ECONOMIC POTENTIAL OF SEA RANCHING AND ENHANCEMENT OF SELECTED SHELLFISH SPECIES IN CANADA

PREPARED FOR

OFFICE OF THE COMMISSIONER FOR AQUACULTURE DEVELOPMENT

JUNE 2001

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SUMMARY

1. OVERVIEW

This report presents an estimate of the potential economic impact of sea ranching or enhancement of selected shellfish species. These techniques involve culture of shellfish (or finfish) to the juvenile stage for release (bottom seeding in the case of shellfish) and eventual harvest in open waters. Sea ranching (or enhancement) is distinct from conventional aquaculture in two ways:

- first, the approach relies on *extensive* rather than *intensive* techniques, in other words, growth occurs in the natural habitat and not in cages or nets; and

- second, the approach is closely integrated into the commercial fishing industry.

The potential for sea ranching remains largely unexplored. The main objective of this study is to assess potential based on biophysical estimates of suitable area. Nine shellfish species are examined:

West Coast:
- Geoduck clam (*Panope generosa*).
- Manila clam (*Tapes philippinarum*).
- Northern abalone (*Haliotis kamtschatkana*)
- Japanese scallop (*Patinopecten yessoensis*)

East Coast:
- Sea scallop (*Placopecten magellanicus*)
- Soft shell clam (*Mya arenaria*)
- Green sea urchin (*Strongylocentrotus droebachiensis*)
- American oyster (*Crassostrea virginica*)
- Northern quahaug (*Mercenaria mercenaria*)

The production models and results presented in this report are hypothetical in the sense that there are few examples in Canada demonstrating the biological, technical and economic feasibility of culturing the species in question using a bottom seeding approach. In light of this, the results should be interpreted as *indicative*, rather than definitive, of what is possible. In addition to this caution, several other points are worth noting:

- Suitable habitat exists for each of these species since each occurs naturally in Pacific and Atlantic waters.

- Bottom culture builds largely on existing technology, capacity and skills.

- ♦ Bottom seeding is carried out successfully in other areas where developmental work has been conducted.
- ♦ Hatchery technology and protocols for producing seed/juveniles are well developed for each species.
- ♦ Predation from crabs, starfish, snails and birds is arguably the greatest limiting factor with bottom culture.
- ♦ A considerable investment in research and development is needed in order to bring the vision of a wide-scale culture-based fishery in Canada to fruition. Success elsewhere (eg, Japan, China, the US) is the best indicator that the vision is achievable.

Bottom seeding high-valued shellfish species is successfully practiced on a large scale in Japan and China. In Japan, upwards of half the approximately 400,000 t (round weight) of scallop production originates from bottom seeded beds (the balance is produced using suspension techniques). Hundreds of square kilometres of seabed in large bays in northern Japan are dedicated to bottom seeding. A key to success is that commercial fishermen have worked closely with government to develop and manage the fishery. And success was not easily won. It took some 20 years of development work (1960s-1980s) before production reached high and what appear to be sustainable levels. Prior to the successful development of culture methods, production from the wild fishery fluctuated widely and never reached more than 15,000 t.

2. PRODUCTION ESTIMATES

Sea ranching fisheries could eventually generate a landed value in the range of $1.0 to 1.5 billion annually on Canada's Pacific and Atlantic coasts. These fisheries would create or stabilize thousands of jobs, and strengthen many coastal communities.

Developing production estimates follows a systematic approach. This approach, outlining assumptions and results for each species, is summarized in Table 1.

3. ECONOMIC IMPACTS

The hypothetical sea ranching fisheries assessed in this report generate annual landed value of $1,255 million. Of this, $769 million originates from the west coast fisheries, and $486 million from the east coast.

Total employment impact is 28,650 person years, while total GDP impact is $1,860 million taking direct, indirect and multiplier effects into consideration.

Table 1: Culture-Based Fisheries Production – Assumptions and Results

	Pacific Culture Fisheries				Atlantic Culture Fisheries				
Parameter	Geoduck Clam (1)	Manila Clam (1)	Northern Abalone (1)	Japanese Scallop	Sea Scallop (2)	Soft Shell Clam (1)	Green Urchin	American Oyster	Northern Quahaug
Total estimated habitat area (ha)	20,600	8,000	11,000	10,000	6,830,000	310,000	780,000	6,200	n.a.
Total culture area (ha)	3,000	3,000	2,500	3,000	250,000	7,500	5,000	3,000	2,000
Grow out cycle (years)	6	3	5	3	5	3	5	5	6
Area seeded annually (ha/year)	500	1,000	500	1,000	50,000	2,500	1,000	600	333
Planting density (# seeds/square metre)	20	375	40	8	10	350	300	30	300
Annual seed requirements (millions)	100	3,750	200	80	5,000	8,750	3,000	180	1,000
Survival (% to adult)	0.30	0.60	0.30	0.20	0.20	0.65	0.10	0.40	0.40
Final density (adults/square metre)	6.00	225.00	12.00	1.60	2.00	227.50	30.00	12.00	120.00
Potential harvest (millions/year)	30	2,250	60	16	1,000	5,688	300	72	400
Harvest efficiency (%)	0.85	0.95	0.95	0.85	0.85	0.75	0.80	0.90	0.85
Seed price ($/seed)	0.1400	0.0090	0.1000	0.0150	0.0150	0.0050	0.0300	0.0300	0.0150
Nursery price ($/seed)	0.4000	n.a.	0.1000	n.a.	0.0100	0.0150	n.a.	n.a.	n.a.
Seeding cost ($/ha)	$25,000	$10,000	$120,000	$20	$20	$10,000	$20	$25	$25
Total annual seeding cost ($)	$12,500,054	$43,750,000	$100,000,000	$1,220,000	$101,000,000	$25,000,175	$90,020,000	$5,415,000	$15,008,333
Average adult weight (kg)	0.685	0.018	0.095	0.125	0.016	0.010	0.100	0.095	0.020
Market size (min)	(3)	38 mm	75 mm	(3)	10 g	38 mm	60 mm	76 mm	50 mm
Total harvest weight (millions kg)	17.5	38.5	5.4	1.7	13.6	42.7	24.0	12.2	6.8
CPUE (kg/day)	900	800	200	300	400	300	1,500	250	1,500
Effort (vessel-days)	n.a.	n.a.	n.a.	5,667	34,000	n.a.	n.a.	0	0
Effort (diver or digger-days)	19,408	48,094	27,075	n.a.	n.a.	142,188	16,000	48,600	4,533
Landed price ($/kg)	$20.00	$5.00	$40.00	$6.50	$13.00	$2.75	$5.50	$3.50	$2.50
Total revenue ($)	$349,350,000	$192,375,000	$216,600,000	$11,050,000	$176,800,000	$117,304,688	$132,000,000	$42,525,000	$17,000,000

1. Seeding cost reflects predator control in the form of protective netting.
2. Average weight and total harvest are for meats only.
3. No minimum legal size

I.

INTRODUCTION

1. OVERVIEW

This report presents an estimate of the potential economic impact of culture-based fisheries. These are defined as fisheries that culture shellfish or finfish to the juvenile stage for release (bottom seeding in the case of shellfish) and eventual harvest in open waters. Culture-based fisheries are distinct from conventional aquaculture in two ways: first, the approach relies on *extensive* rather than *intensive* techniques, in other words, growth occurs in the natural habitat and not in cages or nets; and second, the approach is closely integrated into the commercial fishing industry.

This report finds its rationale in the recognition that Canadian fishing interests have been content to rely almost exclusively on the capture fishery – what nature delivers – as the basis of the industry. This carries with certain risks, as those in the Atlantic groundfish fisheries know only too well. Aquaculture is emerging as an important industry in its own right, but is heavily dependent on a single species – salmon – and is concentrated in just two provinces, British Columbia and New Brunswick. Canada's primary fish production is valued at over $2.4 billion (based on ex-vessel and farm gate prices). The commercial (capture) fisheries account for about 77% of this, while aquaculture contributes the other 23%.

Against the backdrop of a commercial fishing industry that is structured and managed around the principles of natural variability and chance, the potential for culture-based fisheries remains largely unexplored. This is unfortunate because the experience elsewhere indicates that established commercial interests have everything to gain from involvement in culture-based approaches (sea ranching and enhancement). The main objective of this study is to assess culture potential based on biophysical estimate of area available for this activity, either as fishing ground, area under culture, or both. Nine shellfish species are examined:

West Coast:

- Geoduck clam (*Panope generosa*).
- Manila clam (*Tapes philippinarum*).
- Northern abalone (*Haliotis kamtschatkana*)
- Japanese scallop (*Patinopecten yessoensis*)

East Coast:

- Sea scallop (*Placopecten magellanicus*)
- Soft-shell clam (*Mya arenaria*)
- Green sea urchin (*Strongylocentrotus droebachiensis*)
- American oyster (*Crassostrea virginica*)
- Northern quahaug (*Mercenaria mercenaria*)

The selection of candidate species is based on two criteria: the apparent scope for expansion (based on size of potential habitat and historic commercial landings), and potential for economic production. These are not the only species meeting these criteria, but are ones that could be considered given the scope of the study. The study budget allowed seven species to be examined in some detail, and two (northern quahaug and American oyster) to be examined at a less exhaustive level.

2. APPROACH

Our general approach to estimating economic impacts follows several steps:

- Determining the biophysical characteristics for each species;
- Estimating the areas meeting these characteristics;
- Selecting a potential culture area for case study purposes;
- Developing the elements of a culture-based approach including seeding density and method, seed requirements and source, predator control (if any), survival rate assumptions, harvesting method, and price and revenues;
- Estimating the costs of each of the stages: seed production, seeding and harvesting; and,
- Running the costs through an input-output model to determine economic impacts in terms of employment and gross domestic product.

It should be noted at the outset that the culture models and results are hypothetical. While the best information available is used as the basis for the analysis, there are few examples in Canada demonstrating the biological and technical feasibility of a bottom seeding approach. For example, survival rates, a key factor to success, can only be estimated. Also, areas offering optimal growing conditions are not well documented. Accordingly, potential production levels and the costs and revenues generated in the analysis are presented with wide confidence limits.

3. OUTLINE

Following this introduction, Chapter II sets out in summary form the nine culture-based fisheries case studies. It provides highlights for each species as well as a detailed matrix providing key assumptions and results. Economic impacts are presented in Chapter III. It outlines the methodology and the direct, indirect and induced impacts on employment and gross domestic product. Chapter IV provides an overview of the Japanese experience with scallop culture, examining both bottom seeding and suspension techniques. To put our own industry and prospects in perspective, the landed value of cultured scallops in Japan is in the $475-525 million range.

The Annex sets out the case studies in detail (oyster and quahaug, excepted), outlining biophysical requirements, culture methods and assumptions, and results.

II.

CULTURE FISHERIES CASE STUDIES

1. OVERVIEW

The production models and results presented here are hypothetical in the sense that there are few examples in Canada demonstrating the biological, technical and economic feasibility of culturing the species in question using a bottom seeding approach. In light of this, the results should be interpreted as *indicative*, rather than definitive, of what is possible. In addition to this caution, several other points are worth noting:

- Suitable habitat exists for each of these species since each occurs naturally in Pacific and Atlantic waters. So the first challenges are determining the extent of suitable habitat, and then specifying the culture area within this that forms the basis for the analysis. Specifying this area is subject to considerable uncertainty given data limitations, so a conservative approach is used. Also, for most species, the analysis does not distinguish between public ocean space and that used by the commercial fishery. In other words, areas used by the commercial fishery are included when specifying potential culture area, since this is the area that is likely to benefit most from enhancement.

- Bottom culture builds largely on existing technology, capacity and skills. Seeding is straightforward and would be carried out using conventional fishing vessels and existing crews. Commercial harvesters would take the catch in the same manner as the wild fishery. Some institutional and management changes could be expected in order to create and protect rights, and to assign responsibilities.

- Bottom seeding is carried out successfully in other areas where developmental work has been conducted on such key issues as seed production (or collection), optimal seed size and planting densities, optimal location and timing, predator control, and management. Examples include:
  - scallop culture in Japan, China and Canada (Magdalen Islands and New Brunswick),
  - oyster in Chesapeake Bay and in Prince Edward Island,
  - soft-shell clam in the US northeast,
  - quahaug along the southern coast of the US (Florida and South Carolina) and in a few areas along the Northumberland Strait, and
  - Manila clam and geoduck in British Columbia.

- Hatchery technology and protocols for producing seed/juveniles is well developed for each species. Hatcheries are assumed to meet all seed demand, particularly given the inherent unreliability of natural availability. To develop culture fisheries on the scale anticipated in this analysis would require a substantial expansion of production capacity and considerable effort to develop improved broodstock.

- Predation from crabs, starfish, snails and birds is arguably the greatest limiting factor with bottom culture. Predator control, therefore, is critical to success. Control methods have been developed and are used in other areas (eg, net protection, dredging and trapping). Strategies such as starting with larger seed and seeding when predators are relatively inactive are also used. Intensive culture approaches control predation through suspension techniques or by using bottom cages. But these approaches are capital and labour intensive, with generally poor economics for most slow-growing shellfish species.

- A considerable investment in research and development is needed in order to bring the vision of a wide-scale culture-based fishery in Canada to fruition. Success elsewhere (eg, Japan, China, the US) is the best indicator that the vision is achievable. But many years and much investment are essential. The joint industry-science initiatives now under way (eg., geoduck in British Columbia, scallops in the Magdalen Islands, and oysters in Prince Edward Island) are important early steps that need to be nurtured and supported.

2. PRODUCTION ESTIMATES

Culture-based shellfish fisheries could eventually generate a landed value in the range of $1.0 to 1.5 billion annually on Canada's Pacific and Atlantic coasts. These fisheries would create or stabilize thousands of jobs, and strengthen many coastal communities.

Developing production estimates follows a systematic approach. This approach, outlining assumptions and results for each species, is summarized in Table 1. Detail for each species is provided in the annexes to this report. An explanation of each of the assumptions and results appears on the page opposite Table 1.

3. SPECIES HIGHLIGHTS

PACIFIC

Geoduck

- The commercial fishery is stable after several years of decline due to overfishing. This is a dive fishery, managed with individual quotas.
- Formal studies of the area meeting optimum geoduck habitat conditions have not been conducted, though identified harvestable beds are known to cover some 20,600 ha. The area selected for analysis is set conservatively at 3,000 ha, based on a combination of likely optimum conditions, culture development costs, and fishery constraints including competing interests.

Geoduck (continued)

- ♦ Recruitment is naturally low and variable.
- ♦ Commercial harvesters are engaged in an enhancement program using hatchery-produced seed, on-grown in nurseries before seeding.
- ♦ Mechanized seeding machines have been developed.
- ♦ Net protection is used and contributes to an expected 25% survival rate.
- ♦ Markets are strong and are expected to remain so for the foreseeable future.
- ♦ Current landed value is in the $41 million range. The case study suggests potential landed value could reach the $350 million range.

Manila Clam

- ♦ Strong demand in the early 1980s led to unsustainable harvest levels by the late 1980s and a gradual decline in stocks. The fishery today is characterized by substantial excess harvesting capacity and short area openings.
- ♦ Some 664 commercial clam beaches cover about 8,100 ha along the south coast. This provides the basis for a substantial expansion of the culture fishery. Potential along the north coast is not known. The area selected for culture is set at 3,000 ha based largely on under- or un-exploited beaches.
- ♦ Natural seed production is highly variable and inadequate to support a major expansion of the culture fishery.
- ♦ The culture fishery accounts for about half of the total Manila clam production in BC by weight and 75% by value. Seed is purchased from commercial hatcheries.
- ♦ Net protection is used for newly seeded areas and contributes to a 60% survival rate.
- ♦ Markets are strong, particularly for cultured product, and are expected to remain so for the foreseeable future.
- ♦ Current landed value is in the $3-4 million range. The case study suggests potential landed value could reach the $190 million range.

Northern abalone

- ♦ A demand-limited fishery up to the early 1970s, gave way to a rapid expansion of effort and catches in response to strong demand in the late 1970s. Unsustainable harvests led to a sharp decline in stocks and the closure of the fishery in 1990. The species is now listed as “threatened” by the Government of Canada. An illegal harvest continues, spurred by high prices.
- ♦ Formal studies of the area meeting abalone habitat conditions have not been conducted. Abalone feed primarily on nereocystis kelp. Recent surveys indicate that beds of nereocystis cover about 11,000 ha. Experienced abalone divers indicate that 20-50% of these beds are suitable for a culture-based fishery. We take the lower end of this range, 2,500 ha, as the basis for the analysis.

Table 1: Culture-Based Fisheries Production – Assumptions and Results									
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Parameter	Geoduck Clam (1)	Manila Clam (1)	Northern Abalone (1)	Japanese Scallop	Sea Scallop (2)	Soft Shell Clam (1)	Green Urchin	American Oyster	Northern Quahaug
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Total culture area (ha)	3,000	3,000	2,500	3,000	250,000	7,500	5,000	3,000	2,000
Grow out cycle (years)	6	3	5	3	5	3	5	5	6
Area seeded annually (ha/year)	500	1,000	500	1,000	50,000	2,500	1,000	600	333
Planting density (# seeds/square metre)	20	375	40	8	10	350	300	30	300
Annual seed requirements (millions)	100	3,750	200	80	5,000	8,750	3,000	180	1,000
Survival (% to adult)	0.30	0.60	0.30	0.20	0.20	0.65	0.10	0.40	0.40
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Seed price ($/seed)	0.1400	0.0090	0.1000	0.0150	0.0150	0.0050	0.0300	0.0300	0.0150
Nursery price ($/seed)	0.4000	n.a.	0.1000	n.a.	0.0100	0.0150	n.a.	n.a.	n.a.
Seeding cost ($/ha)	$25,000	$10,000	$120,000	$20	$20	$10,000	$20	$25	$25
Total annual seeding cost ($)	$12,500,054	$43,750,000	$100,000,000	$1,220,000	$101,000,000	$25,000,175	$90,020,000	$5,415,000	$15,008,333
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Effort (vessel-days)	n.a.	n.a.	n.a.	5,667	34,000	n.a.	n.a.	0	0
Effort (diver or digger-days)	19,408	48,094	27,075	n.a.	n.a.	142,188	16,000	48,600	4,533
Landed Price ($/kg)	$20.00	$5.00	$40.00	$6.50	$13.00	$2.75	$5.50	$3.50	$2.50
Total revenue ($)	$349,350,000	$192,375,000	$216,600,000	$11,050,000	$176,800,000	$117,304,688	$132,000,000	$42,525,000	$17,000,000

1. Seeding cost reflects predator control in the form of protective netting.
2. Average weight and total harvest are for meats only.
3. No minimum legal size

Table 1 (continued): Definitions

Total estimated habitat area: this is based on minimum biophysical conditions including temperature, salinity, substrate, depth and food availability. The estimates are based on existing documents and information (west coast), or are derived from a combination of documents and charts where estimates are unavailable (east coast).

Total culture area: this reflects the area that is likely to offer optimal conditions for growth and is also constrained by estimates of what is reasonable by way of seed production, cost of seed and seeding, and harvesting capacity.

Grow out cycle: this indicates the length of time needed for growth from seed to commercial size in natural habitat. The typical time of 4-5 years makes conventional aquaculture approaches relatively unattractive from an economic perspective.

Area seeded annually: we assume a rotating harvest approach, where the area in to be seeded in any year would equal the total culture area divided by the number of years needed to reach commercial size. This way, hatchery and harvesting capacity are used efficiently.

Planting density: determining optimal planting density is a matter of trial and error. Too high a density limits individual growth; too low a density wastes space and increases harvesting costs. The densities given are based on actual culture experience or are grossed-up from known final densities in the wild fishery to reflect mortality due to predation.

Annual seed requirements: this is given by multiplying seeding density by units of area (m^2). In some cases the annual requirements substantially exceed current capacity. The hatchery sector is assumed to adjust over time.

Survival: this indicates the percentage of seeds/juveniles likely to recruit to the fishery. The percentage varies across species depending mainly on efforts to control predators, or on the use of larger seed sizes (providing greater resistance to predators).

Final density: this is derived by applying the survival percentage to the initial planting density.

Potential harvest: the total number of animals derived by applying the final density to the area seeded annually.

Harvest efficiency: this gives the percentage of the potential harvest actually caught and reflects the relative efficiency of the fishing method.

Seed cost: this is the current estimate of seed prices based on hatchery posted prices and information provided by growers. With expanded capacity, economies of scale and lower prices are likely.

Nursery cost: this is the cost associated with growing seeds from the minimum viable size to a size that decreases vulnerability to predators to acceptable levels.

Seeding cost: this covers the cost of seeding (broadcast from vessel or by hand, mechanized or diver) and the costs of predator control through the use of protective nets. Nets are used for geoduck, Manila, and abalone on the Pacific coast, and soft shell clam on the Atlantic coast.

Total annual seed/seeding costs: the sum of seed, nursery and seeding costs.

Average adult weight: the average weight of an animal meeting commercial size criteria at the end of the grow out cycle.

Total harvest weight: obtained by multiplying average weight by potential harvest as adjusted for harvest efficiency.

CPUE (Catch per unit of effort): an estimate of the level of effort needed to harvest the total weight. The estimate, obtained from the commercial catch data, should be accurate for the culture fisheries since final density is based on the wild fishery.

Effort: the number of commercial fishing days or diver-days required to catch the total harvest weight.

Landed price: the current ex-vessel price for each of the species. Actual prices could be expected to soften somewhat with the increased production postulated in these case studies. But given the hypothetical nature of the exercise and the scope for error in other variables, no attempt is made to incorporate price elasticities when estimating total landed value, and nor is it deemed necessary to conduct a sensitivity analysis around prices.

Total revenue: derived by multiplying total harvest weight by landed price.

Northern abalone, (continued)

- Seed collection from wild stocks is inadequate due to depletion. Substantial production from hatcheries is needed to support the culture fishery. Technology is available. Nursery facilities are also required to grow seeds to a juvenile stage before seeding.
- Net protection is used for newly seeded areas and contributes to an expected 30% survival rate.
- Markets are strong and are expected to remain so for the foreseeable future.
- The case study suggests potential landed value could reach $200-220 million.

Japanese Scallop

- Culture production began in 1995, and is currently in the order of 30 t, with a value of $200,000.
- Culture potential seems excellent, but expansion of production is constrained by land use conflicts and habitat conflicts with DFO.
- Hatchery seed and grow out technology are available.
- Estimates of scallop habitat area are unavailable, but using geoduck habitat as a proxy suggests that the area meeting scallop biophysical requirements could be in the order of 10,000 ha. For this study, we assume 3,000 ha would provide optimal habitat for scallop growth.
- Markets are strong and are expected to remain so for the foreseeable future.
- The case study suggests potential landed value could reach the $10-12 million range.

ATLANTIC

Sea Scallop

- The commercial fishery is divided into offshore and inshore sectors. The offshore sector (mainly Georges Bank and western Scotian Shelf) is stable and well-managed producing 4-6,000 t of meats annually with a landed value in the $90-110 million range. The inshore sector (mainly Bay of Fundy) has a history of weak management, overfishing, and declining stocks.
- Sea scallop ranges over a wide area, with suitable habitat in inshore and nearshore waters estimated at some 68,300 km^2. The area selected for analysis is set conservatively at 2,500 km^2, based on a combination of likely optimum conditions, culture development costs, and fishery constraints including competing interests (eg, lobster fishery).
- Seed supply on the scale required exceeds that available from wild stocks. Hatchery seed is available, but capacity would have to be expanded substantially to meet requirements reflected in the case study.

- To achieve an acceptable survival rate, seed stock would be transferred to a nursery area and held in collector bags until grown to a suitable size for seeding (25 mm). A survival rate of 20% is assumed.
- Markets are strong and are expected to remain so for the foreseeable future.
- The case study suggests potential landed value from the culture fishery could reach the $175 million range.

Soft Shell Clam

- The soft-shell clam sustains a commercial small fishery in Atlantic Canada, with landings valued at $4-5 million in the southern Gulf of St. Lawrence and in the Bay of Fundy.
- Suitable habitat is estimated at 3,100 km^2. The area assumed to be optimal for culture is 25 km^2 (2,500 ha).
- Seed supply on the scale required exceeds that available from wild stocks. Hatchery seed is available, but capacity would have to be expanded substantially to meet requirements reflected in the case study.
- Net protection would be used for newly seeded areas and could lead to a 65% survival rate.
- The case study suggests potential landed value from the culture fishery could reach the $100-120 million range.

Green Urchin

- The commercial fishery for urchins began in the late 1980s, with the major fishery in the waters off Nova Scotia. Landings increased from about 100 t to over 1,200 t in the mid-1990s in response to a sharp increase in prices. Disease reduced stocks and landings dropped to the 900 t range by 2000.
- Urchins feed on kelp moving in “grazing fronts” through the beds. Harvesting is by diver only, with each vessel limited to four divers. The fishery is managed by limited entry, with each license-holder given exclusive access to specified zones.
- Disease, not fishing, is the major threat to biological and economic sustainability. A catastrophic die-off in the early 1980s, reduced the biomass on the Scotian Shelf by an estimated 270,000 t.
- Suitable habitat (kelp beds) is estimated at 7,800 km^2. Of this, 100 km^2 (10,000 ha) form the basis of the case study; 2,000 ha would be seeded annually.
- Hatchery seed is available, but capacity would have to be expanded substantially to meet requirements reflected in the case study.
- The case study suggests potential landed value from the culture fishery could reach the $130 million range. The major risk associated with urchin culture arises from periodic catastrophic die-off. This is unpredictable.

American Oyster

- Several attempts to restore oyster beds are underway in PEI and New Brunswick. These initiatives involve spat collection, cultivating shell beds (cultch) for oyster spat to set on, predator control (mainly starfish traps), and relaying oysters to re-establish populations. Some of the projects are well-advanced, showing substantial increases in production.
- Seed supply on the scale required exceeds that available from wild stocks. Hatchery seed is available, but capacity would have to be expanded substantially to meet requirements reflected in the case study.
- Oyster culture has been practiced in Atlantic Canada since the mid-1860s. Public beds and leased areas cover some 6,200 ha, though many of the leases are small and inactive, and much of the ground unproductive. Production has increased moderately over the past 20 years, largely as the result of initiatives aimed at restoring beds. Commercial landings are valued at $7-8 million.
- Much of the 6,200 ha of good oyster ground would have to be restored as a first step in any culture initiative. Half the potential area (3,000 ha) is assumed for case study purposes, with 600 ha seeded annually.
- The case study suggests potential landed value from the culture fishery could reach the $40 million range.

Northern Quahaug

- This is a tough, hardy species, with excellent culture prospects. There is a commercial fishery, with landings estimated in the $1 million range. The commercial fishery in the US (between Maine and Florida) generates a landed value in the $50-60 million range.
- Culture is practiced on a small scale in Atlantic Canada, mainly in the warm waters of the Northumberland Strait. Quahaug culture in the US is a major industry, particularly on Cape Cod in the southern states where relatively warm waters allow culturists to grow a marketable clam in 2-3 years (compared with 5-6 years in Canada).
- Hatchery seed is available, but capacity would have to be expanded substantially to meet requirements reflected in the case study.
- To achieve an acceptable survival rate, seed stock would be transferred to a nursery area and held in collector bags until grown to a suitable size. They are seeded with or without net protection. A survival rate of 40% is assumed.
- A reliable estimate of suitable habitat is not available, but using clam habitat as a rough guide, we expect the total area to exceed several thousand ha. The area assumed to be optimal for culture is 2,000 ha, with 335 ha seeded annually.
- The case study suggests potential landed value from an established culture fishery could reach the $17 million range.

III.

ECONOMIC IMPACTS

1. OVERVIEW

Canada's oceans offer a productive habitat for a broad range of marine species. These species are exploited primarily through capture fisheries. The success of these fisheries depends on natural variability and the ability to sustain stocks by controlling harvesting levels.

Canada has enjoyed mixed success in fisheries management. A rapid expansion of harvesting capacity occurred in the 1970s and 1980s as Canadian fishing interests sought to reap the benefits of extended fishing jurisdiction (the 200-mile limit). By the mid-1980s, capacity greatly exceeded resource availability, and harvests occurred at unsustainable levels. DFO's attempts to bring capacity and resource availability into line through quotas and various input controls produced limited results. By the early 1990s, many stocks had declined on both coasts, throwing thousands out of work.

Against this backdrop, four important trends emerged: i) There was a gradual transition from competitive fishing to rights-based approaches involving individual quotas; ii) DFO introduced buy-back programs to reduce capacity (the number of vessels dropped by 30% during the 1990s); iii) a substantial expansion in shellfish stocks offset the precipitous decline in groundfish stocks on the east coast (the shellfish share of total value rose from 50% in 1990 to 82% in 1999); and iv) aquaculture emerged as a significant contributor to the value of Canada's fish production (particularly on the west coast where by 1999, farm gate value almost equalled the landed value from the commercial fishery).

These trends carry at least two important implications for culture-based fisheries.

- One of the factors limiting the development and expansion of culture-based fisheries is security of investment – that the individual or organization who seeds and maintains an area should expect exclusive access to the "crop". Conventional aquaculture provides this through a lease. The shift to a rights-based approach in the capture fishery carries with it the promise of a framework that would provide such security in the culture-based fisheries. It would require the extension of the system of quota rights to one of territorial rights much like that currently in effect in the urchin fishery in Atlantic Canada.

- ♦ Aquaculture is established as a major contributor to seafood production in Canada, accounting for just under 25% of total landed value. But aquaculture production is dominated by a single species, salmon, accounting for about 80% of total value. It is also a capital-intensive approach to production. Considerable potential exists not only for a range of other finfish and shellfish species, but for innovative and less costly approaches. Bottom-seeding represents one such alternative.

In short, the waters off the east and west coasts hold the potential for substantially greater cultured production (ie, conventional aquaculture as well as bottom-seeding approaches). But attempts to expand, and to diversify beyond a few species, face formidable challenges. Resources available for research and development are inadequate. Moreover, established commercial and recreational users of coastal waters are opposed, fearing loss of ocean access as well as potentially adverse environmental effects arising from intensive culture, particularly of finfish species.

Not all aquaculture methods and species pose such threats. *Extensive* techniques (also termed enhancement), such as seeding natural habitat, represent potential alternatives to conventional cage and suspension methods. Bottom-seeding, if adapted to Canadian conditions, holds out the potential of substantially increasing production while providing the foundation for thousands of additional fisheries jobs in coastal communities.

It is also important to note that a culture-based fishery would not displace established commercial interests. Rather, these interests would form the foundation of the fishery, just as they do the commercial fishery. In all cases, conventional harvesting techniques would continue to be used. The fishery would simply take place within a more cooperative environment, one where rights were clearly defined. The Japanese approach involving fishermen’s cooperatives serves as one possible model (more on this in Chapter IV).

2. ECONOMIC IMPACTS

APPROACH

Economic impact analysis has a simple objective: to estimate how expenditures made in the production of a particular good or service are likely to affect the economy as measured by such indicators as income and employment. This analytical technique is to be distinguished from economic efficiency analysis whose objective it is to determine whether or not the productive activity makes economic sense – whether it represents the best use of resources.

It is not possible at this point to conduct an economic efficiency (feasibility) analysis of culture-based fisheries. One limiting factor to assessing economic efficiency is the lack of high quality data on area-specific biophysical variables and how they relate to survival and growth. Also, the costs associated with the years of research and development needed to bring culture fisheries into a mainstream activity are not known. It took the Japanese some 20-30 years of trial and error before producing the impressive results of the past decade.

Accordingly, this analysis proceeds from the assumption that culture-based fisheries can be feasible. It is then a matter of making reasonable assumptions about key variables and estimating costs of production. These costs are broken down into specific commodities and used to drive an economic model in order to generate impact estimates.

More specifically, the approach breaks down into the following steps:

1. Determine input requirements for each of three stages of culture production: seed production, seeding and harvest. These are presented in Chapter 1, Table 1.

2. Develop estimates of production costs (operating only) for each stage. Costs are broken down by commodity and expressed as percentage of the total. For example, the main cost items for a hatchery are labour, utilities and feed; for seeding the main items are fuel, vessel maintenance, crew and netting (for predator control); while for harvesting the main items are fuel, maintenance, provisions, gear costs, insurance and crew. A margin representing return on capital (normal profit) is included as a cost item for commodity purposes (this margin is included in the commodity breakdown for each stage).

3. Specific expenditure values for each commodity are required to drive the economic model. These are derived by applying the percentages from step 2 to the expenditure totals at each stage. These totals appear in Table 1. For harvesting, the total production cost is the value of landings.

4. The expenditure totals by commodity are used to drive an input-output model to derive economic impact. For this analysis, we use a variant of the Statistics Canada Inter-Regional Input-Output Model (1994 version). The Model generates impact estimates for employment and gross domestic product by province (GDP) at the direct, indirect and induced levels. For reporting purposes, the provincial totals for the Atlantic Provinces and Quebec are aggregated to an east coast total. The Pacific total is that for British Columbia.

   - **Direct Impacts** – arise from the expenditures made in carrying out the activity in question: eg, on the goods and services needed to produce seed and harvest the output. So, expenditures on wages and salaries generate jobs and contributions to GDP.

- **Indirect Impacts** – arise from the linkages into the broader economy. For example, if fishing gear is manufactured or vessels are maintained, plants and yards would have to increase their output to meet the demand. An increase in gear required leads to an increase in demand for such inputs as steel and twine, which in turn result in an increase in activity in industries supplying the goods and services needed to produce these items, and so on.

- **Induced Impacts** – also arise from linkages into the broader economy. They result from the spending and re-spending of incomes earned in the sectors that expand to meet direct and indirect demand. For example, crews on vessels spend their incomes on clothing and food. These expenditures help to support retail businesses that in turn pay wages that are spend and re-spent, and so on.

3. RESULTS

OVERALL IMPACTS

The hypothetical culture-based fisheries outlined in Chapter II generate annual landed value of $1,255 million. Of this, $769 million originates from the west coast fisheries, and $486 million from the east coast.

Total employment impact is 28,650 person years, while total GDP impact is $1,860 million.

Values are given in Table 2.

Direct

The fisheries would generate about 15,000 person-years of direct employment and just over $900 million in direct GDP. This would occur in hatcheries, on vessels for seeding, and in the commercial fisheries for harvesting (crews, divers and diggers).

Indirect

Indirect employment is estimated at just under 3,000 person-years, and GDP at $110 million. This would occur in the industries supplying goods and services to the hatchery and commercial fishing sectors. The numbers are relatively low because the input requirements ordinarily represent less than half the operating costs of these sectors (the balance is accounted for by returns to labour and capital), and also because the industries supplying goods and services tend to be fairly capital intensive (eg, utilities, refineries).

Induced

Induced employment is estimated at just over 10,000 person-years, and GDP at $830 million. The numbers are relatively high because a substantial share of the direct expenditures is in the form of labour income (eg, crew shares) and returns to capital. This means a relatively high proportion of direct expenditure finds its way into the retail sector thereby generating high induced impacts.

Table 2
Economic Impact of Culture-Based Fisheries

	East Coast	West Coast	Canada Total
Landed value ($millions)	492	768	1,260
Employment (person-years)			
Direct	6,950	8,500	15,450
Indirect	1,050	1,900	2,950
Induced	3,650	6,600	10,250
Total employment	11,650	17,000	28,650
GDP ($ millions)			
Direct	350	570	920
Indirect	30	80	110
Induced	280	550	830
Total GDP	660	1,200	1,860

SENSITIVITY ANALYSIS

The results set out in Table 2 are derived using many assumptions because data on key variables are limited. Consequently, the results have wide confidence limits. This means that changes in key assumptions could lead to a substantial change in impacts. This is illustrated in Table 3, where two variables – potential culture area and survival rate – are varied simultaneously by plus and minus 25, 50 and 100 percent (survival rates for Manila clam and soft-shell clam are not varied because the models incorporate predator control and relatively high survival rates). The potential revenues generated vary from $314 million (assuming a 50% cut in area and survival rates) to $4.4 billion (assuming a 100% increase in area and survival rates). The economic impacts would change in proportion to the change in revenues.

Table 3: Sensitivity Analysis – change in total revenue resulting from changes in assumptions for culture area and survival rates (values in millions of dollars)

Percent Variation	Geoduck Clam	Manila Clam	Northern Abalone	Japanese Scallop	Sea Scallop	Soft Shell Clam	Green Urchin	American Oyster	Northern Quahaug	Total
-25	197	108	122	6	99	66	74	24	10	706
-50	87	48	54	3	44	29	33	11	4	314
-100	0	0	0	0	0	0	0	0	0	0
Base Case	349	192	217	11	177	117	132	43	17	1,255
25	546	240	338	17	276	147	206	66	27	1,864
50	786	289	487	25	398	176	297	96	38	2,592
100	1,397	385	866	44	707	235	528	170	68	4,401

IV.

SCALLOP CULTURE IN JAPAN

1. OVERVIEW

The Japanese experience is invaluable because it works, and also because it forms the basis for virtually all current worldwide culture and enhancement activity. The Japanese use a combination of bottom seeding and suspension (pearl and lantern net, ear hanging) culture techniques, with considerable success in both approaches. The industry is based on the yesso scallop (*Patinopecten yessoensis*), a species in the same family (Pectinidea) as the sea scallop found in east coast waters in Canada. Over the past 25 years, scallop production has risen from just a few hundred tonnes to between 300 and 400 thousand tonnes (live weight) annually. With an ex-vessel price in the $10/kg range, the scallop culture fishery in Japan is worth some $475 to $525 million annually.

To achieve and sustain this level of harvest, the industry evolved from a traditional wild fishery to one based heavily on cultivation. Indeed, the fishery is based entirely on an intensive and directed effort to collect scallop spat and then grow out the spat into marketable scallops on the bottom, in hanging nets, and on hanging lines. Bottom culture dominates production in Hokkaido, while hanging culture is the principal method in Aomori.

2. CAPTURE TO CULTURE: A BRIEF HISTORY

Scallop harvesting dates back to ancient times in Japan. The modern culture-based scallop fishery has its roots in the early 20th century with spat collection and seeding experimentation being conducted in the early 1930s. Wide fluctuations in landings were reported in the period 1910 to 1945, after which time landings suddenly declined sharply. Landings remained below 10,000 t until the early 1970s, when the concerted effort to develop the industry through stock enhancement began to show results. By 1980 landings had risen to the 100,000 t range, and by 1990 to the 200,000 t range. The average for the 1990s was just under 235,000 t. Much of the credit for this success is directly attributed to the cooperation of fishermen and governments working to enhance and manage their fisheries.

Scallop seeds were sowed on the bottom in the Hokkaido capture fishery as early as 1936. In recent times, the development of coastal communities in northeast Hokkaido has been linked directly to the enhancement of the traditional capture or “wild” fishery. Historically, sowing culture and wild production from the sea bottom in Hokkaido have contributed about 40 to 45% of total Japanese scallop production. The sustained landings in Hokkaido are attributed to spat collection, bottom sowing, juvenile protection and rotating harvesting methods in wild harvest areas. The traditional scallop fishery has thus evolved to become heavily reliant on culture techniques to enhance the capture fishery.

Hanging culture really took off in Aomori Prefecture in the early 1970s when spat collection techniques were perfected. In the early 1970s, spat collection was so successful that 2.3 million spat bags collectors were deployed and 40 billion seeds collected. The rapid increase in production in that time is directly attributed to the success of spat collection efforts and the perfection of hanging culture. Mass mortalities were experienced in the mid-1970s, but scientist determined an optimal level of spat introduction and subsequently addressed the mortality problem. Hanging culture dominates production in Aomori with about 30% of total production coming from bottom culture.

Generally speaking, the scallop fishers and their Fishery Cooperative Associations (FCAs) enhance and harvest areas in which they have use rights. These use rights are based in legislation and reflect historical uses and rights. These rights and the fishery system are discussed in more detail below.

3. SUCCESS FACTORS

Over time, the traditional capture fishery evolved into one based on culture. As techniques for spat collection, bottom sowing and hanging culture evolved, operating fisheries adopted the techniques and supplemented production. The history of the Japanese scallop fishery must therefore be viewed as a process of innovation and cooperation directed at increasing production.

Indeed, it is clear that a directed effort by governments, harvesters and other interests over a long period of time was required to transform the wild scallop fishery in Japan into a culture-based fishery. This is not a transformation involving the displacement of harvesters by culturists – rather, harvesters themselves gradually adopted enhancement techniques to increase stocks and stabilize and expand production. The wild fishery gradually evolved into a culture-based fishery as spat collection and grow out techniques were perfected.

Factors that have been widely credited with the success of Japanese coastal fisheries, and the scallop fishery in particular, include:

> **Enhance productive areas.** Enhancement activities are directed at traditionally productive areas. On-going economic and statistical assessments ensure that enhancement activities are cost-effective and provide value-added.
>
> **Spat collection and propagation**. A large number of wild spat are collected, grown out and transferred to hanging or bottom culture. The cost-effective collection and grow out of spat is perhaps the single biggest factor to the success of the Japanese scallop fishery.

Science and technology improvement. It is an on-going priority of governments, fishers and the private sector to develop and improve enhancement and grow out technology. Governments also direct resources at developing production technologies to assist the industry. Science actively supports enhancement activities. This includes providing direction of spat collection and propagation and when to harvest marketable scallops. The contribution of science to enhancement is discussed in more detail in the Techniques section below.

Fishery Cooperative Associations (FCAs). The FCAs support all aspects of their members' businesses. FCAs started as organizations to administer fishery regulations, but gradually expanded into other areas, such as marketing, credit, processing, leasing out fishing equipment, joint supply purchasing, education and the like. The cooperative approach in all aspects of the fishery is cited in much of the literature as an important success factor.

Use rights are established. Property rights for cultivation and culture are clearly established and owned by the FCAs. Individual fishers and companies are granted the right to enhance and fish areas through their membership in the FCAs. Due to clearly delineated use zones, conflicts between fishers and gear types are generally avoided. FCAs require members to adhere to regulations and the threat of expulsion from the FCA (and hence expulsion from the fishery) ensures that members adhere to management measures.

Flexible management plans: 5 to 10 year management plans are developed, with the flexibility to update and amend as needed. There is also flexibility to tailor fishery regulations to reflect local management objectives.

Education. Formal and informal training is regularly provided for fishers to increase their understanding of enhancement and management practices. In Hokkaido, associations and the prefecture government support education institutes and programs.

Fisher participation in enhancement and management. Use rights and the co-operative association structure provide incentive for harvesters to participate in enhancement activities and fisheries management. For example, spat collection and grow out are financed by governments and harvesters. FCAs and harvesters also conduct enhancement activities independent of government.

4. THE ROLE OF GOVERNMENT

Under the *Fisheries Cooperative Association Law of 1948*, fishing rights are conferred to the FCAs that are used to govern the use of specified fishing zones. Harvesting regulations are developed at the prefecture level, but flexibility exists for the FCAs to adopt the regulations to suit local management objectives. Fishermen and their FCA then manage the fishery within their zones with a minimal level of intervention from the prefecture government.

Regulations: Regulations governing the management of a fishery are set by a Fishery Coordination Committee (FCC) that is independent from the prefecture (state) government. The FCC formulates a plan that is submitted to the prefecture (state) Governor for approval. These plans are amended or adjusted over 5 and 10-year periods. For example, in Aomori the Fishing Industries Promotion Association meets yearly to discuss the previous year, and to discuss management plans for the new season.

On approval of the plan, the Governor issues fishing rights to the FCAs. These rights are granted as a common fishing right, which covers the coastal sea adjacent to the FCA, and extends seaward based on the type of fishing activity and the availability of the resource.

The Governor then issues licenses that restrict access, fleet characteristics, area (zone), season etc. Licenses are granted to individuals or companies. To obtain a license, membership in an FCA that has been issued the right to an area is usually required. The Federal government issues licenses for vessels fishing in two or more prefectures, the EEZ, or on the high seas.

There is flexibility for the FCAs to tailor the management plan to suit local objectives. The FCAs can set goals and objectives for their use areas, and implement management measures. The FCAs therefore have the ability, in cooperation with government, to set the direction of their fishery.

Scallop Science: The prefecture governments support extensive and comprehensive scallop research, including a number of large and well-funded research centers. These centers include management, research, laboratory and hatchery complexes. Real time monitoring is also being conducted. Research centers predict spawning timing and distribution, collect and grow out spat, and study the physiology genetics of scallops as well as methods of culturing techniques. Recommendations on when to harvest the scallops are also made.

Technology Development: National and prefecture governments are active in technology development. This is done through the fishery research centers as well as on a project basis through funding programs.

Credit: All FCAs extend credit functions to their members. A series of credit institutions also exists at the federal and prefecture levels to support priority areas such as debt reduction and modernization. The government underwriting also guarantees credit at a reduced rate for the FCAs and the fishers. Access to subsidized capital has been sited as a major strength for the modernization of the scallop fishery.

5. BIOLOGY

The Japanese scallop *Patinopecten yessoensis* (Jay) is a cold-water species living in northern Japan, Sakhalin, Kuril Islands and northern Korea. It is a member of the family Pectindae and tolerates seawater temperatures from 5 to 20^{o}C.

Typically animals spawn once they are two years of age or older. Females produce in the order of 8 to 18 million eggs once they reach a shell size of 12 to 15-cm. Males produce three to four times as many sperm relative to female egg capacity. Males and females can be identified by the colour of their gonad, with females being reddish orange and males pale yellow to creamy.

Spawning is a once a year affair and is closely correlated to water temperature (discussed below in the Techniques section). Spawning commences in early March is complete by mid-April. After 30 to 40 days, larvae attach themselves, using a byssal thread, to a solid substrate. After 4 to 5 months, when the spat reach a shell size of 8 to 10 mm, they lose their byssal thread and settle to the benthos. Natural predation is then reported to be in the order of 90%.

Surviving animals reach a shell size of 20 to 50 mm after one year, 50 to 90 mm after two years, and 80 to 120 mm by year three. Maximum growth after 10 years is in the order of 200 mm and 1 kilogram in weight.

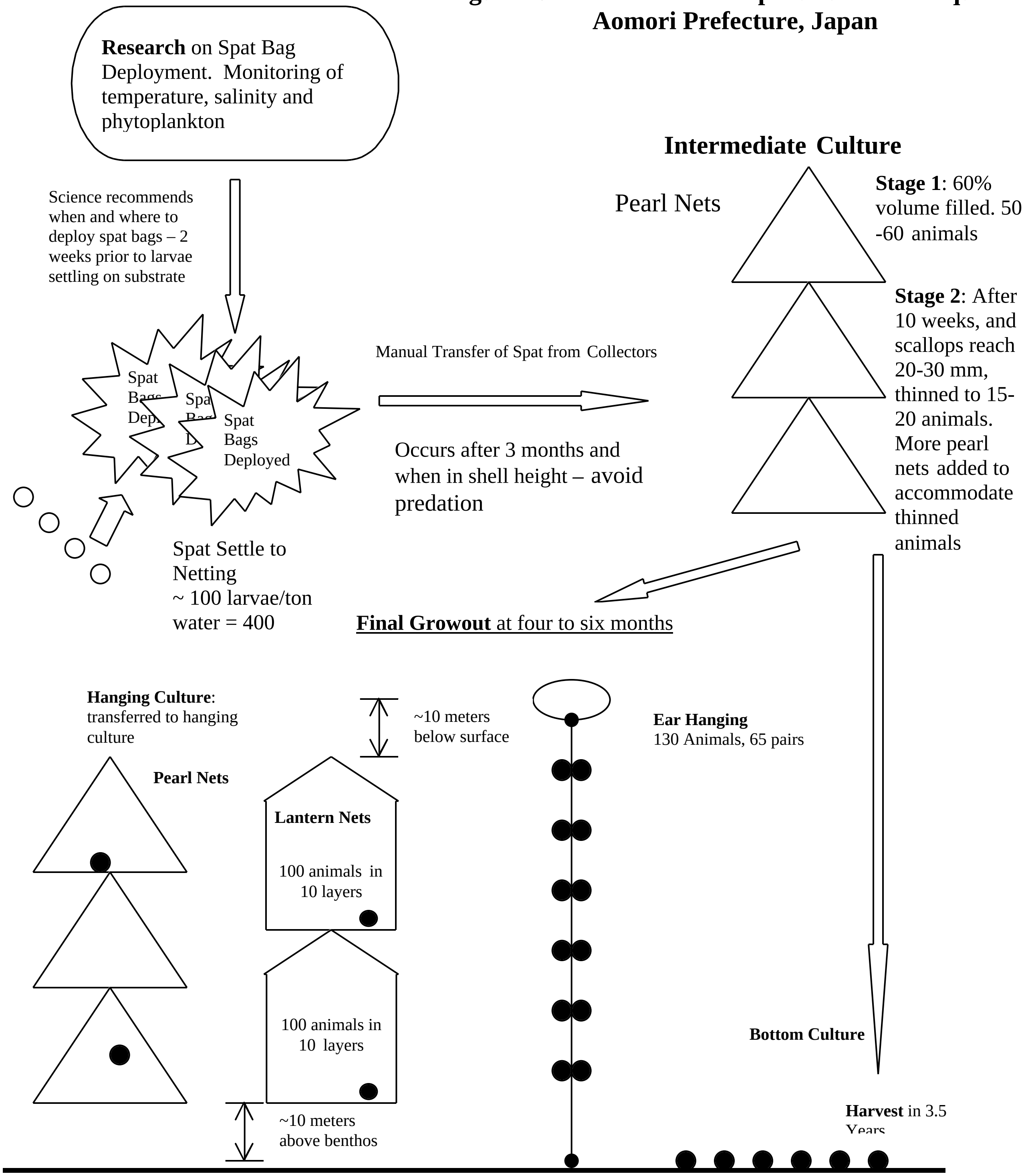
6. TECHNIQUES

The following section provides an overview of the techniques used in Japanese scallop culture. Figure 1 presents a graphical overview of the techniques.

Spat collection

Spat collection is at the heart of the success of the Japanese model. Three factors are important here: spat collection bags; research to predict spawning; and, spat bag harvesting.

Figure 1: Overview of Scallop Culture Techniques in Aomori Prefecture, Japan



Spat collection bags

Once an efficient method for collecting spat immediately after spawn and growing out spat for the first 40 to 70 days (up to 10 mm in shell size) was perfected, cultivation soared. An efficient spat collector was developed in the 1960s using an onion bag with a small mesh size (5 to 8mm) and cedar branches. The cedar branches provided an increased area on which the small seed could stick using byssal thread. The outer mesh bag contained the young scallops and prevented them from settling on the ocean floor, thus avoiding predation.

Modern methods include the use of blue synthetic bags (about 0.66 of a meter long and 0.33 of w meter wide) with a mess aperture of 5 to 6 mm. Monofilament (often gill nets) stuffed into the bags serves as a substrate to which the seeds can attach by their byssal thread. In offshore areas, where larval densities are lower, the bags have a finer mesh size (1 to 1.5mm). It has been observed that spat attach themselves better to clean gear.

Research to predict spawning

A considerable scientific effort is undertaken to predict the timing and distribution of spawning and therefore the optimal time and place to deploy spat collection bags.

Research scientists use data on water temperature, salinity and concentrations of phytoplankton to predict when spawning will occur. Optimal conditions include sustained currents of approximately 6 cm/second ($1/10^{th}$ of a knot) and water temperatures in 6^{o} C to 7^{o} C. In Mutsu Bay, Amori, three automated buoys are used to collect monitoring information. The cost of the entire monitoring, telemetry and display/recording system is in the order of $4.5 million.[1] Using this system, scientists can predict a month in advance when spawning will occur.

The timing of spat collection bag deployment can be identified by monitoring the gonad index of the adult scallops (the relation of weight of the gonads to the entire body weight). Research has shown that water temperatures in the previous year during the September through December period are strongly correlated to gonad maturation. Indeed, the data indicate that the higher the average fall temperature, the longer the period of gonad maturation and hence the later the spawning. Spawning occurs shortly after the gonad index approaches 20%.

Larval abundance surveys (planktonic sampling of larvae through tows) are also used to identify optimal locations for spat collection. In Mutsu Bay, as many as 50 sites are sampled. Fishermen assist with sampling so that they can gain an understanding of larval densities and spatial distribution. Fishermen deploy their bags once 50% of scallop larvae in the water column exceed a shell length of 0.2 mm.

[1] All values are reported in 2001 Canadian Dollars.

Time series data on larval distribution are available since 1950. Surveys for Mutsu Bay indicate maximum larvae densities in the range of 6,000 per tonne of seawater, with recent observations in the 20,000 to 40,000 range. Observations indicate that 400 scallops will settle in the bags when there are 100 larvae per tonne of seawater.

Spat bag harvesting

Spat bags are hung in a vertical series of bags on longlines that are suspended 5 to 10 meters below the surface and 10 to 15 meters above the bottom. This technique has the dual effect of minimizing predation from crabs and starfish, and minimizing wave induced stress on the growing spat. Spat settle out approximately 40 days after spawning.

Spat are generally harvested within three months of bag deployment. This is because recruitment of starfish into the bags cannot be avoided, and the scallop spat must be harvested before predation results in high losses. As a general guide, spat bags are harvested in about three months, and once the scallops reach a size of 8 to 10 mm. They are then transferred to the next grow out stage.

Intermediate culture

The next stage in the grow out is intermediate culture. Spat are transferred to pearl nets (developed originally for pearl culture) via wet newspapers to avoid transfer mortalities and stress. It has also been observed that to limit mortality, speed is of the essence during the transfer from the spat bags to the pearl nets.

The nets are then hung from a buoyed line, with the last pearl net attached to a weight and suspended 4 to 5 meters above the benthos. The first net is placed about 15 meters below the surface. The nets are placed less than a meter apart with about 10 or so bags on each buoyed line. The nets are stocked with between 50 and 60 scallop seeds that remain in the nets until they occupy about 60% of the volume of the net. High mortality rates have been observed when a greater volume is exceeded.

After about 10 weeks or so, and once the juvenile scallops reach a size of 20 to 30 mm, they are thinned to about 15 to 20 animals. Extra pearl nets are added to accommodate the excess scallops. This usually happens in mid-September to mid-October. The scallops remain in the pearl nets for about six months and are then transferred to the next grow out stage.

Bottom culture

Seeding takes place usually twice a year when scallops are either 30 mm (November – December) in shell height or 50 mm (March). Dredging for starfish and other predators takes place prior to seeding.

Seeding densities ranges between 5 to 6 per square meter of sea bottom, and is closely correlated to natural densities. It has been observed that there are different success rates (i.e. seed input to harvested adult) for areas and that statistical analysis is required to identify successful practices for certain areas.

Once established, the animals take about one year longer to mature to market size than net hung animals (i.e. 3 to 4 years). Three reasons are cited:

1. Less phytoplankton relative to the water column;
2. Sediments interfere with filter feeding; and,
3. Predation and the subsequent loss of feeding time due to a flight response.

Bottom cultured scallops are harvested by either divers or with the use of a drag.

Hanging culture

After about six months, the scallops, having reached a size of 10 cm or so, are then thinned and either ear hung or net hung.

Ear hanging is a practice where holes are drilled into the shell of the animals (near the byssal or right ear notch) and then pairs of animals are attached onto a longline at 6 cm intervals. Each line holds about 130 individuals and is suspended below the surface and above the benthos to avoid predation and wave action. The lines are also anchored to the ocean floor.

The animals are attached via a plastic insert and small rope. If conducted manually, about 2,000 animals can be attached in one day. Mechanized ear drilling and attachment machines, however, enable the attachment of 2,500 to 3,000 individuals an hour.

The scallops remain on the longlines until harvest time in 1.5 to 2.5 years, and when they have reached a meat weight of 100 to 130 grams and 10 to 12 cm shell height.

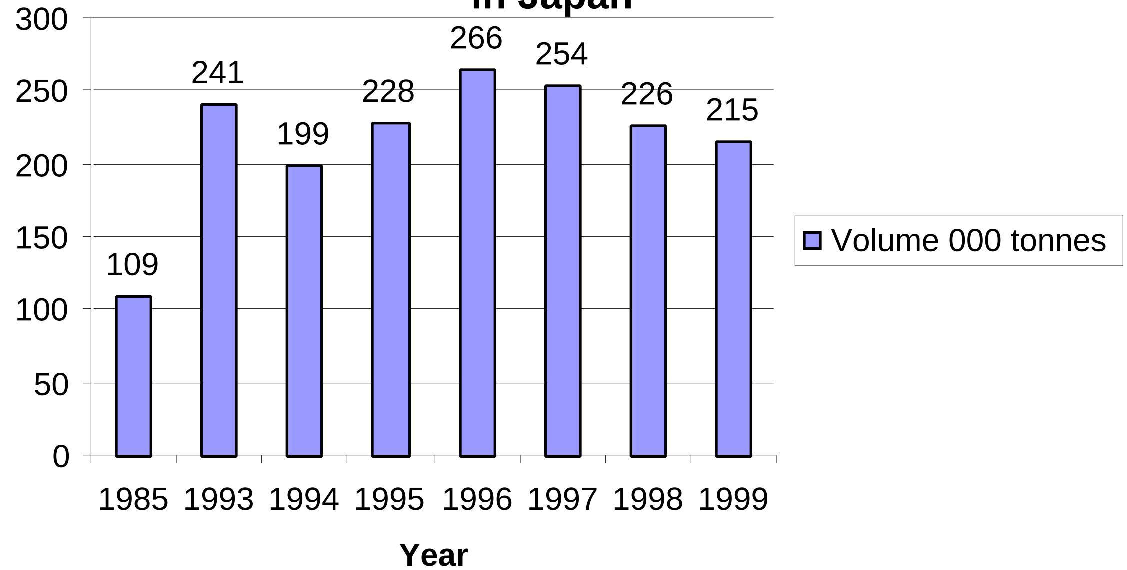
Net hung scallops are transferred from the pearl nets (intermediate grow out), to either new clean pearl nets or lantern nets. Lantern nets are hung in a similar fashion to the pearl nets, with 10 or so nets to a longline. Within each lantern net, scallops are stocked about 10 to a level for a total of about 100 per net. Lantern nets are larger than pearl nets; with a mesh size ranging between 12 to 22 cm. The smaller pearl nets hold about 60 scallops on six levels with a mesh size of about 9 mm.

In Aomori prefecture, about 70% of all scallops are hung, whereas about 30% are based on bottom culture. Seventy percent of Hokkaido's scallop harvest is from bottom culture.

7. PRODUCTION

Production of cultured scallops is centered in Hokkaido and Aomori. Cultured scallops from these two Prefectures (states) account for almost 90% of the landed volume in Japan. In 1999, 215,000 t of cultured scallops (live weight) were harvested, with an average landed volume over the 1993 to 1999 period of 233,000 t. This represents an increase of approximately 100% from 1985 levels (Figure 2).

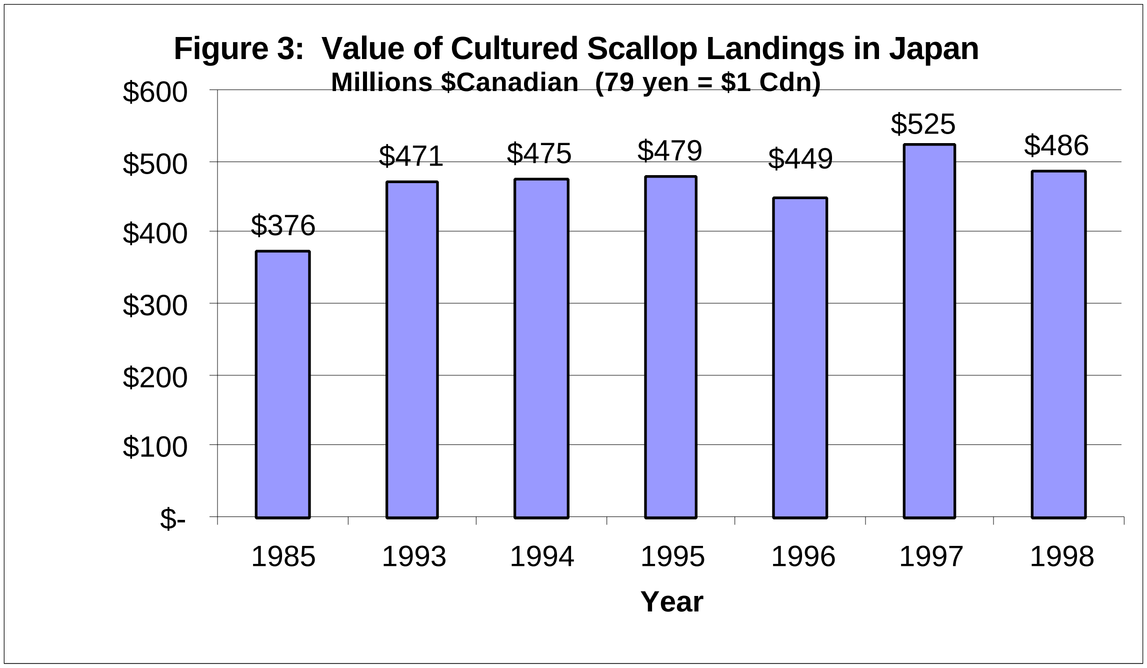
Figure 2: Volume of Cultured Scallop Landings in Japan



Source: Annual Statistics of fishery and Aquiculture Production, Ministry of Agriculture, Forestry and Fisheries, Government of Japan

The corresponding value is presented in Figure 3. As would be expected with fluctuating landings, values have also fluctuated since 1993, with a total value of $486 million in 1998. The average landed value between 1993 and 1998 was $465 million, which represents an increase over 1985 of 24%.

Due to an abundance of available spat, large-scale bottom farming of scallops can be expected in the near future along the coast of Okhotsk Sea, Hokkaido. This area once produced 60,000 tonnes of scallops annually. Development strategies include systematic engineering and newly developed harvesting machines such as suction dredges.



Source: Annual Statistics of fishery and Aquiculture Production, Ministry of Agriculture, Forestry and Fisheries, Government of Japan.

8. LESSONS LEARNED

A number of factors contribute to the success of the scallop fishery in Japan. These include:

Research

- Well-planned and funded basic and applied research;
- Development of grow out techniques and outreach education;
- Monitoring for spat collection and harvesting; and,
- Predation control

Environmental Conditions

- Enhancement areas are those that have had a traditional fishery; and,
- Spat grow out areas are selected to minimize wave and spat transfer stress.

Marketing

- Consistent supply of scallops
- New processing investments to compete in international markets; and,
- Diversified product line.

Organization and Management

- Cooperation among fishermen to manage their fisheries;
- Cooperation between and amongst industry and government;
- Strong government focus on science and technology development;
- Legislation to confer use rights;
- Cooperative fisheries management organizations; and,
- Consistent vision amongst stakeholders to maintain sustainable and high harvest levels.

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ANNEX

SPECIES CASE STUDIES

A.

GEODUCK CLAM

1. BACKGROUND

The geoduck clam (*Panope generosa; P. abrupta*) is a native BC marine bivalve considered the largest burrowing clam in the world and potentially one of the longest lived, reaching ages in excess of 100 years. Its range extends from Baja California to Alaska but its main concentrations are found in British Columbia and Washington State.

Prior to the late 1960s, the harvest of geoduck was limited to intertidal stocks. This changed when large sub-tidal populations were found off the Washington coast and a new subtidal fishery developed in Puget Sound. Based on the initial success in the US, a dive fishery for geoduck in British Columbia began in 1976. The fishery expanded rapidly until 1979 when entry into the fishery was limited by regulation and harvest quotas were established in order to protect the resource from overfishing. In 1989, after several years of overfishing, a system of individual vessel quotas was established, resulting in the creation of equal quotas for the licensed 55 vessels. The result was a more efficient, year round harvest generating a highly beneficial impact on market value.

Quotas are structured on a formula, allowing for the annual harvest of 1% of the existing harvestable population, as determined by survey. Geoduck landings peaked in 1987 at 5,734 t, but by 2000 had decreased to 1,960 t. Currently the fishery is valued in excess of $41 million annually (James, 2001). As a result of significant harvest pressure and a naturally low recruitment rate, harvestable populations have declined and are showing limited signs of recovery in some areas. In response, an organization of commercial harvesters (Underwater Harvesters Association) and one other group began to experiment with an enhancement program in 1994.

2. BIOPHYSICAL REQUIREMENTS

Habitat Characteristics

The geoduck clam occurs throughout coastal British Columbia in beds featuring substrates consisting of a sand, silt, gravel, and shell mix. Geoducks are normally distributed at depths ranging from 3-20 m with identified harvestable beds covering approximately 20,600 ha. (C. Hand, DFO 2001, pers. comm.). The following table indicated various biophysical parameters conducive to geoduck growth and survival.

Summary of optimal biophysical parameters for Geoduck culture.

Substrate	**mud/sand/pea gravel**
Depth	**3-20 m**
Associated fauna/flora	**68 identified species**
Temperature	**8-18 degrees Celsius**
Salinity	**26-31 ppt**
Clarity (Secchi)	**2>10 m**
Current	**<1.5 kt**
Productivity	**15-200 (mg.L -l)**

3. GEODUCK ENHANCEMENT

Seed Production

Due to unpredictable natural recruitment, existing enhancement programs have to rely upon hatchery-produced seed. Hatchery technology for the geoduck has been developed and commercialized. Seeds are grown to 3-6 mm in the hatchery before transfer to a nursery for further out-growing.

Nursery

Survival during nursery and grow out phase increases with the size of the animal. Various nursery systems have been developed in order to raise hatchery-produced seed from 3-6 mm size to about +18 mm considered optimal for grow out:

- In ponds - with supplemental feeding (from 6 mm to 12 mm)
- Benthic Tables – *in situ* nursery- making use of naturally occurring algae and netting protection (from 6-20 mm) over-winter rearing.
- Floating upwelling system (FLUPSY) – A pump maintains the water flow of this nursery system, bringing food (naturally occurring algae) to the shellfish and carries away waste, permitting seed to be grown from 6 to 18 mm under optimal conditions.

Once they reach a size between 12 –20 mm, seed are ready to be planted into the marine substrate where they will grow to market size.

Seeding

Existing enhancement groups have developed mechanized seeding machines capable of planting between 20,000 and 50,000 seed per day depending on seed size, substrate type, tenure size, water and weather conditions. Newly seeded areas are protected with nets.

4. CULTURE-BASED FISHERY MODEL

Overview

Many of the elements of the geoduck case study are based on information contributed by individuals who are intimately involved with the fishery, and with enhancement and culture of the geoduck in British Columbia. The values and assumptions used are well within actual and acceptable ranges familiar to these individuals. Ongoing development in hatchery, nursery and grow out technologies, unexpected natural changes and market conditions of course will impact the validity of the numbers.

Potential Culture Area

The known commercial concentrations of geoduck occur within an estimated area of 20,600 ha (C. Hand, DFO, 2001, pers. comm.). Not all this area offers good prospects for culture. Less than 40% may offer optimal growing conditions because of three main factors:

- ♦ Geoduck requires a suitable substrate such that they can penetrate to a depth of at least one metre. A given area may have only 50% suitable bottom consistency.

- ♦ Citing criteria may eliminate certain areas. For example, consideration must be given to existing biological diversity. For example, an area may contain pockets of eelgrass (*Zostera marina*) covering as much as 15% of the useable area.

- ♦ Current culture approach utilizes netting to protect planted geoduck from predators. To adequately place and maintain netting, corridors are required between planted rows. In this regard 15% or more area may be required as a working area and thus not used for actual production.

This model assumes that some 3,000 ha offers good potential. This area could be divided into many farming units ranging between 5 and 10 ha each. The case study is build around an assumption that one 500 ha unit is developed annually for six years, with production from the first unit available in year six, and the harvest rotating through the units thereafter.

Assumptions

- Planting density = 20 juveniles/m^2
- Survival = 60% to seed (3-6 mm); 50% to juvenile (18 mm)
- Final density = 5 adults/ m^2
- Total habitat area = 20,600 ha
- Assumed culture area = 500 ha/year.
- Annual seed requirements = 100 million
- Survival (@25%) = 25 million/year
- Grow out cycle = 6 years
- Total culture area 500 ha x 6 Years = 3,000 ha
- Seed cost = $0.14/seed (to 6 mm)
- Nursery cost = $0.40/seed (to 1.5 cm)
- Grow out cost = $0.12/seed (to 685 g)
- Total annual seed/grow out cost = $67 million
- Market size = no legal minimum
- Average harvest weight = 685 g
- Total harvest weight = 17 million kg
- CPUE = 900 kg/day/diver
- Effort = 18,900 diver-days x $500/day = $9.5 million
- Sale price = $20.00/kg
- Total revenue = $340 million

Discussion

Survival rate

After many years of combined research it appears that the majority of planted animals will grow out to 680 g animals within six years. Survival rates vary greatly depending on habitat characteristics and predation levels. All persons providing information for this report feel that 25% is a likely and achievable survival rate from hatchery to harvest, provided certain minimum seed sizes are used. Any drop in seed size, technological developments, harvest size, disease, natural destruction (storms) would all have an impact on this survival assumption.

Seeding density

There is a common approach amongst aquaculture companies to maximize seeding densities in an attempt to reduce costs, and make maximum use of available area. Unfortunately, the result of this practice often initiates disease outbreaks, unnatural accumulation of predators and waste byproducts, and may result in exceeding the carrying capacity of the area (E. Gant 2001, pers comm..). It is incumbent upon all participants in such activities to seed all species at environmentally sustainable levels.

Response from a number of commercial geoduck divers, based on their personal experience, is that a density of 5-8 animals/m^2 appears to be the norm in wild stocks. In this regard and in order to support the concept of environmentally sustainable enhancement/culture techniques this example utilizes 5 animals/m^2 as a final density in calculating seeding requirements, useable tenure area, growth rates, etc.

Harvest

Currently harvest is undertaken by the use of underwater SCUBA or Hooka Gear, with the divers using pressurized water jets, referred to as a stinger, to extract the geoduck's from the sediment. In the wild fishery, an experienced diver could expect to harvest 2,000 lb. (909 kg) in a 6-hour working day (E. Gant 2001, pers. comm..). This CPUE is used in the case study.

Only a certain percentage of geoduck "show" ie, have their siphons visible, allowing a diver to find the animals for harvest. It could take up to two years of repeated harvesting attempts in order to remove all of the geoduck present on a site. To reflect this, an assumed harvest efficiency of 85% is built into the overall 25% survival/recovery assumption.

Price

The global wild fishery for the geoduck clam is limited to British Columbia, Washington State and Alaska, with the largest production, and highest quality clam, coming from BC.

Over the years, the Underwater Harvesters Association (UHA) has developed a value-added market for the geoduck. With increasing concern over the absolute freshness of product, many buyers (especially for hot pot and sushi restaurants) have become increasingly aware of the value of live animals. Improved handling of product by fishermen has allowed those geoduck destined for the live market to remain in optimal condition. As a result, the average wholesale price of live geoduck has increased from a low of $0.92/kg in 1981, to a high of $23.70/kg in 1995. Current market values are in the range of $23/kg.

As a result of increased quality, limited supply, an increasing standard of living in Asian countries and an increase in ethnic restaurants in North America, the price structure of the geoduck clam is likely to remain stable for the foreseeable future.

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B.

MANILA CLAM

1. BACKGROUND

The Manila clam (*Tapes philippinarum)* was accidentally introduced into British Columbia through the importation of Pacific oyster (*Crassostrea gigas*) seed from Japan in the mid-1930s The first naturalized specimens were found in Ladysmith Harbour in 1936.

Clams historically were harvested as a source of meats, which were used in chowders, sauces, etc. As a result, up until the mid-1970s, the larger native butter clam (*Saxidomus giganteus*) dominated the landings. With an eventual change in market demand to a smaller "steamer" clam, sold in-the-shell for restaurant use, both the smaller native littleneck clam (*Protothaca staminea)* and the Manila clam began to dominate the harvest after this time.

Even as wild populations began to decline, market demand resulted in an increase in the continued escalation in the harvest of little neck and Manila clams, which reached a peak combined harvest of 4,360 MT in 1988. From that time the volume of harvest began a gradual decline until 1998 when the Manila clam harvest was only 1,115 MT.

In 1998 as a result of 6 years of consultation with industry, First Nations and the public, license limitation was introduced in the commercial intertidal clam fishery in the south coast. The fishery was oversubscribed with approximately 2000 licenses, and openings were reduced to the point that some areas were fished only 2 or 3 days per year. License limitation reduced the number of participants to 1184, of which approximately 50% are First Nations people (Webb, 2001).

As the wild Manila clam fishery began to decline, culture techniques for the production of Manila clam hatchery seed developed in Washington State were introduced to British Columbia (Broadley, T.A, et. al., 1988). As seed became available and grow out techniques became fully developed, many oyster farmers added Manila clam to their farm production. The production of farmed Manila clams has since increased continually with production by 1999 reaching a volume of 900 MT valued at $3.8 million farm gate and $6.6 million wholesale value (Hadden, 2001, pers. comm.).

2. BIOPHYSICAL REQUIREMENTS

The wild Manila clam ranges throughout the southern part of the Strait of Georgia and along the West Coast of Vancouver Island. Since the introduction of hatchery produced seed, the Manila clam has been introduced in various bays throughout much of British

Columbia, but colder water in the north often precludes spawning and, therefore, natural distribution. As a result many of the beaches in central and northern BC are populated with native littleneck clams rather than the Manila.

Populations of Manila clams are generally most abundant between the 1.5-2.5 meter tide height, in substrates containing a mixture of sand, shell, small gravel and mud (Miller, 1982). As Manila clam populations cannot be sustained in a moving substrate they are most often found on such beaches in protected bays and coves.

General water temperatures that are above 13 degrees C for at least 6 month of the year will support the growth of Manila clams. Salinities generally falling within the range of 24-28 ppt are acceptable. Other biophysical parameters are summarized in the following table.

Summary of optimal biophysical parameters for Manila Clam.

Substrate	**shell/gravel/sand/mud**
Tide Height	**1.5-2.5 m**
Temperature	**>13°C for 6 months.**
Salinity	**24-28 ppt**
Exposure	**protected from wave**
Productivity	**phytoplankton –moderate/continuous**

3. MANILA CLAM ENHANCEMENT

Seed Production

Natural recruitment of Manila clam seed on any particular beach is unreliable and unpredictable due to normal annual fluctuations in water temperature, weather, wind and currents. Once the development of hatchery technology made Manila clam seed available on a reliable and consistent basis the culture industry in the province began to develop

In BC at least two hatcheries (Innovative Aquaculture Products Ltd. and Island Scallop Ltd.) produce Manila clam seed. Most of the seed is purchased at very small size from suppliers in Washington and/or California and raised to sizes required for grow out.

Grow Out

The technology and protocols for the grow out of Manila clam is well developed in Canada. Normally the beach area is prepared for planting by digging out any existing clam populations. This aerates the substrate and reduces competition from wild clams. All manila clams are subject to predation by starfish; moon snail, crab, fish such as rock sole, English sole, starry flounder and pile perch, and various birds (Toba, et. al., 1992).

In order to prevent seed destruction, a diamond mesh predator netting made of extruded polyethylene, is placed onto the beach prior to seeding. Optimal mesh size is 1.2 cm with smaller mesh sizes discouraged as it increases the trapping of sediment and clogging. Larger mesh sizes fail to protect against predation.

Once the beach is adequately prepared and netted, seeding takes place by broadcast distribution of clams just as the water reaches the planting site. This ensures the clam seed is placed in a few cm of water. This prevents dehydration and breakage of the seed. Healthy clam seed will dig themselves into the substrate within 0-30 minutes.

The density that seed is planted at, directly effects the survival of seed. Culturists in Canada and Washington typically plant Manila clams seed at densities between 375-400 seed per m^2. Once growers evaluate growth and survival rates for their sites they usually adjust densities to optimize return.

4. CULTURE-BASED FISHERIES MODEL

Overview

The following case study is based on information contributed by several individuals who are intimately involved with the fishery and culture of Manila clams in British Columbia. In this regard the numbers used are well within actual and acceptable ranges experienced. Ongoing development in hatchery, nursery and grow out technologies, unexpected natural changes, and market conditions course will affect the validity of the numbers.

This culture fisheries model assumes planting of seed into the natural environment for grow out and harvest using conventional means (raking or digging). The model assumes netting will be used for predator control.

Potential Culture Area

Clam surveys carried out by Federal fisheries in 1989 indicated the wild fishery on the south coast of BC was supported by 664 commercial beaches covering approximately 8,100 ha (Harbo, 1990). Some Manila clam beaches were identified along the north coast, but lack of water quality testing and PSP monitoring precluded commercial harvest at that time.

Though some 8,100 ha support the existing fishery, not all beaches offer optimal biophysical conditions (especially substrate) and nor do all beaches offer suitable access for culture development. In the absence of a more detailed assessment of biophysical conditions and quality of access, this case study assumes that 3,000 ha could be considered suitable for culture-based fisheries development. This area could be divided into many farming units ranging between 5 and 10 ha each. The case study is build around an assumption that 1,000 ha are developed annually for three years, with production from the first area available in year three, and the harvest rotating through the areas thereafter.

Assumptions

- Planting density = 375 seeds/m^2
- Survival = 60% to adult with 95% recovery
- Final density = 225 adults/m^2
- Total habitat area = 8,000 ha
- Assumed culture area = 1,000 ha/year.
- Annual seed requirements = 3,750 million
- Recovery (@57%) = 2,140 million/year
- Grow out cycle = 3 years
- Total culture area 1,000 ha/year x 3 Years = 3,000 ha
- Seed cost = $0.009/seed
- Nursery cost = not applicable
- Grow out cost = $0.00025/seed
- Total annual seed/grow out cost = $33.75 million
- Average harvest weight = 18 g
- Total harvest weight = 38.5 million kg
- Market size = 38 mm
- CPUE = 800 kg/day
- Effort = 48,125 days x $1,760/day = $84.7 million
- Sale price = $5.00/kg
- Total revenue = $192 million

Discussion

Seed

Seed size of 12 mm is assumed for this case study. This can be purchased from commercial hatcheries at a cost of $9.00/1000.

Survival Rates

For this study, a survival rate of 60% is assumed. Seed clams are usually available from hatcheries at a size of 6-8 mm seed for between $6.50 – $7.50/1000 (Saunders, 2001, pers. comm; Hadden, 2001, pers. comm.). Survival rates to harvest in the range of 40-60% are reasonable in seed planted at this size. Some growers, rather than accepting lower survival rates choose to purchase seed at 12-15 mm in size which is available at a rate of $9.00/1000 seed (Hadden, 2001, pers. comm.,). Survival rates between 50-65%+ can be expected for seed planted at this size. For planning purposes the differential in cost between 6-8 mm and 12-15 mm seed can be considered an operational cost for the nursery phase for a grower.

Seeding Density and Grow Out

A seeding density of 375 clams/m^2 is assumed for this case study. There is a common approach amongst aquaculture companies to maximize seeding densities in an attempt to reduce costs, and make maximum use of available area. Unfortunately, practice may result in disease outbreaks, unnatural accumulation of predators and waste byproducts, and the stunting of animal growth. In British Columbia Manila clams are not seeded above a density of 375 clams/m^2 for this reason.

Sites with optimal biophysical capacity may grow a commercial size Manila clam (38 mm or 1.5 inches) in 2-3 years. We assume three years in this case study.

Harvest

Harvesting is undertaken by manual raking or digging of the substrate and removal of legal sized clams. While the mechanical harvest of clams is allowed in other jurisdictions, this is not acceptable practice in British Columbia. A “good digger” may be expected to remove around 148 kg per hour over a 5.5 hour tide or 800 kg per tide. Harvesters are often paid piecework and a reasonable rate of remuneration in British Columbia ranges between $1.87 kg. –$2.42 kg with $2.20 a common level of payment. The latter is assumed in this case study for costing purposes.

Occasionally, clams may be damaged during harvest, or are stunted or deformed during grow out. In order to anticipate this, the harvest rate in this case study is 95%, with 5% of clams assumed to be missed, damaged or unusable. This loss level is combined with the 60% survival rate to produce an overall recovery rate of 57%.

Sale price

The sale price of cultured Manila clam is fairly stable in British Columbia at about $5.00/kg at the farm gate. This price is used in the estimate of total value from enhancement.

The majority of all Manila clams produced in British Columbia are exported to the United States. A 1993 marketing survey indicated that the bulk of the wild harvest of Manila clams is sold into the retail market sector, whereas the most cultured clams are sold into the foodservice (restaurant) sector. Those sold into the foodservice sector have more stringent requirements for size and shape, and command a premium price. Supply is the major limiting factor in expanding sales. The relatively small BC production is sold into a very large global market (over 1.1 billion t), so even a substantial increase in supply from enhancement in British Columbia would have little or no measurable effect on prices.

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C.

NORTHERN ABALONE

1. BACKGROUND

The Northern or "Pinto" Abalone (*Haliotis kamtschatkana*) is a native marine gastropod whose historical habitat ranges from Southern Alaska to Northern California. In British Columbia this species was once widely, but very irregularly, distributed in appropriate habitat throughout coastal waters. As a result of over-harvesting since the 1970s, populations have been reduced over and the abalone is now a "threatened" species.

Historically this species made a significant contribution to west coast First Nations, providing value for food, social and ceremonial use. Commercial harvests were first recorded in 1910 and continued sporadically until past 1926. The fishery was essentially demand-limited during the post-war years and into the 1970s, with an annual mean harvest of just 7.7 t annually.

Increased market demand in Asia coupled with good stock abundance and unrestricted access to the resource caused commercial harvests to increase rapidly, rising to 433 t by 1978. In 1979 harvest quotas were introduced and distributed among 26 existing license holders. Stocks declined sharply after 1978, despite license restrictions and an annual quota set at 47 t from 1985-90. In 1990 the fishery was closed for conservation purposes and to allow for the recovery of stocks. An illegal fishery continued, stocks continued to decline, and in 2000 the northern abalone was listed as "Threatened" by the Government of Canada.

With populations failing to recover, DFO, First Nations, coastal communities, interested companies and individuals held a workshop in February of 1999 to develop a strategy for rebuilding abalone stocks. Currently six organizations are involved in pilot projects to develop the technology and seed necessary for restocking abalone populations.

2. BIOPHYSICAL REQUIREMENTS

Habitat Characteristics

Northern abalone has a wide habitat tolerance with a good portion of coastal British Columbia falling within its historical range. Typically, abalone favors areas containing rocky substrates, clean water, high salinity, fast water flow rates, and optimal macroalgae resources. Abalone is distributed to depths of 20 m, with adults normally inhabiting depths of less than 10 meters.

Summary of optimal biophysical parameters for Northern Abalone

Substrate	**rock/boulder**
Depth	**optimal 8-12 m**
Associated fauna/flora	**urchin, macro kelps**
Temperature	**1.5 – 14°c**
Salinity	**30-34 ppt**

Abundance and Density

No empirical density estimates of northern abalone were made in British Columbia before 1976. Based on discussions with fishermen of that period and a biologist who worked on abalone prior to 1976, the density of northern abalone on the north coast of BC was estimated to be 2.5 abalone per m^2. In extensive surveys of the eastern Queen Charlotte Islands, (Breen and Adkins, 1979) estimated mean density at >16/m^2 (with a range of 0-28/ m^2). The highest density within one 1 m^2 quadrant was 56.

Estimating the total biomass for northern abalone populations is not practical due to the tendency of the animals to climb. Density of abalone appears highest in the kelp zone but decreases rapidly by depth. Loose substrates yield no abalone, Macrocystis canopy yield few numbers of large abalone and exposed Pteryogophora communities on bedrock sustain dense populations of small abalone. It appears that juvenile abalone set in deeper water and as they grow they move into shallower water.

3. ABALONE ENHANCEMENT

Seed Production

The population of wild northern abalone has been severely compromised and, as a result, the collection of wild abalone seed is not an option. The feasibility of any enhancement program must rely on the production of hatchery based juveniles (seed). An attempt at developing hatchery technology in British Columbia in 1985 failed due to disease problems.

Currently, each of the six pilot projects initiated under the Fisheries and Oceans Canada abalone restocking program are investing in hatchery technology to produce abalone seed. Such technology is available from national and international experience. Northern abalone seed stock reach a shell length of 10-15 mm in 4-5 months at which time they may be transferred from the hatchery to a nursery to begin the process of grow out to market size.

Nursery

In British Columbia the over-wintering of juveniles is required to reach the minimum size for planting. As seawater temperature drops, abalone growth will slow and may even stop during very low temperature. In order to allow continued growth, water temperature in the nursery facility must be elevated to 12-14 degrees C.

Once the juvenile abalone has reached approximately 1.5 cm, it can be transferred out of the nursery facility. The animals are hardy and require only feeding and protection from predators. Seeding juveniles at this size avoids high capital costs associated with intermediate culture, but survival rates for 1.5 cm seed are usually poor (±10%) due mainly to predation. Survival rates increase markedly with seed size, so there is a trade-off between the additional costs of protecting juveniles and the higher revenues attributable to a higher survival rate.

4. CULTURE-BASED FISHERY MODEL

Overview

The model is based on information contributed by individuals who were licensed abalone fishermen, hatchery personnel and government biologists from a number of countries who have knowledge of the enhancement and culture of various abalone species. As the northern abalone has yet to be commercially cultured to market in BC the numbers remain theoretical. Ongoing development in hatchery, nursery and grow out technologies, unexpected natural changes and market conditions of course will impact the validity of the numbers.

This culture fishery model assumes full release of seed into the natural environment for grow out and eventual harvest using conventional commercial means (diving). No intermediate culture methods are assumed. Increasing the survival rate is achieved by growing the seed to 2 cm at the hatchery stage.

Potential Culture Area

Northern abalone historically ranged throughout coastal British Columbia. While suitable biophysical characteristics for northern abalone have been identified no formal studies have been conducted to determine the area of coastal British Columbia that would support abalone populations.

Adult abalone feed primarily on Nereocystis Spp. of kelp. Surveys for this species have been undertaken throughout coastal British Columbia. Recent surveys indicate that beds of Nereocystis and Mixed Nereo/Macro cover approximately 11,020 ha. in BC (Sutherland, 1996; 1990; 1989). Discussions with abalone divers indicate that some 20-50% of these beds would be suitable for a culture-based fishery.

This case study assumes that 2,500 ha would be suitable for this culture, with 500 ha coming into development each year for five years. Production would then rotate through each 500 ha area on an annual basis.

Assumptions

Indicative production, cost and revenue assumptions are set out below. These capture most of the variables, though some cost items (eg, nursery and seeding) are not included.

- Planting density = 40 juveniles/m^2
- Survival = 60% to seed (6 mm); 55% to juvenile (1.5 cm)
- Final density = 12 adults/ m^2
- Total habitat area = 11,000 ha
- Assumed culture area = 500 ha/year.
- Grow out Cycle = 5 years (4-6 range)
- Total culture area 500 ha x 5 Years = 2,500 ha
- Seed cost = $0.10/seed (to 6 mm)
- Intermediate cost = $0.48/seed (to 1.5 cm)
- Total annual seed cost = $78 million
- Average harvest weight 6 cm animal = 95 g
- Total harvest weight = 5.7 million kg
- Market size = 75 mm
- CPUE = 200 kg/day/diver
- Effort = 28,500 diver-days x $500/day = $14.25 million
- Sale price = $40.00/kg
- Total revenue = $228 million

Discussion

Survival Rates

We use an overall survival rate of 30% based on moderate survival rates gauged from various studies. Preliminary studies from South Africa indicate the survival of hatchery produced extensively dispersed abalone seed increased from 21% to 55% over a six month trial by increasing plant out size from 1.5 to 2.7 cm (de Waal, 2001, pers. comm.). Similar results are obtained from enhancement studies in China, where recovery rates increased from 10% to over 70% as abalone seed size increased from 2 to 4 cm. Achieving these larger sizes is possible by using pearl nets at an intermediate stage, or by protecting the abalone seed on bottom with so-called net tanks (simple frames covered with PVC mesh).

Seeding Density

A seeding density of 40/m^2 with a final (harvest) density of 12/m^2 is used in this example. Historical density for wild abalone, from studies conducted in the Queen Charlotte Islands of British Columbia in the late 1970s, were determined to be 16/m^2 with a range of 0-28, (Breen and Adkins, 1979). Seeding densities for enhanced bottom reared abalone ranged from 10/m^2 for unprotected enhanced to 250/m^2 for caged (Shen, J. and S. Kuang, 1996).

Harvest

It is common in abalone not to be able to get every animal due to their tendency to hide in crevasses, under rocks, etc. Experienced abalone harvesters estimate that over a period of time they can extract about 95% of available animals. The CPUE in the wild fishery is estimated at 200 kg/diver/day, at a cost of $500/diver-day.

Size at harvest

An average size of 75 mm (95 g) is used in this study. Cultured abalone of various species are harvested at sizes ranging from 50 to 90 mm (Gordon, 2001). The smaller sizes (50 to 75 mm) are directed to a value added “cocktail” market. Production at this size reduces grow out time by 1-2 years.

Spawning

Abalone become mature at sizes over 50 mm and thereafter contributes to the natural recruitment of the population. Maintaining a harvest size of 75 mm should result in animals spawning 1-2 times prior to harvest thus contributing to the recruitment/enhancement of abalone in the general area.

Sale price

While pricing of abalone products seem to vary greatly when expressed in terms of “in shell” weight, the world price for the same size and quality “in shell” abalone tends to converge regardless of the form to market. An analysis of world pricing for all species of abalone converted to an “in shell” commodity price is approximately CDN$19.00/kg. (Gordon, 2001). Numerous producers in North America focus on value adding cultured abalone by selling a smaller sized “cocktail” abalone (50-75 mm). Recent pricing of this product has been quoted as CDN$49/kg, about 2.5 times world commodity prices. In this analysis we use $40/kg based on the farm gate value of the cocktail size.

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D.

JAPANESE SCALLOP

1. BACKGROUND

Thirteen species of scallops occur in the coastal waters of British Columbia. Most of these are small, or rare, but four species are of sufficient size to make them attractive to the market. Of these species, the pink scallop (*Chlamys rubida*), the spiny scallop (*C. hastata*), the weathervane scallop (*Patinopecten caurinus*) and the purple hinge rock scallop (*Crassadoma gigantea*), fisheries exist only for the pink and spiny scallops.

The populations of these two species are small and occur in scattered beds. In 2000 the fishery for these two species resulted in landings of 52.2 t with a value of $250,000. Due to concerns over the limited data available for this fishery, the Federal Minister discontinued commercial scallop licenses in 2000. Scallop fisheries now are allowed under scientific license only.

Strong international markets for scallop species, but limited harvestable biomass in British Columbia, encouraged the Federal Department of Fisheries and Ocean's scientists to examine the feasibility of scallop aquaculture beginning in the early 1980s. To initiate the process, Japanese scallop broodstock were imported to British Columbia, held and spawned in quarantine to avoid the possibility of transfer of disease to BC waters. Resulting seed was out-planted at eight sites in BC. Encouraging growth and survival rates were found at some sites. Research into the development of hatchery, nursery and grow out technology was carried out by both federal and provincial governments, and eventually by industry.

In 1989, Island Scallops Ltd., with federal and provincial funding assistance, built a marine shellfish facility to commercialize the hatchery technology for the Japanese scallop. Hatchery work progressed to a commercial stage and grow out work began at several sites where appropriate scallop culture methods were developed.

A disease caused by a protozoan of unknown type (SPX) was found in scallops grown at several sites in British Columbia. After experiencing one year of excellent growth and survival, typically 60% of scallops died during the second year of grow out, with some locations experiencing virtually 100% mortality. (Bower, et. al., 1992). Fortunately, a few survivors were resistance to SPX and formed the basis of a broodstock that today supports a small aquaculture industry (30 t production in 1999, valued at $200-300,000).

In order to overcome disease induced mortality, a disease resistant hybrid was developed (*Pacific scallop*) resulting from a cross between the Japanese scallop females (*P. yessoensis*) with males of the local weathervane scallop (*P. caurinus*) females. This hybrid forms the basis of this case study.

2. BIOPHYSICAL REQUIREMENTS

The Japanese have identified three basic characteristics to be considered when selecting a site for scallop culture:

- maintenance of low moderate water temperatures (7-10^{0}C.);
- sustaining high water column salinity (>28 ppt); and,
- minimizing movement, or motion, of the culture apparatus (if suspension methods are used).

Both the Japanese and weathervane scallops are a cold-water species, preferring water temperatures ranging between 7-10°C. Growth slows when water temperatures exceed 12.5°C and mortalities may occur at temperatures exceeding 16°C (Cross, 1993). Salinities between 28-31 ppt are tolerated, through 30-31 ppt are optimal (Heath, 1993).

Coastal BC has numerous areas that provide sheltered, deep water sites with good water flow. Due to the intrusion of rain and snowmelt, brackish water may be a problem and for this reason optimal culture depths usually exceed seven meters in order to maintain proper salinity.

Scallops do well in areas with good (but not excessive) water circulation. These currents will supply an adequate level of planktonic food and water exchange for respiration and excretion. Scallops are susceptible to “sea sickness”; as a result any hanging technology should be located in areas with wave heights less than 1 m. The optimum is <0.75 m. The bottom seeding approach under consideration in this study avoids this constraint.

Key biophysical parameters are set out in the following table.

Summary of optimal biophysical parameters for Pacific scallop.

Substrate	**gravel/sand/shell**
Depth	**10-50 m**
Temperature	**7-10 degrees C**
Salinity	**28-31 ppt**
Oxygen	**> 2.0 cc/L**
Productivity	**phytoplankton –moderate/continuous**

Abundance and Density

There is no wild fishery for the hybrid Pacific scallop in British Columbia. Estimates of natural abundance and density are not available.

3. SCALLOP ENHANCEMENT

Seed production

Collection of wild scallop seed is not an option given the very small population. The feasibility of any enhancement program must rely on the production of seed from hatcheries. Two hatcheries in British Columbia provide scallop seed in commercial quantities.

Nursery/intermediate culture

Seed scallops have a relatively low tolerance for temperature and salinity fluctuations but require optimal plankton availability. It is important, therefore, when the seed are placed in a nursery site to ensure they are deep enough to avoid temperature and salinity fluctuations yet have access to plankton in the water.

Scallop seed may be moved out into a nursery by April or May, once seed is still less than 1 mm in size. Seed, held in “spat” or “Japanese Onion” bags are suspended from longlines in optimal growing areas. Densities of 1,000 seed per nursery bag are common.

By June or July seed has usually reached a size of 1-1.5 cm and it detaches from the “collector” material and is loose within the bags. At this stage seed is sorted and may either be seeded directly onto the bottom for final grow out, or transferred to “pearl” nets for further growth. Further growth would increase the survival rate (and revenues), albeit with higher capital and operating costs. Direct seeding would result in higher mortality (and lower revenues), but with lower capital and operating costs. The optimal approach would vary depending on the relative costs and benefits, and could only be determined through experimentation.

4. CULTURE-BASED FISHERY MODEL

Overview

There are currently no established commercial scallop culture operations in British Columbia using the bottom seeding method. Consequently, parameters and assumptions that would help in defining a culture model for local waters are not available. Instead, the model relies on assumptions identified through research papers, personal communications, the Japanese experience with this species, and examples of similar work (different species) taking place in eastern Canada. Ongoing development in hatchery, nursery and grow out technologies, unexpected natural changes and market conditions of course will affect the validity of the assumptions.

The Japanese experience with rebuilding of their scallop industry provides a commercially successful example of the culture-based fishery concept. Over half that country’s approximately 400,000 t scallop production is derived from bottom seeded culture operations. An outline of the Japanese experience appears in Chapter IV.

Potential culture area

Estimates of potential culture area based on actual fisheries experience or habitat suitability are not available. It is possible to provide a very rough estimate of potential scallop habitat based on the area suitable for geoduck. The biophysical requirements are broadly similar, though geoduck has a more stringent substrate requirement. Approaching the estimate in this way would suggest that at a minimum, the area meeting the scallop biophysical requirements could be in the order of 10,000 ha.

For this study, we assume an area of 3,000 ha would provide optimal conditions for scallop growth. The case study is developed around the assumption that 1,000 ha are developed annually for three years (a 3-year grow out cycle), with production from the first area available in year three, and the harvest rotating through the areas thereafter. To put this figures in perspective, it is worth noting that in just one bay in Japan (Mutsu Bay), some 20,000 ha (200 km^2) are dedicated to bottom seeding.

Assumptions

- Planting density = 8 seeds/m^2
- Survival = 15% to adult
- Final density = 1.2 adults/m^2
- Total habitat area = 10,000 ha
- Assumed culture area = 1,000 ha/year.
- Annual seed requirements = 80 million
- Recovery (@15%) = 12 million/year
- Grow out cycle = 3 years
- Total culture area 1,000 ha/year x 3 Years = 3,000 ha
- Seed cost = $0.02/seed
- Nursery cost = not applicable
- Grow out cost = not applicable
- Total annual seed cost = $ 1.6 million
- Average harvest weight = 125 g
- Market size = no legal minimum
- Total harvest weight = 1.5 million kg
- CPUE (dredge) = 300 kg/day
- Effort = 5,000 vessel-days
- Landed price = $6.50/kg
- Total revenue = $9.75 million

Discussion

Seed

Seed size of 30 mm is assumed for this study. This can be purchased from commercial hatcheries at a cost of $20/1,000. Smaller seed would be viable, but would face very high mortality levels. Using this larger seed adds to cost, but the trade off is seen as worthwhile because of the higher survival rate.

Survival rates

For this study, a survival rate of 15% is assumed. This figure is adjusted downwards from the Japanese experience (35% survival) to account for an assumed lack of predator control in British Columbia. Japanese fishermen practice predator control by dragging starfish mops over the bottom before seeding, and also by using starfish traps. Mopping is ruled out in this case study because of the cost, and also because we assume it would not be permitted in Canadian waters.

Seeding density and grow out

A density of 8 seeds per m^2 is assumed for this study. This is based on the Japanese experience and also the experience of one British Columbia company involved in bottom culture. Intensive bottom culture in Japan begins with animals of 30-50 mm. They are grown to this size in pearl nets to reduce mortality due to predation. Seeding is carried out based on optimal carrying capacity of 1,200 g/m^2 or approximately six commercially sized animals per m^2 (Tanaka, 1980).

In British Columbia, Island Scallop Ltd. has being carrying out bottom seeding since 1993, with 18,000,000 3-4 mm seed planted in 2000 (Saunders, 2001, pers. comm.). This project utilizes extensive culture protocols involving low density seeding using broadcast methods. Due to the area in question, no predator protection is used for bottom culture. The grow out period for 3-4 mm seed is expected to be three years. No estimates are yet available on survival rates.

Harvest

The case study assumes scallops are harvested using conventional dredge technology. Diving is also possible, but the relatively low density of adult scallops would render this uneconomic. Based on mean 10-year data for the wild pink and spiny scallop in British Columbia, a CPUE of 24 kg/hr tow time is assumed (DFO, 2001). This works out to about 300 kg/day.

Landed price

Moderate levels of cultured scallops have been harvested and sold in British Columbia since 1995. In 1999 scallop production reached 30 t with a landed value of $200,000 or $6.60/kg. This price is used in the analysis. Based on an average expected harvest weight of 100 g per animal, each marketable animal is valued at $0.67 each. Larger scallops (11 cm or 125 g) sell for as much $1.00 each (Saunders, pers. comm., 2001).

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E.

SEA SCALLOP

1. BACKGROUND

The sea scallop *Placopecten magellanicus* ranges from North Carolina to the northern Gulf of St. Lawrence, and supports among the most lucrative shellfish fisheries on the East Coast. Scallops range from shallow water to >200 m and are epifaunal suspension feeders occupying hard or coarse substrates. The fishery formerly included many inshore areas and bays, but is now largely restricted to offshore banks and selected inshore beds (e.g. Bay of Fundy).

Inshore fishery

The inshore fishery is concentrated in the Bay of Fundy, though significant landings are recorded in Quebec and Newfoundland. The stocks in the Bay of Fundy have suffered from competitive fishing and limited management for many years. The fishery developed strongly in the mid-1980s, following the closure of offshore grounds (mainly Georges Bank) to inshore vessels. In the absence of quotas, landings peaked at about 4,500 tonnes in 1989, but dropped sharply thereafter largely due to excessive fishing pressure. Landings fell to 1,754 tonnes in 1995. In the face of a complete collapse of the stocks, a quota was finally introduced in 1997. Stocks continued to decline, and by 1999, landings had dropped to about 785 tonnes against a quota of 760 tonnes. About 190 vessels are active, down from over 350 at the height of the fishery.

Offshore fishery

Canada's offshore scallop fishery is conducted mainly off the southwest coast of Nova Scotia on Georges Bank and to a lesser extent on several banks on the Scotian Shelf: Browns Bank, German Bank, Sable Bank and Western Bank.

For Georges Bank the long-term objective is to regulate the fishery with the aim of optimizing yield or value. This objective is met by regulating the size of the scallops that may be harvested (30 meats/lb) and by controlling the overall effort of the fishery by quota and individual quota. The once large (77-vessel) offshore fleet now operates with some 20-25 vessels. Fleet rationalization is largely due to the introduction of enterprise allocations (company quotas) that eliminated competitive fishing and the need for excessive harvesting capacity. The offshore fishery typically generates a landed value exceeding $60 million.

Scallops reproduce in September- October, but some populations also display a spring spawn. Sea scallops enter the fishery at 5-6 years of age. Although the harvest fishery is reasonable healthy, it is in some locations sustained by a few successful year classes. DFO has extensive long-term data on scallop stock dynamics and there is a large scientific literature on sea scallops specific to eastern Canada. The fishery is largely oriented toward adductor muscles, although there is some export of whole scallops for the shell-on trade. Due to the high value of scallop meat, there has been wide interest in aquaculture of this species. Bottom seeding has been a successful mode of culture-based fishery for various scallop species elsewhere, and trial seeding with sea scallops has been attempted (Cliche, et. al., 1997).

Bottom culture has the advantage of low capital and maintenance costs, but the detriment of high mortality and often slower growth. The most extensive attempts at bottom culture have been conducted in Gulf of St. Lawrence waters. These include projects on the Magdalen Islands, in the Baie des Chaleurs (Maritime Fishermen's Union), and in the Northumberland Strait (Botsford Professional Fisherman Association). There is undoubtedly ample scallop habitat on the East Coast, and restoring stocks to these areas would result in a significant fishery yield. On this basis, the estimation of the value of a harvest arising from seeding potential grounds is undertaken. It is emphasized that harvest of scallops will require extensive dredging of inshore habitats. Scallop dredging has been shown to have negative impacts on natural benthos (Thrush, at al., 1998), so an increase in this activity is not a casual undertaking.

2. BIOPHYSICAL REQUIREMENTS

Scallops require high oxygen concentrations. This species is stenohaline, requiring a salinity of at least 30 ppt. It is highly sensitive, and relatively intolerant of pollution and high concentrations of suspended particulate material (Cranford and Gordon, 1992). Scallops are very sensitive to temperature fluctuations. In the past, mass mortalities of scallops in shallow water (12 to 20 m or less) have been attributed to oscillations in the thermocline. The absolute upper lethal limit is 22.5^{o}C, although significant stress occurs much below this limit. Optimal temperatures for growth are 10 to 15 ^{o} C. Below 8^{o} C growth slows.

Summary of optimal biophysical parameters for sea scallop.

Substrate	**shell/gravel/sand/muddy sand**
Seeding depth	**5-100 m**
Temperature	**>0-18**
Salinity	**>30 ppt**
Turbidity	**low**
Exposure	**below surf zone**

3. SEA SCALLOP ENHANCEMENT

Seed production

Two complementary methods of obtaining sea scallop seed are natural spat collection and hatchery production. Natural collection is less expensive but still requires the use of moored hardware usually consisting of mesh bags filled with netting (commercially available) or other material (e.g., netron) with high surface area, on which scallops will settle. The timing of collector deployment relative to scallop spawning is also critical so that collectors are in the water during spatfall (usually autumn). In addition, there are known locations (e.g. Passamaquodddy Bay, NB) with increased success of collection.

Collectors are left in the water for a matter of weeks after which they are recovered and small scallops removed. Spat are too small to be successfully seeded and must undergo intermediate culture (see below). Hatchery production is a more reliable method of obtaining spat in the long run. Some of the initial technical problems have been overcome, and much larger scale hatchery production than now exists is feasible. Despite the initial capital costs and required technical expertise, this approach avoids the uncertainty, field expense and logistics of spat collection. Moreover, it is possible to raise spat to sufficient size to reduce or avoid intermediate culture.

Nursery

Intermediate culture in containers such as pearl nets allows scallops to attain greater size in a protected environment prior to seeding. This step requires purchase and establishment of anchors, lines, and nets in a defined area over a period of ~1 year, adding considerable to the costs and handling of the culture cycle. Moreover, the culture sites must be leased and licensed for this purpose. Given the cost and effort in setting up culture nets, it would be difficult to justify sowing the juveniles to the bottom where losses would be likely >70%, as opposed to simply continuing suspended grow out.

Alternatively, intermediate culture may take place in the collector bags at half the cost per spat compared to pearl nets, but growth may be reduced by 30% (Cliche, et. al., 1997). In this case the costs and stability of the collector anchors must be equivalent to that of the pearl nets, but the capital costs of the containment structures are less. It should be noted that larval predators that settle into the collectors will mature there at the expense of the scallops. The collectors may need to be moved from the spat collection site to a favourable nursery area with adequate food, where they remain for ~1 year at which scallops may reach 25 mm size. Commercial mechanized equipment is available for sorting of scallops washed from the collectors.

Seeding

Scallops occur on many different substrates, and are most common on cobble, gravel, and sand. Scallops are intolerant of high temperatures, low salinity, and excessive turbidity, such that soft muddy bottoms and/or shallow estuaries are less suitable. *Placopecten* lives in areas of high tidal flow, but not in wave-exposed shallow sands. Rocky bottoms will make harvesting problematic.

Scallops are subject to handling and exposure stress, which may increase mortality (Fleury, et. al., 1996). Prior to seeding, they must be kept immersed or suitably wetted on the seeding vessel. Once on the bottom, they may be faced with swimming and predator avoidance. These stresses will enhance initial mortality and/or predation risk. We note that in the present consideration of seeding, factors such as growth and survival are not assumed to be substrate specific, because these dependencies are not well known, and because we do not know the substrate characteristics of much of the coastline.

4. CULTURE-BASED FISHERIES MODEL

Overview

The scenario for bottom culture of sea scallops is based on seeding experiments cited below as well as on commercial scale seeding conducted in Quebec. We assume that harvestable densities resulting from seeding will be similar to natural densities, i.e. that seeding does not enhance natural abundance. We also assume that seeding would occur in areas on existing commercial scallop beds. These areas may be closed to promote optimal growth. The value of area or rotational closures to promote scallop growth has been amply demonstrated with the 1999 re-opening of the scallop fishery on the US side of Georges Bank after a five-year moratorium. Stocks had recovered sharply from levels in the early 1990s, and much of the catch was composed of large scallops, i.e., <10 meats per pound. (Gardner Pinfold, 2000).

Potential Culture Area

In the present study, the depth range for potential sea scallop habitat was considered to be 5 to 100 m. Potential habitats were chosen where depth contours were well-spaced, indicating gentle shelving. Sea bottom types include sand, shell, and gravel, and where possible exclude mud. Areas of low water exchange or excessive turbidity, when identifiable, were excluded. Total potential habitat taking these and other factors (eg, low water temperature) into consideration is estimated to be 68,300 km^2.

Geographic specifics are as follows. Eastern Newfoundland is an exposed, rocky coast with many bays and inlets. Small areas of potential sea scallop habitat were located in several bays, although no commercial fisheries are supported. The coast of northeastern Newfoundland is generally exposed, although several islands and gently sloping seabed in the inner Notre Dame Bay area provide potential habitat for scallops. Of particular interest are areas between Fogo Island and Bacalhao and the area between Hare Bay and

Belle Isle. The coast of southern Newfoundland provides significant potential scallop habitat both in nearshore areas (i.e. in Placentia Bay) an on offshore banks (Burgeo, St. Pierre). A large area in and around Port-au-Port Bay was identified as potential scallop habitat. This area supports a productive commercial scallop fishery, so can be assumed to be actual rather than potential scallop habitat. The bays and the seafloor offshore on the western coast of Newfoundland appear to be potential habitat for sea scallops. The northern limit was considered to be Belle Isle, so the coast of Labrador was not examined.

Large areas in the southern Gulf of St. Lawrence are considered to be potential sea-scallop habitat because of suitable depth ranges and bottom types, and extant fisheries are conducted there. On the eastern coast of Nova Scotia there are abundant bays and inlets, which may be potential scallop habitat. Large areas of the seabed between the shore and the 50-fathom depth line may be suitable as scallop habitat but they have not been included in these calculations. The bottom types are not well enough known to make any reasonable estimates of areas available. Also, the exposure here limits the ability to harvest. Although there are many bays and inlets on the western to southwestern coast of Nova Scotia, they are quite shallow and thus prone to rapid warming in the summer periods, which is a significant cause of mortality in nearshore scallop populations. Thus, although some of these inlets may currently sustain small scallop populations, for the present exercise they are not considered as potential scallop habitat.

For purposes of this analysis, we assume a culture area of 2,500 km^2 (250,000 ha). This is conservative and somewhat arbitrary, and an area substantially smaller than that considered as suitable habitat (68,300 km^2). Three main factors explain this conservative assumption: a) optimality - the area providing optimal conditions is likely to be substantially smaller than that which provides minimum conditions; b) manageability - from the standpoint of seeding operations and cost; and c) accessibility - obtaining exclusive use of ocean space may be difficult, given competing fisheries and other uses.

Assumptions

- Seeding density = 10 juveniles/m^2
- Survival = 15% to adult with 85% recovery
- Final density = 1.5 adults/m^2
- Total habitat area = 68,300 km^2 (6,830,000 ha)
- Assumed culture area = 50,000 ha/year.
- Annual seed requirements = 5,000 million
- Recovery (@ 20%) = 1,000 million/year
- Grow out cycle = 5 years
- Total culture area 50,000 ha/year x 5 Years = 250,000 ha
- Seed cost = $0.015/seed
- Nursery cost = $0.010
- Grow out cost = not applicable
- Total annual seed/grow out cost = $ 101 million

Assumptions (continued)

- Average harvest meat weight = 16 g
- Market size (min. meat weight) = 10 g
- Total harvest weight = 14 million kg
- CPUE = 400 kg/day
- Effort = 35,000 vessel-days
- Sale price = $13/kg
- Total revenue = $176.8 million

Discussion

Seed

Following nursery culture, seeded scallops are assumed to be 25 mm shell length.

Survival rates

One of the most significant limitations facing sea scallop culture is mortality due to predation by crabs and starfish that can be catastrophic after seeding (Hatcher et. al., 1996). Several strategies have been employed to reduce predation, including seeding at low water temperatures to reduce predator activity, and removal of predators prior to seeding. The substrate chosen for seeding will also be important in that cobble or more complex topography provides more refuge from predation than featureless bottoms. In addition to predation, scallops will swim or be transported by tides, such that initial seeding density is reduced. For these reasons, it is recommended that spat be seeded at no less than 25 mm shell height. At this size, survivorship up to 30% may be anticipated, but a value of 20% is probably more realistic.

In countries such as Japan, predator removal has been undertaken either via predator trapping or dredging, or by application of biocides. Our opinion is that this would not be an acceptable practice in Canadian waters due to either habitat alteration or effects on commercial fisheries such as lobster.

Seeding density and grow out

Scallop growth rate is a function of food quality, and scallops from deeper habitats tend toward slower growth (MacDonald and Thompson, 1985). Growth rate on the bottom is also reduced compared to suspended culture. Depending on substrate type, much of the population will be recessed into the sediment. Shells may be colonized by other epifauna. It is anticipated that scallops will require 5 years on bottom to reach marketable size, and that adult density will be 1-2 scallops m^2

Harvest

Bottom seeded scallops will be harvested by dredging as in the wild fishery. However, the extent of seeding would require large-scale dragging of coastal seabeds, with potential habitat consequences. Further development of gear types that increase efficiency and reduce incidental mortality of juvenile scallops and other benthos is desirable. A bottom grow out time of 5 years is likely. Alternatively, a smaller product for the shell-on market is possible after 3 years. Based on fishing mortality, we assume that the harvest yield would be 85% of the seeded year class surviving to age 5.

Sale price

The US is the dominant market for sea scallops. Prices were fairly stable during the latter half of 1990s, with landed values in the $12-14/kg range. Prices weakened somewhat in 2000, following the re-opening of grounds on the US side of Georges Bank. Nonetheless, the combination of limited supply (sea scallops are found only on the northeast coast of North America) and a growing US market should see steady to rising prices for the foreseeable future.

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F.

SOFT-SHELL CLAM

1. BACKGROUND

The soft-shell clam *Mya arenaria* is found from the southeastern US to the subarctic as well as throughout northern Europe. It ranges from soft mud to clean sand, and is a mainstay of temperate and boreal benthic communities. The fishery has a long local tradition in New England and the Maritimes. There are established fisheries along the Gulf shore in New Brunswick and PEI, and on the New Brunswick and Nova Scotia coasts in the Bay of Fundy. The fishery has declined substantially since the 1950s, when landed values exceeded the $20 million mark (at current prices). Landings today are in the $4-5 million range. The loss of harvesting areas due to contamination is one of the main causes of the decline.

Mya populations are subject to bacterial contamination due to their proximity to land and urban runoff, as well as to harmful algal blooms. There is a history of land-based depuration plants for this species, but the infrastructure for this practice is now less common. Although there is some interest in culture of *Mya*, there is limited published information on culture practices.

Development work to address culture opportunities and practices has been on-going in PEI and New Brunswick since the early 1990s. These efforts suffered a set-back in the late 1990s, when an outbreak of soft-shell disease wiped out stocks on several re-seeded flats. Re-seeding of clam flats with wild-caught juveniles has been practiced on a community basis, especially in Maine, for many years.

Despite the rather sedentary existence of adult clams, juvenile tend to be highly mobile, making recruitment events often short-lived. Hatchery rearing is not problematic, and spat are commercially available from Maine and Nova Scotia. Soft-shell clam ecology is well known through numerous studies, including growth, feeding, and burrowing behaviour. There are a variety of stock assessments for various Maritime locations through DFO and provincial surveys. Some of the information below is summarized from experiences in the Maine fishery, collated in Ellis, (1998).

2. BIOPHYSICAL REQUIREMENTS

Maximum clam abundances are usually found in protected sandy/muddy lower intertidal zones where temperatures are less than 28 ^{o}C and salinities greater than 4 to 5 ppt. (Abraham & Dillon, 1986). Soft-shell clams are eurythermal and euryhaline. Overwintering clams can survive sub-zero temperatures. Values for summer-acclimated clams are between 32.5 to 34.4 ^{o} C (Abraham & Dillon, 1986). The juveniles (< 15 mm) have higher heat tolerances than the adults. During times of short-term natural heat stress, clams withdraw their siphons and live anaerobically in the cooler mud. Soft-shell clams are isoconformers, and natural estuarine salinity fluctuations have little effect. However, the combination of high temperatures and low salinities has led to mass mortalities of soft-shell clams (Abraham & Dillon, 1986). Soft-shell clams are tolerant of oxygen fluctuations and are relatively tolerant of turbidity.

Summary of optimal biophysical parameters for Soft-shell clam.

Substrate	**shell/gravel/sand/muddy sand**
Seeding depth	**low-mid intertidal**
Temperature	**>0-25**
Salinity	**>5 ppt**
Turbidity	**medium**
Oxygen	**tolerant to low levels in sediment**
Exposure	**below surf zone**

3. SOFT-SHELL CLAM ENHANCEMENT

Seed production

Soft-shell clams spawn in spring and summer. Spat collection methods for soft-shell clams have a smaller research history of field testing than scallop spat collectors. Spat collection of clams in suspended collectors is possible, but has not been extensively examined. Bottom-based collection using complex surfaces that are attached to the substrate and become buried is also feasible. There have been a variety of attempts to encourage settlement by increasing local deposition with structures such as snow fences and 'clam tents', or other mesh devices on the sediment surface. In addition to encouraging settlement, mesh may reduce predation. (see http://www.whoi.edu/seagrant/education/bulletins/clams.html).

Fixed structures are difficult to maintain in macrotidal areas such as the Bay of Fundy where many of our clam beds occur, and any structures must be removed prior to winter ice scour. Some flats have more dependable recruitment, and harvesting of juveniles has been conducted on a research basis with mechanical devices that fluidize and sieve mud. Unfortunately, clam recruitment is not a dependable event. This variation occurs in part because larvae may be imported from adjacent bays, and do not necessarily reflect the reproductive state of local populations (Roegner, 1997). Given the difficulty in natural spat collection, increased capacity of hatchery production is recommended. The collection of wild spat has potential as a supplement to hatchery sources, but requires more formal evaluation of techniques.

Nursery

As with scallops, holding until a suitable size is reached will increase field survivorship. Clams are also highly mobile as juveniles, and entire cohorts have been observed to disappear in a matter of days likely due to tidal advection. Seeding them at larger sizes reduces this problem. A likely approach to nursery culture is the use of a FLUPSY

(Floating Upweller System) in which early juveniles are kept in field containers supplied with upwelled seawater via a pump until reaching sufficient size for intermediate culture (~5 mm) (see http://www.coastalaquacultural.com/upweller.htm). The FLUPSY may be deployed directly in the field at sheltered sites as a dock-type arrangement to take advantage of natural food sources in incoming waters. After upwelling culture or even straight from the hatchery, clams of 2-20 mm have been overwintered (~ 6 months) in floating field cages with high survivorship. This step avoids the ice season and allows clams to be seeded at a larger size.

Seeding

Clams live in a wide range of sediment types, so many intertidal areas are suitable. Most typical clam flats are muddy, and the extensive Fundy mudflats are among the largest block of suitable habitats. However, the excessive turbidity of the Minas Basin seems to limit *Mya* occurrence there. Other typical habitats include sandy areas behind barrier islands, and sand bodies within inlet mouths. Wave exposed sands are unsuitable. In some areas, extensive tidal flats allow a broad range of intertidal heights for seeding. The low intertidal provides increased feeding due to greater immersion time (Roegner, 1997), but allows greater exposure to predators. In addition, workers are faced with increased transport time and reduced working time in the low intertidal.

In seeding, clams are dispersed by hand in an attempt to produce densities of 200-400 individuals m^2. Mechanical seeders are used in culture of other clam species, and could be adapted to *Mya* culture. Tilling of the flats prior to seeding is practiced in some cases to condition the sediment surface to improve burrowing. Culture density is potentially important in subsequent clam growth and dense aggregations will attract predators.

4. CULTURE-BASED FISHERIES MODEL

Overview

The scenario for intertidal culture of soft-shell clams is based on experiments conducted in Maine, parctices from the harvest fishery, and intertidal culture of other clam species. We assume that harvestable densities resulting from seeding will be similar to natural densities, i.e. that seeding does not enhance natural abundance. Existing clam flats are included in the areas considered for seeding.

Potential culture area

Potential soft-shell clam habitat is intertidal, located on sand and sandy-mud substrate on relatively protected shorelines. The areas available from the hydrographic charts are total area of the intertidal zone, whereas clams are expected to occur in variable densities at different tidal heights. We estimate an area of some 310,000 ha is suitable for clam culture on the Atlantic coast. But substantial parts of this area are contaminated from urban waste and agricultural runoff and would have to be remediated before seeding could take place. Other areas are suboptimal habitat due to vegetation, cobble, tidal creeks, tidal height, etc.

The intertidal areas of Prince Edward Island and many of the protected bays of New Brunswick, Quebec and Nova Scotia provide a large area of potential habitat for soft-shell clams. Few clam habitats are identified in Newfoundland. The areas in Newfoundland are considered marginal habitat for soft-shell clams because of the low water temperatures and relatively severe ice conditions during the winter period.

PEI appears to have large areas of 'potential' clam habitat because of the sedimentary nature of its coastline. Several areas with potential soft shell clam habitat were identified in the bays, particularly around Malpeque, Rustico, Cardigan Bay, Murray Harbour, Hillsborough and Egmont Bays. Many of the barrier island estuaries of the north shore of PEI contain protected deltaic features that support clam populations.

On the New Brunswick coast, in the area around Miramichi Bay to Baie Verte, there are many suitable areas for potential clam habitat, and many of these areas support a commercial fishery. Several of the bays in Nova Scotia have potential habitat for soft-shell clams. Extensive sand/mud flats occur in Chezzetcook, Petpeswick Inlets and Clam Harbour. Many of these flats support large recreational and moderate commercial clam harvests.

We base the case study on optimal clam flats with a total area of 7,500 ha. This could be increased with remediation. We assume a rights-based approach would be taken to promoting and managing culture development. Rights could take the form of leases. We assume individuals would divide their lease areas into three equal parts, with one part seeded each successive year and a harvest in the third year.

Assumptions

- Seeding density = 350 juveniles/m^2
- Survival = 65% to adult with predator mesh
- Final density = 228 clams/m^2; 0.3 kg wet weight/m^2 (harvested)
- Total habitat area = 310,000 ha
- Assumed culture area = 2,500 ha/year (7,500 ha in total).
- Annual seed requirements = 8,750 million
- Recovery (@ 75%) = 4,265 million/year
- Grow out cycle = 3 years
- Total culture area ha/year x 3 Years = 7,500 ha
- Seed cost = $ 0.005/seed
- Nursery cost = 0.015
- Seeding cost (including mesh) = $10,000/ha
- Total annual seed/grow out cost = $25 million
- Average harvest weight = 0.010 g
- Market size = 38 mm
- Total harvest weight = 43 million kg
- CPUE = 300 kg/day
- Landed price = $2.75/kg
- Total revenue = $117.3 million

Discussion

Seed

Seeding size in the spring depends on the size used in nursery culture, but transplanting to the field at 10 -15 mm size is reasonable.

Survival rates

Mortality occurs from a variety of predators including gastropods, crabs, nemerteans, fish, and shorebirds. Less dense seeding of *Mercenaria* (1 m^2) has been shown to produce survivorship up to 35% (depending on substrate), even in the absence of predator exclusion (Peterson, et. al., 1995). Sparse seeding may be an effective strategy for re-seeding natural beds rather than for intensive aquaculture. Any attempts at denser seeding require predator nets of flexible plastic with a recommended mesh size of ~6 mm. Finer mesh will induce fouling and sedimentation, while coarser mesh will allow predators. The netting is depressed into the sediment, anchored at its edges, and held off the sediment surface using floats. Intertidal bivalve culture has a long history of using various predator exclusion devices (PEDs) (e.g. Cigarria and Fernandez 2000; Grabowski, et. al., 2000), and suitable application to various Canadian *Mya* culture areas would not be difficult.

Grow out

As with juveniles, intertidal culture of infaunal clams requires protection from predators, the most common form being nets or mesh. Addition of gravel is sometimes used, but this is less practical on the muddy substrates where *Mya* is often found. PED's need to be maintained throughout the culture cycle to remove fouling and replace mesh, anchors and floats. Published statistics are scarce on the rate of return of seeded clams, but Beal, et. al., (1995) report 75% survival on protected clams cultured in the intertidal. The literature on other clam species suggests that with predator control, survival may be as high as 70% per year. To be conservative, we use 65% in the analysis. Grow out time for market clams (38 mm) will be on the order of 2 years, but growth rate is variable in different populations (Witherspoon, 1982). We assume three years for the analysis.

Harvest

It is anticipated that harvest will be conducted at low tide. Traditional clam harvest involves raking, but automated raking is possible at reasonable costs. Landry and Ouellette, (1993) determined that a hydraulic clam rake harvested 0.7-0.86 kg wet wt of clams m^2 area fished. Manual clam rakes yielded 50% of these amounts in three times the effort. The tidal flat used for this study contained clams at densities of 75 clams m^2, a typical density, so this harvest rate is reasonable for application over larger scales. The present fishery is conducted with hand hacks, and it is assumed that a harvest rate of 0.3 kg wet wt of clams m^2 area fished applies.

It is possible that predator exclusion will result in a higher yield than the natural fishery, but in the absence of relevant data, clam productivity equivalent to the harvest fishery is used in calculations. Differential size and density at various intertidal levels is not considered. All harvest methods cause incidental mortality in uncaptured clams, and likely of recruits.

Sale price

The current market price of $2.75/kg is used in the analysis.

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G.

GREEN SEA URCHIN

1. BACKGROUND

The range of the urchin is circumpolar. It extends from the Aleutian Islands down to Oregon on the west coast and in the North Atlantic from Greenland to Cape Cod. Kelp is a preferred food of adults, although urchins also graze on other plant and animal material both living and dead. The largest populations of green urchins are usually found in and around kelp beds in the exposed, rocky subtidal zone. In these habitats, the water is oxygen-saturated or supersaturated and water exchange rates are rapid.

Urchins have gained a lot of attention in recent decades due to the value of their gonads in Asian markets. This had led to diver harvesting of formerly unexploited stocks and concern about overfishing. But the diver fishery is unlikely to pose a threat to sustainability because of reproductive refuges, and maturity at below legal size. Urchins have a close ecological linkage with their kelp food source and adult urchins commonly form feeding aggregations, or ‘grazing fronts’ (Breen & Mann, 1976) which move slowly but steadily through kelp beds. It is these adult urchins that are targeted by the fishery.

Sea urchins are long-lived herbivores, with strong affinity for brown algae as a food source. The quality of the roe is dependent on season, urchin size and nutritional status, with higher gonad condition in healthy stands of kelp (Hagen, 1998). Bottom culture of sea urchins is inherently different from the bivalve culture discussed above in that urchins have a requirement for hard bottom, as well as sufficient macroalgal food sources. Due to the macroalgal requirement, it is more difficult to define suitable habitat from maps without the benefit of groundtruthing.

Three scenarios for urchin enhancement are possible:

Collection of wild seed for intermediate culture and eventual seeding

Larval settlement of urchins onto plate-like collectors has been carried out in Japan, but there is no comparable experience in eastern Canada that would allow estimation of settlement rates, survivorship, and growth. In California, experimental kelp culture attracted settling urchins sufficient to decimate the kelp plants (Tegner, 1989).

Movement of barren ground urchins to kelp beds for gonad conditioning

Transplantation of barren ground urchins to stands of kelp has potential since barrens may be extensive, urchins are easy to collect there, larger size of transplants increases survivorship, and gonad output will be enhanced once they reach the kelp beds. Although recruitment may be greater to barrens than to kelp bed due to reduced numbers of small predators, once the barrens are cleared of urchins for transplantation elsewhere, they may regenerate as kelp beds, and decline as a source of recruits.

Disease outbreaks may also affect the availability of this source of urchins. It is risky to assume that the balance between kelp beds, barrens and urchin recruitment can be managed in a way that is sufficiently dependable to provide a consistent source of subadults for transplantation. A variation of this scenario, transplantation to 'feedlots' where barriers constrain movement and algal or other food sources are added, has significant logistics associated with setup and maintenance. This approach has been attempted on a pilot scale in British Columbia (Clayton, W.E.L., 2001, pers. comm.).

Hatchery production of juveniles for re-seeding

This approach is detailed below and forms the basis of the case study.

2. BIOPHYSICAL REQUIREMENTS

Habitat characteristics

Green urchins can tolerate temperatures between -1^{o}C to 20^{o}C (Scheibling & Stephenson, 1984). Seasonal acclimitization of metabolism in winter allows urchins to feed at high rates and produce gonad mass. However, it has been found that gonad mass and quality are higher in warmer water. Green urchins are found in areas where spring temperatures do not exceed 6-8^{o}C. because the larvae are intolerant of warmer water.

Green urchins are considered to be stenohaline because of the lack of excretory organs and their poor osmoregulatory ability. However, some populations have become adapted to lower salinities. Sea urchins exposed to a larger range of salinity variations that that to which they have become adapted suffer significant mortality. The juveniles are particulary sensitive to salinity fluctuations. Green urchins are pollution-intolerant and developmental abnormalities in this species are often used as an indicator of marine pollution.

Summary of optimal biophysical parameters for Sea Urchin culture

Substrate	**rocky bottom/kelp beds**
Seeding depth	**intertidal to 10 m**
Temperature	**-1 to 20°C**
Salinity	**>30 ppt**
Water exchange	**rapid for high oxygenation**
Exposure	**below surf zone**

3. URCHIN ENHANCEMENT

Seed production

The green sea urchin can successfully be reared in hatcheries, although it is not yet readily available on demand. Sea urchins have been used as model animals for studies of morphogenesis, so their fertilization and early development are well known.

Nursery

Juvenile urchins from hatchery production will be kept in land-based hatcheries (or potentially sea cages) for ~ 1 year until seeding at a size of 10-15 mm. This scenario is similar to that of cultured abalone, where juveniles are fed high quality diets to improve vigour for grow out. Diet has been shown to regulate urchin growth rate (Vadas, et. al., 2000), and further development of optimal diets for juvenile urchins is a good investment in adult gonad yield.

Seeding

Juvenile urchins will be seeded on existing kelp beds. In order to create an ‘urchin front’ and optimize their feeding, it may be desirable to seed in clumps of several hundred urchins. Kelp are often found in wave-exposed conditions, but it may be prudent to seed beyond the breakers to reduce initial stress on juvenile urchins.

Based on natural populations, it is possible that urchins can reach commercial size (60 mm) in 3 years, but given the range of food conditions in the natural environment, 5 years is probably a more reasonable estimate. It is important to visit the culture site using divers so that problems with urchin disease or overgrazing of kelp can be monitored. Urchins will be reproductively ripe during winter and early spring. Gonad condition should be monitored to optimize the value of the harvest. Large-scale production and re-seeding has the potential to graze kelp beds faster than they can re-populate, a process that impacts the sustainability of the fishery. The alternation between kelp and barren grounds cannot be rigidly controlled, so a culture-based fishery should be phased in slowly, with unseeded kelp stands left as reserves for kelp propagules.

4. CULTURE-BASED FISHERIES MODEL

Potential culture area

Potential sea urchin habitat identified is one where kelp beds are expected to occur. These areas are largely on moderately exposed, rocky coastlines. We estimate the total area offering potential at 780,000 ha. Depth ranges are 1 to 10 m, where depth contours are gentle, bottom types identified as rocky and emergent rocks not abundant. On some of the charts, kelp beds are specifically marked.

We caution that the extent of kelp coverage of the coast cannot be accurately quantified by this method, so conservative estimates of potential area are used. Potential urchin habitat is very sensitive to habitat boundaries, since successful seeding requires kelp beds. Accordingly, we assume an area of 5,000 ha offers optimal potential (with 1,000 ha seeded annually). This not only reflects concerns about habitat suitability, but is also sensitive to industry structure and growth potential.

Assumptions

- Seeding density = 300 juveniles/m^2
- Survival = 10% to adult with 80% recovery
- Final density = 30 adults/m^2
- Total habitat area = 7,800 km^2 (780,000 ha)
- Assumed culture area = 1,000 ha/year
- Annual seed requirements = 3,000 million
- Recovery (@ .1 x .8) = 240 million/year
- Grow out cycle = 5 years
- Total culture area – 1000 ha/year x 5 Years = 5,000 ha
- Seed cost = $0.020/seed
- Nursery cost = $0.010
- Grow out cost = not applicable
- Total annual seed/grow out cost = $90 million
- Average harvest weight = 0.100 g
- Market size = 60 mm
- Total harvest weight = 24 million kg
- CPUE = 1,500 kg/day/vessel
- Effort = 16,000 vessel-days
- Sale price = $5.50/kg
- Total revenue = $132 million

Discussion

Survival Rate

Juveniles may be subject to high levels of predation on kelp bottoms. Predators include lobsters, crabs, other invertebrates and fish. This source of mortality may inhibit urchin recruitment to overfished kelp grounds. Although predation pressure is reduced on barren grounds, the quality of urchin roe is also compromised due to food limitation. Studies of seeding in other urchin species show widely varying mortality rates (Tegner, 1989), and it would be prudent to assume high losses for seeded juveniles in Atlantic Canada, estimated herein as 90% loss from seeding to harvest (10% survival rate). It is anticipated that predation mortality of adults will be relatively low compared to juveniles.

The green sea urchin is also susceptable to catastrophic infections by a pathogenic amoeba (*Paramoeba invadens*) which can cause 99% mortality. It was responsible for mass mortalities of green sea urchins along the Atlantic coast of Nova Scotia in 1980-1983 (Scheibling & Hennigar, 1997), and in some areas again in the late 1990s. The occurrence of this diseases is strongly temperature-dependent, and its progression ceases below 10 - 12 ^{o} C. Catastrophic die-off is a major risk factor in any attempt at urchin enhancement through bottom seeding.

Seeding Density

Seeded urchins will likely aggregate, and based on natural densities on kelp beds, we estimate that adult densities will be 100 individuals m^2 in aggregations assumed to occupy 10% of the bed, and 20 individuals m^2 assumed to occupy 90% of the kelp bed. Seeding will thus need to be conducted at an average density of ~300 individuals m^2 in order to achieve this mixture.

Harvest

Harvest will be conducted by diver as is currently the case. The harvest is expect to continue to occur between September and April, with a concentration of landings in the December-April period to coincide with spawning. A rotational harvest may be advisable in which all urchins are harvested from 20% of the seeded beds in any one year. This will allow kelp re-growth post harvesting. The density of adult urchins is assumed to be patchy in the kelp beds due to urchin grazing aggregations, with 10% of the area containing 100 individuals/m^2, and 90% of the area containing 20 individuals/m^2. We assume that divers harvest 80% of adult urchins from kelp stands, and that roe is 10% of total wet weight.

Landed price

Prices vary with world-wide supply (rising) and market conditions in Japan, the principal market. Over the past five years prices have varied between $4.00 and $6.50/kg. We use a long-term price of $5.50/kg in the analysis.

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H.

AMERICAN OYSTER AND QUAHAUG

1. BACKGROUND

These species are not specified for detailed analysis in the terms of reference for this study. They are included because they provide excellent potential for enhancement using a bottom seeding approach.

Substantial habitat exists for both species in the southern Gulf of St. Lawrence.

- Oysters require estuarine habitat, with firm, stable bottom. Estimates place the total potential area at about 6,200 ha (Lavoie, 1995). For this analysis, we assume that 3,000 ha offer optimal conditions for growth. We further assume that 600 ha are conditioned and seeded annually, with a rotational harvest. Grow out time is five years.

- Quahaugs occupy the intertidal zone to a depth of 2-3 m in muddy and sandy bottom. An estimate of the total potential area is not available. For this study, we assume an area of 2,000 ha offer optimal conditions for growth. We assume that 500 ha are seeded annually, with a rotational harvest. Grow out time is six years.

There are commercial fisheries for both species. PEI is the major oyster producing area, accounting for about 85% of the $7 million harvest in Atlantic Canada in 1999. There is a long history of oyster development in the province, with several on-going programs aimed at rehabilitation of known beds. These programs involve spat collection, cultivating shell beds (with cultch), predator control (mainly starfish traps), and relaying oysters to re-establish oyster populations. An expansion of such programs is essential if the potential set out in the case study is to be realized.

The quahaug occurs mainly from Miramichi Bay in New Brunswick to Cape Breton Island in Gulf of St. Lawrence waters (including PEI). It is a tough, hardy species with a thick predator resistant shell. The species supports a thriving bottom culture industry in the eastern and southern US. Developmental work aimed at culturing the species is taking place in PEI and New Brunswick. Hatchery seed is available, and experiments are being conducted on methods of predator control. The commercial fishery based on wild and cultured stocks generates an estimated $1 million annually.

2. DEVELOPMENT POTENTIAL

Assumptions and results of the case studies are summarized in Chapter II, Table 1.