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BIOLOGICAL AND ECONOMIC FEASIBILITY OF FOUR GROW-OUT METHODS FOR THE CULTURE OF GIANT SCALLOPS IN THE BAY OF FUNDY

by

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ABSTRACT

Wildish, D. J., A. J. Wilson, W. Young-Lai, A. M. DeCoste, D. E. Aiken, and J. D. Martin. 1988. Biological and economic feasibility of four grow-out methods for the culture of giant scallops in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1658: iii + 21 p.

Four final grow-out methods for culture of the giant scallop were tested in small, pilot scale trials at two locations near St. Andrews, N.B. With all of these methods: long-lines anchored by concrete blocks, weir-pole stakes, benthic cages and benthic relaying, it was biologically feasible to produce market-size giant scallops. Site differences in predator mortality of benthic scallops were evident, suggesting the need to choose sites with low predation pressure. The benthic cages proved to be susceptible to predators; this could be rectified in future by reducing the hole size of the cage walls. Fouling of all cages, except benthic cages, was an operational problem in the Bay of Fundy. Growth rates of all suspended cultures inclusive of benthic cages involved an approximately 15-mo period, following intermediate culture of 1 yr in pearl nets, to reach marketable size of 90-mm shell height; versus ~36-48 mo for scallops placed directly on the sediment surface.

Based on our pilot scale experience, we have attempted an economic analysis of each final grow-out method employed. The economic feasibility is for the period 1987-1996 and based on 1987 prices. The analysis assumes a 5% annual increase in cost of labor and materials and predicts a 6.55% annual increase in landed price of scallops. Ten-year predictions show that only one of the four grow-out methods, benthic relaying, to be economically feasible.

RÉSUMÉ

Wildish, D. J., A. J. Wilson, W. Young-Lai, A. M. DeCoste, D. E. Aiken, and J. D. Martin. 1988. Biological and economic feasibility of four grow-out methods for the culture of giant scallops in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1658: iii + 21 p.

Quatre méthodes de grossissement final du pétoncle géant ont été mises à l'essai (sur une petite échelle) à deux emplacements situés près de St. Andrews, N.-B. Les quatre méthodes employées étaient l'élevage sur des palangres mouillées au moyen de blocs de béton, l'élevage en suspension sur des bordingues, l'élevage dans des cages en milieu benthique et le reparcage en milieu benthique. Or ces quatre méthodes ont prouvé que sur le plan biologique, il est possible de produire des pétoncles géants commercialisables. Le taux de mortalité par prédation des pétoncles élevés en zone benthique diffère d'un site à l'autre, d'où la nécessité de choisir des sites où la prédation est moins importante. Les cages en milieu benthique se sont révélées susceptibles à la prédation, mais il est possible de régler ce problème en réduisant l'ouverture dans les murs de la cage. L'encrassement de toutes les cages, sauf celles en milieu benthique, constitue un problème dans la baie de Fundy. Pour toutes les cultures en suspension, y compris les cages en milieu benthique, la croissance exige environ quinze mois, suivis d'une période intermédiaire d'un an dans des filets perlés, afin d'atteindre la taille comerciale de 90 mm (hauteur de la coquille). Par ailleurs, il faut de 36 à 48 mois pour cultiver des pétoncles placés directement sur les sédiments.

D'après notre expérience pilote, nous avons entrepris une analyse économique de chaque méthode de grossissement final. Cette étude de faisabilité visant la période allant de 1987 à 1996, et elle est fondée sur les prix de 1987. On a présumé une augmentation annuelle de 5% dans les coûts de la main-d'oeuvre et du matériel ainsi qu'une augmentation annuelle de 6,55% du prix des pétoncles au débarquement. Les prévisions basées sur une période de dix ans révèlent qu'une seule méthode serait viable, soit le reparcage dans un milieu benthique.

INTRODUCTION

The general biology of the giant scallop, Placopecten magellanicus Gmelin, is reasonably well known (see review by Young-Lai and Aiken 1986). More recently, new information on the giant scallop has been provided by Beninger (1987) regarding the reproductive cycle; LePennec et al. (1988) and Beninger et al. (1988) the gill anatomy; and Shumway et al. (1985), Wildish et al. (1987) and Wildish and Kristmanson (1988) on feeding in relation to seston quality and flow speed.

The giant, or sea, scallop is of considerable economic importance in Atlantic North America being dredged from Cape Hatteras in the south to Newfoundland in the north. Georges Bank provides the most productive fishery for the giant scallop within its geographic range, e.g. 55,978 tonnes round weight landed in 1985 (Anon. 1985). Only recently has the giant scallop been considered as a potential mariculture species in Canada (Stewart 1974; Naidu and Scaplen 1975; Tremblay 1988).

Pioneering work in Japan during the late 1960's on culture of the Japanese scallop, Patinopecten yessonensis (Say) has resulted in an industry producing 100,000-t round weight of scallops per year by 1975 (Imai 1977; Ventilla 1982). Present day production (1987) is in excess of 150,000 t and this has been achieved by learning how to capture natural spatfall and devising a grow-out methodology which includes an intermediate suspension culture stage followed by further suspension culture from long-lines or benthic relaying of half-grown scallops.

For the few successful mariculture species in Canada, the followni criteria are common:

- the species should yield a high-priced, gourmet product for an established (e.g. salmon) or newly established (e.g. blue mussels) market,
- the production capacity of the fishery supporting the established market should be unable to keep up with demand due to declining catches or increased demand,
- culture is biologically feasible at production costs which allow this to be a profitable venture.

It is the purpose here to examine all three of these criteria with respect to the mariculture of the giant scallop in the Bay of Fundy using methods adapted to local conditions, but based on those devised for the culture of the Japanese scallop (Imai 1977; Ventilla 1982). Four different methods have been tested for the final grow-out stage: long-line suspension, weir stake suspension, benthic cage, and benthic relaying culture and a conclusion reached regarding the biological and economic feasibility of each in the Charlotte County, N.B. area.

Preliminary studies for this work were begun in Charlotte County, New Brunswick, in 1985 at Brandy Cove, although an additional site in Lime Kiln Bay, L'Etang Inlet, was utilized in 1986. Results reported here refer primarily to the period spring 1986 to spring 1988. Prior to this, in 1980, an economic analysis of scallop culture trials in Newfoundland waters had been published (Frishman et al. 1980). This study, using Japanese long-line suspension and benthic relaying techniques, concluded that suspension culture was not economically feasible although benthic relaying was marginally so, yielding rates of return of 14-16% on investments. During our study, two economic analyses from Quebec waters were also published. One study was based on a Japanese long-line suspension culture system (Anon. 1987) and showed that this method was not economically feasible in Quebec conditions - even with various forms of government financial assistance included. The second study (Anon. 1988) compared earhanging and lantern net culture and suggested that, in Quebec conditions, the former is marginally economically feasible. Because our study tested some methods not previously assessed and because we believe that biological and economic success in growing giant scallops will prove to be defined regionally, just as it is in agriculture where certain areas are best, e.g. for fruit or dairy farming, we persisted and present the results herein.

EXPERIMENTAL METHODS

BIOLOGICAL

Field grow-out experiments were conducted at two sites (Fig. 1): in Brandy Cove and Lime Kiln Bay. A 50-m long-line was installed at each site consisting of two 450-kg concrete block anchors, 3/4" main line and ancillary 1/4" rope to carry pearl and lantern nets and benthic cages. Six weir stakes were driven in Brandy Cove in 1986 as an additional means of support for nets or cages. Bottom relaying of scallop was carried out in two 6 x 6 m grid areas at a site marked by a buoy approximately 50 m from the shore in a small cove near the Salmon Demonstration Farm. The depth of water at low water was -5 m.

Experimental scallops set out in May 1987 were obtained as follows:

- wild spat were captured in collectors which consisted of onion bags having a 2-mm mesh stuffed with 500 g of monofilament nylon webbing. The collectors were suspended from buoys at 15 m depth either at Tongue Shoal or L'Etang in Lime Kiln Bay prior to spat settlement in September 1986 by M.J. Dadswell and R. Chandler. Typical numbers of spat caught averaged 200-400 per collector at Tongue Shoal (Dadswell and Chandler, pers. comm.). The collectors were harvested in May 1987 when the juvenile scallops averaged 10 mm shell height. These scallops provided the first year-class recruits for the intermediate culture trials. Pearl nets with a bottom area of 0.12 m^2 were used in intermediate culture,
- year-classes 2, 3 and 4 were obtained by dredging at Oak Bay with a Digby scallop dredge. The dredged sample contained 2276 scallops.

Many of the scallops used in the growth experiment were tagged by placing a numbered plastic disc (from Hallprint Ltd., Holden Hall, Australia) on the upper, left valve and gluing

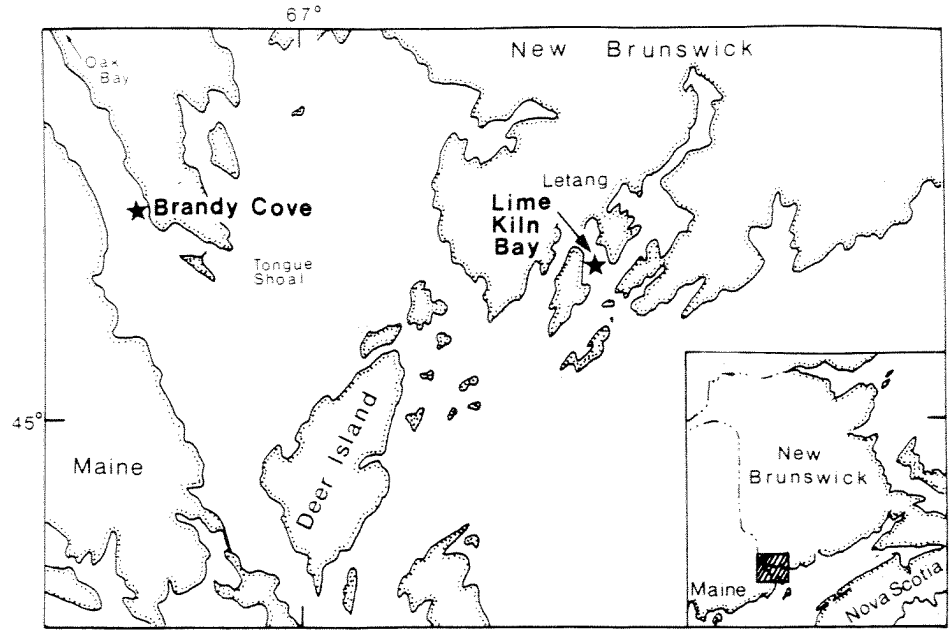

Fig. 1. Map showing the position of the Brandy Cove (1) and Lime Kiln Bay (2) scallop grow-out sites.

with Super Glue ®. Each tagged scallop was measured for shell height as in Fig. 2 with Vernier calipers accurate to 0.1 mm. On a subsample of scallops from the dredge sample, the following additional parameters were measured:

- total wet weight, inclusive of shell, after draining pallial water,
- wet weight of shucked adductor muscle,
- an index of shell size based on the sum of shell height, length and thickness in mm (Fig. 2) and divided by 10.

Then from the standard shell height measurement, the growth could be expressed as one of these from the relationship between shell height and each additional growth measure. Initial growth measurements were made in May 1987, again in November 1987 and final measurements in May 1988 when the experiment was terminated.

Four final grow-out treatments were compared during this study (Fig. 3). They included:

1. Long-line with lantern nets (Fig. 4).
2. Weir stakes with lantern nets (Fig. 5).

   Lantern, or accordian, nets consisting of 5 or 10 compartments, each with an available floor area of 0.2 m². The polyethylene mesh used in the cages ranged from 20-30 mm mesh size.

3. Benthic cages (Fig. 6).

   The self-stacking cages made of white plastic were obtained from Can-Am Containers, Springhill, Nova Scotia.

   Cage dimensions were 41.5 cm wide x 72.5 cm long x 7.5 cm high. The cage bottom

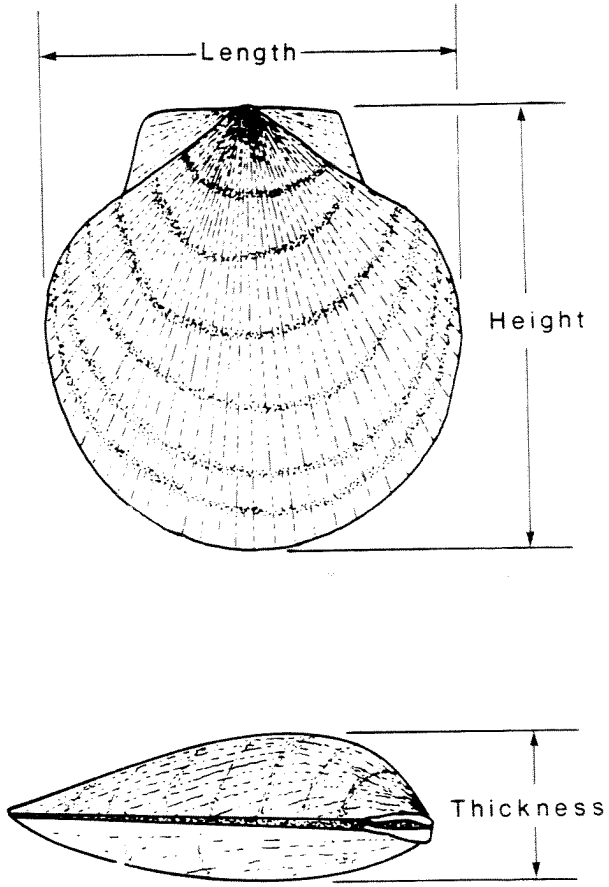

Fig. 2. Diagram showing measuring origins of shell of giant scallops used in growth analysis.

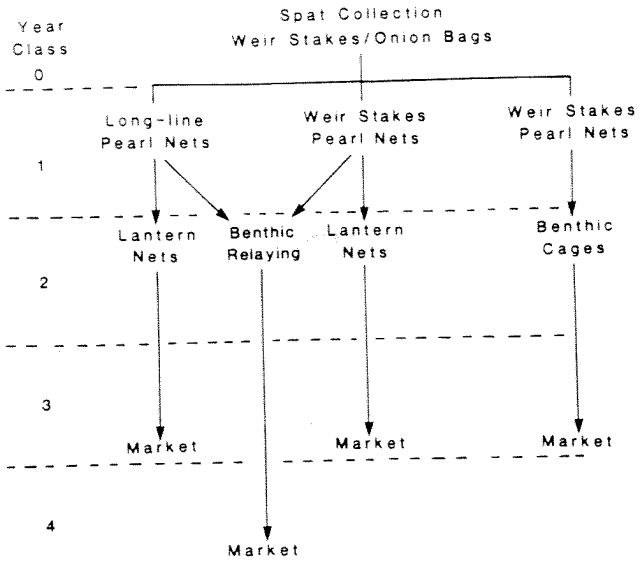

Fig. 3. Composite diagram showing the grow-out methods used in the 1987-88 giant scallop trials.

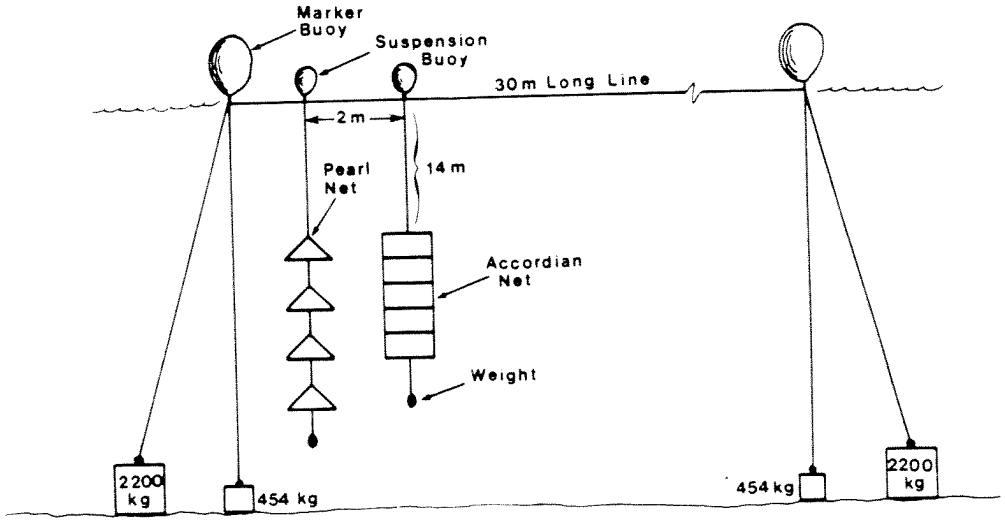

Fig. 4. Diagram of 50-m long-line with pearl and lantern nets.

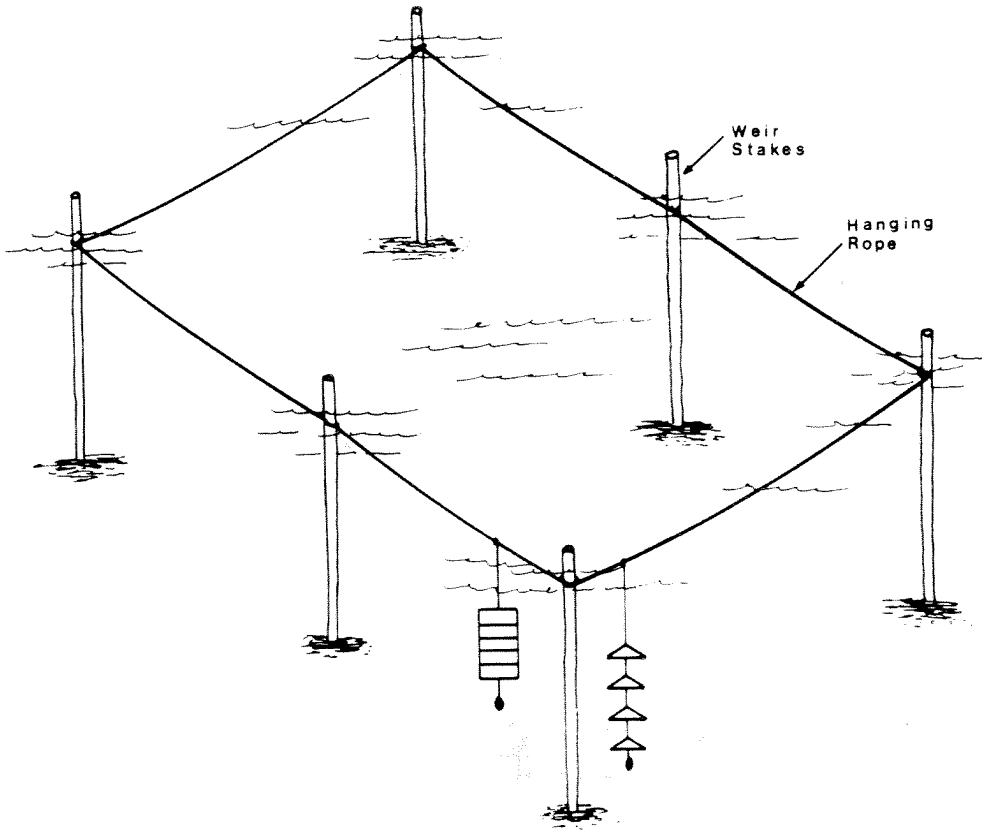

Fig. 5. Diagram of weir stakes carrying pearl and lantern nets.

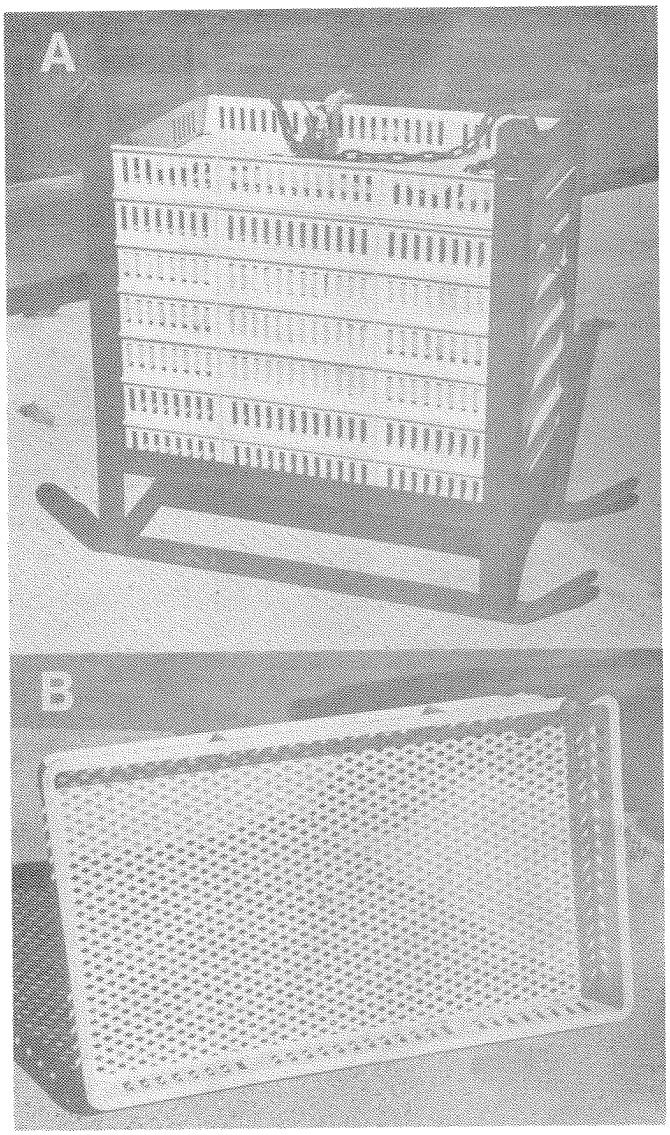

Fig. 6. Supporting frame (A) and an individual plastic tray (B) used in benthic cage culture.

had diamond shape holes of 13 x 8 mm dimensions. Openings in the side and end walls were slits of 10 x 45 mm. Five to ten trays were stacked in each metal frame (Fig. 6) so that the bottom tray was 30 cm above the sediment. An empty tray was placed on top to close the cages. Frames were provided with sleds for support on the sediment surface and were made locally.

4. Benthic relaying

Scallops were distributed by SCUBA divers in a grid of 6 x 6 m marked off in 1-m squares so that a density of five scallops per m^2 was achieved. During sampling, the grid area plus a 2 m wide strip around the grid was carefully searched by SCUBA divers.

The overall experimental design is shown in Table 1, which includes details of the gear mesh size used, stocking density of scallops used, and the total number of scallops tested per treatment.

ECONOMIC PARAMETERS

Production costs are based on 1987 values at the time that the experiment was started. Production costs are based on estimates involved in a:

- 100 m long-line,
- a 100-m line supported by weir stakes,
- a 100 x 200 m area of the sea floor.

Individual costs were estimated for spat production, intermediate culture, benthic relaying, benthic cage culture, suspended culture with lantern nets, and processing costs. Marketing costs involved in direct selling to the consumer are not included in the analysis. Income from the sale of scallop meats was calculated based on historical data of the prices paid to fishermen for shucked scallops at the dock (landed price).

Both income and production costs have been quoted on a per scallop basis to clarify presentation. For business prediction purposes the same raw data could be used, without including cost savings which could be made if volume production was undertaken. Savings due to discounts on materials, lower unit costs if longer lines were employed and the more efficient use of labor which could be implemented in a larger unit, could be expected.

Replacement costs of materials and labor have been based on a 5% annual rate of increase in inflation from 1988. The annual rate of increase of scallop landed prices was calculated for the period 1976-1986 and the average increment during this period was used to predict prices from 1988 to 1996.

BIOLOGICAL RESULTS

Although all of the growth data obtained were based on shell height measured in mm, it was necessary for various purposes to have other measures of size. The data used to do this involved subsamples of 30 scallops from each of the three initial size groups dredged, plus subsamples in November 1987 and again in May 1988 for each of the 12 treatments shown in Table 1. Regression relationships shown below are thus based n 750 pairs of input variables. The relationship between shell height (X in mm's) and fresh weight of the adductor muscle (Y in g) was found to fit a power curve:

$$Y = 1.39 \times 10^{-6} X^{3.54}, \; r^2 = 0.99 \quad .... \; 1$$

This relationship was used to calculate the adductor muscle meat weights of experimental subjects. Shell height (X) was also related to an index of size (S) by:

$$S = 0.16 X^{1.08}, \; r^2 = 1.00 \quad .... \; 2$$

The index of shell size, S; was related to fresh weight of the adductor muscle (Y) by a power curve:

$$Y = 5.91 \times 10^{-4} S^{3.30}, \; r^2 = 0.98 \quad .... \; 3$$

Table 1. Design of the giant scallop grow-out trials of 1987-88.

Year-class	Initial size (mm)	Treatment	Gear	Gear mesh size (mm)	Stocking density	Total per treatment	Stock density m^{-2}
1	5-20	(1) Long line	Pearl nets	3 x 3	100/cage	700	833
		(2 Weir stakes	Pearl nets	3 x 3	100/cage	700	833
2	25-50	(1) Long line	Lantern nets	20 x 20	20/level	300	100
		(2) Weir stakes	Lantern nets	20 x 20	20/level	300	100
3	55-70	(1) Long line	Lantern nets	25 x 25	10/level	250	50
		(2) Weir stakes	Lantern nets	25 x 25	10/level	250	50
		(3) Benthic trays	Trays	10 x 45	46/tray	230	153
		(4) Bottom relay	-	-	5/grid	180	5
4	75-85	(1) Long line	Lantern nets	30 x 30	10/level	250	50
		(2) Weir stakes	Lantern nets	30 x 30	10/level	250	50
		(3) Benthic trays	Trays	10 x 45	30/tray	300	100
		(4) Bottom relay	-	-	5/grid	180	5

The total fresh weight of a scallop, inclusive of shell (W in g) was linearly related to fresh weight of the adductor muscle or meat (Y in g) by the relationship:

$$Y = 0.12\ W^{1.00},\ r^2 = 0.99 \qquad \ldots\ 4$$

Thus, using equation 1, we can determine that in the conventional scallop fishery where a size limit of 40 meats per 0.45 kg (or 1 meat = 11.4 g) is used, that the minimum shell height to achieve this size limit is: X = 90 mm.

We have also calculated the maximum stocking densities suggested by Japanese authors in suspended cage culture of Patinopecten yessonensis (Imai 1977) and used these as a guide for the giant scallop. The calculations were made by assuming that πr^2 adequately represented the surface area of the scallop where r = 0.5 x shell height in cm. The data (Table 2) assume that the giant scallop responds to density as does the Japanese scallop and thus that the surface area of cultured scallops should not be greater than one-third of the available cage bottom available (Imai 1977). Comparison of Tables 1 and 2 show that the densities used in our experiment are well below maximal, although in the economic analysis we have used maximum permitted densities as shown in Table 2. The relationship used in Japan was originally determined by empirical tests, although the biological mechanisms do not appear to have been studied. Presumably some form of interference competition is involved, e.g. an upstream scallop preferentially filtering a common water flow, or interference during escape swimming reactions ("biting syndrome"). We found evidence of the latter mechanism because pairs of swimming scallops had locked shells, involving shell or adductor muscle damage resulting in death of some of these individuals.

The inverse logarithmic relationship between shell height and maximum permissible stocking density of Table 2 (see also Fig. 7) has implications for the costs of the later stages of grow out. Consideration of Fig. 7 shows that with a

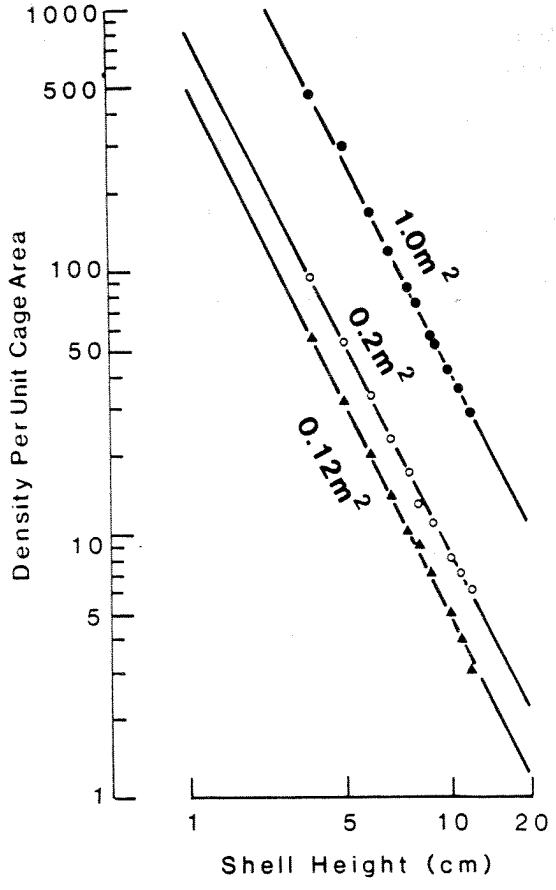

Fig. 7. Relationship between shell height of giant scallops (cm) and allowable density assuming that only one-third of available cage area can be covered.

Table 2. Maximum permissible stocking densities of giant scallops in suspended cage culture, assuming that the area of the cage bottom which can be occupied is once-third of the total available.

Shell height (cm)	Calculated scallop area m^{-2}	Numbers per unit cage bottom area in m^{-2} 0.12	0.2	0.3	0.5	1.0
1.0	7.850×10^{-5}	170	283	425	708	1415
2.0	3.140×10^{-4}	124	213	319	531	1062
3.0	7.065×10^{-4}	56	94	143	236	472
4.0	1.256×10^{-3}	32	53	79	132	298
5.0	1.963×10^{-3}	20	34	51	85	169
6.0	2.826×10^{-3}	14	23	35	59	118
7.0	3.847×10^{-3}	10	12	26	43	86
7.5	4.416×10^{-3}	9	13	22	37	75
8.5	5.670×10^{-3}	7	11	17	29	56
9.0	6.360×10^{-3}	6	10	15	26	52
10.0	7.850×10^{-3}	5	8	12	21	42
11.0	9.500×10^{-3}	4	7	10	17	35
12.0	1.130×10^{-2}	3	6	9	15	29

pearl net of 0.12 m^2 bottom area available, the initial stocking density of 500 individuals of 1 cm shell height juveniles must be reduced to six individuals at 9 cm shell height when they are of market size. Even with lantern nets of 0.2 m^2 available bottom area, the number of scallops stocked is reduced to 10 by the time they reach market size.

GROWTH DATA

Growth data for the long line and weir stake treatments are shown in Fig. 8. It is of interest to note that we found growth in both summer and winter months during these experiments. Winter growth ranged from 9-16% of the summer increment of shell height.

Because the experiment only lasted for 1 yr, we were not able to follow a given cohort through spat collection to market size. Consequently, overlap errors in growth (Fig. 8) were obvious because growth in suspension culture was higher than when scallops were placed directly on the bottom. We have constructed a composite graph (Fig. 9) based on Fig. 8 which compares all forms of suspension culture - inclusive of benthic cage culture - and natural or benthic relaying growth.

A market size scallop of 90 mm shell height (11.4 g meat weight) takes approximately two and one-half growing summers to achieve acceptable size from spat; whereas, a bottom growing scallop requires four or five summer growth periods to achieve this size (Fig. 9). The latter information is consistent with published data concerning growth rates of scallops within Passamaquoddy Bay.

Treatment effects on growth rates of scallops within the experiment are shown in Table 3. In order to account for small differences in the growing period and to minimize differences in initial size within year-classes, the growth data has been converted to daily growth increments as a percentage of the initial size.

MORTALITY DATA

The data for 1987-1988 are shown in Table 4 and includes summer and winter mortality rates.

Possible causes of loss occurring during the field experiments include:

1 - natural mortality not associated with culture conditions,

2 - stress-related deaths caused by capture, tagging and/or exposure to air and drying during growth measurements,

3 - interference competition as mentioned earlier, which should be a function of stocking density,

4 - predation, particularly by the starfish Asterias rubens,

5 - build-up of fouling organisms on the cages which impaired water flow and hence hindered feeding, eventually resulting in some deaths,

6 - escape by swimming from the culture area. Practically, this is only a possibility in the benthic relaying treatment.

Because the experimental design did not allow us to assign causes of loss during the grow-out experiment, the interpretation presented here is speculative. Summer mortality ranged from 9.1 to 45.3% for all year-classes (Table 4) with an average of 20.6% and a high value for treatment 3 (benthic cage) of 75.2% for year-class 3 scallops. This is suggested to be a predation caused mortality -- starfish were found inside the cage, obviously being able to enter the 10 x 45 mm slits of the cage walls. Cluckers, or clean empty shells, were also present within the cage. Interestingly, the mortality for larger year-class 4 scallops was 23.7% that is within the range of the other treatments, suggesting a size limitation

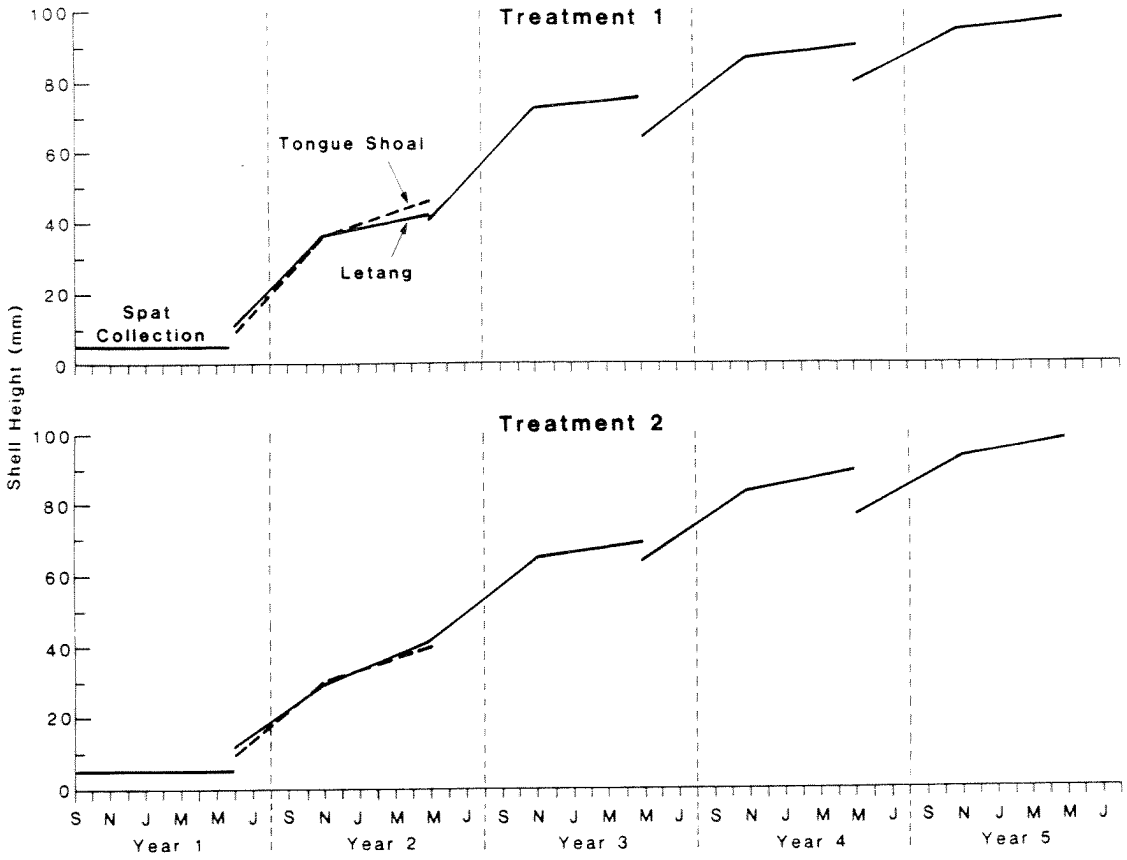

Fig. 8. Plot showing summer (May-November 1987) and winter (November 1987-May 1988) growth rate as shell height of giant scallops.

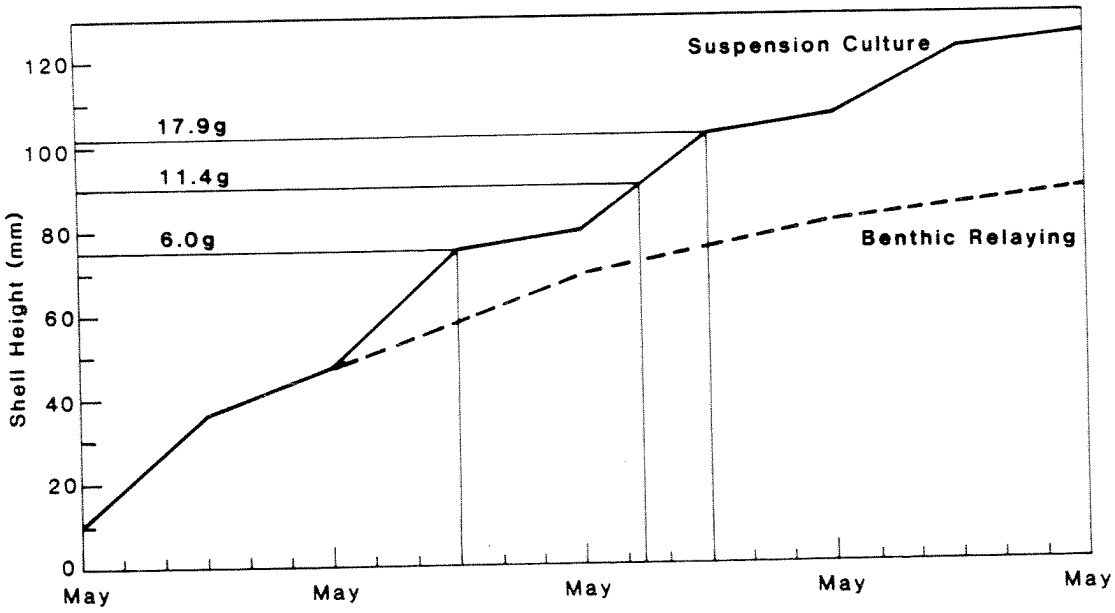

Fig. 9. Composite plot showing lifetime growth rates of a suspended and bottom relaid giant scallop in Passamaquoddy Bay.

Table 3. Giant scallop daily growth rates as shell height in the period May 1987 to May 1988 and total gain expressed as a percentage of the initial shell height. (Treatments: 1 = long line 2 = weir stakes, 3 = benthic trays, 4 = benthic relaying).

Year-class	Treatment	Duration (d)	Initial shell height (mm)	Daily gain (mm/d)	Total gain (% of initial)
1 (Tongue Shoal spat)	1	313	9.19	0.1166	397
	2*	313	9.11	0.0982	338
1 (L'Etang spat)	1	290	11.08	0.1083	283
	2*	290	10.41	0.1047	292
2	1	365	40.52	0.0957	86
	2	365	40.94	0.0744	66
3	1	365	62.64	0.0748	44
	2	365	62.89	0.0706	41
	3	365	63.43	0.0350	20
	4	365	61.84	0.0638	38
4	1	365	78.95	0.0534	25
	2	365	76.01	0.0609	29
	3	365	76.26	0.0207	10
	4	365	74.68	0.057	22

*At Brandy Cove.

Table 4. Summer and winter mortality rates for giant scallops of different age and treatments (1-4 as in Table 1). Average for May to November 1987 (summer) and November 1987 to May 1988 (winter).

Year-class	Treatment	Percent mortality			N	Stocking density m^2
		Summer	Winter	Total		
1	1	9.1	31.9	41.0	700	833
	2	14.9	27.7	42.6	700	833
2	1	25.7	16.1	41.8	300	100
	2	45.3	2.4	47.7	300	100
3	1	16.7	33.6	50.3	250	50
	2	22.3	25.6	47.9	250	50
	3	75.2	53.2	100+	230	153
4	1	12.9	35.4	48.3	250	50
	2	15.0	32.8	47.8	250	50
	3	23.7	29.0	52.7	300	100
3 & 4	4	-	-	36.1	360	5

to predation. Winter mortality averaged 26.1% with a range of 2.4 to 35.4%. The causes of this mortality probably include natural phenomena and interference competition; but principally stress-related deaths associated with handling during growth measurements.

For comparative purposes, we include mortality data from a similar, earlier experiment (Appendix 1). The results for different year-classes are summarized in Appendix 2. Although year-class 1 mortality for summer 1986 is higher than for 1987, the remaining year-classes for both longline and weir-stake supported lantern nets show lower mortality than in 1987. One significant difference between the 1986 and 1987 data is the lower mortality of the benthic relaying treatment in 1987. This must be due to differences in predation pressure between the two sites used -- there being much less predation at the Lime Kiln Bay site, ~36% mortality over 1 yr versus an average of 64.9% for 6 mo at Brandy Cove for combined year-classes 3 and 4.

NET AND CAGE FOULING

Considerable net fouling was experienced (Fig. 10) on suspended cages with the peak months being September/October. Overwintering fouling also occurred on suspended cages put in the water in November and removed in May of the next year, although less severe than the summer fouling shown in Fig. 10. The fouling buildup physically reduced the seawater flow through the cages and the fouling organisms themselves (e.g. ascidians and bryozoans) competed for sestonic food with the scallops thus increasing the likelihood of interference competition by scallops within the cage. Net fouling was less intense at the Brandy Cove site, suggesting regional differences in this phenomenon.

The benthic cages remained relatively free of fouling throughout the experiment. This is attributed to their contact with the sediment surface which allowed surface grazers such as gastropods and decapods to browse on the developing epi-fauna and flora on the cage surfaces, thus keeping them relatively clean. Contact with the sediment surface by the benthic cage supporting system also provided a route of entry for predators, such as Asterias rubens, to move onto the cages.

CONCLUSIONS

It is biologically feasible to grow giant scallops by any of the methods used herein. For suspended culture, inclusive of benthic cages where scallops are off bottom, the time to reach market size of 90 mm shell height is 2.5-3 growing seasons in the Passamaquoddy Bay area versus 4-5 growing seasons for scallops relaid on the sediments of Lime Kiln Bay.

We believe that the high mortality rates experienced during our experiment are due principally to stress-related deaths caused by capture and exposure to air during growth measurements. In commercial grow-out of the giant scallop, high mortalities can be avoided because capture, tagging, and extensive growth measurements would be unnecessary. We believe that a realistic range of mortalities is 5-25% per year excluding the possibility of predator mortality. Because we are unable to distinguish between predation and escapement away from the area during bottom relaying trials, it is difficult to assess the contributions of each to overall mortality. We believe the difference in mortality between the Brandy Cove and Lime Kiln Bay sites indicates a real difference in predation pressure. Obviously, choosing a site where predation was low would help, although it may be that the presence of relaid scallops would eventually attract predators. Predator control measures would then become a necessity (see Imai 1977, Ventilla 1982).

ECONOMIC RESULTS

PRODUCTION TRENDS IN THE TRADITIONAL GIANT SCALLOP FISHERY

From peak levels in 1977, landings of giant scallops declined to less than half by 1983 (Fig. 11). Catches in the short term are not expected to increase and future landings will depend on recruitment levels and the management strategies adopted, particularly for the Georges Bank scallop fishery which is the largest contributor to North American landings (Anon. 1985). Historical production trends for the Georges Bank scallop fishery are shown in Fig. 12 as fresh meat weights. Updated information from NAFO statistical Bulletins available to 1985 is included in Fig. 11 and 12.

RETURNS PER UNIT SIZE

Available data from Statistical District 50 are given as price per pound of shucked meats and as individual value per meat (Table 5). For the 11-yr period 1976-1986, there is an annual average increase of 6.55% in the price paid to fishermen which is higher than the general inflation rate - here assumed to be 5%. There is a distinct seasonality to the landed price received by fishermen (Table 6), reflecting the seasonal nature of supply. Highest returns would be obtained in the period November to March and the scallop culturist should aim at processing his product during this period.

The landed returns shown in Tables 5 and 6 would include processing costs, as the fishermen usually shuck the scallops while at sea, but not marketing and distribution costs. Because of a controllable scallop supply, the preferred strategy for the farmer would be to market and distribute the product directly, e.g. to a dealer or restaurant chain in large cities, thereby receiving the higher wholesale price. Unfortunately, no statistics on wholesale prices are available from the Department of Fisheries and Oceans.

COMPARATIVE COST OF LONG-LINE VERSUS WEIR-POLE INSTALLATION

The relative costs of a 100 m long-line, and weir-pole suspension system (Appendix 3) suggest that the latter is less expensive to construct. Since it has proved to be satisfactory, we have used this method for all further calculations except where the standard, concrete block, long-line is specified.

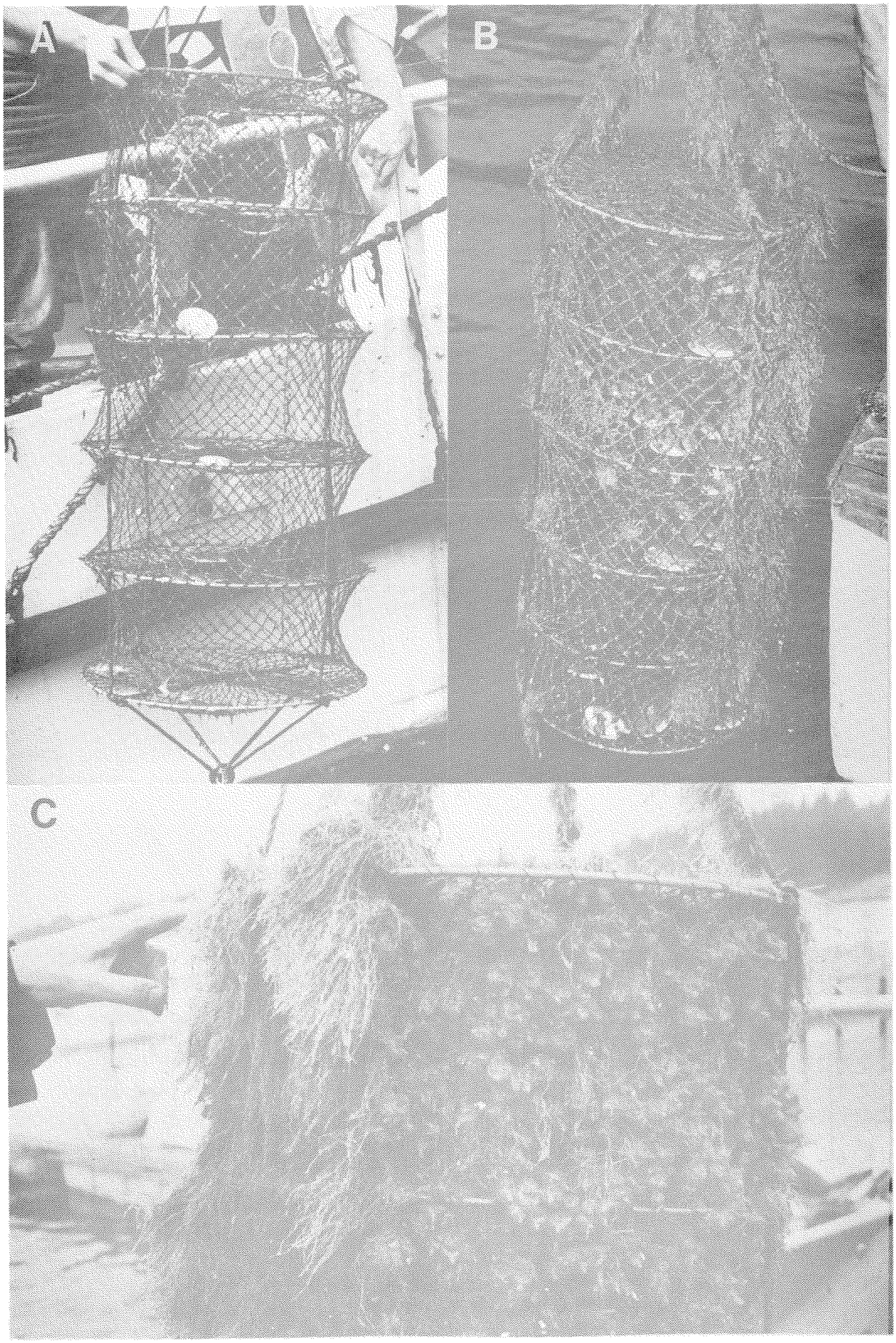

Fig. 10. Photographs showing fouling on lantern nets. A - clean net, B - October 1988 at Brandy Cove, C - October 1988 at Lime Kiln Bay.

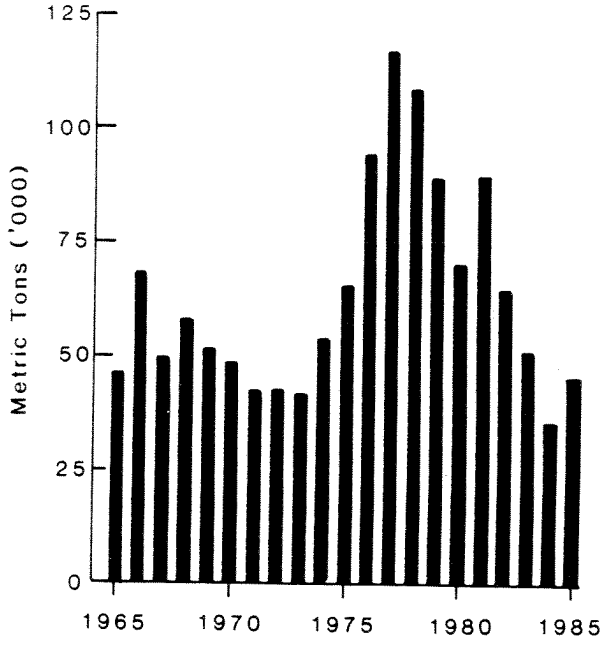

Fig. 11. Canadian landings of giant scallops as round weight from NAFO subareas 1-6 (Anon. 1985).

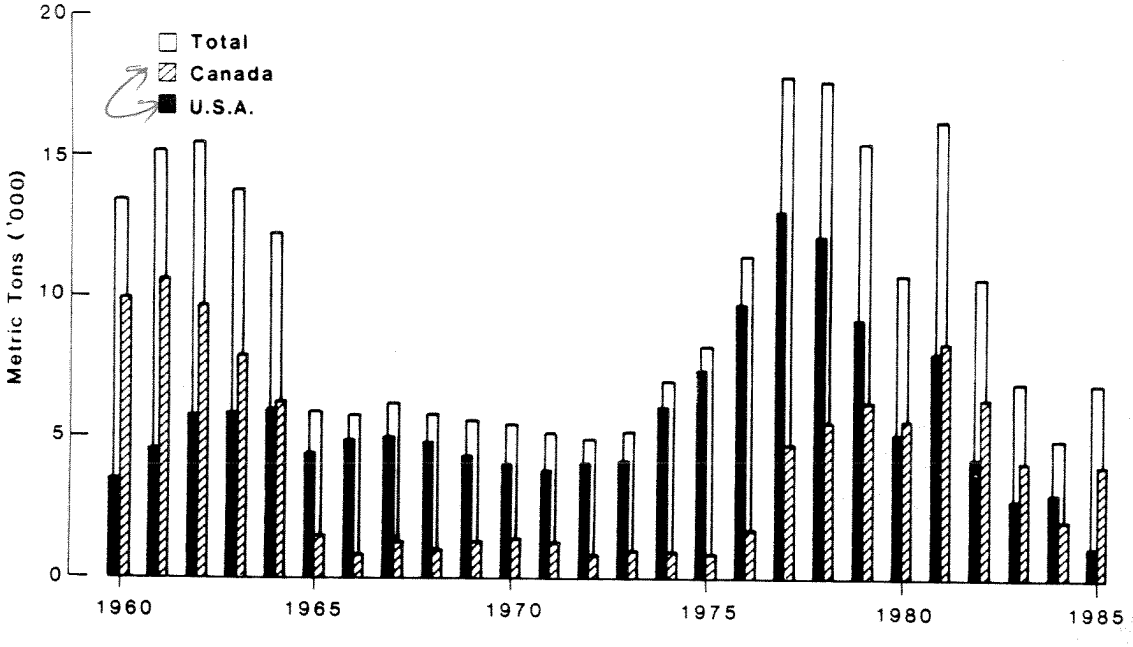

Fig. 12. Canadian (dark) and U.S. ~~(white)~~ hatched landings of giant scallops as meat weight from the Georges Bank fishery (Anon. 1985).

Table 5. Average annual return per unit size of giant scallops as landed price to fishermen in Statistical District 50, Bay of Fundy. Predicted prices based on a 6.55% annual increase are shown for 1988-1997. Average value for individual meats of stated size in grams.

Year	Average $ per lb meats	17.9 g ¢	11.4 g ¢	6.0 g ¢
1976	3.76	14.83	9.44	4.97
1977	2.21	8.71	5.55	2.92
1978	2.42	9.54	6.08	3.20
1979	3.67	14.47	9.22	4.85
1980	4.25	16.76	10.67	5.62
1981	4.58	18.06	11.50	6.06
1982	3.70	14.59	9.29	4.89
1983	5.62	22.16	14.11	7.43
1984	7.15	28.19	17.95	9.45
1985	6.97	27.48	17.50	9.21
1986	7.14	28.15	17.93	9.44
1987	5.21	20.54	13.08	6.89
1988	5.55	21.89	13.94	7.34
1989	5.91	23.32	14.85	7.82
1990	6.30	24.85	15.82	8.33
1991	6.71	26.48	16.86	8.88
1992	7.15	28.21	17.96	9.46
1993	7.62	30.06	19.14	10.08
1994	8.12	32.03	20.39	10.74
1995	8.65	34.13	21.73	11.44
1996	9.22	36.37	23.15	12.19
1997	9.82	38.75	24.67	12.99

Table 6. Average monthly landed price in cents per standard giant scallop meat of 11.4 g for NAFO Subarea 4X -- Bay of Fundy/Browns Bank.

Month	Year 1982	1983	1984	1985
January	10.77	12.82	19.31	18.93
February	9.55	13.10	18.60	18.93
March	8.74	13.07	18.24	17.99
April	8.11	12.92	17.38	16.19
May	8.08	12.01	15.71	15.13
June	8.34	12.92	14.14	13.86
July	8.79	14.42	13.96	13.63
August	8.79	14.97	14.42	12.74
September	9.37	15.56	15.0	12.90
October	11.02	16.37	16.16	14.95
November	11.96	17.25	16.34	15.45
December	12.01	18.32	16.47	16.27

COST OF SPAT COLLECTION

The major determinant of cost in natural spat collection is the average number of spat caught per bag. This is because the unit cost of an onion bag collector (see Appendix 3) is fixed and does not vary with catch rates. The relationship is an inverse logarithmic one (Fig. 13) and obviously suggests the need to locate spat collectors at places of maximum larval abundance. Mortality associated with removing the juvenile scallops from the collectors after approximately

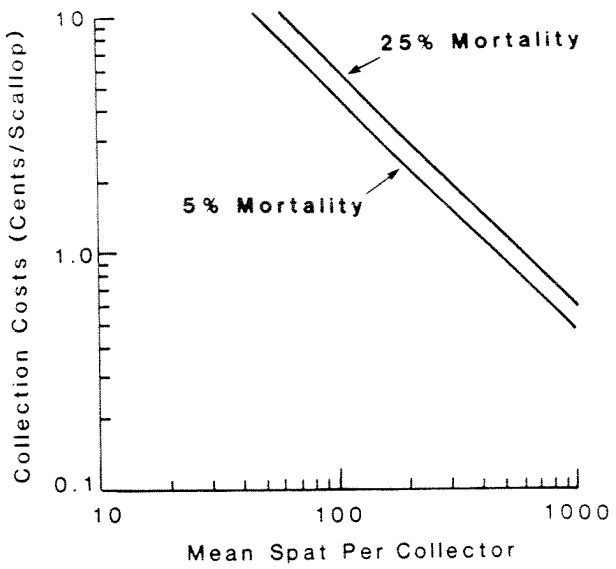

Fig. 13. Relationship between the average number of giant scallop spat caught per onion bag collector and cost in cents per scallop for two assumptions of transfer mortality.

6-9 mo in the water may also be significant in determining the final cost of spat.

COST OF INTERMEDIATE CULTURE

Two strategies are feasible for this stage of culture:

- initial stocking with the final permissible density (32, 3.8 cm height scallops see Table 2) or
- changing of densities during the first season's growth, e.g. initial densities of:

  May - 1 cm shell height - 124 per pearl net
  July- 2 cm shell height - 32 per pearl net
  Nov.- 3.8 cm shell height transferred to grow-out culture

In the calculations shown in Appendix 3D, we have assumed that the number of pearl nets needed to raise 19,000 scallops to grow-out size (allowing for 5% mortality on 20,000 prior to the final density change) is 19,000 ÷ 32 = 594. The 594 pearl nets would only be needed in the period July to November if the multiple changing of strategy was employed.

BENTHIC RELAYING CULTURE

The costs associated with this method consist of:

- placing the scallops on bottom,
- losses due to predation mortality or escapement from the seeded area,
- recovering fattened scallops after 3-4 yr on bottom.

BENTHIC CAGE CULTURE

For benthic cage culture, the following apply:

- May-November - 75 mm final size or 22 scallops per 0.3 m² cage. Market at 6 mo - 6 g meat weight,
- November-July - 90 mm final size or 15 scallops per 0.3 m² cage. Market at 15 mo - 11.4 g meat weight,
- July to November (or later in winter) - 102 mm final size or 12 per 0.3 m² cage. Market at 18+ mo at 17.9 g meat weight.

Changes of stocking density could be made at the same times, that is: 6, 15 and 18 mo.

LANTERN CAGE CULTURE

For lantern cage culture on weir stakes or a long-line, the following apply:

- May-November - 75 mm final size or 13 scallops per compartment of 0.2 m². Market at 6 mo - 6 g meat weight,
- November-July - 90 mm final size or 10 scallops per compartment of 10.2 m². Market at 15 mo - 11.4 g meat weight,
- July to November (or later in winter) - 102 mm final size or 8 per compartment of 0.2 m². Market at 18+ mo of age at 17.9 g meat weight.

Changes of stocking density to be made at 6, 15 and 18 mo.

PROCESSING COSTS

An expert could shuck 100 scallops in 5 min, therefore 84 h would be required to shuck 100,000 scallops. Processing would also include the cost of containers and temporary storage facilities in a refrigeration unit.

COMPARISONS OF COSTS AND RETURNS

The cost estimates calculated in Appendix 3 do not include capital costs associated with scallop culture. At a minimum, this would include a boat or scow equipped with a winch (see Appendix 4) for hauling nets or cages.

Cost and return estimates excluding these capital costs are shown in Table 7 and are based on predicted average 1987-96 prices.

Table 7. Cost and return estimates per scallop, exclusive of capital costs, for giant scallop cultures in the Bay of Fundy, average annual costs of 1987-1996 for 100 m lines.

Item		Initial number stocked	Final number harvested	¢ per scallop	Assumptions
C. Spat collection		150,000	112,500	2.95	A mean of 200 spat per collector and 25% mortaltiy
D. Intermediate culture		20,000	19,000	5.00	Two changes of density during the season.
E. Benthic relaying		100,000	50,000	0.25	Four summer seasons of growth and 50% overall losses
F. Benthic cage	Year 1	11,000	10,450	16.86	5% annual loss
	Year 2	7,500	7,125	24.73	Market at 15 mo or 90 mm size
G. Weir stake line	Year 1	6,500	6,170	6.10	5% annual loss
	Year 2	5,000	4,750	7.93	Market at 15 mo or 90 mm size
H. Long line	Year 1	6,500	6,170	7.47	5% annual loss
	Year 2	5,000	4,750	9.70	Market at 15 mo or 90 mm size
I. Processing costs			100,000	1.13	-
Average returns for 1987-1996 as 11.4 g meat (¢)		-	-	17.69	See Table 5. Range 13.08-31.8¢

Totals C+D+E+I = 9.33; C+D+F+I = 50.67; C+D+G+I = 23.11; C+D+H+I = 26.57.

CONCLUSIONS

Although our statistical data base on the production capacity of the conventional scallop fishery is not comprehensive, it does suggest that current production is low (Fig. 11, 12), although in the medium or long term could increase again. The giant scallop provides a high priced, gourmet product for an already established market. The average predicted price for the 11.4 g meat in the period 1987-96 is $15.52 per kg of meats, ranging from $11.47 to $21.64 per kg. The predicted price in this period, based on limited data (Table 5) from 1976-1986, should rise at a rate of 6.55% annually, although there were 3 yr during that 11-yr period when a drop in price actually occurred, e.g. from 1976-77, 1981-82 and 1984-85. The year 1987 also saw a drop in landed prices. Lower prices are generally associated with high production - the latter due often to strong year-classes. Year-class strength is probably physically controlled and although the present fishing pressure is high, it is considered difficult to "fish-out" scallop stocks. Some scallop stocks are present in unfishable, rocky areas and newer grounds may be established or discovered by the scalloping fleet. Thus a scallop aquaculture industry in direct competition with the established, conventional one, could expect some uncomfortable price variances in the medium-term future. A better strategy would be to produce a product distinct from the conventional one, perhaps a 6 g meat at 75 mm final size.

The economic feasibility of three of the four grow-out methods tested is dubious (Table 7). All three use cages. We believe that our results show that grow-out in cages is uneconomical: as the scallop increases in size it uses significantly greater cage area, the cost of cages is a significant fraction of the materials cost, there are losses due to the "biting syndrome" and the cages are also subject to fouling. As found also by Frishman et al. (1980), benthic relaying was the only economically viable method of culture that we tested.

DISCUSSION

Our field experiments show that with all methods of grow-out tested, it is biologically feasible to produce giant scallops of marketable size within 3 yr from spat fall by suspension culture and 4.5-6 yr by benthic relaying techniques. The reason for the difference in growth rates of scallops in suspension culture and those living on the sediment may be understood as a direct result of the "seston depletion effect" (Wildish and Kristmanson 1979, 1984, 1985). Scallops living directly on the sediment are present within the benthic boundary layer. This layer may be physically defined as a discrete body of water in which flow is restricted by its contact with the bottom. Within this layer, food particles or seston are mixed by turbulent flow (except for a narrow laminar layer just above the bottom). It is not surprising that the combined feeding of benthic suspension feeders may cause a depletion of seston within the benthic boundary layer and hence limitation of population growth and production. In our earlier modelling of this phenomenon (Wildish and Kristmanson 1979), we ignored physical processes which may add seston to the benthic boundary layer, e.g. by advection from the bulk layer or resuspension from the sediment, without seriously violating our conclusions regarding seston depletion. By contrast, scallops in suspension culture are present in bulk layer flows with a high seston concentration, which generally have not been utilized by upstream suspension feeders. If, as occurs in the Bay of Fundy, the whole water column is turbulent, suspended scallops may have access to the seston within a considerable volume of water (defined by the flow path length, depth of water less the boundary layer, and flow characteristics). For this reason, the seston concentration and turbulent seston supply rates will be higher in the water column above the benthic boundary layer, resulting in greater growth rates there.

Although all of the grow-out methods tried are biologically feasible, only one of them, benthic relaying, shows any possibility of economic success. Further biological research required to support this technique should include a thorough investigation of losses, which may be due to predation or escapement, and a study of possible methods of predator control. Two aspects of scallop grow-out culture by benthic relaying may be obstacles to its widespread use:

- a farm producing 1 million scallops per year - at a stocking density of five scallops per m^{-2} - requires 3-4 separate 0.2-km^{-2} fattening areas (depending on the age marketed) in addition to spat collection and intermediate culture long lines. This may conflict with traditional common use of scalloping grounds. The problem could be overcome if the venture was a cooperative one involving all conventional scallop fishermen.

- the grow-out time is nearly 2 times greater than for suspension culture, meaning that invested funds for spat collection and intermediate culture are tied up for 2-3 yr longer in benthic relaying.

One method of suspension culture used by the Japanese: - earhanging or pocket culture (Imai 1977) - should be considered in a further study. Results from Quebec suggest that scallop grow-out by earhanging is marginally economically feasible (Anon. 1988). Earhanging culture allows the rapid scallop growth characteristic of suspension culture and appears to be a relatively cheap method of production (Table 8). However, we have no direct experience with it - particularly in how to assign labour costs, which are estimated in Table 8 and represent the largest cost item involved. Nor do we have any realistic evidence regarding mortality or possible problems with fouling in this type of grow-out culture in Bay of Fundy conditions.

The cheapness and reliability of weir-poles as a means of carrying suspended bivalve cultures in the local area has been demonstrated during this study, and could be readily adapted as the suspension system for grow-out by earhanging or pocket culture.

We conclude that only two methods of grow-out need be considered in further experimental trials of economic feasibility: bottom relaying and earhanging/pocket culture. For the latter , one

Table 8. Estimated average annual costs (1987-96) for giant scallop culture by ear hanging on weir pole suspension in the Bay of Fundy.

Item	¢ per scallop	Assumptions
Spat collection	3.0	200 spat per collector and 25% mortality
Intermediate culture	5.0	5% mortality
Grow-out Year 1*	6.0	5% mortality per year
Grow-out Year 2*	0	Market at 15-18 mo
Processing costs	1.0	
Total	15.0	

*Based on 10-yr average annual costs of a 100-m line on weir stakes (mean annual cost = $83.16)

100 lines of 10 m depth and 200 scallops per line
Polypropylene rope 1/4" = $25
20,000 plastic ear tags = $200
Tag applicator = $150
Estimated labor 50 h at $10/h in 1987. Annual average for 1987-96 = $628.90
Initial scallops stocked = 20,000 Year 1
Final number harvested = 18,050 Year 2.

possible culture strategy is to transfer larger spat directly into pocket suspension culture in May followed by harvesting in July to November of the next year. Harvested scallops should be 55-75 mm in shell height at these times which is equivalent to a 2.0-6.0 g wet weight meat. Before the culture of giant scallops in the Bay of Fundy can become economically feasible, much greater research and development effort has to be focussed on each step in culture in an effort to minimize production costs.

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Appendix 1. Summer mortality rates of giant scallops of different age and treatment for the period May-October 1986. Longline data from Lime Kiln Bay, Weir stake and benthic relay data from Brandy Cove.

Year-class	Treatment	% mortality	Initial N	Density m^{-2}
1	Longline pearl net cages	18.4	250	208
1		71.6	250	208
2	Longline - lantern cages	7.2	500	250
		12.2	500	250
		10.4	500	250
		16.4	500	250
		2.0	250	125
		6.0	150	75
3	Longline - lantern cages	5.5	200	100
		9.0	100	500
		16.4	110	55
		37.0	100	50
4	Longline - lantern cages	14.0	50	25
		6.0	100	50
1	Weir stakes - pearl net cages	12.6	500	416
1		19.6	250	208
2	Weir stakes - lantern cages	6.4	125	62
		5.0	400	200
		6.7	150	75
3	Weir stakes - lantern cages	3.0	200	100
		12.7	110	55
4	Weir stakes - lantern cages	14.0	50	25
		4.0	100	50
2	Benthic relaying	92.6	500	5
3		74.5	400	5
4		55.3	300	5

Appendix 2. Summary of 1986 summer (May-October) mortality data.

Year-class	Average % mortality		
	Longline	Weir stakes	Benthic relaying
1	45.0	16.1	-
2	9.0	6.1	92.6
3	17.0	7.9	74.5
4	10.0	9.0	55.3

Appendix 3. Cost estimates in Canadian dollars of various stages of giant scallop culture for the period 1987-96. Replacement costs assume 5% annual inflation.

Item	Quantity	Unit cost	Total	Estimated replacement cost per year 2	3	4	5	6	7	8	9	10
A. 100-m longline												
Concrete blocks (1000 lb)	4	117.00	468.00	–	–	–	–	–	–	–	–	–
Buoys, 60"	2	33.25	66.50	–	–	–	–	84.88	–	–	–	–
Foam buoys	25	4.00	100.00	–	–	46.30	–	51.00	–	56.30	–	62.10
Polypropylene rope, 3/4"	100 m	1.90/lb	62.70	–	–	–	–	80.03	–	–	–	–
Labour	24 h	10.00	240.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Estimated annual cost for 10-yr period = $149.78/yr												
B. 100-m line on weir stakes												
Weir stakes*	3	58.00	174.00	–	–	67.15	–	–	77.74	–	–	90.00
Polypropylene rope, 3/4"	100 m	1.90/lb	62.70	–	–	–	–	80.03	–	–	–	–
Labour	10 h	10.00	100.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Estimated annual cost for 10-yr period = $83.16/yr												
C. Spat collection on 100-m line												
Onion bags	750	1.00	750.00	787.50	826.88	868.22	911.63	957.21	1005.08	1055.33	1108.10	1163.51
Polypropylene rope, 1/4"	375 m	1.75/lb	29.53	–	–	34.19	–	–	–	41.57	–	–
Gillnetting	84 lng	45.00	3870.00	–	–	–	–	–	–	–	–	–
Labour	250 h	10.00	2500.00	1500.00	1575.00	1653.75	1736.44	1823.26	1914.42	2010.14	2110.65	2216.18
Estimated annual cost for 10-yr period = $3235.86/yr												
D. Intermediate culture on 100-m line												
Pearl nets*	594	2.60	1544.40	–	–	451.48	–	–	522.64	–	–	605.02
Polypropylene rope, 1/4"	300 m	1.75/lb	23.63	–	–	–	28.72	–	–	–	–	35.94
Labour	50 h	10.00	500.00	525.00	551.25	578.81	607.76	638.15	670.05	703.55	738.74	775.67
Estimated annual cost for 10-yr period = $950.08/yr												
E. Benthic relaying culture												
Labour: sowing	4 h	10.00	40.00	42.00	44.10	46.31	48.63	51.06	53.61	56.29	59.10	62.06
harvesting	16 h	10.00	160.00	168.00	178.40	185.22	194.48	204.20	214.41	225.13	236.39	248.21
Note: Assuming 100,000 scallops and dragging as the form of harvesting and in 4 min, 800 scallops can be collected												
Estimated annual cost for 10-yr period = $251.56/yr												

Appendix 3. (cont'd)

Item	Quantity	Unit cost	Total	Estimated replacement cost per year 2	3	4	5	6	7	8	9	10
F. Benthic cage culture on 100-m weir stake line												
Cage support stands	50	175.00	8750.00	-	-	-	-	-	-	-	-	-
Polypropylene rope, 1/2"	1500 m	1.75/lb	438.38	-	-	253.74	-	-	-	308.43	-	-
Cages	500	12.00	6000.00	-	-	-	-	-	-	-	-	-
Rope bridles , 1/2" (50 @ 0.62 m)	31 m	1.75/lb	9.06	-	-	10.49	-	-	-	12.75	-	-
Labour	8 h	10.00	80.00	84.00	88.20	92.61	97.24	102.10	107.21	112.57	118.20	124.11
Estimated annual cost for 10-yr period = $1678.91/yr												
G. Lantern cage culture on 100-m weir stake line												
Lantern cages*	50	19.50	975.00	-	-	-	-	622.19	-	-	-	-
Polypropylene rope, 1/4"	120 m	1.75/lb	35.07	-	-	20.31	-	-	-	24.70	-	-
Labour	10 h	10.00	100.00	105.00	110.25	115.76	121.55	127.63	134.01	140.71	147.75	155.14
Estimated annual cost for 10-yr period = $293.51/yr												
H. Lantern cage culture on 100-m longline												
Lantern cages *	50	19.50	975.00	-	-	-	-	622.19	-	-	-	-
Polypropylene rope, 1/4"	170 m	1.75/lb	49.68	-	-	28.75	-	-	-	34.94	-	-
Foam buoys	10	4.00	40.00	-	-	46.31	-	-	-	56.29	-	-
Labour	10 h	10.00	100.00	105.00	110.25	115.76	121.55	127.63	134.01	140.71	147.75	155.14
Estimated annual cost for 10-yr period = $311.10/yr												
I. Processing costs												
Shucking labour (20/min)	84 h**	10.00	840.00	882.00	926.10	972.41	1021.03	1072.08	1125.68	1181.96	1241.06	1303.11
Plastic cartons	1200 of 1 kg cap.	0.05	60.00	63.00	66.15	69.46	72.93	76.58	80.41	84.43	88.65	93.08
Estimated annual cost for 10-yr period = $1132.01/yr												

*Estimated prices.

**Based on 100,000 scallops, 87.72 meats of 11.4 g in 1 kg.

Appendix 4. Estimate of 1987 capital costs for a scallop farm in the Bay of Fundy.

	$K
Suspension culture	
Powered scow, with winch	15.0
Tender boat - Eastporter	8.0
Building	20.0
Refrigeration unit	3.0
Truck	15.0
Benthic relaying	
Scallop dragger	30.0
Scallop drags	6.0
Tender boat	8.0
Building	20.0
Refrigeration unit	3.0
Truck	15.0