

THE EFFECTS OF SIZE-SELECTIVE FEEDING BY STARFISH (*ASTERIAS VULGARIS*) ON THE PRODUCTION OF MUSSELS (*MYTILUS EDULIS*) CULTURED ON NETS

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ABSTRACT

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Laboratory feeding trials were conducted in which excess rations of four different size classes of mussels were provided to three different size classes of starfish. Although differences in size-selective feeding behaviour occurred between different size classes of starfish feeding separately and those feeding aggregately, the total food intake remained the same. The consumption of mussel meat by starfish based on the relative ash-free dry weights of both prey and predator ranged from 6 to 8.6% day⁻¹. Patterns of size-selective feeding behaviour and feeding rates of starfish observed in the laboratory appear consistent with the changes in relative abundance among year class cohorts of mussels and starfish residing on culture nets at a mussel farm. It is concluded that the impact of starfish predation at the mussel farm is not likely to affect adversely the marketable yield of older mussels, and may provide a beneficial influence through the culling of undersized mussels.

INTRODUCTION

The growth and survival of natural populations of *Mytilus edulis* is limited by predation and inter- and intraspecific competition. Paine (1977) indicates that in the absence of predators, *Mytilus* is often the dominant competitor for food and space in the marine intertidal zone.

Methods of off-bottom mussel culture have been successful in minimizing losses caused by many benthic predators (Mason, 1976). Hancock (1955) observed that mussels are preferred by *Asterias* over other molluscan species,

and Lutz and Incze (1980) suggest that predation on young seed mussels by *Asterias* sp. could be a serious problem in suspended mussel culture in eastern North America. Sutterlin et al. (1981) have observed the settlement and growth of starfish on mussel culture gear in eastern Canada.

A. vulgaris produces pelagic larvae capable of settling on off-bottom culture gear. Three to 4 weeks after spawning the ciliated brachiolaria larvae settle and metamorphose into young starfish (Smith, 1940). At the Garden Cove mussel farm in Newfoundland, mussel spat settles between mid July and mid August and starfish settlement occurs in September and October (Sutterlin et al., 1981). Because both organisms settle each year, at harvest, the gear will contain not only 25-month-old marketable mussels, but also undersized 1-year-old mussels, recently-settled mussel spat and 2 year classes of starfish. Predation by the older starfish could be detrimental especially if the marketable mussels are consumed. On the other hand, if predation is restricted to the younger cohorts of mussels, thereby reducing competition for food and space, the marketable yield of older mussels could be improved.

The object of this study was to examine size-selective predation by different size classes of starfish on different size classes of mussels, to document yearly changes in relative abundance of starfish and mussels on culture gear and to determine rates of daily food intake of starfish in order to assess the starfish predation at a mussel farm.

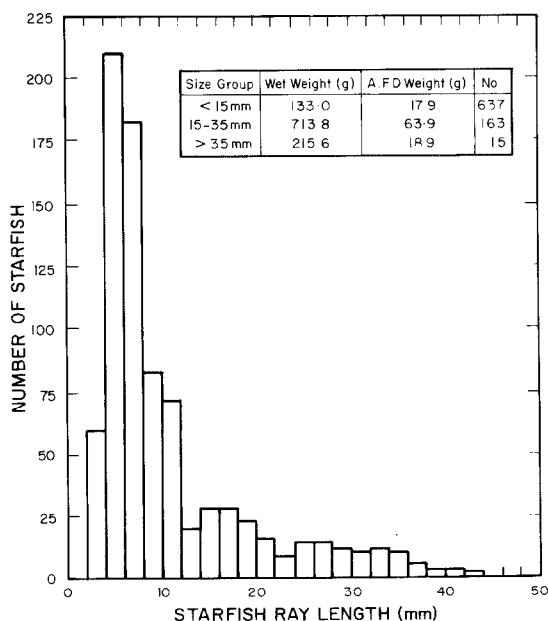


Fig. 1. Size-frequency distribution of starfish inhabiting one net of a 22-month old array (May 1980).

MATERIALS AND METHODS

Field studies

The Garden Cove mussel farm (47°50'N, 54°10'W) is situated at the head of Placentia Bay along the south coast of Newfoundland, Canada. Mussels are cultured on polypropylene nets (4 × 4 m) supported by a buoyed head line (Sutterlin et al., 1981).

With the aid of SCUBA divers, all starfish were removed from a cultured net that had been in water for 22 months. The maximum ray lengths (Fig. 1) were measured using the procedures of Hancock (1955) and Smith (1940). Three size classes of starfish (A: 1.0–1.5 cm, B: 1.65–3.5 cm, C: 3.6–5.0 cm ray length) were kept in flowing seawater and maintained on excess mussel rations for subsequent laboratory experiments. Divers also sampled mussels from culture nets that had been in the water for 7, 19, 21 and 31 months respectively; the mussels were measured and length : frequency distributions were prepared (Fig. 2). Sections of culture nets that had been in the water for 22 months were stripped of mussels, and after removal of debris and fouling organisms, the total weight of mussels on the section was determined. Live mussels were sorted into four groups of different lengths (I: 1.0–1.9 cm, II: 2.0–3.0 cm, III: 3.5–4.5 cm, IV: 5.0–6.0 cm), and held in running seawater.

Laboratory feeding trials

Two trays of a wet bench were partitioned with perforated PVC into 32, (15 × 20 cm) compartments. The trays were continually flushed with 16°C seawater to simulate the mean summer temperature at the mussel farm.

To determine feeding rates and the degree of size-selective preferential feeding, randomly-arranged duplicates of seven combinations (treatments) of the three size classes of starfish (A, B and C) were offered an equal weight of whole mussels from each of the four size classes (Table I). Based on preliminary feeding trials, the maximum daily ration of mussel meat was adjusted to ensure that excess mussels would be available at the completion of a feeding trial. Twice the maximum ration of each size class of mussels was offered to each group of starfish. A total weight of 20 g wet weight of starfish was placed in each compartment. Feeding trials lasted 3 days during which time empty mussel shells were removed daily, dried, weighed and replaced with live mussels of the same size. Daily food consumption rates were calculated as dry weight and ash-free dry weight (AFDW) uptake of mussel meat as a percent of the dry weight or ash-free dry weight of the starfish (Crisp, 1971). Linear regression equations were used to relate length, dry weight and ash-free weight (Table II).

A fully-crossed analysis of variance (ANOVA), consisting of the following factors, was used: eight levels of starfish treatment factors, four levels of

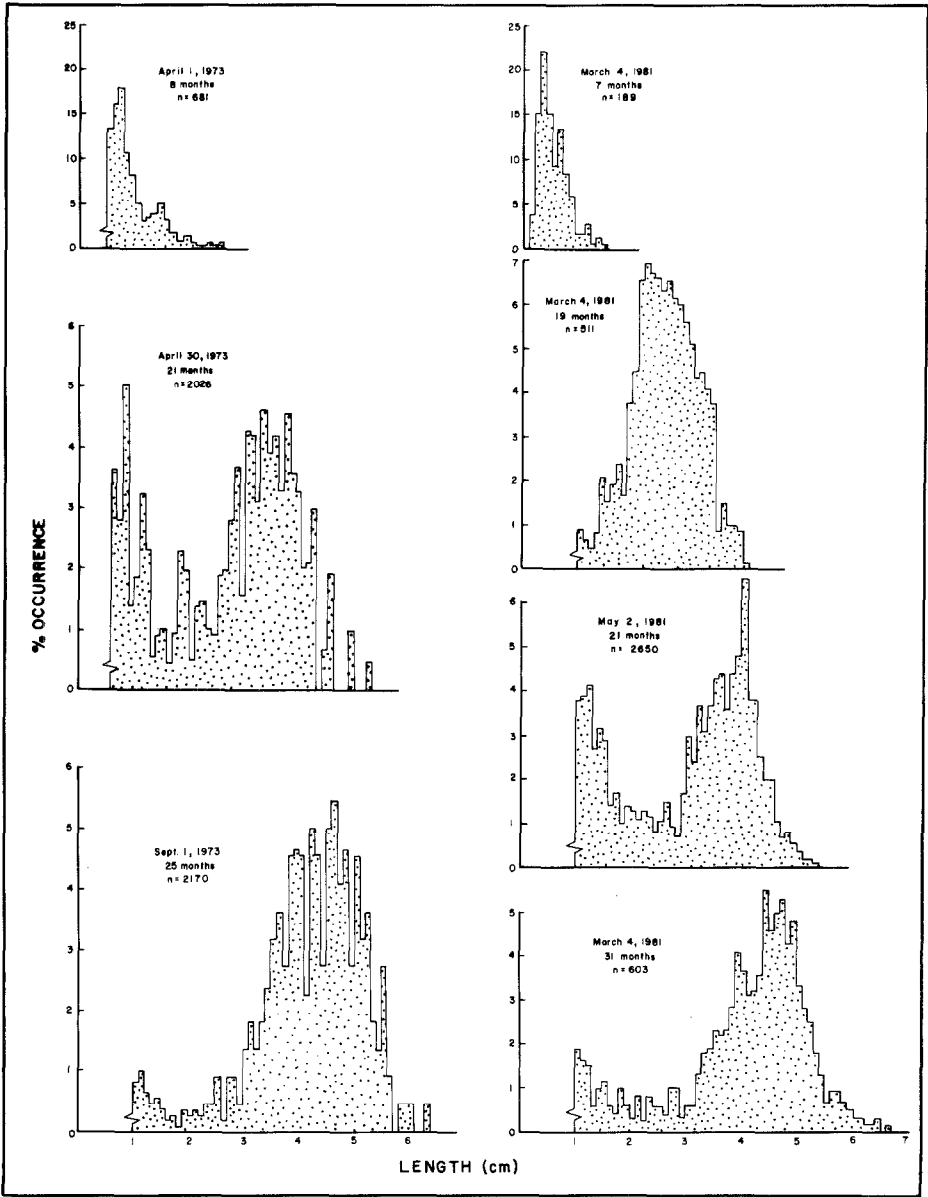


Fig. 2. Two reconstructed time series of year class distributions of mussels on culture nets in Garden Cove. The sampling time and number of months since initial spatfall are indicated.

mussel size class factors and two levels of replicate factors. Student–Newman–Keuls (SNK) tests (Sokal and Rohlf, 1969) were performed on means to reveal significant differences.

TABLE I

The reduction in dry weight of mussel meat in different starfish treatments. Size of starfish in the groups are: A is 1.0–1.9, B is 2.0–3.0 and C is 3.5–4.5 cm. Lengths of live mussels in the groups are: I is 1.0–1.9, II is 2.0–3.0, III is 3.5–4.5 and IV is 5.0–6.0 cm

Treatment	Starfish groups present	Mussel size class							
		I		II		III		IV	
		mg	%	mg	%	mg	%	mg	%
1	A	88.6	(94.2)	5.40	(5.7)	—	—	—	—
2	B	81.2	(73.7)	28.9	(26.3)	—	—	—	—
3	C	39.6	(44.5)	49.4	(55.5)	—	—	—	—
4	A + B	81.0	(74.3)	28.0	(25.7)	—	—	—	—
5	A + B + C	91.9	(46.7)	50.7	(25.6)	37.6	(18.9)	17.9	(9.1)
6	A + C	88.6	(46.8)	49.9	(26.3)	33.6	(17.7)	17.4	(9.2)
7	B + C	77.9	(50.0)	40.5	(23.9)	22.4	(13.2)	28.6	(16.8)
8	None	3.5		11.6		—		—	

TABLE II

Conversion factors used in feeding studies

	x (g)	y (g)	$y = ax + b$	n	r
<i>Starfish</i>	Wet weight	Dry weight	$y = 0.172x + 0.049$	69	0.99
	Dry weight	Ash-free dry weight	$y = 0.506x - 0.015$	10	0.99
<i>Mussels</i>					
Shell length	Shell weight	Meat dry weight			
Intervals					
1.0–1.9 cm	Shell weight	Meat dry weight	$y = 0.053x + 0.001$	25	0.92
2.0–3.0 cm	Shell weight	Meat dry weight	$y = 0.155x - 0.003$	25	0.76
3.5–4.5 cm	Shell weight	Meat dry weight	$y = 0.111x + 0.016$	24	0.97
5.0–6.0 cm	Shell weight	Meat dry weight	$y = 0.058x + 0.331$	24	0.52
	Meat dry weight	Meat AFDW	$y = 0.888x - 0.015$	9	0.99

RESULTS

Predation trials in the laboratory

The ANOVA conducted on data relating the dry weight of mussel meat absent in each treatment, revealed certain significant differences: among starfish treatments ($P < 0.001$), among size classes of mussels ($P < 0.001$) and treatment vs size class of mussels ($0.01 < P < 0.025$). SNK tests showed that in each of treatments 1–7, there was a significantly greater reduction in the total weight of mussel meat than in treatment 8 which did not contain starfish (Table I). This is attributed mainly to predation on group I mussels in all

starfish treatments. Significant predation on group II mussels occurred only in treatments 3, 5, 6 and 7. Treatments 5, 6 and 7 resulted in losses of group III and IV mussels that are also presumed to be attributable to predation. Losses of larger mussels (group III and IV) only occurred when large group C starfish were present together with smaller starfish (Table I).

To determine the mortality due to starfish predation, the observed natural mortality for each mussel group in treatment 8 was subtracted from the other seven treatments. The calculated feeding rates of the three different size classes of starfish in treatments 1–3 indicate significantly ($P < 0.001$) higher feeding rates by the small and intermediate size starfish as compared to the larger starfish (Table III). The rate of food intake among the three starfish groups ranged from 5.9 to 8.6% (AFDW) day⁻¹.

The combined consumption of mussels by different size classes of starfish feeding together in treatment 5 can be compared with the projected consumption of each size class of starfish feeding individually as revealed in treatments 1–3. The total mussel consumption per day by starfish groups feeding either separately or in aggregation was not significantly different. Similarly, total consumption during aggregate feeding by starfish groups A+B, B+C and A+C, could be predicated from the additive individual feeding rates.

TABLE III

Feeding rates (percent dry weight intake per day) of starfish feeding on mussels in the laboratory and comparisons of food uptake of starfish groups feeding individually or aggregately. (AFDW is shown in parenthesis)

Starfish Treatment	Starfish group	Mussel size class (cm)				Total
		1.0–1.9	2.0–3.0	3.5–4.5	5.0–6.0	
<i>A. Feeding rate</i>						
1	A	3.48 (6.94)	0.08 (0.09)	0.00	0.00	3.66 (7.03)
2	B	4.26 (6.76)	1.17 (1.86)	0.00	0.00	5.43 (8.62)
3	C	2.10 (2.71)	2.37 (3.20)	0.00	0.00	4.47 (5.91)
<i>B. Food Uptake (g)</i>						
Aggregate		0.2260	0.1053	0.0952	0.0448	0.4713
treatment 5		(0.1857)	(0.0641)	(0.0769)	(0.0379)	(0.3646)
(A+B+C)						
Projected from		0.2789	0.1461	0.0000	0.0000	0.4250
treatments 1–3		(0.2327)	(0.0997)			(0.3324)

As noted earlier, mussels greater than 3.5 cm were consumed only when large starfish from group C were in combination with one or both of the smaller size classes of starfish. This shift in size selection, as will be discussed later, is attributed to a shift in preference of large starfish for larger mussels. This assumption is supported by observations of only larger starfish feeding

on large mussels in treatments 5, 6 and 7. Cooperative or collective behaviour, in which several starfish feed on the same mollusc has been reported for *Asterias rubens* by Anger et al. (1977) and Doering (1981). This was not observed in the present study, possibly because a range of different size classes of mussels was always available.

DISCUSSION

Size-selective feeding behaviour and feeding rates

Feeding rates of starfish in the present study could not be directly compared with rates reported in the literature, because the units of measurement differed. Using the average caloric value of wet and dry echinoderms and molluscs (Brawn et al., 1968), however, it was possible to recalculate the feeding rates of sea stars feeding on molluscs given by Feder (1956) and Hatanaka and Kosaka (1959). Their values range from 5.5 to 6.7% caloric intake per day compared with 6.9% determined in this study.

Laboratory feeding experiments indicate a size-selective feeding pattern by starfish. Both large (3.6–5.0 cm ray length) and small to medium (1.0–3.5 cm ray length) starfish are capable of feeding on small mussels (<2.0 cm), but the feeding rate (% AFDW intake per day) of the small starfish is greater. Neither of the above starfish size classes, when isolated, appears to consume large mussels (>3.5 cm). However, when all three starfish sizes are combined, the intraspecific competition among starfish results in increased consumption of larger mussels.

Menge (1972b) studied the coexistence of two species of starfish, *Pisaster ochraceus* and *Leptasterias hexactis* (*Pisaster* being the larger species of the two), and suggested that coexistence was based upon a degree of "specialization by each predator for different-sized prey". However, in Menge's study, the food supply was assessed as being limited and admittedly tended to restrict the feeding performance of *Leptasterias*. Because food was not limited in either size or abundance in the present study, this source of bias was eliminated.

Dodson (1974) notes that several studies have shown that invertebrate predators have strict limitations on the size and shape of their prey. In support of a size-limited predator-prey relationship for starfish, Paine (1976) indicates that for *Pisaster ochraceus* of a particular body size, there exists an upper limit to the size of *Mytilus* that can be consumed and this limit increases as the body size of the starfish increases. A minimal size, apparently below which mussels are not attractive to very large *Pisaster*, is also noted.

Studies on feeding behaviour of the starfish *Astropecten* (Christensen, 1970) indicate that the rank of the attractiveness of the prey is primarily linked to species and only secondarily to the size of the prey. Menge (1972a) also notes that the prey species which is "best" must also be readily available

if specialized feeding behaviour (i.e. size selectivity) by the predator is to occur. The ecological significance of size dependent predation and mortality rates is further discussed by Paine (1976), Brooks and Dodson (1965) and Ansell (1960).

Feder and Christensen (1967) give several reasons for the existence of size-specific predatory behaviour by starfish feeding on molluscs. As expected, small starfish require a greater expenditure of time (and probably energy) to initiate shell opening in large bivalves. As bivalve size relative to the starfish size increases, the hydraulic exertion of the sea star becomes limiting and effective stomach insertion can not be accomplished. As well, Feder and Christensen note that an equally inefficient situation could occur when large starfish are feeding on small-sized molluscs, wherein only a small portion of the digestive capabilities of the stomach can be effectively utilized on such small prey. To our knowledge, the energetic cost of foraging and shell opening by starfish has not been determined.

Based on the existing literature and the size preference in feeding behaviour revealed in this study, it is probable that smaller starfish are more efficient competitors for small mussels. Thus the results of the aggregate feeding trials suggest that when the larger and smaller starfish are feeding together, the larger starfish alter their feeding strategy to include larger mussels, thereby extending the food resource.

The behavioural or sensory mechanisms responsible for this change in food preference or apportionment remain uncertain. Possibly some tactile contact among different size classes of starfish permits a degree of segregation during feeding.

Projected impact of starfish predation at a mussel farm

Starfish settle approximately 2 months later than mussel spat at the Garden Cove Farm. This delay apparently permits the growth of mussels to a size not subject to starfish predation during the first year of life. It is also probable that the mussels grow faster than starfish during the first year as no starfish larger than 1 cm are found on culture nets that have been in the water for 1 year. It is conceivable that the larger 2-year-old starfish could consume some of the larger 2-year-old mussels as well as the 1-year-old mussels. However, the relative abundance of large group C starfish on culture nets at the beginning of the second summer is low compared to size groups A and B (Fig. 1). Evidence for predation on smaller mussels during the second summer can be seen in a depletion, over time, of the cohort representing 1-year-old mussels (Fig. 2).

It is possible to estimate predation rates occurring on the culture nets during the second summer by taking into account the following factors:

(a) Total number and size distribution of starfish inhabiting a culture net in May (Fig. 1).

(b) Total weight and size distribution of mussels present on a culture net in May (Fig. 2).

(c) Size preference and consumption rates of starfish feeding aggregately in the laboratory (Table III).

During 6 summer months of active feeding by starfish, it is estimated that only 1.1% of the total dry weight of mussels >3.5 cm, residing on a culture net, will be consumed. These mussels would normally be marketed in the fall at age 24–25 months. Losses of intermediate size mussels (2.0–3.0 cm) are estimated at 19.6% and virtually all small mussels (<2.0 cm) would be consumed. In early spring, prior to heavy predation, the three size classes of mussels (from small to large) contribute 6, 19 and 75% of the total dry weight meat yield contained on a culture net. The calculated losses do not take into account seasonal changes in growth or reproductive condition of either the prey or predator, nor do they include possible starfish predation during the second winter.

It is concluded that starfish predation under these culture conditions does not pose a serious constraint to the 2-year production schedule. Predation on smaller, younger mussels, may in fact be beneficial in that greater space and food could become available to larger mussels.

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REFERENCES

- Anger, K., Rogal, U., Schriever, G. and Valentin, C., 1977. In-situ investigations on the echinoderm *Asterias rubens* as a predator of soft-bottom communities in the western Baltic Sea. Helgol. Wiss. Meeresunters., 29–30: 439–459.
- Ansell, A.D., 1960. Observations of predation of *Venus striatula* (Da Costa) by *Natica alderi* (Forbes). Proc. Malacol. Soc. London, 34: 157–164.
- Brawn, V.M., Peer, D.L. and Bentley, R.J., 1968. Caloric content of the standing crop of benthic and epibenthic invertebrates of St. Margarets Bay, Nova Scotia. J. Fish. Res. Board Can., 25(9): 1803–1811.
- Brooks, J.L. and Dodson, S.I., 1965. Predation, body size, and composition of plankton. Science, 150: 28–35.
- Christensen, A.M., 1970. Feeding biology of *Astropecten*. Ophelia, 8: 1–134.
- Crisp, D.J., 1971. Energy flow measurements. In: N.A. Holme and A.D. McIntyre (Editors), Methods for the Study of Marine Benthos. IBP Handbook No. 16. Blackwell Scientific Publications London, pp. 197–279.
- Dodson, S.I., 1974. Adaptive change in plankton morphology in response to size-selective predation: A new hypothesis of cyclomorphosis. Limnol. Oceanogr., 19: 721–729.
- Doering, P.H., 1981. Observations on the behaviour of *Asterias forbesi* feeding on *Mercenaria mercenaria*. Ophelia, 20: 167–177.

- Feder, H.M., 1956. Natural history studies on the starfish *Pisaster ochraceus* (Brandt, 1835) in the Monterey Bay area. Doctoral Dissertation, Stanford University, Stanford, CA, 294 pp.
- Feder, H.M. and Christensen, A.M., 1967. Aspects of asteroid biology. In: R.A. Booloolo-tian (Editor), *Physiology of Echinodermata*. Interscience Publishers, New York, pp. 87–128.
- Hancock, D.A., 1955. The feeding behaviour of starfish on Essex oyster beds. *J. Mar. Biol. Assoc. U.K.*, 34: 313–331.
- Hatanaka, M. and Kosaka, M., 1959. Biological studies on the population of the starfish, *Asterias amurensis*, in Sendi Bay. *Tohoku J. Agric. Res.*, 4: 159–178;
- Lutz, R.A. and Incze, L.S., 1980. Mussel culture: an east coast perspective. In: R.A. Lutz (Editor), *Mussel Culture and Harvest: A North American Perspective*. Elsevier Scientific Publishing Company, Amsterdam, pp. 99–140.
- Mason, J., 1976. Cultivation. In: B.L. Bayne (Editor), *Marine Mussels: Their Ecology and Physiology*. Cambridge University Press, Cambridge, pp. 385–410.
- Menge, B.A., 1972a. Foraging strategy of a starfish in relation to actual prey availability and environmental predictability. *Ecol. Monogr.*, 42: 25–50.
- Menge, B.A., 1972b. Competition for food between two intertidal starfish species and its effect on body size and feeding. *Ecology*, 53: 635–644.
- Paine, R.T., 1976. Size-limited predation: an observational and experimental approach with the *Mytilus–Pisaster* interaction. *Ecology*, 57(5): 858–873.
- Paine, R.T., 1977. Controlled manipulations in the marine intertidal zone, and their contributions to ecological theory. In: C.E. Goulde (Editor), *The Changing Scenes in the Natural Sciences, 1776–1976*. Academy of Natural Sciences, Philadelphia, PA, pp. 245–270.
- Smith, G.F.M., 1940. Factors limiting distribution and size in the starfish. *J. Fish. Res. Board Can.*, 5: 84–103.
- Sokal, R.R. and Rohlf, F.J., 1969. *Biometry*. W.H. Freeman and Co., San Francisco, CA, 776 pp.
- Sutterlin, A., Aggett, D., Couturier, C., Scaplen, R. and Idler, D., 1981. Mussel culture in Newfoundland waters. *Mar. Sci. Res. Lab. Tech. Rep. No. 23*, Memorial University of Newfoundland, St. John's, Nfld., 82 pp.