg buoy; however, the new buoy incorporates upgraded control systems and has a 907 kg (one ton) feed capacity. It consists of a surface buoy, moorings attached to the four-cage grid, a feed transfer hose, industrial feed dispensing machinery and a telemetry/control system. The buoy is taut-moored above the submerged SS3000 cage. The major dimensions and the arrangement of the hopper, dispensing machinery, generator, pumps and other internal systems of the feed buoy are shown on Figure 6. The main body of the buoy consists of a 2.5 m diameter cylinder that is 5.0 m tall. The section is split into two parts; the lower section is made of steel, while the upper section is aluminum (it is important to note that the dissimilar metals are electrically isolated). The aluminum upper portion was used to reduce the weight so that the center of gravity is significantly lower than the center of buoyancy, offering a substantial righting moment.

Feed is loaded into the buoy through the top hatch and stored in the hopper. A stainless steel rotary airlock dispenses the feed and seals the hopper from getting wet. The airlock consists of a  $\frac{1}{2}$  hp motor which drives an 8 vane rotary unit within a sealed housing. The vanes can rotate at 10 rpm dosing approximately 18 kg/min (the dosing rate can be adjusted by changing the rpm). The feed drops into a mixing chamber below the airlock valve where it mixes with water. The feed mixture is then pumped out of the buoy and through a 100 m long transfer hose to the cage.

The 907 kg feed buoy also incorporates a self-contained power supply, control and telemetry systems. The systems built for the 907 kg buoy are substantially different than those designed for the 227 kg buoy. With increased feed capacity, the power requirements were also increased and therefore required a 5 kW diesel generator as the major power source. The control system was also upgraded. In the previous feeder, it was designed to be passive (i.e., conditional testing was not necessary for operation). The control system in the 907 kg buoy, however, is designed to check if certain components (like the diesel generator) are running

Figure 7  
Halibut growth in weight  
(solid line). The dashed  
line is seawater  
temperature.





before the feed process starts. In addition, since the generator is capable of producing hazardous voltages in excess of 240 VAC, more safety precautions are incorporated to maintain a safe situation. Emergency stop systems, accurate current limiting circuits, wiring that complies with the 2003 National Electric Code, interior lighting, and a fire extinguishing system are all part of the existing safety precautions. If any safety problem does occur (e.g., circuit breaker tripped, emergency stop system activated, etc.) the information is logged by the internal computer and transmitted to shore.

The telemetry system is similar to the one used with the 227 kg buoy and allows for full control and acquisition of all data. The user has the ability to choose which days and hours they want the buoy to feed and to vary the rate at which the fish are fed. The control and telemetry system was developed to complement a web-based control center that will allow engineers/technicians and managers to be able to monitor and certain personnel to control many aspects of the operation.

Presently, the 907 kg feed buoy is moored in a temporary configuration. The permanent mooring system is designed to keep the buoy from colliding with the cage during extreme storms, since the buoy has a 7 m draft. The design consists of a two-point mooring system with two highly stretchable (220%) rubber hoses. Each mooring hose is approximately 15 m long with a 7.63 cm internal diameter and a 10.67 cm outside diameter. The hose is flooded with water and the ends capped to prevent compression of the wall under significant tension. Packed inside the flooded hose is a length of coiled rope, which in the severe event of possible overstretching, the rope member would prevent damage to the rubber. The remaining length of the mooring consists of 2.5 cm braided nylon rope. Mooring tethers would be attached to the west and southwest grid corners. A third rubber hose with less stretch would supply feed from the buoy to the cage approximately 33 m long. However, it is expected that this hose would see minimal forcing and therefore is not considered part of the two-point mooring used for the buoy.

## Open Ocean Aquaculture Species

### *Atlantic Halibut*

In addition to investigating equipment for open ocean aquaculture, work is being conducted to develop culture techniques for cold water marine species in New

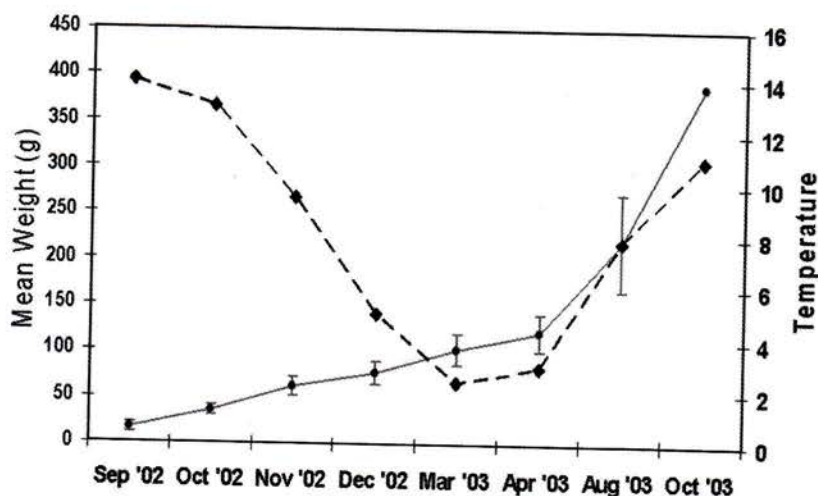


Figure 8  
Haddock growth in weight (solid line). The dashed line is seawater temperature.

England.<sup>(11)</sup> One of the first cold water species to be stocked at the site was Atlantic halibut. In May of 2001, approximately 2000 juvenile halibut averaging 30 g were acquired from R&R Development located in Digby, Nova Scotia. The halibut were transferred to the UNH Coastal Marine Lab (CML) in New Castle, NH at a density of 22 kg/m<sup>3</sup>. All fish survived the 17 hour trip. At the CML, the fish were held in 2 m<sup>3</sup> tanks with flow-through seawater and fed 4% body weight/day with belt feeders. During this time, stocking density increased from 4.7 to 12.7 kg/m<sup>2</sup> as the fish grew. Transfer to one of the SS600 cages occurred in October 2001<sub>3</sub> when the halibut had reached 100 g mean weight. Transfer was conducted in 1 m<sup>3</sup> fish boxes. Fish were placed into rubber coated trays and then stacked into the fish boxes, which were supplied with oxygen and flowing seawater. After the cage was stocked, it was submerged to 12 m. Since stocking, fish have been fed (Shur Gain and Dana Feed halibut ration), approximately twice per week, at a rate of 3 to 4% body weight during warmer summer months and 1 to 2% during cooler winter months. Monthly sampling of the fish has been performed to track growth and survival. The growth results in weight are shown on Figure 7 and survival is approximately 68%. The mortalities were caused by fat cell necrosis syndrome (FCNS) or "sun burn". The syndrome is a degeneration of the subdermal fat deposits, and is caused by the imbalance of oxidants and anti-oxidants in the diet along with excessive sunlight. This condition occurred during the summer months when the cage was at the surface for cleaning. In addition, the warmer surface temperatures created heavy fouling by the colonial hydroid *Tubularia* sp., which have stinging nematocysts. Divers observed minor skin irritations on the ventral (non-ocular) side of the fish, indicating that halibut are sensitive to the stinging cells, and are reluctant to settle onto substrates populated by *Tubularia*. The halibut cage is kept submerged during summer months to reduce the risk of FCNS and cleaned more frequently so the fish can achieve their maximum growth potential. Presently the halibut are 2.5 kg and should be ready for harvest in the spring of 2004 at 3 kg.

#### **Atlantic Haddock**

Another cold water species being investigated is Atlantic haddock. This work is part of a collaborative study initiated in September of 2002 between UNH and Heritage Salmon Limited located in New Brunswick, Canada. Although the company concentrates on the production of Atlantic salmon, they have also been conducting extensive and very successful research aimed at producing haddock. The objective was to study the performance of haddock in offshore net pens with haddock in inshore pens. The National Research Council Laboratory in Halifax, Nova Scotia, Canada, produced the 3000 juvenile haddock (16 g mean weight) for the study. The fish were transferred to UNH in insulated containers at a density of 23 kg/m<sup>3</sup>. The haddock were placed in a 35 m<sup>3</sup> nursery pen located near the UNH Coastal Marine Laboratory and fed a formulated diet (3-5mm, DANA Feed) three times a day by a solar powered, automatic feeder. The fish were later transferred to the other SS600 cage at a mass of 78 g in December 2002 and fed a Zeigler and Skretting Marine diet using the 227 kg feed buoy twice a day. The growth performance in the open ocean is shown on Figure 8 and little mortality has been observed, except for fish handled during sampling. The intention is to leave the fish in the open ocean cage until they reach market size (2 to 3 kg).

#### **Atlantic Cod**

The third cold water species being investigated is cod. This work is being per-



formed in collaboration with Great Bay Aquaculture (GBA). Cod production began at GBA early in 2003 using eggs and sperm collected from wild broodstock. Larval rearing techniques were changed to incorporate information learned over the last 2 years about water quality management, live food enrichment, causes of hyperinflation of the swim bladder, and larval stocking density. Hatching success, larval growth and survival were remarkable. For example, growth rates of up to 5% per day were recorded, and at day 100, survival was approximately 25%. A total of 200,000 juveniles were produced during the first run. All the fish were dip vaccinated with Vibrogen 2 (Aqua Health Ltd.), and repeated tests for the presence of nodavirus were negative.

In April of 2003, a total of 30,000 cod (3 g mean weight) were transferred to two 35 m<sup>3</sup> nursery pens near the CML in New Castle, NH. Fish in both pens were initially fed 3 times per day by hand, and later with an automatic, solar powered feeder. As the fish grew, approximately half the fish from each pen were moved into two other 35 m<sup>3</sup> pens to reduce stocking density. In September, the 50 g cod were moved to the open ocean site and placed inside a 200 m<sup>3</sup> nursery net (12.5 mm stretch mesh) suspended within the SS3000 cage. Approximately 600 fish were maintained in the inshore net pen so that a comparison could be made between the two locations. Transport of the fish was facilitated by pumping the fish through a 30 mm diameter hose into large tanks aboard a 30 m, fish transfer vessel from Maine. Transfer of the fish from the vessel to the cage, (while it was at the surface) was also done using the fish pump. Following the transfer, the cage was submerged to 10 m. Fish have been fed commercial diets especially formulated for cod (Zeigler or Skretting) since the transfer. In November, fish in the offshore nursery net were released into the SS3000 cage. The cod will stay in the submerged cage and be fed via the 907 kg feed buoy until they reach a market size of 3 kg.

## Summary

Significant engineering challenges still exist to make open ocean aquaculture more economically feasible. As grow-out takes place, it will become more evident that other technologies such as harvesting systems and uniquely engineered support vessels need to be developed in support of cost-effective open ocean aquaculture. The development of these and other technologies will require an integrated systems engineering approach considering biological and environmental design criteria. The engineering and operational costs must be balanced with the appropriate seafood product and market and reflect responsible environmental practices. The challenges are substantial, but many believe that open ocean aquaculture can be performed economically at a scale that can make a significant impact on the global need for seafood.

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## **Offshore Aquaculture in Canadian Waters: Legal Issues and Challenges**

**Gloria Chao**

Although commercial aquaculture operations in Canadian waters are currently being carried out in coves, bays and nearshore areas well within 3 nautical miles (nm) of the shoreline, there is growing interest in the possibility of operating aquaculture farms in the offshore area. Offshore aquaculture, occurring hundreds of nm from the shore, could prove an attractive option, especially as nearshore areas approach their carrying capacity for both aquaculture and non-aquaculture activities, increasing the likelihood of conflicts between aquaculturists and users of coastal areas over the next decade.

However, even if technology permitted offshore aquaculture operations to be cost-effective in the near future, there are a number of legal issues and challenges associated with such activity. The key one is the uncertainty surrounding the regulation of Canada's offshore area, which is divided along constitutional and territorial lines. Such multijurisdictional regulation creates both regulatory overlap and gaps among different governmental levels and departments.

This paper examines these jurisdictional complexities as well as the integration attempts initiated by the federal and a number of provincial governments in the regulation of marine aquaculture. This paper concludes by identifying the key issues in regulating offshore aquaculture and suggesting a number of regulatory models for future consideration should offshore aquaculture ever be commenced in Canadian waters.

**"As aquaculture operations continue to expand in Canadian waters, one can expect the interest in operating in the offshore area will also grow. "**

### **Introduction**

The aquaculture industry in Canada has experienced significant growth in the last decade, with increased growth projected in the near future. In the next 15 years, it is projected that at an annual growth of 10 to 15 percent, Canada's aquaculture output could reach \$2.8 billion annually in farm-gate revenues.<sup>(1)</sup> Such growth will require increased marine areas to be allocated to aquaculture. Currently, the total area occupied by aquaculture operations in Canada is approximately 30,971 hectares, equivalent to an area measuring 17.6 km long by 17.6 km wide (approximately the size of the core area of the average Canadian provincial capital city).<sup>(2)</sup>

As aquaculture operations continue to expand in Canadian waters, one can expect the interest in operating in the offshore area will also grow. Although there are no commercial aquaculture operations currently underway in Canadian offshore waters, there is already interest in examining the economic feasibility of



aquaculture activities that go beyond the nearshore area, such as sea ranching or the enhancement of selected shellfish species.<sup>(3)</sup>

However, even if technology permitted offshore aquaculture operations to be cost-effective in the near future, there are a number of legal issues and challenges associated with such activity. The key one is the uncertainty surrounding the regulation of Canada's offshore area, which is divided along constitutional and territorial lines. Such multijurisdictional regulation creates both regulatory overlap and gaps among different governmental levels and departments, resulting in inconsistent standards and uncertain sustainable development in the aquaculture industry.

### Scope and Organization

This paper is divided into three parts. The first part provides an overview of the general jurisdictional complexities of regulating aquaculture in the nearshore and offshore areas. The second part examines a number of the integration attempts that have been initiated by the federal and provincial levels of government to coordinate their regulation of aquaculture in nearshore areas. The paper concludes by identifying the key issues in the regulation of offshore aquaculture and the possible regulatory models that may be considered should offshore aquaculture operations be undertaken in Canadian waters.

### Regulating Nearshore and Offshore Aquaculture Activities in Canadian Waters: Jurisdictional Complexities

Because of the constitutional division of powers between the federal and provincial governments, the regulation of aquaculture is inherently multijurisdictional and complex.<sup>(4)</sup> The federal government can legislate in respect of aquaculture activities in relation to a number of constitutional heads of power, including: sea coast and inland fisheries;<sup>(5)</sup> shipping and navigation;<sup>(6)</sup> trade and commerce;<sup>(7)</sup> interprovincial and international matters;<sup>(8)</sup> Indians and lands reserved for Indians;<sup>(9)</sup> and federal works and undertakings and matters declared to be within federal jurisdiction.<sup>(10)</sup>

The provincial governments also play an important role in the regulation of aquaculture. In nearshore areas, the principal aspect of private aquaculture, the farming of aquatic organisms within a leased area, is most likely to be a matter under the provincial head of power over property and civil rights.<sup>(11)</sup> Other provincial heads of power include all matters of a merely local or private nature in the province,<sup>(12)</sup> as well as, the regulation of the subaquatic lands underlying freshwater lakes and rivers, and tidal areas within bays, inlets and estuaries (with minor exceptions).<sup>(13)</sup>

With the various heads of power divided between the two levels of government and then further divided under different subject matter within each level, the regulation of aquaculture consists of a patchwork of statutes, administered by multiple departments and ministries. Beyond the *Oceans Act*,<sup>(14)</sup> there is no overarching federal statute that regulates either aquaculture or coastal zone management, in contrast with other federal states, such as the United States.<sup>(15)</sup> The role of aboriginal communities, through the exercise of aboriginal rights, especially title claims and the right to be consulted,<sup>(16)</sup> also contribute to the multijurisdictional regulation of aquaculture development. Adding to the regulatory complexity is the fact that most of the statutes that currently regulate aquaculture were originally conceived for wild fisheries management and have been adapted, some more successfully than others, to apply to aquaculture activities.

**"Adding to the regulatory complexity is the fact that most of the statutes that currently regulate aquaculture were originally conceived for wild fisheries management and have been adapted, some more successfully than others, to apply to aquaculture activities."**



**"Coming into force in 1997, the federal *Oceans Act* articulated a new order of oceans governance based on LOSC principles as well as other emerging international law principles, including: sustainable development, integrated management and the precautionary approach. . . . But the *Oceans Act* does not resolve the jurisdictional issues of multiple regulators and multiple ownership of the ocean spaces."**

Extending the purview of aquaculture activities to the offshore area further exacerbates the jurisdictional complexity of aquaculture regulation. The national regulation of offshore areas of the oceans is a relatively new phenomenon, becoming more and more prevalent in the latter part of the twentieth century, with the United Nations Convention on the Law of the Sea ("LOSC"), the defining document of international oceans law, signed in 1982. LOSC governs a range of matters, including: fisheries, navigation, marine pollution, scientific research, compulsory dispute settlement procedures, and the means by which a state is to delimit the outer edge of its continental shelf. In force since November 16, 1994, its 144 parties (including Canada, whose ratification came on November 6, 2003)<sup>(17)</sup> include all major developed countries.

Coming into force in 1997, the federal *Oceans Act* articulated a new order of oceans governance based on LOSC principles as well as other emerging international law principles, including: sustainable development, integrated management and the precautionary approach. Sections 31 to 33 of the *Oceans Act* require that the Minister of Fisheries and Oceans facilitate the development and implementation of plans for the integrated management of all activities affecting Canadian estuaries, coastal waters, and marine waters. Integrated management is intended to bring together interested parties, stakeholders, and regulators to reach general agreement on the best mix of conservation, sustainable use, and economic development of coastal and marine areas for the benefit of all Canadians.<sup>(18)</sup>

Other than setting out these legislative imperatives, the *Oceans Act* does not elaborate further on how integration may be achieved. The federal government has just recently articulated its very general *Oceans Strategy*,<sup>(19)</sup> as required by the *Oceans Act*. Accompanying the release of *Canada's Oceans Strategy*, the "Policy and Operational Framework For Integrated Management of Estuarine, Coastal and Marine Environments in Canada" sets out how Fisheries and Oceans Canada is addressing its responsibilities for integrated management under the *Oceans Act* and *Canada's Oceans Strategy*.<sup>(20)</sup> Thus far, at least two integrated management plans are currently being developed to examine the management mix of coastal activities, including aquaculture.<sup>(21)</sup>

The Act also reiterates ocean zones that had previously been claimed by Canada, either through legislation or unilateral action, including:

- The Territorial Sea—12 nm (previously 3 nm) from the baselines;
- The Exclusive Economic Zone—200 nm from the baselines, for the purpose of exploring, exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the exclusive economic zone of Canada; and
- The Continental Shelf—350 nm from the baselines for the purpose of exploring, exploiting the mineral and other non-living natural resources of the seabed and subsoil of the continental shelf of Canada, together with living organisms belonging to sedentary species (organisms that, at the harvestable stage, either are immobile on or under the seabed of the continental shelf of Canada or are unable to move except in constant physical contact with the seabed or the subsoil of the continental shelf of Canada).

But the *Oceans Act* does not resolve the jurisdictional issues of multiple regulators and multiple ownership of the ocean spaces. As subsections 9(5) and 21(1) of the Act state, nothing in the Act "shall not be interpreted as providing a basis for



any claim, by or on behalf of a province, in respect of any interest in or legislative jurisdiction over any area of the sea in which a law of a province applies under this section or the living or non-living resources of that area, or as limiting the application of any federal laws."

The trilogy of offshore jurisdiction cases heard by the Supreme Court of Canada in the last forty years have shown how difficult it is to determine ownership of offshore areas. First, in the 1967 case, *Reference re: Ownership of Offshore Mineral Rights (British Columbia)*,<sup>(22)</sup> the Supreme Court of Canada held that the territorial sea (offshore the west coast of Vancouver Island) was not part of British Columbia and was owned by the federal government. Next, in the 1984 *Reference re: Seabed and subsoil of the continental shelf offshore Newfoundland*,<sup>(23)</sup> the Supreme Court of Canada held that Newfoundland did not have jurisdiction over the continental shelf as it did not have such jurisdiction at the time of entering Confederation.<sup>(24)</sup> The third case is the 1984 *Reference Re: Ownership of the Beds of the Strait of Georgia and Related Areas*,<sup>(25)</sup> where a majority of the Supreme Court of Canada held that the Georgia Strait land and waters between Vancouver Island and the mainland were within British Columbia at time of entering Confederation and thus remained within the province.

Given the political and judicial difficulties in determining territorial boundaries, the federal and provincial governments have for the most part chosen to address jurisdictional questions in the development of aquaculture in a manner that does not decisively determine such issues. However, without further regulatory coordination, the multijurisdictional regulation of aquaculture in the near or offshore areas by a number of different agencies and departments will continue to result in delays, inconsistencies in standards, and uncertainty for the sustainable development of the industry.

### **Aquaculture Integration Initiatives**

As the nearshore aquaculture industry has grown in the last few decades, efforts have been made to integrate the decision-making processes among the various government levels and departments in the regulation of marine aquaculture development. The following sections summarize only some of the key integration initiatives undertaken by the federal and provincial government, some of which can be used as the basis for the regulation of the offshore area.<sup>(26)</sup>

One of the key integration initiatives is through the use of vertical integration between the federal and provincial governments, through the delegation of power, and the signing of memoranda of understanding. Federal administrative power has been delegated to provincial levels of government in a number of instances. For example, federal control over freshwater fisheries has been transferred to the provincial governments.<sup>(27)</sup> The federal government has also signed several memoranda of understanding (MOUs) on aquaculture with provinces and territories, including British Columbia, Québec, Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador. In general, these MOUs set out the areas of exclusive jurisdiction and the areas of cooperation between the two levels of government. The MOUs also include provisions creating Management Committees (or Coordinating Committees, in the case of Prince Edward Island).

Another important integration initiative is the formation of federal-provincial or federal-aboriginal bodies or programs. The Canadian Council of Fisheries and Aquaculture Ministers (CCFAM), composed of federal, provincial and territorial Ministers, was formed to allow the Ministers to discuss national and global issues affecting the fisheries and aquaculture sectors and identify shared policy objec-

**". . . without further regulatory coordination, the multijurisdictional regulation of aquaculture in the near or offshore areas by a number of different agencies and departments will continue to result in delays, inconsistencies in standards, and uncertainty for the sustainable development of the industry."**



**"Currently, there are at least 17 federal departments and agencies delivering programs and services to the aquaculture industry. . . . This fragmented approach has been identified by the Office of the Commissioner for Aquaculture Development as a critical area for reform if Canada is to ensure a sustainable aquaculture industry."**

tives and principles. In 1999, the members of the CCFAM signed the Agreement on Interjurisdictional Cooperation With Respect to Fisheries and Aquaculture. The Agreement is intended to foster a significant improvement in federal-provincial relations with respect to the management of fisheries and aquaculture. Under the Agreement, both levels of government commit to work together to contribute effectively, with sector stakeholders, to the development of ecologically sustainable and economically viable fisheries and aquaculture resources, habitats, and industries.<sup>(28)</sup>

Another recent integration initiative is the Federal Aboriginal Aquatic Resource & Oceans Management Programs, announced on October 9, 2003.<sup>(29)</sup> The programs are the Aboriginal Aquatic Resource and Oceans Management Program (AAROM) and the Aboriginal Inland Habitat Program (AIHP). Together, they will enable Aboriginal groups to become more involved in the processes used for aquatic resources and oceans management, which could include aquaculture activities.

The integration initiatives listed above are a good start for establishing the basis for an offshore aquaculture regulatory framework. However, it is important to note that Canadian aquaculture regulation is fragmented among a number of federal and provincial departments and agencies. For example, even though the review of the environmental effects of aquaculture operations occurs through the Canadian Environmental Assessment Agency, which coordinates a centralized environmental assessment process, the granting of leases and permits remain for the most part, a multi-departmental process at the provincial level. Currently, there are at least 17 federal departments and agencies delivering programs and services to the aquaculture industry.<sup>(30)</sup> This fragmentation is due in large part to the fact that legislative provisions governing aquaculture have been enacted by both federal and provincial levels of government over an extended period of time, often on a species—or geography specific basis—and typically as part of fisheries regulation.<sup>(31)</sup> This fragmented approach has been identified by the Office of the Commissioner for Aquaculture Development as a critical area for reform if Canada is to ensure a sustainable aquaculture industry.<sup>(32)</sup>

#### **Consideration of Issues and Possible Models of Offshore Aquaculture Regulation**

Given the inherent difficulties in regulating offshore aquaculture activities in a coordinated and integrated manner, this section identifies some of the initial issues that must be addressed when establishing a regulatory framework. It concludes with a brief examination of a few regulatory models that may be considered in order to ensure efficient regulation of offshore aquaculture in Canadian waters.

#### ***Key Issues in Regulation of Offshore Aquaculture***

A number of issues arise when deciding how offshore aquaculture should be regulated. The following list sets out only some of these initial 'start-up' concerns, including:

- Current Regulatory Scheme
  - Will the current scheme requiring the proponent to undergo a multiplicity of processes to obtain licences & permits be considered a deterrent to offshore aquaculture development?
  - What are some of the limits of applying the existing nearshore

aquaculture regulatory framework to offshore aquaculture?

- Conflicts with Other Offshore Users
  - What are the other offshore uses that may conflict with offshore aquaculture (e.g. wild fishery, shipping & navigation, the protection of the marine environment and species at risk, and development of oil & gas reserves)?
  - How should they be accommodated if offshore aquaculture interferes with their operations?
  - What are the mechanisms for pre-empting or resolving conflicts (e.g. mapping, regional strategic environmental assessment to establish no go areas, and alternative dispute resolution)?
- New Processes Necessary for Offshore Aquaculture
  - How will quasi-property rights (such as leasing) be accorded over ocean areas, which have traditionally been considered common property?
  - How will offshore aquaculture be regulated to ensure that international effects of the activity (escapes/pollution in high seas) are minimized and controlled?
  - Should a department or agency be given the explicit authority to lease areas of the ocean for aquaculture activities? If so, should the department or agency be federal, provincial or joint?
  - What other regulatory frameworks can be used as a possible model for Canadian offshore aquaculture? (e.g., The United States is currently considering the development of a Policy Framework for Offshore Marine Aquaculture in the 3-200 Mile U.S. Ocean Zone.)<sup>(33)</sup>

#### **Possible Models of Offshore Aquaculture Regulation**

In conclusion, there are a number of possible models for regulating offshore aquaculture in Canadian waters. The following list is not meant to be comprehensive. Instead, it is intended to be simply to identify some components of regulatory models that can be considered for use in regulating offshore aquaculture.

- Federal-Led Regulation of Offshore Areas Beyond a Certain Ocean Zone
  - Would likely require explicit legislation or MOUs;
  - May be difficult to draw a bright line in the ocean space from which point the federal government would take the lead regulatory role;
  - May result in inconsistencies as most nearshore areas would be under provincial leases whereas offshore areas would be under federal leases.
- Provincial-Led Regulation of Offshore Areas Beyond a Certain Ocean Zone
  - Would likely require explicit legislation or MOUs;
  - Seems unlikely given wording of *Oceans Act* enabling the federal government to take the lead coordination role.
- Adjustment of Existing Federal and Provincial Framework to be Appropriate for Offshore
  - Would be a conservative, incremental approach to reforming the fragmented regulatory framework for both nearshore and offshore areas;
  - Less likely to be difficult to implement (from a practical or political perspective) than the other options;



**"Offshore  
Aquaculture Boards  
could be created . . .  
with an equal  
number of federal  
and provincial  
appointees and a  
jointly selected chair  
to award leases,  
licences and permits,  
and to review  
environment impact  
statements and  
safety and  
environmental plans"**

- May be perceived as too slow to adequately respond to the projected growth in the industry.
- Joint Federal-Provincial Offshore Aquaculture Board
  - Could follow the model of the Offshore Petroleum Boards in Atlantic Canada, which were created by the enactment of joint Accord legislation;
  - The Accord legislation, and accompanying Regulations, Guidelines and Policies, make up the regulatory framework governing oil and gas operations on the East Coast. Offshore Aquaculture Boards could be created in the same manner, with an equal number of federal and provincial appointees and a jointly selected chair to award leases, licences and permits, and to review environment impact statements and safety and environmental plans;
  - Although the Board's jurisdiction can comprehensively cover offshore aquaculture activities, it cannot oust the jurisdiction of other federal or provincial departments or agencies and its creation can result in added bureaucracy and delays in regulatory decision-making.

In considering these various regulatory models for offshore aquaculture, it is important to note that no model will be a panacea to the overlapping mandates and jurisdictional complexity inherent in regulating aquaculture activities in Canadian offshore areas. Instead, the development of an effective regulatory framework for aquaculture activities in Canadian offshore areas will require meaningful participation and integration among and between the various federal and provincial governments, aboriginal groups, and other interested parties.

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# Cod Grow-out in Newfoundland: History and Future Considerations

Christopher I. Hendry

The development of Newfoundland culture has been based in the wild cod fishery. However, with natural and regulatory limitations on access to the fishery, there is an increasing need to integrate fishing and aquaculture technologies. Cod grow-out is such a marriage, as it uses the established technology, infrastructure, and knowledge of traditional cod harvesters to procure wild cod during the fishing season. The cod are maintained in cages and fed until late fall or early winter. The advantages of this approach are that market demand and prices are traditionally higher at that time of year and the fish are larger and are in better condition than when they were caught in the fishery. In 1997, seven cod grow-out sites collectively increased a starting stock of 32 tonnes to 41.3 t (round weight). The industry grew to 14 active sites by 2002 and increased production from 187 t to 285 t (round weights). In terms of market value, the industry grew from \$123,000 to \$850,000 (~600%) during those 7 years. Key factors to the success of the industry will be feed supply, fish health, marketing, and over-wintering. Currently, the largest constraint to the expansion of cod grow-out is access to starting stock from the wild.

**Figure 1**  
Wild-caught cod being transferred from a seasonal grow-out cage to a sorting cage in Trinity Bay.



## Introduction

The discovery of North America by Europeans is largely based on the cod fishery,<sup>(1)</sup> and the cultural evolution and social climate of Newfoundland has been

greatly influenced by this resource. There has been a global trend, not only in the cod fishery, of declining catches and dwindling stock sizes.<sup>(2)</sup>

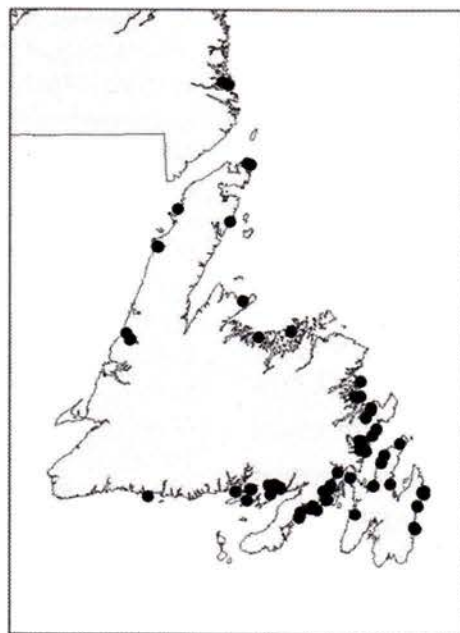
Aquaculture production is expected to fill the gap between increasing consumer demand for seafood and decreasing harvests from fisheries.

Atlantic cod (*Gadus morhua*) were first cultured in Newfoundland by Adolph Neilsen, a Norwegian scientist working on behalf of the Newfoundland government in the 1890s.<sup>(3,4)</sup>



**Figure 2**

In 2002, at the peak of cod grow-out production, there were 48 developmental licenses issued in Newfoundland. These are presented here, combined with the research and commercial licenses issued.

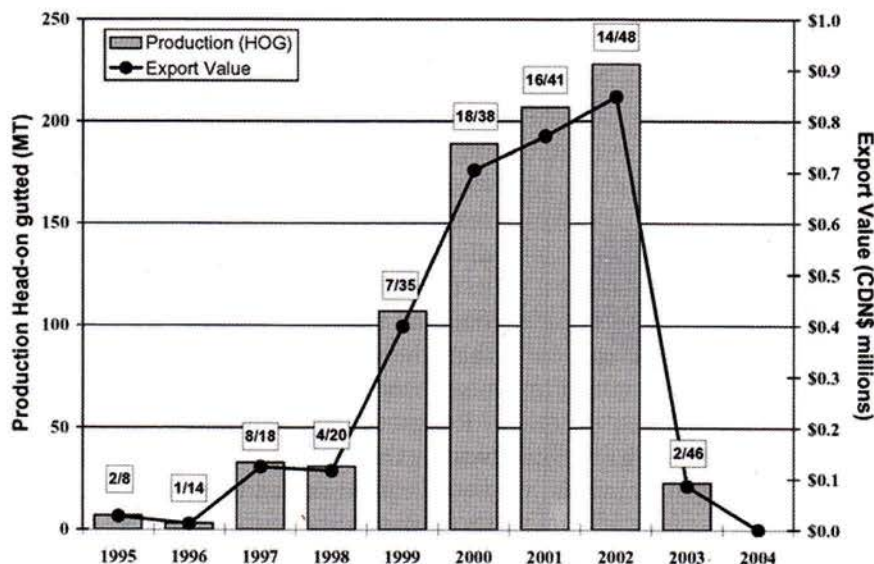


The objective was to enhance wild stocks and the operation involved hatching, early rearing and release of first-feeding cod into Trinity Bay. The work was discontinued in 1897, a year after financial support for the hatchery was halted.

The concept of cod grow-out utilizing adult cod captured in the wild fishery has been around since the mid 1980s. In recent years, there has been renewed interest in holding cod obtained from cod traps, increasing their weight over the summer months, and harvesting them in the fall when market demand and prices are traditionally higher (Fig. 1). More detailed explanations of the cod grow-out process are provided by Wells<sup>(5)</sup> and Murphy.<sup>(6)</sup> With the re-opening of the cod fishery in 1997, eight growers became involved in cod culture and by 2002 there were 48 sites licensed in Newfoundland for cod grow-out (Fig. 2). Over this period, there was a 600% increase in the production and value of cod from this sector of the industry (Fig. 3). In addition, significant assistance from many governmental and other agencies through the Canada/Newfoundland Fisheries Diversification Program<sup>(7)</sup> (administered by the Newfoundland and Labrador Department of Fisheries and Aquaculture) aided in the industry's evolution.

### Advantages of Cod Grow-out

Aside from Newfoundland's intimate relationship with Atlantic cod, there are many advantages to the process of cod grow-out. First, the system uses existing technology from traditional cod harvesters, including boats, cod traps, and nets, and the established infrastructure (i.e., processor relationships and networks) needed to maintain cage sites and sell fish. These existing relationships also pro-



**Figure 3**  
The cod grow-out industry in Newfoundland and Labrador increased annually in both tonnes of head-on, gutted harvest and value until 2002, after which reductions in quotas limited access to starting stock. Numbers above each bar indicate the ratio of the number of licenses used to the number of licenses issued.

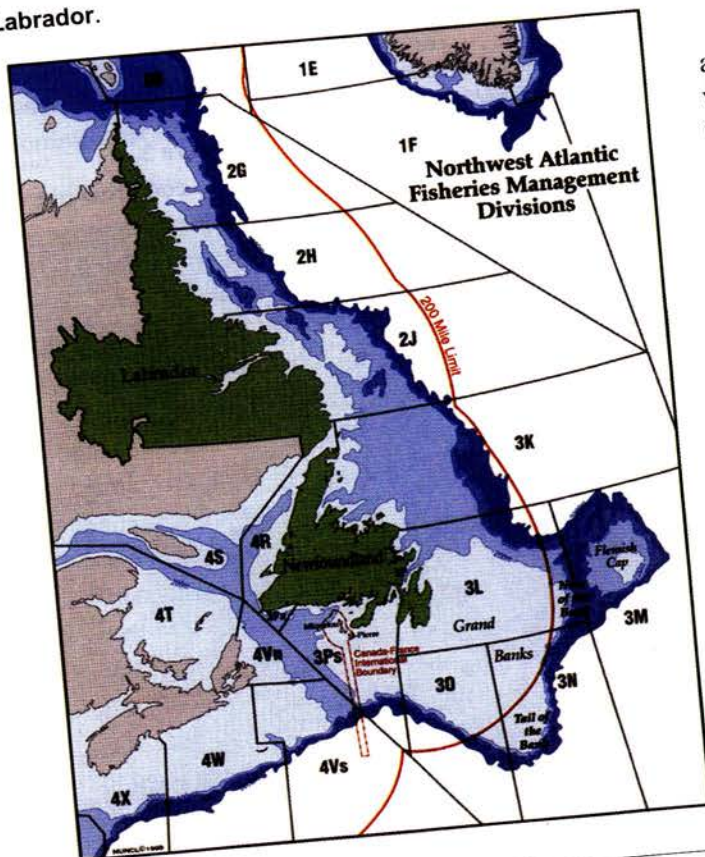


vide easier access to supplies of feed, including herring, capelin, mackerel and squid. In addition, the availability of better-conditioned fish with higher yield (potentially 100% gain) to the market in the late fall/early winter commands a higher price and more efficiently fulfils market demand. Aside from the economic benefits, cod grow-out poses no environmental risk from escapees. Should cod escape, they would be returning to waters from which they were initially procured.

### Access to Starting Stock

The limitation for expanding the cod grow-out industry is access to cod from the wild fishery. Although this has been a potential constraint on cod grow-out since the industry's inception, until recently federally-allocated quotas were sufficient to fulfil the demand for starting stock. In 2003, however, the quotas were drastically reduced and fishing was restricted to the NAFO 3Ps region, which encompasses Placentia Bay and the surrounding area on the south coast of the island (Fig. 4). Many of the grow-out sites ceased operation because they were unable to obtain cod. As a result, the grow-out industry was reduced to the 3Ps area, because transport of wild-caught cod to other areas is not economically feasible. Growers in 3Ps in 2003 were not even able to catch enough cod to establish significant grow-out operations. The only harvest from cod culture in 2003 was from two sites that over-wintered cod on an experimental basis to determine the feasibility of extending the harvest period. This resulted in little or no growth into the second year; however, with practice operators have learned that yield and quality is improved, provided that feeding is consistent.

**Figure 4**  
North Atlantic Fisheries  
Organization (NAFO)  
fishing zones around  
Newfoundland and  
Labrador.



### Product Quality

Due to the dispersal of grow-out farms around Newfoundland, the cod used are of various geographic origins. This may contribute to the differences in quality of the product found in the marketplace. In addition, the bait used for food varies because different species predominate in different parts of the island. Therefore the nutritional profiles of the cultured fish may vary. Use of a standard feed would ensure consistency among sites and could help reduce the impact of feed on product quality. Although there is potential for the use of a manufactured feed, initial experiments indicate that dry pellets are not very palatable to cod and the economics of feed production and purchase make it unprofitable at this time. Further work is needed to develop a suitable feed for captive cod.

Recent investigations into handling, harvesting and transport practices have identified the factors that can negatively affect product quality and mitigating strategies have been developed. The three main fac-



tors affecting quality of the fish are: 1) the condition of fish before slaughter, 2) chemical and microbiological changes occurring after slaughter, and 3) damage/defects caused by handling and processing. In 2001, the Marine Institute of Memorial University conducted a Flesh Quality Study<sup>(8)</sup> using tank-reared and wild cod. Many comparisons between the two were made and an attempt was made to determine the best harvesting method. Overall, the wild fish scored lower for texture than farmed cod. Crowding of cod for up to 8 h before harvest does not improve nor detract from flesh quality. The best harvest practice does not require the fish to be stunned before slaughter. Killing the cod with a percussive blow coupled with gill severing does not improve flesh quality compared to gill severing alone, although the use of a percussive blow is warranted to lessen struggling at harvest. Processing methods also affect the quality of the product. The flesh of cod that are grown out responds differently to processing than that of wild-caught cod, especially with respect to the time after slaughter that the fillet enters rigour. As a result, the processing schedule for cod harvested from grow-out needs to be altered from the traditional process. When chilled, grow-out cod can be in full rigour by 24 h post-harvest and can remain in rigour for up to 120 h post-harvest. As a result, cod must be filleted prior to rigour, although this will result in higher drip loss than if fillets are produced while the fish is in rigour or beyond. Fish should be filleted 0-2 d post-mortem and kept at low temperatures to increase the time spent in rigour and thus decrease damage. Filleting before rigour produced the best results.

**“Overall, the wild fish scored lower for texture than farmed cod.”**

### **Feed Supply**

In some cases, availability of fresh or frozen feed to grow out sites has been a problem. Due to the relatively small scale of cod grow-out, a processor selling frozen bait would profit more by selling en masse to the fishing industry than in the smaller quantities required by grow-out operators. As well, it is often a gamble for individual cod growers to try and catch their own bait, considering the variation in distribution of bait species around the island. One possible solution would be for cod growers to unite into a larger entity that could purchase large quantities of frozen bait from processing plants. Additionally, agreements could be made prior to the commencement of a grow-out operation for the purchase of feed, in order to reduce the risk.

### **Marketing**

It is widely recognized that a fragmented cod grow-out industry cannot be maintained in the long term if the sector is to become viable. With that in mind, one of the key objectives of a marketing program is to establish a co-ordinated harvesting and sales program to explore potential niche markets.

The cod grow-out initiative has experienced relatively good prices for both whole cod and fillets over the past 3 yr. To date, the sale of farmed cod and the prices received come from the spot market for fresh cod, primarily in late fall in eastern US markets. The prices are not predictable, however, and growers should explore other avenues to achieve top value for their product. It was expected that cod grow-out production would increase significantly over the following five years, and the establishment of secure markets in the early marketing phase should ensure the highest possible return to the growers in the years to come.

One challenge is that the market does not distinguish between cod from grow-out operations and those caught in the wild fishery. As a result, there is no market premium for the higher quality of cod harvested from grow-out. The



**“The positioning strategy should be to establish cod from grow-out operations as a premium, environmentally and ecologically friendly, all natural, high quality, semi-wild fish yielding consistently large, thick white fillets ideally suited for high-end restaurant menus.”**

Newfoundland Aquaculture Industry Association did extensive work in 2002 to identify and establish markets for cod grow-out beyond the commodity market into which the cod had traditionally been lumped. The study<sup>(9)</sup> made several marketing recommendations:

- The target market should be high-end, white tablecloth restaurants located in large cities, whose celebrity chefs have a predisposition to menu fare featuring cod fillets.
- The positioning strategy should be to establish cod from grow-out operations as a premium, environmentally and ecologically friendly, all-natural, high-quality, semi-wild fish yielding large, thick white fillets ideally suited for high-end restaurant menus.
- The product strategy should be the processing of fresh, whole head-on, gut-removed cod, 8 to 12 lbs (3.6-5.5 kg) each, well iced, and packaged in 50-lb (23 kg) Styrofoam™ cartons.
- The pricing strategy should be to demand a premium price in recognition of cod's intrinsic value, seasonality of supply, and the cod grow-out story.
- The production strategy should be to negotiate a partnership with a processor(s) to maximize efficiencies, maintain a consistent high-quality product, and ensure a reliable source of feed.
- The harvest strategy should be to develop a protracted and orderly harvest schedule, designed to maintain a strong market presence over a minimum of 3 months.
- The distribution strategy within an area should be to centralize processing among one or two processors and to centralize distribution according to geographic market segmentation and target market orientation.

#### **Lack of Cohesion**

As already mentioned, there are problems associated with cod growers working and operating independently from one another. These challenges include procurement of bait, achieving an adequate price from a processor, and market supply. Operating independently, cod growers do not have the same appeal to processors because of the small amount of product they produce relative to that available from the conventional fishery. As a result, it can be difficult for newer, or even established, growers to negotiate a consistent supply of bait or a defined market price, either during or before the grow-out season starts. This is also evident in the aforementioned special processing requirements of grow-out cod, which at smaller volumes is not cost-effective considering the downtime and adjustments required to the processing line. Furthermore, all the risk of cod grow-out is currently borne by the growers. If one or more processors would enter into a formal agreement with the growers (i.e., to supply bait, process harvest, and distribute product), this could alleviate some of the risks associated with cod grow-out.

Consolidation also benefits marketing, as market demand could be better met during a broader window. Product quality could be regulated (e.g., with a grading system), and a market price could be negotiated based on the larger volume that the market knows can be met.

#### **The Future of Cod Grow-out**

In 2002, the Newfoundland and Labrador All-Party Committee on the 2J3KL and 3Pn4RS Cod Fisheries was established and directed to prepare a unified position on possible fisheries closures, identify measures needed to aid the recovery



of the cod stocks, and assist those who would be significantly impacted by the closures. This was in response to the possible closure of fisheries at that time, which were to be announced in the spring of 2003. In its report,<sup>(10)</sup> the Committee provided reasons for continuation of a limited cod fishery in these NAFO areas around Newfoundland and Labrador, and cod grow-out was one of those sustainable measures, because of its profitability, employment, and efficient use of a limited resource. Contrary to the report's recommendations, the 2K3KL and 3Pn/4Rs fisheries were closed, allowing a cod fishery only in the 3Ps zone.

In light of the greatly reduced 2003 cod grow-out season, possibilities for continuing the industry into 2004 include coupling the culture industry with the sentinel fishery, transferring cod from the 3Ps area, and possible enhancement operations.

The current sentinel fishery was implemented in 1994 to monitor the evolution of cod stocks after the moratorium. This program, involving a number of fish harvesters around the island, aims to develop a time series of abundance indices to be used in the assessment of cod stocks. This program has the potential to provide starting stock for cod grow-out in areas around Newfoundland. However this fishery is normally a destructive fishery; cod are lethally sampled for assessment of fecundity, diet, age, etc., and the fishery would have to be modified if the cod growers are to gain any benefit from it.

The transfer of cod caught in the 3Ps area to other areas around Newfoundland has several economic obstacles, whether transport is via water or land. Aside from fish health issues and mortality due to transport, there are costs for fuel, time, labor, and truck rental (if by land). It would be more economical to move the cod grower than the cod! However, there has been little interest in relocating cod grow-out sites.

A partial move toward stock enhancement could also shed light on the value of cod grow-out, with advantages to both growers and the fishery. One issue with grow-out is that it removes fish from an already depleted stock. However, given the nature of cod grow-out and its method of increasing the yield of a set amount of fish, there is an opportunity to return a portion of these fish to the wild. For example, a cod grower may procure 18,000 kg of cod from the wild and, over the grow-out season, the yield may increase (conservatively) to 27,000 kg by harvest. The grower could release 18,000 kg of cod back to the wild, which are healthier, bigger, and have a higher fecundity<sup>(11)</sup> than naturally-occurring cod. However, this approach has not been attempted.

Finally, there is currently a rapidly growing full-cycle, or egg-to-plate, cod aquaculture industry in Newfoundland, whose goal is to produce 32,000 tonnes of farmed cod for the market by 2010. This will require at least 30 marine cage sites. The potential is illustrated by the current construction of a cod hatchery in Bay Roberts, with a capacity estimated at 10 million juveniles annually. It is certain that some of the knowledge gained from cod grow-out could be directly transferable to the full-cycle aquaculture industry. This is especially true for growers who have gathered extensive experience in over-wintering (year-round) grow-out.

One obstacle to this latter suggestion is that there are obvious size and financial differences between cod grow-out and full-cycle aquaculture. For example, it is estimated that to be economical, full-cycle operations should produce 500 tonnes annually just to break even, with 1000 tonnes recommended to minimize the cost per kilogram of cod produced.<sup>(12)</sup> However, such issues can be mitigated through partnerships and business relationships that have yet to be discussed.

**“... it can be difficult for newer, or even established, growers to negotiate a consistent supply of bait or a defined market price...”**



**"... there is currently a rapidly growing full-cycle, or egg-to-plate, cod aquaculture industry in Newfoundland, whose goal is to produce 32,000 tonnes of farmed cod for the market by 2010."**

## Conclusions

Cod grow-out, the practice of taking wild-caught cod in the early summer, holding them in cages and feeding them, and ultimately selling them in the fall when prices are higher and fish are larger, has already proven its viability to participating Newfoundland and Labrador cod fishermen and the province's aquaculture industry. With continued support, this sector has the opportunity to continue its marked increase of almost 600% between 1997 and 2002.

## Acknowledgements

The success of cod grow out would not be possible without the cooperation of cod growers, the Newfoundland and Labrador Department of Fisheries and Aquaculture (NL DFA), Fish, Food and Allied Workers Union (FFAW), Newfoundland Aquaculture Industry Association (NAIA), Fisheries and Oceans Canada (DFO), Fisheries and Marine Institute of Memorial University of Newfoundland (MI), and the various Regional Economic Development Boards (REDB) around Newfoundland.

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# Creating a Culture-Based System of Management for the Geoduck Clam Industry in British Columbia

**Eric Gant**

The commercial geoduck clam (*Panopea abrupta*) fishery began in British Columbia in 1976. Since then, decreasing supply, increasing price, uncertainty in the sustainability of the wild fishery, and the introduction of aquaculture have necessitated a change in the system of management. In this paper, various options are proposed to create a spirit of co-operation within the management system so that the industry will more effectively evolve to its next level of development.

## Introduction

It is axiomatic to say that creating the right system of management for an industry is critical to the prosperity of its parts. Of equal importance is the ability to change the system of management as an industry passes from one phase of its dynamic existence to another. The necessity for change can also be an opportunity to develop the industry to a new level of moral and mental maturity.

People within any system of management become accustomed to a certain way of doing things and to a certain way of thinking. Over time, they build vested interests and relationships within the system. This mindset tends to make them reluctant to change, even when it becomes critical to the health of the industry. The challenge facing the geoduck industry in British Columbia is to replace the existing system of management with a culture-based system that will increase the value and sustainability of the industry.

## Background

The geoduck clam (*Panopea abrupta*) is the largest burrowing clam in its natural range throughout Alaska, British Columbia, and Washington State (Fig. 1). The commercial fishery began in British Columbia in 1976 and at that time the animal sold for about \$0.55 per kilogram. Since then, the price has increased to several dollars per kilogram. Annual production peaked in 1988 at 5,800 tonnes, but has since decreased to less than 1,800 tonnes. The long term sustainability of the wild fishery has become increasingly uncertain in the past few



**Figure 1**  
Adult geoduck clam





years because the total allowable catch (TAC) of the fishery is based on an estimate of natural recruitment. This is virtually impossible to do on a coastline the size of British Columbia's, particularly with a species that is not uniformly distributed. In the early 1990s it became obvious that aquaculture had the potential to dramatically improve the industry.

The factors of decreasing supply, increasing price, uncertainty in the sustainability of the fishery, and the introduction of aquaculture, require that the global system of management be changed to allow research into commercial-scale aquaculture. Unfortunately, the change to the management system had to be designed to overcome political opposition to aquaculture, rather than creating a truly supportive system for the development of aquaculture. For example, a 5-year moratorium was put in place which limited research and development (R&D) work to one company working in a joint venture with the existing fishermen's association, preventing many quality-minded people in the aquaculture industry from becoming involved.

Despite this flaw in the system, grow-out technology for both intertidal and subtidal culture of geoducks has finally been developed. There is still a great deal of room for improvement, but we now have well over 100 hectares of grow-out sites in BC and Washington State producing commercial quantities of cultured geoducks (Fig. 2). Several hatcheries are producing seed, with mixed results. An enhancement program has been established that will help ensure the sustainability of the wild fishery. Political opposition to geoduck aquaculture has been reduced to the point where we have the opportunity to develop the system of management in a way that will allow us to significantly reduce the resistance that has been present for the past few years.

Examining some of the mistakes made by past systems of management of the geoduck industry could help us create a better system for the future. When the wild fishery began in the early 1970s, an interim system of management was put in place which essentially called for the biological managers to estimate a TAC for each fishing area. An opening date was set for the harvest and on that date all

the fishing vessels would shoot out of port like pellets from a shotgun, each scrambling to get the greatest possible share of the TAC.

This management system fostered a multitude of adverse human behaviors. Fishermen died fighting their way out of port in bad weather in order to beat each other out. Divers were killed trying to work under the water in heavy storm surges and extreme tidal currents. Many divers suffered multiple cases of "the bends" (neuroembolism) from working beyond the limits of the decompression tables. Product was smashed and spoiled in the rush, and fishermen behaved as though other fishermen were enemies, rather

**Figure 2**  
Intertidal planting of  
geoduck seed in  
Washington State.





than allies. Market prices collapsed from oversupply during the opening of the fishing season, then atrophied from a lack of supply when the areas were shut down for the year.

Probably the worst aspect of the management system was that the regulators considered the harvesting efficiency of the fishermen a threat to the ocean's ecology. This caused fishery managers to incorporate strategies to reduce the productivity of the industry to protect the ocean's ecology. The fishermen viewed these repressive government strategies as a threat to their prosperity—even to their very survival. They responded by working longer, harder, and smarter, with better equipment and bigger boats. This increased their productivity, which in turn caused the government to become more restrictive, and so on. Eventually the two entities—industry and government—behaved as if they were enemies, struggling to co-exist within a system of privileged oppression.

Oppression finally won out over productivity, causing the management system to collapse in 1989. It was replaced with an individual quota (IQ) system, which resolved many of the problems. However, even under the IQ system, productivity is viewed as a threat to the ocean's ecology. Fishermen have voluntarily reduced their productivity to the point where they are using 41 boats to do a job that could easily be done by five. The lesson is clear:

*If we allow the productivity of the geoduck culture industry to be defined as a threat to the ocean's ecology, the end result will be a system of management designed to suppress that productivity.*

We will be limited, for example, to small tenured areas, which naturally causes us to intensify our productivity to the point that it may become a threat to the ocean's ecology. We may well end up fulfilling the very definition that we should be striving to rise above. The intensity of our productivity may become a threat to the ocean's ecology.

If we are willing to move beyond the intensive mindset of monoculture and put into place an extensive, low density strategy that fits into the natural ecology of the ocean, then government will probably feel more comfortable about creating a system of management that allows us to have much larger tenures. We must be willing to move beyond the present concept of "economic sustainability" that is in fashion within our industry. This concept means that as long as we are making a long-term profit everything is fine. Most of us know within our minds and hearts that this is simply not true.

We need to accelerate the movement within our industry towards greater acceptance that our responsibility to care for the quality of life in the ocean goes beyond the species on which we focus for profit. We need to become "profitable ecological caretakers". How will this strategy be of immediate help to us beyond the obvious benefit of long-term ecosystem sustainability?

The biological managers of the wild fishery estimate there are about 20,000 hectares of commercial concentrations of wild geoduck beds in the Province of British Columbia. It is within these naturally productive areas that the aquaculture industry should strive to secure its tenures, as this will give the industry the best chance of success. However, under the existing system of management, the wild fishery needs all this area for its own production.

If the aquaculture industry helps the fishery move from a system based on estimating natural recruitment to one based on extensive, low-density culture, fishermen would maintain their current level of production from fewer than 300 ha, rather than the 20,000 ha they are now using (assuming an adult density of 5 animals per square meter and that the animals grow to a size of 1 kg over a 7-yr

**"An opening date was set for the harvest and on that date all the fishing vessels would shoot out of port like pellets from a shotgun, each scrambling to get the greatest possible share of the TAC."**



**"Under an appropriate system of management, aquaculture will resolve end-user conflict over the limited coastal area."**

grow-out period). The fishery could become vastly more productive on a fraction of the present fishing area, freeing up room for new members who want to become a viable part of the geoduck industry. If the new entrants also take a low-density, extensive approach to culturing their product, they should also be able to secure large tenures within the most naturally productive areas of the coast, in a manner compatible with the fishery. Under an appropriate system of management, aquaculture will resolve end-user conflict over the limited coastal area.

### **The Triple Helix Tenure Model Area**

The Triple Helix is a simple concept intended to help us to see at a glance how we fit together as components of a whole (Fig. 3). In this gestalt, industry generates wealth, which is taxed by government so that it can provide funding to academia, which educates the labour force used in industry to create greater wealth, for greater tax revenue, and so on. The new system of management could go beyond simple wealth creation with the Triple Helix concept if government allows certain generic entities, which work on behalf of the whole, to secure geoduck tenures within a model tenure area. These entities could work within this model tenure area in an open spirit of co-operation, advancing industry at a far more efficient rate than under the existing system of management. Each tenure would act as an economic taproot for its respective generic entity, generating the revenue that would allow it to become vastly more effective in the work that it does on behalf of the whole. The following are some suggested generic entities for such a model area:

- **The Center for Shellfish Research (CSR) at Malaspina University-College.** Its tenure would also become a student training ground and a scientific R&D site.
- **The Alliance of Independent Companies (AIC).** This is a group of companies focusing on the development of cutting-edge technology for the industry as a whole.
- **The British Columbia Shellfish Growers Association (BCSGA) and the Underwater Harvesters Association (UHA).** Members of these groups would be able to go into the generic model area to learn of the latest advances and to seek out graduating students to help them run their farms.
- **Geoduck Enhancement Aquaculture Research (GEAR).** The revenue generated from this tenure would be used for generic market development and to

help create co-operative marketing mechanisms. Unlike finfish culture, geoduck culture does not have the costs of adult containment, feeding, or early mortality, which normally forces growers to dump their product onto the market at the earliest possible moment. What we really need is to market our product in a co-operative rather than a competitive manner. This will not be easy because it will require a fundamental shift in mindset. GEAR can help us do this.

**Figure 3**  
**Triple helix management model**



### **Tri-Party Model Area**

Another model area that we are advising be set up within the new system of management would involve a First Nations village, the AIC



and the UHA. Within this model area, each of the three entities would be granted their own tenures. They would strive to independently develop their respective tenures with an open spirit of communication and cooperative support amongst the three basic entities. People do have the capacity to rise above clan and individual gamesmanship if they are allowed to work within a system of management that supports the finer side of their nature. History has proven this many times.

This project would need to be undertaken with carefully selected, quality-minded individuals representing the three larger entities. It would also have to be given proper political support within the new system of management. The goal would be to make the model area vastly more productive, in an environmentally-sound manner, than if the area was left within the existing system of management. If successful, this project could be used as a model for other coastal villages (Native and otherwise). The long-term goal would be for the cooperative production to evolve over time into co-operative marketing, thus avoiding the problems we have seen with cultured salmon as a result of aquaculture being allowed to develop within an improper system of management.

### **Residual Natural Stocks on Prospective Individual Aquaculture Tenures**

What to do about residual natural stocks on prospective aquaculture tenures is an issue that needs to be resolved within the new system of management. The protocol that was used to remove the residual natural stocks from the initial experimental culture sites in BC needs to be improved upon. On these sites the fishing vessels were forced to harvest the stocks off the sites by working within a fishery management plan that has been deliberately designed to make them dysfunctional. They harvested at the wrong time of the year, when plankton blooms impaired visibility, or when the siphons were down due to bad weather. Several boats were sent onto the same site at the same time, compounding the turbidity and silting problems of harvest. The boats had to apply the sparse residual harvest from the tenures against their regular boat quotas in the fishery, instead of being able to take their regular quotas in areas where the higher densities would have reduced their fishing effort. This angered the fishers, creating conflict where none needed to exist. Some of the boats were accused of wandering off the culture sites to harvest in other areas but applying their harvest to the aquaculture sites, all the while accusing the aquaculture company of having taken away viable fishing areas. Lack of a properly coordinated harvesting protocol resulted in boats harvesting residual stocks in areas that had been freshly seeded. All this resulted in the aquaculture company having to put a monitoring boat on the grounds whenever the harvesting boats were present. This cost the aquaculture company over \$50,000 because of the unnecessarily long period of time that it took to complete the pre-seeding harvest.

Under the new system of management we are recommending that the pre-seeding harvest be done outside of the regular management plan for the fishery, so that it can be done more efficiently. We are proposing that one vessel be allowed to start the harvest at \$2.20 per kilogram to the boat, with the remaining profits going to assist the generic entities mentioned earlier. This funding will help the generic entities develop their sites. Once the first vessel can no longer make a profit at \$2.20 per kilogram, a second vessel should be allowed to harvest at about half the full market value of the product, followed by a third vessel at just below market price. By the time the third vessel is done there would not be enough stock left to be of concern.

**"People do have the capacity to rise above clan and individual gamesmanship if they are allowed to work within a system of management that supports the finer side of their nature."**



**"Waiting for a fishery to collapse prior to starting up commercial scale aquaculture is a tragic solution that we are trying to avoid by the creation of a cooperative system of management."**

This strategy will enable the boats to harvest far more efficiently, without conflict, in series rather than in parallel, using an incremental, competitive auctioning process to keep harvesting costs down. They would be able to harvest at the right time of the year, with the lion's share of the profits going to where it will do the most good for the overall well being of the whole.

### **Visual Impact**

Various aquaculture systems of management used around the world have often paid little attention to the appearance of aquaculture. As a result, our industry often developed in ways that were ugly, crude, noisy and smelly. This has created opposition to the expansion of our industry that has wasted a massive amount of our time, money and energy. The AIC is advising that the basic strategy for dealing with this problem is for industry to strive to be either invisible or inoffensive to the eye. Dive boats, for example, should be clean, neat, good looking, and quiet.

The AIC is working within this strategy in two basic ways. We now have subtidal geoduck grow-out technology that leaves no visible trace of our work on the surface of the ocean. We have also incorporated this strategy into our land-based operations. The AIC, for example, developed an intertidal lagoon as a 7 million liter algal pond for use at their Gartley Point Shellfish Facility. How we were able to do this in the heart of a residential, estuarine area without serious resistance from the local residents, the environmental movement and the federal government is an article in its own right. Suffice it to say that paying attention to appearance was the cornerstone of our strategy. The goal with this project was to create a natural algal pond for our own purposes that would also act as an economically viable guardian for the sensitive estuarine area, and would enhance both the ambience and the property values of the residential area.

### **Fishermen's Mitigation Program**

The traditional conflict that often develops between the fishing and aquaculture industries when a new species begins to be cultured usually creates a massive waste that terminates in cutthroat marketing. Waiting for a fishery to collapse prior to starting up commercial scale aquaculture is a tragic solution that we are trying to avoid by the creation of a cooperative system of management. Specific individuals have resisted the development of this spirit of cooperation, but that does not mean that the entire industry should suffer because of the mindset of a few individuals. A morally and mentally mature system of management should help people to evolve in kind over time. So we are advising that a fishermen's mitigation program should be set up in an ecologically healthy zone where the fishermen would be allowed to secure tenures as a form of mitigation for their partial loss of access to the common resource due to aquaculture. Giving fishermen the opportunity to acquire tenures will encourage them to make a personal investment in culture rather than fighting against it as an encroachment into their lives. The foundation for the new geoduck industry has now been laid. It is time to create the managerial framework that will allow the industry to advance to its next level of commercial development. Hopefully this advisory will help.

### **Author**

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# Progress in Commercialization of Sablefish (*Anoplopoma fimbria*) Farming

Gidon Minkoff and Craig Clarke

Hatchery production of juvenile sablefish was first achieved in 1998. Since then, the numbers of juveniles produced by the private sector and by Fisheries & Oceans Canada increased from a few individuals in 1998 to over 10,000 in 2000. Notwithstanding these achievements, the numbers of juveniles produced and sold to farms has not surpassed 10,000 to 20,000 fish per annum. The current technology for hatchery production of sablefish requires further research to increase larval survival and improve the quality of the juveniles. Overcoming the impediments to hatchery production has enabled some of the commercial fish farms to develop growout methods. Growout trials have demonstrated the feasibility of sablefish reaching 3 to 4 kg within two years. Most of the production has been obtained using commercial diets developed for salmon or yellowtail. There is, however, a need to develop diets specifically for sablefish. Market analysis performed for the British Columbia Ministry of Agriculture, Food & Fisheries has forecast a demand ranging from 2,000 to 16,000 tonnes by the year 2021 with a value to the Canadian economy of \$22 to \$114 million annually. There is a requirement for continued research funding so that these objectives can be realized.

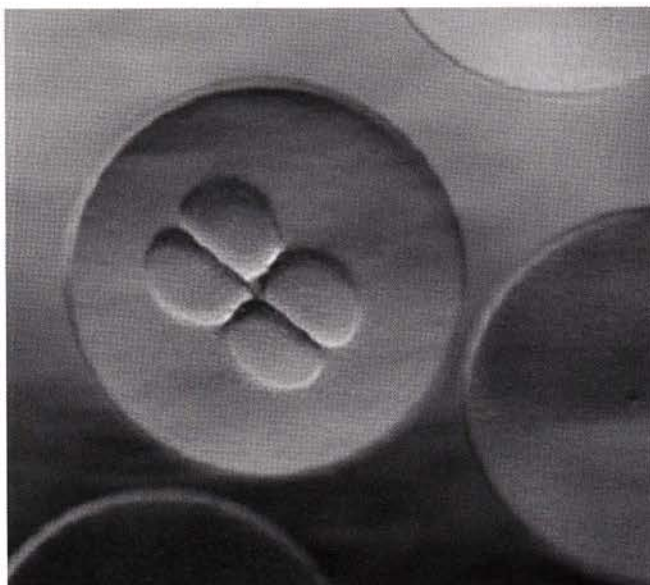
## Introduction

Adult sablefish occupy waters of the continental shelf and slope at depths of 300 to 1,500 m, from central Baja California to the Bering Sea and Japan. They grow quickly, with mature females reaching an average length of 55 cm in three to five years. Although frequently known as blackcod in North America, this species is a member not of the cod family but of the skilfish family. Sablefish meat has a soft texture and a high oil content, making it popular for smoking.

Research on sablefish aquaculture was initiated more than 30 years ago, but progress toward commercialization has been slow due to intermittent effort and limited funding for research and development. Early work by Kennedy<sup>(1)</sup> demonstrated that captured sablefish adapted readily to confinement and grew well. His research was discontinued because it was not possible to obtain a reliable supply of juveniles from the wild for stocking of farms. Research at the Pacific Biological Station (PBS) was restarted in 1985 to develop techniques for induced spawning of captive broodstock, incubation of the eggs and feeding of larvae.<sup>(2-5)</sup> The program was interrupted due to lack of funding, but resumed in 1996 via collaboration between industry and Fisheries & Oceans Canada. In 1998, the first juveniles were produced at PBS and in a commercial hatchery built by Island Scallops

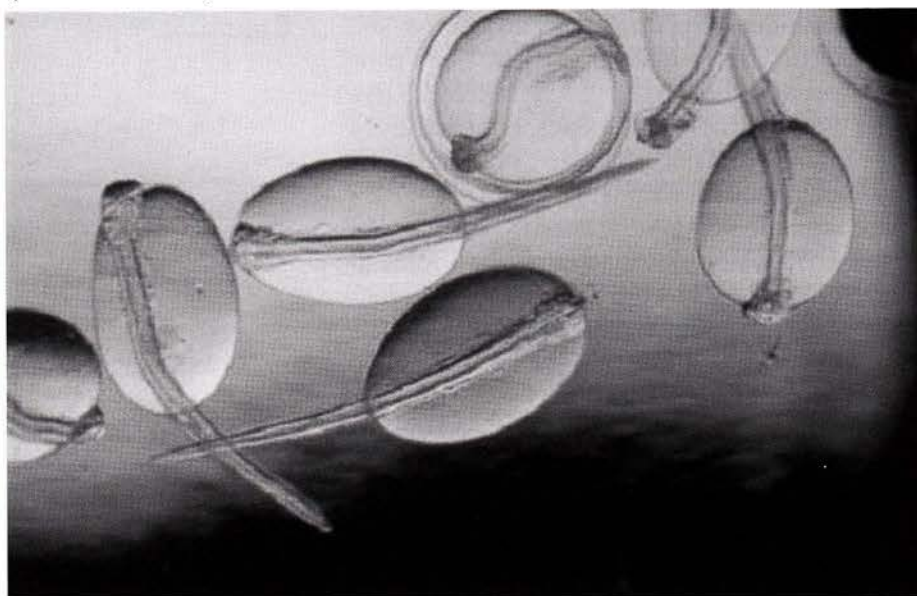
**"Despite a slow start, sablefish aquaculture is poised for expansion in British Columbia."**





**Figure 1**  
Sablefish egg at 4-cell  
stage, 8 h after  
fertilization  
(incubated at 6°C).

**Figure 2**  
Sablefish larvae at hatch,  
13 days after fertilization  
(incubated at 6°C).



Ltd. near Qualicum Beach, British Columbia (BC).<sup>(6)</sup> By 1999, larger numbers of juveniles produced at PBS and at Island Scallops Ltd. enabled growout trials to be undertaken at commercial farms.

### Existing Fishery

The commercial fisheries for sablefish in Canada and the United States have been managed by individual quotas since 1990 and 1995, respectively. This allowed the fishing season to be extended and product quality to be improved. In future, total landings are expected to be relatively stable at approximately 30,000 tonnes annually, down from a peak of 50,000 tonnes in the late 1980s.<sup>(7)</sup> The BC commercial fishery had a landed value of \$16.6 million in 2002.

### Market Demand

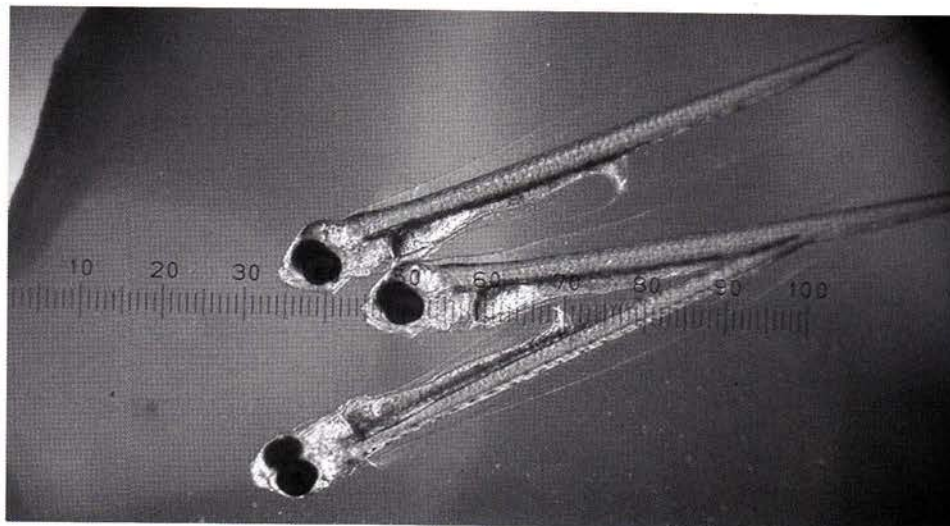
The majority of the catch from the Canadian commercial fishery is exported to Japan and increasing amounts are being sold to Taiwan and China.<sup>(7)</sup> In North America, sablefish is known mainly as a smoked product, although in recent years it is being featured by high-end restaurants.<sup>(7)</sup> Un-smoked sablefish is usually sold Japanese-cut ('J-cut'; head and collar off and belly flap intact), although a growing North American market has increased demand for headed and gutted fish with collar on. Sablefish are also sold in the form of fillets and steaks with the pinbone in or out. Current prices for Canadian sablefish in the Japanese market for frozen, J-cut product is \$15.40/kg and in Seattle fresh J-cut sells for \$17.60/kg.

The main competition for sablefish in the Japanese and North American markets is the Patagonian toothfish (a.k.a. Chilean sea bass, *Dissostichus eleginoides*). Imports of this fish into the United States amounted to 11,000 tonnes in 2001 but declined to 6,275 tonnes in 2003. Catches of the Patagonian toothfish in the Southern Ocean are declining due to over-exploitation. It is estimated by the Convention on the Conservation of Antarctic Marine Living Resources that the total catch of Patagonian toothfish declined from 100,978 tonnes in 1996/97 to 33,660 tonnes in 1999/2000.<sup>(8)</sup>

Harvest from sablefish farms could offset the reductions in the harvest



from the wild fishery for sablefish. Sablefish could also take the place of the Patagonian toothfish in North American as well as Japanese markets and create a novel live product custom-made for ethnic fish markets.<sup>(7)</sup> Market analysis commissioned by the BC Ministry of Agriculture, Food & Fisheries has forecast a demand ranging from 2,000 to 16,000 tonnes by 2021 with a value to the Canadian economy of \$22 to \$114 million annually.<sup>(7)</sup>



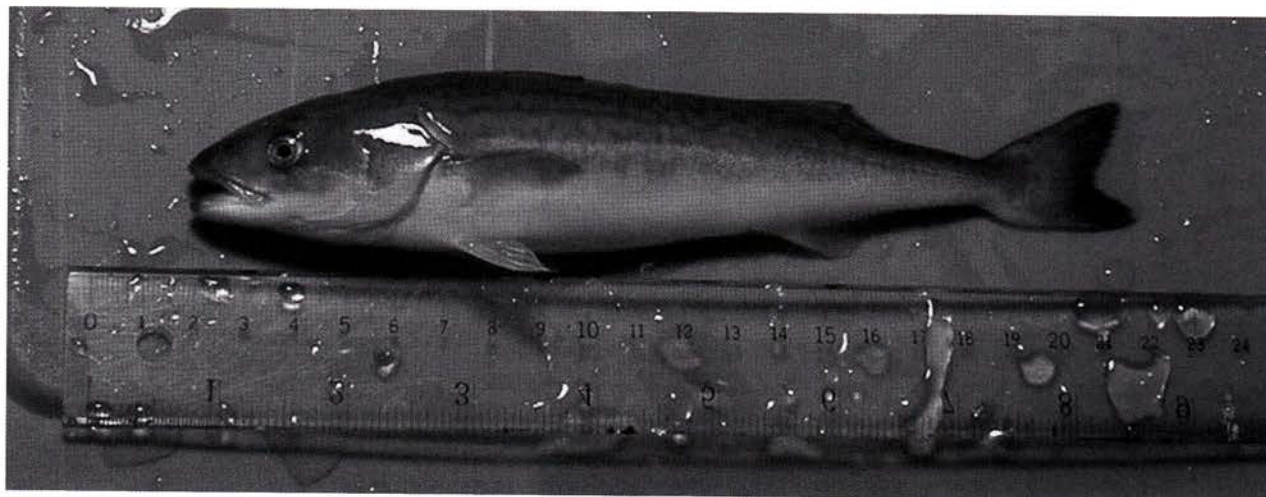
**Figure 3**  
Larvae ready to be fed one month after hatch.

### Rearing Technology

Sablefish broodstock are held at 6°C to promote sexual maturation and spawning. The spawning season can be shifted by photoperiod manipulation so that eggs are available over a prolonged period and producers can make more efficient use of hatchery facilities. Females spawn batches of eggs at 2 to 3 day intervals. Output from a single female can total 3 to 6 L, or 450,000 to 900,000 eggs per season.

The eggs have a diameter of 2 mm and hatch after 12 to 13 days at 6°C<sup>(9)</sup> (Fig. 1, 2). During the yolk stage the larvae are kept in incubators under darkness at 6°C for a month and are then transferred to tanks for feeding (Fig. 3). Live food organisms—first rotifers, then artemia—are presented during the early stages. Weaning onto manufactured diets begins after a month on live feed at temperatures of 9° to 11°C. Juveniles weigh about 0.5 g at an age of two months and are approximately 40 g at four months, at which time they can be stocked into netpens for growout (Fig. 4).

**Figure 4**  
Juvenile sablefish at 4 months of age ready for stocking into netpens.





Growth of sablefish in netpens continues steadily for two years to a size of 3 to 4 kg (Fig. 5, 6). There have been some instances of vibriosis and furunculosis reported during growout trials with unvaccinated fish. In experiments, sablefish responded well to vaccination against the bacterial agents causing these diseases. Sablefish are resistant to infection from infectious hematopoietic necrosis virus and viral hemorrhagic septicemia virus, which have caused substantial losses of herring (*Clupea pallasii*), sardine (*Sardinops sagax*) and farmed Atlantic salmon (*Salmo salar*) in the Pacific region.<sup>(10)</sup> Furthermore, current experience suggests that sablefish have a high tolerance for algal blooms during the growout stage.

To date, most of the feeds used for rearing sablefish have been developed for other species such as Atlantic salmon or yellowtail (*Seriola quinqueradiata*). A laboratory experiment with juvenile sablefish has indicated that they are able to utilize dietary lipid levels up to at least 22% of dry matter with no enlargement of the liver. Current research is examining the potential for partial replacement of marine oils with cold-pressed flaxseed oil in sablefish diets.

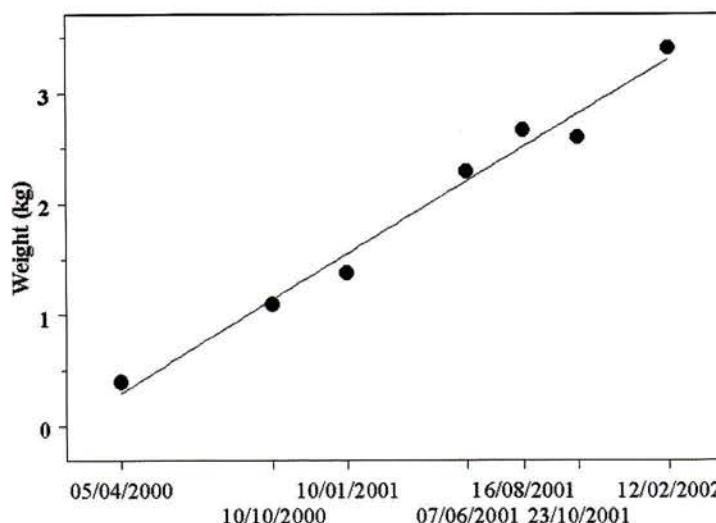
### Technical Constraints

Although there have been substantial advances in the cultivation of sablefish, there are important gaps in our knowledge. There is a need to develop diets designed specifically for growout of larger sablefish to harvest size. There is also a requirement for diets that optimize the health and reproductive performance of broodstock.

Survival during the early feeding stages prior to metamorphosis is variable and needs to be improved through optimization of rearing conditions and development of probiotics. Although progress has been made, spinal deformities have been prevalent in some batches; further research is required.

Males grow more slowly and mature earlier than females, so it would be advantageous to develop the technology for delaying or suppressing sexual maturation of males.

Even though sablefish have been vaccinated successfully in experiments, there is a need to understand the ontogeny of the immune system in order to determine the optimum time for administering vaccines.



**Figure 5**  
Growth of sablefish from 0.4 to 3.4 kg in a netpen while being fed a commercial salmon diet.

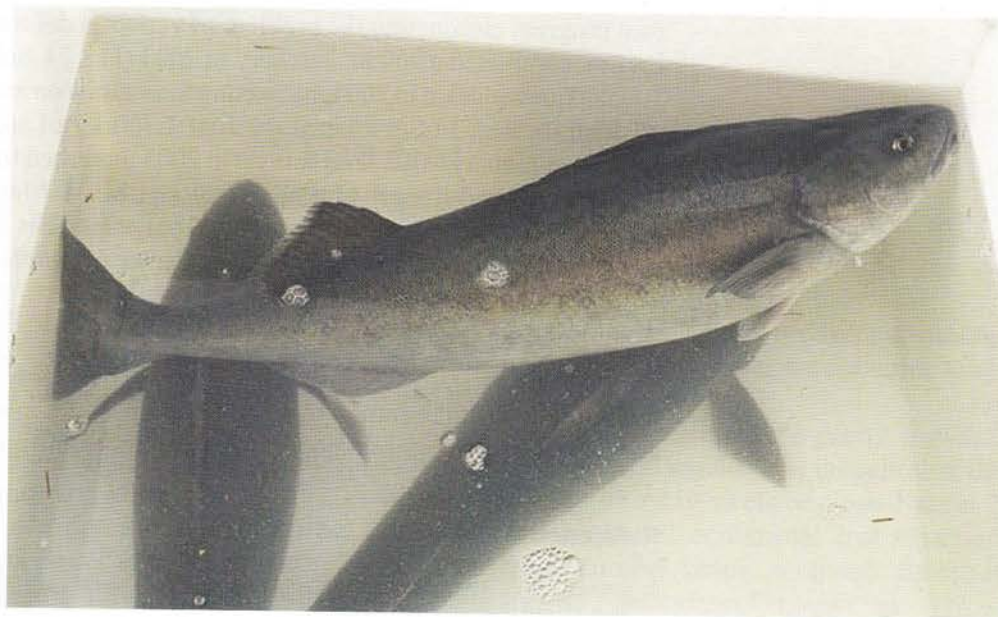


### Existing Producers

As of December 2003, there were 33 commercial salmon farm sites in British Columbia licensed to produce sablefish and another 16 had applications under review. However, most of these farms were not holding sablefish at this time. This was due both to the depressed state of the aquaculture industry as a result of low salmon prices and to the need to build the confidence of farmers that a secure supply of juveniles is available for stocking net-pens on a commercial scale.

Island Scallops Ltd. initiated research into the commercial production of juvenile sablefish in 1994 and completed the first commercial sablefish hatchery in 1997. In spring 1998, it concluded the first trials on rearing larvae and produced a small number of juveniles. Production rose to 12,000 juveniles in 2000. However, in 2003 the company had a surplus of juveniles for sale.<sup>(11)</sup>

The second hatchery was established by Cluxewe Enterprises Ltd. near Nanaimo, BC in 2002. It is conducting development work and has made signifi-



**Figure 6**  
Sablefish grown in a commercial farm to a size of 4 kg.

**Figure 7**  
A 900-m<sup>2</sup> hatchery built by Sablefin Hatcheries Ltd. in 2003.





cant progress eliminating the problem of vertebral deformity. Sablefin Hatcheries Ltd. completed a 900 m<sup>2</sup> hatchery in 2003 (Fig. 7). Sablefin plans to produce 100,000 juvenile fish in 2004, increasing to two million annually over 5 years.

Totem Oysters Ltd. marketed the first 1,700 kg of sablefish harvested from netpens in January 2002. The harvest in 2003 increased to 10 tonnes from Totem Oysters Ltd. and Target Marine Products LLP. Sablefish have not yet been farmed commercially outside of Canada, but research is being conducted by scientists at the National Marine Fisheries Center in Seattle.<sup>(12)</sup>

### Summary

Despite a slow start, sablefish aquaculture is poised for expansion in British Columbia. For this to become a reality there is a need for investment by the industry and for continued research support from university and government laboratories.

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## "The Eel"

by F.-W. Tesch, with contributions by various authors

This book is a comprehensive review of eel biology, consisting of 8 chapters, covering body structure and function, developmental stages and distribution of eel species, post-larval ecology and behaviour, harvest and environmental relationships, fishing methods, culture, diseases, and trade and processing.

The first chapter would be dry reading if it were not for the unusual characteristics of eels. The skin of eels is much thicker than in most fishes and as a result it has found some unusual uses; in Scandinavia the skin has been used to fashion door hinges. Scales are not formed until the eel is 15 cm in length and take 2 to 3 yr to develop. The larvae have large canine teeth which are lost at the glass eel stage. Eels have a caudal heart, as well as the regular one. The caudal heart beats more rapidly, probably an adaptation to the elongate body form. Eel blood is toxic; 0.2 ml/kg will kill a dog if injected into its blood stream. Persons dissecting or processing eels should wear gloves and ensure that no blood contacts one's eyes. The brain has an inhibitory influence on movements, and excitation is controlled by the tail section. Thus eels can be immobilized by wrapping the tail in a towel. The olfactory surface area of the eel is 6 times the optic surface area, as compared to 0.14 to 1.4 times for other fishes. The eel is ranked second to the dog in terms of olfactory acuity.

As with most chapters, there are numerous errors—more than one would expect for a 3<sup>rd</sup> edition (5<sup>th</sup> if you believe the cover). For example, in Fig. 1.33, the ductus cuvier is in the legend but not identified in the figure; the islets of langerhans are not properly identified in Fig. 1.34; on page 33, "punctuation of the heart" should be puncture of the heart.

Chapter 2 deals with two rather unrelated aspects of eel biology: larval development and speciation. Larval development, metamorphosis and migration have long fascinated eel biologists, and there is still much to be learned. Newly spawned eggs have still not been found at sea. European eel (*Anguilla anguilla*) larvae takes much longer to reach home streams (3-4 years) than American eel (*A. rostrata*) larvae (8-9 months), and consequently are considerably larger as glass eels. It has been concluded that the larvae must swim ac-

tively at about 1.4 body lengths per second. Among the errors in chapter 2 is the incorrect vomerine tooth band word sequence in Table 2.1.

There are some 22 species of the genus *Anguilla*, most in the Indopacific region. It is thought that the common ancestor of today's eels originated about 2 million years ago, before continental drift separated America from Europe-Africa, with the ancestral spawning area near the current Sargasso Sea.

The third chapter, one of the longest and most rambling in the book, deals with some of the poorly understood aspects of eel biology—larval and silver eel migrations. For example it is conjectural as to how larvae manage to navigate along the edge of the European continental shelf after reaching it. The suggestion that they sense reverberations from the ocean bed seems a bit far fetched to me. Glass eel movements once they reach estuarial influences are apparently controlled by positive rheotaxis and negative phototaxis. Consequently during the day and during bright moonlight, glass eels stay near the substrate to keep from being swept back out to sea on ebb tides. Active migration occurs on dark nights, principally during the new moon phase—translating into a 14-d rhythm of activity. Glass eels are currently widely stocked in lakes in Europe, principally Germany, but in the past have had various uses, including being eaten in soup with garlic, canned and used in glue production, and fed to swine.

The section on yellow eels, as with most of the chapter, deals mostly with the European species. The separation into narrow and broad headed forms is probably not relevant to most other species. That sexual differentiation is largely controlled by environmental factors is pretty well accepted at present for most species. This book is somewhat ambivalent about the critical environmental influence. Some sections indicate that population density is critical, with high densities resulting in higher proportion of males, a view supported by some experimental and culture results. In this chapter, however, maleness is thought to be the result of early rapid growth, which is not necessarily coincident with high population density.

Part of chapter 3 deals with silver eel migration,



which brings up another mystery—how do they find their way back to the Sargasso Sea? The preferred mechanism is use of the earth's magnetic field in open sea migration, mainly from elimination of other explanations. More information has been obtained on changes in swimming depth through ultrasonic tracking. Silver eels submerge to 200-600 m during the day, and rise to the surface at night, while maintaining an average swimming speed of 15 km/day.

The figures dealing with migratory patterns are difficult to understand. In Fig. 3.31 the color bars indicate that day and night occur simultaneously. Table 3.17 places the Penobscot River in southwestern New Brunswick, rather than Maine.

Chapter 4 was one of the most difficult to read, possibly reflecting translation difficulties. It also did not utilize some recent syntheses of North American data on harvest trends, such as the ICES workshop on eels held in 2000. Older references are mostly relied on such as Eales (1968) for Atlantic Canada, and Hurley (early 1970's) for the Great Lakes. Harvest trends are similar in both Europe and North America, with most wild stocks declining; the period of decline begins anywhere from 1970 to 1990. World wide fishery production of eels maximized at about 27,000 tonnes in the early 1970's. In comparison, aquaculture production attained 205,000 tonnes by 1975. It is essential that adequate required escapement of glass eels and large silver eels (mostly females) be determined and regulated for heavily exploited species in Europe, Japan, New Zealand and North America.

Chapter 5 is a readable and interesting description of the devices used to catch various life stages of eels. In general the temporal trend has been to larger and more efficient trawls and weirs. Spearing is the oldest fishing method, dating back 10,000 years. Among the errors in the chapter are referral to Fig. 5A,B, and C, but no lettering in the figure, and on page 268 stating that staked stow net bag lengths were as long as 25 cm (should surely be 25 m).

Chapter 6, dealing with eel culture, is only 10 pages so don't buy the book hoping to learn the technicalities of culturing eels. It deals mainly with the geographical distribution and historical development of eel culture. Eel culture still depends upon acquisition of wild glass eels for seed stock. Hence with wild populations on the decline, the long term viability of aquaculture may require ways to successfully culture leptocephalis larvae, in turn requiring improved knowledge of their behaviour and feeding (they apparently feed on cnidarians in the wild).

The Japanese and European eels are of most impor-

tance to aquaculture, with *A. rostrata*, *australis* and *dieffenbachia* (the latter two indigenous to Australia and New Zealand) of minor importance. Total production of eels in 1995 was 205,000 tonnes, with aquaculture production totalling 188,400 tonnes (over 90%). The value of these cultured eels amounted to 3.1 billion US dollars—about 12 % of the total value of all cultured fish species.

China is the leading producer of cultured eels at 120,000 tonnes, followed by Japan (29,000 tonnes) and Taiwan (26,000 t). Europe produces ca. 8,000 t, the rest of Asia 6000 t, Australia 2100 t, and North America only 100 t. The North American eel (*A. rostrata*) is not highly regarded as a culture species in Asia, and sale of elvers depends on the abundance of *A. anguilla* and *A. japonica*. Recent market prices have declined in Japan due to strong Chinese production, with a negative impact on Japanese production. Glass eels supply is often a restriction in Asia but not in Europe. One error noted in this chapter: Fig. 6.2 in the text should be Fig. 6.4 (p.304).

Eels are subject to the usual array of viral and bacterial diseases (Ch.7). As of 1999, 3 viral diseases were of importance; EV2 produces cauliflower-like growths on the jaws, and is specific to *A. anguilla*; EVA is an IPN-like virus affecting *A. anguilla* and *japonica*, inducing swollen gills and hypertrophied kidneys; EVE was isolated in Japan from *anguilla* and *rostrata*, and induces hemorrhage and necrosis of the musculature. Bacterial diseases are categorized as freshwater diseases (e.g. *Aeromonas punctata*, and *Pseudomonas* spp) and salt water disease (*Vibrio anguillarum*). Parasites include nematodes, such as *Anguillicola*, introduced into European populations from Japan, as well as the usual assemblage of trematodes and cestodes.

Chapter 8 deals briefly with world trade and processing, some of it repeating information in the aquaculture chapter. Canada has been exporting wild caught eels live and frozen to Europe since the 1920's, but is not included as one of the more important eel exporting countries (Table 8.1) Eel prices in general are three times higher in Europe than in North America, reflecting perhaps the lower esteem in which the species is held in North America.

In summary the text totals 340 pg with about 50 pg of references, one or two as recent as 2002. As mentioned earlier, some recent compilations of data for North American eels have not been referenced.

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