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MYTILUS EDULIS CULTURE: GROWTH AND PRODUCTION IN WESTERN SWEDEN

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ABSTRACT

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A long-line study of mussel culture occupying an area of 25 × 180 m in a sheltered bay in western Sweden commenced in June 1978 when spat first settled. Settlement on 50 mm × 6 m polypropylene bands hung from the long-lines reached more than 1000 *Mytilus* spat per meter of band and stabilized to about 400—500 per meter of band one year after settlement. The best results were obtained 0—2 m below the surface after the second summer where the highest density, greatest length and biomass, and most prolific production were obtained. The highest increase in biomass and the heaviest standing crop occurred during the second autumn when average mussel lengths of 60 mm were recorded at the 0—2 m depth 17—18 months after settlement. This was considered the optimum time for harvesting; the actual harvest took place in March 1980.

INTRODUCTION

The north-west coastline of Sweden, bordering the Skagerrak (Fig. 1), provides numerous advantages for the cultivation of *Mytilus edulis*. The area is protected by thousands of islands, the tidal amplitude is only 0.1 m and the salinity above the halocline (at about 15 m) is normally between 23 and 30‰. Mussel cultures were introduced to the area in 1971 and are rapidly expanding from a 1981 harvest of about 1 000 tonnes to an expected 1983 production of about 3 000 tonnes. The mussels are grown on vertically orientated, 6-m long suspenders attached to horizontal long-lines. Settlement normally occurs abundantly in June along the Skagerrak coast and the mussels are left untreated until harvest.

An ecologically orientated project, initiated in 1978, included the study of currents, nutrients, phytoplankton, bacteria, environmental effects and the overall development of a *Mytilus* community. Some of these results are summarized in a paper presenting an energy-flow model of the mussel culture unit (Rosenberg and Loo, 1983). The present paper focuses on abundance, biomass, growth and production of *Mytilus* from settlement in

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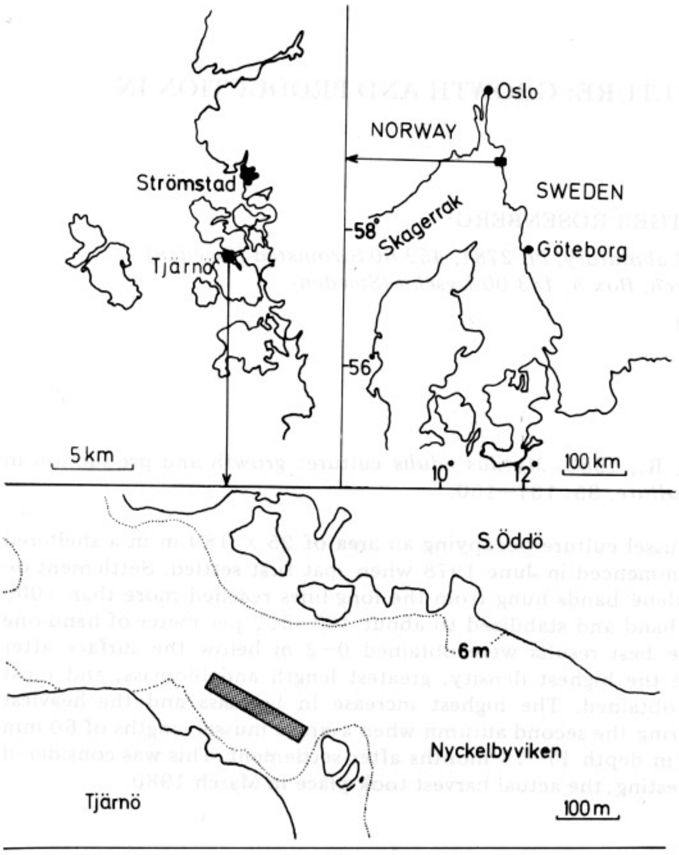

Fig. 1. The area studied. The mussel culture unit was situated in the rectangle and had an area of 25 × 180 m².

June 1978 to the conclusion of the project in March 1980. The mussel culture unit described here was situated in Nyckelbyvik on the northern side of the island of Tjärnö and close to the town of Strömstad (Fig. 1). The summer surface temperature is usually 15–20°C and ice normally covers the area for several weeks in winter. The mussel culture was established in waters 10–15 m deep. The annual mean current speed in the area was 2–3 cm s^{-1} (Larsson, 1983) and primary production in 1979 was 222 g C m^{-2} (Lännergren, in MS). The unit was designed to produce 200 tonnes live weight of *Mytilus*.

MATERIALS AND METHODS

The study unit consisted of 14 parallel long-lines, each 180 m long and spaced approximately 2 m apart, kept afloat by plastic barrels. Submerged, vertically orientated bands woven from polypropylene threads were suspended from the long-lines at intervals of 0.5 m. The bands were 1 mm thick, 50 mm wide and 6 m long. The total length of the bands was estimated to be 30 km. The "Latin square design" (Sokal and Rohlf, 1969) was followed whereby 14 random samples were taken in each horizontal stratum and in three different depth-strata (0—2 m, 2—4 m and 4—6 m). One sample was taken from each row and in each column of a sample grid; thus the samples were broadly distributed over the entire culture unit. A diver collected the samples with a device which enclosed a 0.10-m cluster of mussels and cut off 0.10 m of the band. All samples were deep frozen. All numbers given per meter include both sides of the band and are equivalent to a surface area of 0.1 m^2.

The length-axis of all shells of *Mytilus* from the 1978 settlement were measured and the mean of each sample determined. From these values a mean and standard error (S.E.) were calculated for each sampling date. The mean biomass was obtained by the same procedure. The biomass, including shell, was determined from a length—weight equation determined at different sampling dates as either dry weight (DW) after 48 h at 70°C or ash-free dry weight (AFDW) after 24 h at 500°C (Table I). The weights at the dates (year, month and day) 791012, 791130 and 800307 were obtained from the equations derived for 781004, 781108 and 790306 respectively.

TABLE I

Weight/length regressions ($W = a \cdot L^b$) for *Mytilus edulis* at different dates given as dry weight (DW) and ash-free dry weight (AFDW). W is the weight with shell (in g), L the length (in mm), r the correlation coefficient and n the number of *Mytilus* examined

Time (year, month, day)	DW			AFDW			n
	a	b	r	a	b	r	
780814	$4.94 \cdot 10^{-5}$	2.78	0.97	$1.18 \cdot 10^{-5}$	2.66	0.86	56
781004	$2.26 \cdot 10^{-3}$	1.76	0.96	$6.79 \cdot 10^{-6}$	2.99	0.91	79
781108	$1.11 \cdot 10^{-4}$	2.63	0.98	$1.33 \cdot 10^{-5}$	2.84	0.96	120
790213	$8.67 \cdot 10^{-5}$	2.71	0.98	$1.12 \cdot 10^{-5}$	2.79	0.90	120
790306	$7.18 \cdot 10^{-5}$	2.76	0.93	$1.76 \cdot 10^{-6}$	3.33	0.89	62
790411	$3.38 \cdot 10^{-4}$	2.29	0.88	$3.64 \cdot 10^{-5}$	2.52	0.87	78
790511	$1.26 \cdot 10^{-4}$	2.58	0.98	$1.45 \cdot 10^{-5}$	2.80	0.96	114
790605	$1.44 \cdot 10^{-4}$	2.57	0.95	$4.45 \cdot 10^{-5}$	2.51	0.92	91
790708	$2.22 \cdot 10^{-4}$	2.44	0.98	$3.11 \cdot 10^{-5}$	2.55	0.96	51

Production (P) was calculated per meter of rope as

$$P = \sum_{t=0}^{t=n} ((\overline{N}_t + \overline{N}_{t+1})/2) \cdot (\overline{W}_{t+1} - \overline{W}_t)$$

and the eliminated biomass (E) as

$$E = \sum_{t=0}^{t=n} (\overline{N}_t - \overline{N}_{t+1}) \cdot ((\overline{W}_t + \overline{W}_{t+1})/2),$$

$\overline{N}_t$ is the mean number of *Mytilus* and $\overline{W}_t$ is the mean weight including shell at time "t". Spatial differences in biomass were assessed by a two-way analysis of variance (Sokal and Rohlf, 1969).

RESULTS

Abundance and dominance

The bands were attached to the long-lines during the first week of June 1978 and settlement of *Mytilus* was observed two weeks later. In August, the number of associated species exceeded 29 (polychaetes were not identified) but declined thereafter during the autumn and winter reaching a minimum in May 1979 (Fig. 2). After this date the numbers again increased.

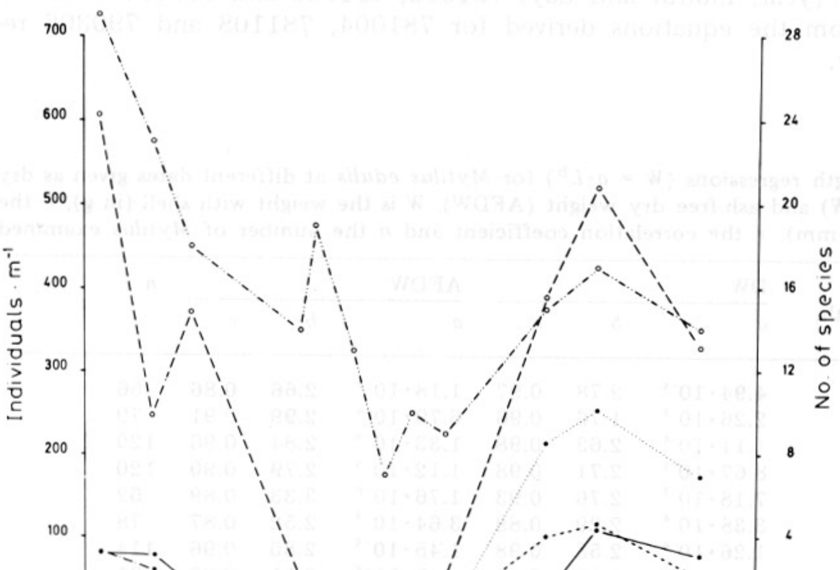

Fig. 2. Number of species (— ··· —), total number of ind. m^{-1} (equal to 0.1 m^2) excluding *Mytilus* (— —), and number of individual *Ciona intestinalis* (····), *Balanus improvisus* (· · ·), *Pomatoceros triqueter* (——) and *Microdeutopus* spp. (—·—·). The values are given as means from 0—6 m. Number of species is exclusive of polychaetes.

The number of individuals (ind.) of these associated species followed a similar pattern reaching a peak in August 1978 of about 600 ind. m^{-1}. The number of *Mytilus* was then about 2000 m^{-1}. At the end of November 1979, the abundance of other species reached a second maximum of 500 ind. m^{-1}. The number of *Mytilus* at that time was about 400 m^{-1} from the

TABLE II

Mean number of macrofauna per meter of band (0.1 m^2) at three depth intervals in August 1978 and November 1979 when the number of species and individuals was highest

Species	1978—08—14			1979—11—30		
	Depth (m)			Depth (m)		
	0—2	2—4	4—6	0—2	2—4	4—6
Mytilus edulis	2550	2129	1613	511	456	370
Microdeutopus sp.	129	74	45			
Rissoa sp.	108	339	88	5	1	
Corophium insidiosum	50	49	33			
Electra pilosa	50	20	23			
Polychaeta, indet	26	10	24	24	19	9
Gammarus locusta	25					
Ciona intestinalis	21	89	23	205	204	353
Balanus improvisus	19	5	10	301	30	19
Diptera larvae, indet	14	12	4			
Ascidiella sp.	10		44	2		14
Bittium reticulatum	10	15	1			
Pomatoceros triqueter	9	67	167	50	109	167
Dexamine spinosa	8	5	3			
Carcinus maenas	7	3	6		1	
Cardium sp.	7	10				
Saxicava arctica	7	2	9	2	7	4
Ostracoda, indet	7	6				
Asterias rubens	3	5	1	2	2	1
Cryptosula pallasiana	3	8				
Phtisica marina	3	26	27			
Musculus discors	2	9	13		1	
Psammechinus miliaris	1	2				
Ericthonius sp.		10				
Hydroida, indet		3				
Echinoida, indet		1				
Macropodia rostrata		1	1			
Indet			7			
Bryozoa, indet				12	3	4
Nucula sp.				1		
Littorina sp.					1	
Corella paralellogramma					1	4
Nucula nitidosa					1	
Anomia sp.						5
Total per meter	3069	2892	2150	1115	836	950

1978-year-class, and about 5 000 m^{-1} from the 1979-year-class. The mussels of the 1978 class provided the greater size and biomass.

The dominant species were *Mytilus edulis*, *Ciona intestinalis* (L.), *Balanus improvisus* Darwin, *Pomatoceros triqueter* (L.) and *Microdeutopus* spp. (Table II). The greatest number of *Ciona* was found in the 2—4 m depth stratum from August 1978 to the spring of 1979 and at 4—6 m from July 1979 until March 1980. *Balanus* was most abundant at 0—2 m during the whole period, whereas the polychaete *Pomatoceros* reached its highest density at 4—6 m. The other individual polychaete species were not identified but *Harmothoe* spp. and *Nereis* spp. were the most prevalent.

The biomass of the epifauna attached to the mussel culture was low; after 15 months, it was about 1% of the dry weight of the mussels.

Numbers of Mytilus

Following settlement of *Mytilus* in mid June 1978, the highest abundance was recorded at 0—2 m in August (Fig. 3). Subsequently abundance decreased successively in all the strata but stabilized at 400—500 ind. m^{-1} from July 1979. From October 1979—March 1980, the number of individuals per meter of the 1979-year-class, which had settled mainly in June, was 5 000—7 000 at 0—2 m, 3 500—5 500 at 2—4 m and 1 500—3 000 at 4—6 m. The results presented here deal only with the 1978 class, as these were the mussels which were to be harvested.

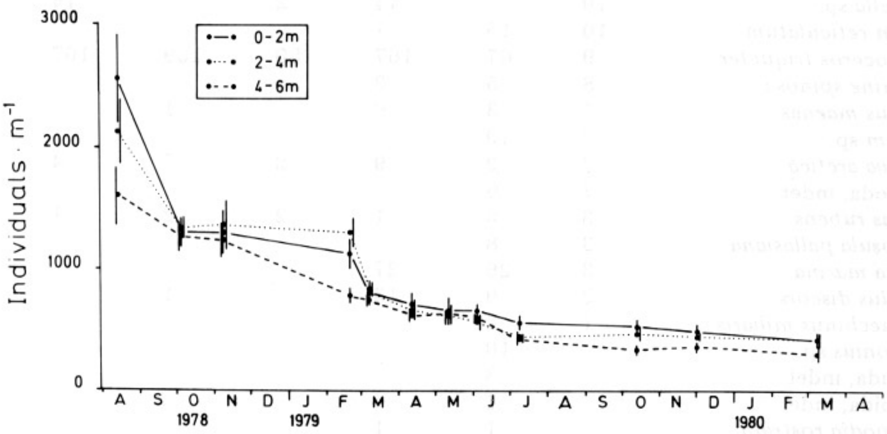

Fig. 3. Mean number (with S.E.) per meter of band of the 1978-year-class of *Mytilus edulis* at three depth strata.

Length and growth of Mytilus

The length frequency distribution of all *Mytilus* of the 1978 settlement is shown for each depth stratum in Fig. 4. Initially the smaller sizes pre-

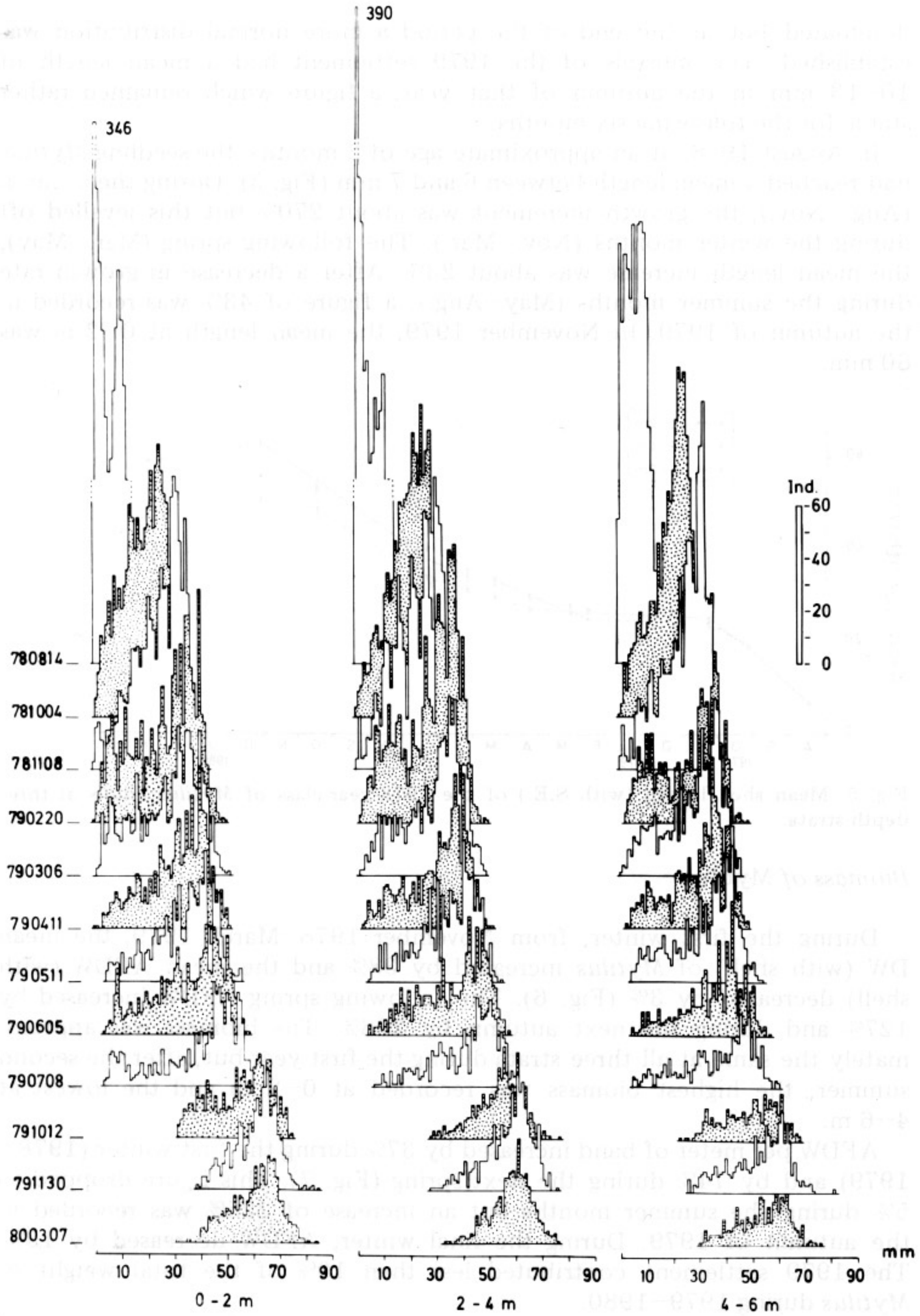

Fig. 4. Length frequency distribution of the 1978-year-class of *Mytilus edulis* at three depth strata with a length class of 1 mm. Dates are given to the left as year, month and day and the abundance scale is given to the right.

dominated but at the end of the period a more normal distribution was established. The mussels of the 1979 settlement had a mean length of 10—13 mm in the autumn of that year, a figure which remained rather stable for the following six months.

In August 1978, at an approximate age of 2 months, the seedling *Mytilus* had reached a mean length between 6 and 7 mm (Fig. 5). During the autumn (Aug.—Nov.), the growth increment was about 270% but this levelled off during the winter months (Nov.—Mar.). The following spring (Mar.—May), the mean length increase was about 23%. After a decrease in growth rate during the summer months (May—Aug.), a figure of 43% was recorded in the autumn of 1979. In November 1979, the mean length at 0—2 m was 60 mm.

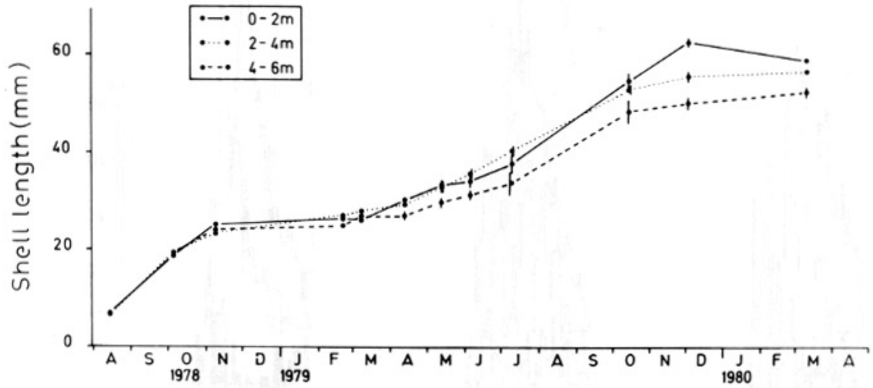

Fig. 5. Mean shell length (with S.E.) of the 1978-year-class of *Mytilus edulis* at three depth strata.

Biomass of Mytilus

During the first winter, from November 1978—March 1979, the mean DW (with shell) of *Mytilus* increased by 38% and the mean AFDW (with shell) decreased by 3% (Fig. 6). The following spring AFDW increased by 127% and during the next autumn by 228%. The biomass was approximately the same at all three strata during the first year but, after the second summer, the highest biomass was recorded at 0—2 m and the lowest at 4—6 m.

AFDW per meter of band increased by 37% during the first winter (1978—1979) and by 74% during the next spring (Fig. 7). This figure dropped to 5% during the summer months but an increase of 225% was recorded in the autumn of 1979. During the final winter, AFDW decreased by 15%. The 1979 settlement contributed less than 10% of the total weight of *Mytilus* during 1979—1980.

Analyses of variation of biomass with distance to the outer margin of the mussel culture indicated significant differences at only a few dates without any clear trends.

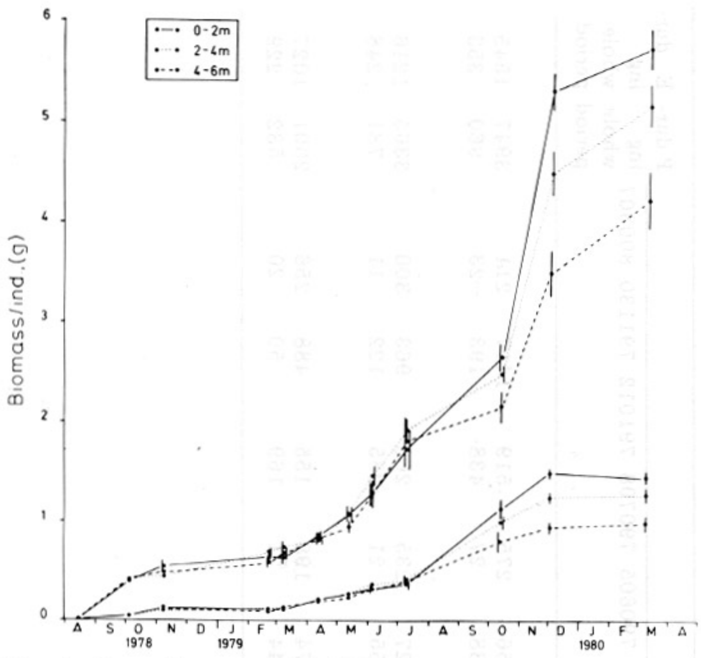

Fig. 6. Mean biomass (with S.E.), including shell, of the 1978-year-class of *Mytilus edulis* at three depth strata. Top: dry weight; bottom: ash-free dry weight.

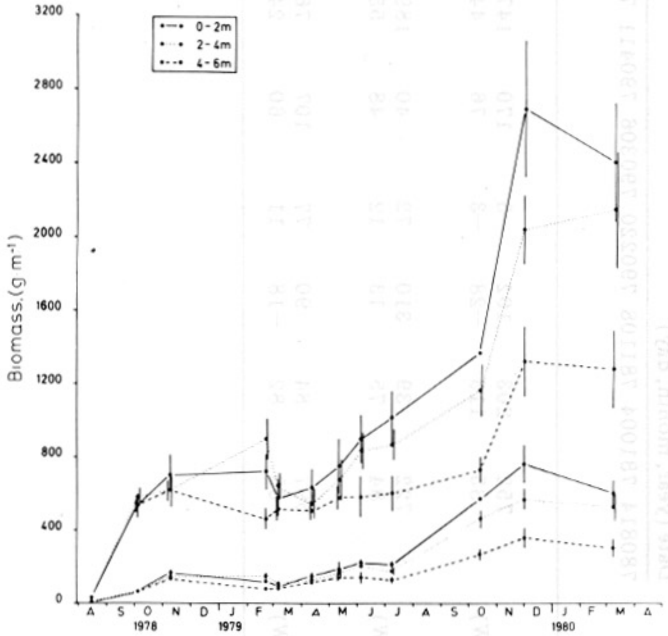

Fig. 7. Mean biomass (with S.E.), including shell, per meter of band of the 1978-year-class of *Mytilus edulis*. Top: dry weight; bottom: ash-free dry weight.

TABLE III

Production (*P*) and elimination (*E*) of *Mytilus edulis* per meter of band in three depth strata as g dry weight (DW) and ash-free dry weight (AFDW) during a period of 571 days

	Date (year, month, day)												P during whole period	E during whole period
	780814	781004	781108	790220	790306	790411	790511	790605	790708	791012	791130	800307		
0–2 m														
P (DW)	752	203	102	–5	170	147	156	275	519	1417	211		3947	1545
P (AFDW)	85	113	–28	–3	76	44	38	27	438	193	–23		960	353
2–4 m														
P (DW)	722	39	310	72	40	189	227	235	268	963	300		3365	1216
P (AFDW)	84	75	13	12	48	55	55	21	285	122	11		781	248
4–6 m														
P (DW)	597	84	90	77	107	76	174	198	155	488	256		2301	1027
P (AFDW)	69	82	–18	11	60	24	44	21	169	50	20		532	229

Production and elimination of Mytilus

The temporal changes in production (including gametogenesis) generally followed those of the biomass (Table III and Fig. 8). The highest production was recorded (as AFDW) during the second atumun after settlement and the lowest during the winters of 1978—1979 and 1979—1980. Taken over the whole cultivation period, the highest production was found in the 0—2 m stratum and the lowest at 4—6 m. Similarly, eliminated biomass was highest in the upper parts of the band and fell away successively with increasing depth (Table III).

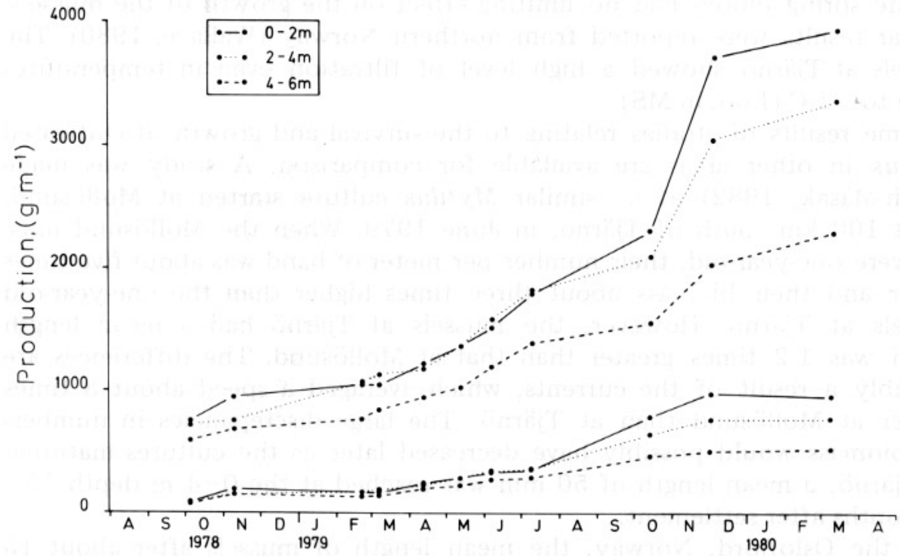

Fig. 8. Accumulated production, including shell, of the 1978-year-class of *Mytilus edulis* at three depth strata. Top: dry weight; bottom: ash-free dry weight.

DISCUSSION

Settlement of *Mytilus* occurred on the bands in June 1978 (Romare et al., 1982) and by August a *Mytilus* community with more than 29 macrofaunal species and about 600 ind. m^{-1} of species other than *Mytilus* had developed (Fig. 2). Later the numbers decreased, probably as a result of increased competition for space during growth, and *Mytilus* continued to be the dominant species throughout the cultivation period. However, during the summer and autumn of 1979, several species recolonized the unit in higher numbers than the previous year but their biomass was low compared with that of *Mytilus*. One reason for the increase in numbers could be the provision, by the growing *Mytilus*, of a surface suitable for attachment. The ability of *Mytilus* to clean their shells with their foot declines with age. In Spain, raft cultures of *Mytilus* were found to accommodate 84 species of invertebrates (Roman and Prez, 1978). The increased incidence of other species did not, however, have any notable effect on the growth and survival of *Mytilus*.

The highest biomass increment of *Mytilus* was recorded in the autumn of 1979, when the number of competitors was highest. Blooms of dinoflagellates during the autumn (Lännergren, in MS) most probably created good feeding conditions at that time (see further discussion in Rosenberg and Loo, 1983). Furthermore, in the spring of 1979, the growth rate was high and the biomass doubled. The low temperature (not exceeding +5°C) during the spring bloom had no limiting effect on the growth of the mussels. Similar results were reported from northern Norway (Wallace, 1980). The mussels at Tjärnö showed a high level of filtration even in temperatures down to —1°C (Loo, in MS).

Some results of studies relating to the survival and growth of cultivated *Mytilus* in other areas are available for comparison. A study was made (Wiigh-Mäsak, 1982) of a similar *Mytilus* culture started at Mollösund, about 100 km south of Tjärnö, in June 1979. When the Mollösund mussels were one-year-old, their number per meter of band was about five times higher and their biomass about three times higher than the one-year-old mussels at Tjärnö. However, the mussels at Tjärnö had a mean length which was 1.2 times greater than that at Mollösund. The differences are probably a result of the currents, which averaged a speed about 3 times greater at Mollösund than at Tjärnö. The large discrepancies in numbers and biomass would possibly have decreased later as the cultures matured. At Tjärnö, a mean length of 50 mm was reached at the 0—4 m depth 15—16 months after settlement.

In the Oslofjord, Norway, the mean length of mussels after about 15 months' growth was similar to that recorded in Sweden (Böhle, 1968). However, in the Oslofjord, the numbers per meter of rope were, for some samples, four times greater, whereas the live weight, at a maximum of 19 600 g m^{-1}, was similar to the Swedish result (Rosenberg and Loo, 1983). In Linne Mhuirich, Scotland, mussels grown on ropes attached to rafts showed a fast growth rate and attained a mean length of 67 mm 14 months after settlement (Mason, 1969).

Investigations of cultivated *Mytilus* on rafts in Ria de Arosa, Spain (Tenore and Gonzalez, 1976), showed numbers 1.3—1.5 times higher than at Tjärnö after 1—1.5 years of growth. In Spain, however, the mussels are thinned out and sorted during the cultivation period to give a maximum yield, and these figures relate to selected large mussels grown on ropes. The *Mytilus* community at Tjärnö was allowed to develop naturally.

Perez and Roman (1979) reported an almost linear growth of cultured mussels from the Ria de Arosa, from 18 mm in April up to 81 mm after 534 days, i.e. 0.12 mm day^{-1}. The same growth rate was obtained at Tjärnö at the 0—2 m depth 515 days from settlement to the peak mean length of 60 mm in November of the year following settlement.

In Maine, U.S.A., the growth of rope-cultured *Mytilus* was investigated at two stations (Lutz et al., 1980). The fastest growth was similar to that at Tjärnö during the first year, whereas the length increment during the second autumn was higher at Tjärnö in the upper 4 m of the bands. *Mytilus* cultivated outside heated effluents in Maine had slower growth. The mean lengths of *Mytilus* at Tjärnö were, in general, higher within 2 m of the surface and decreased with increasing depth. Similar results were recorded in Maine. At Tjärnö, the highest production was again recorded in the upper 0—2 m during the second autumn.

The time taken for cultured mussels to develop from settlement to a shell length of 5—6 cm at different geographical areas is shown in Table IV. The fastest time was reported in Spain but this result was probably influenced by thinning out. Rates of growth were similar in Scandinavia and New England but slower in Canada and the Netherlands.

TABLE IV

Time from settlement to a shell length of 5—6 cm in cultured *Mytilus edulis* (data from Sutterlin et al., 1981, and this study)

Site	Time (months)
Norway and Sweden	14—16
Scotland and Wales	16—18
Netherlands	20*
France	12—18
Spain	8—10
Rhode Island and Massachusetts, U.S.A.	12—13
Maine, U.S.A.	12—22
New Brunswick, Canada	24—28
Newfoundland, Canada	34—35

*Probably bottom cultured mussels.

The production figures given in Table III may be slightly underestimated as calculations were based on population means. In the 0—2 m zone, production was approximately equal to the sum of elimination plus biomass at the end of the period. Elimination was about 40% of production at that time.

Considering the diagrams of biomass (Fig. 7) and production (Fig. 8), it could be concluded that *Mytilus* should ideally have been harvested during November—December 1979, when the mussels were 17—18 months old. After that time the AFDW figures level off and a significant increase could not justifiably be expected until after spawning occurred the following spring. In other cultures left unharvested over a third summer, increasing competition with *Ciona intestinalis* has been observed.

The cultivation described here was planned to provide a yield of 200 tonnes of raw mussels. At the end of 1979, the biomass was approximately

160 tonnes, corresponding to about $280 \cdot 10^6$ kJ flesh weight. Calculated in terms of food-value, and given an individual daily intake of 10 000 kJ, the mussels cultivated at Tjärnö could provide the entire energy requirements for approximately 4 000 people over a period of 7 days.

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