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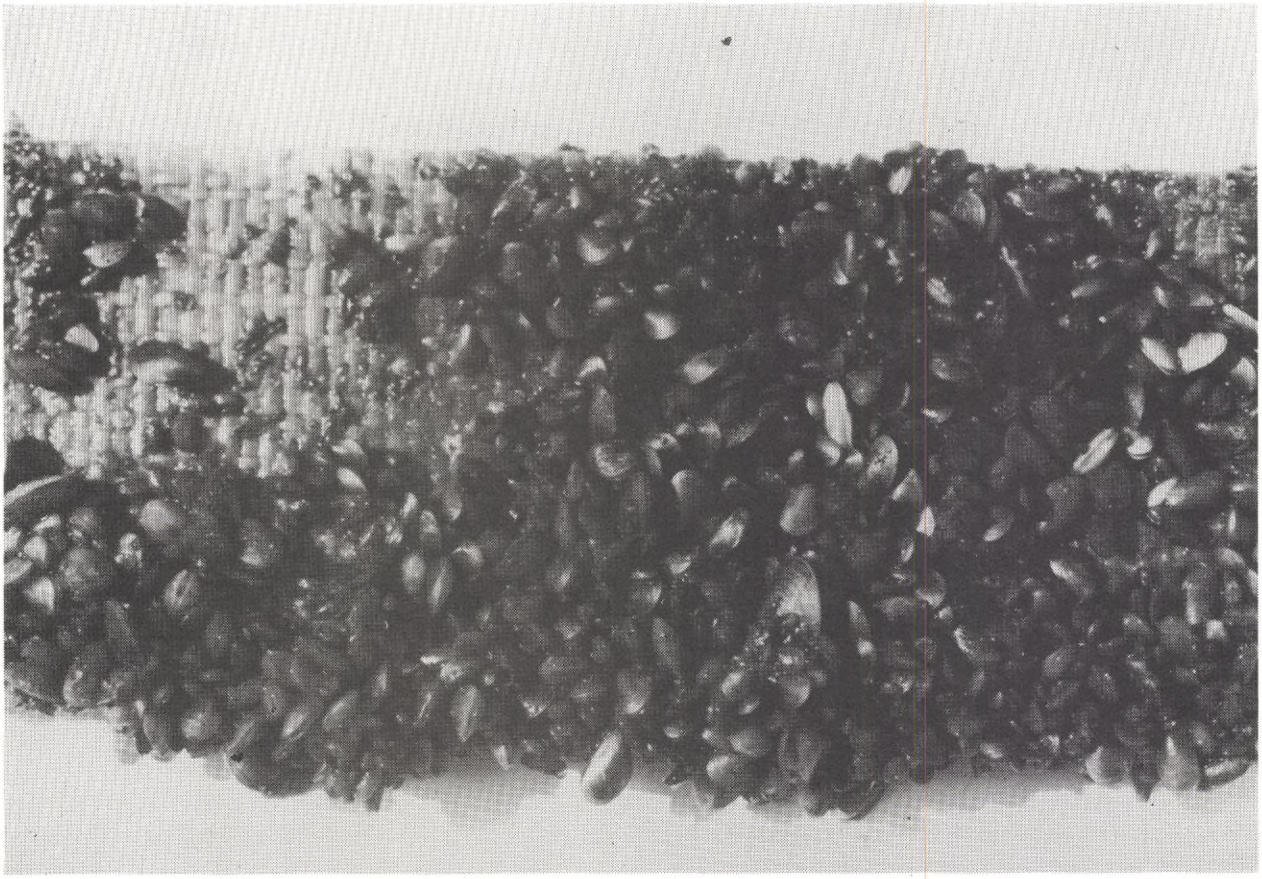

Settlement and subsequent dispersion of the blue mussel *Mytilus edulis* L. on the Swedish west coast.

*Fastsättning och efterföljande spridning av blåmusslan* Mytilus edulis *L. vid svenska västkusten.*

av

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ABSTRACT

This study concerning the settlement and subsequent dispersion, of blue mussel larvae (*Mytilus edulis* L.) was carried out during the summer of 1978 to 1980 at the Tjärnö Marine Biological Laboratory, Strömstad, Sweden.

Suspended collector bands woven from polypropylene threads were used to register time and depth distribution of the settlement at two sites differing in current velocity. Only one settlement period was recorded with its main peak (lasting a couple of days) varying from early to late June. Highest spat densities (around 10 000 - 15 000 per 0.1 $m^2$), were found between 0.5 - 2.5 m depth and below 2.5 m the number of spat declined with increased depth. No differences were observed between sites. The densities on roughened collector bands were found to be four times higher than on original smooth collectors, and 65 % of the spat were larger than 1 mm compared to 15 % on the original collectors, which may indicate the existance of a secondary settlement.

The dispersion of newly settled mussels was studied in experiments using pieces of collector material with attached spat. An upward movement of the spat was found to be the dominating migration pattern, 65 % moved upwards, 2.5 % moved downwards or horizontally when space was available. Floating migration was observed in laboratory conditions, when the collectors had contact with the water surface.

cover: musselband from Grebbestad after about 1.5 months 1982.

## SAMMANFATTNING

Studier av fastsättning och påföljande förflyttning av blåmusslan, Mytilus edulis L., utfördes vid Tjärnö Marinbiologiska laboratorium, Strömstad, somrarna 1978-80.

För att följa hur fastsättningen varierade med tiden och i djupled användes 5 cm breda, flätade polypropylen band, vilka hängdes ut vid två lokaler med olika strömförhållanden. Endast en fastsättningsperiod registrerades under sommaren. Den högsta fastsättningen, vilken varade några dagar, varierade i tid från början till slutet av juni under de tre studerade somrarna. De högsta tätheterna av musslor som nyligen satt sig fast återfanns mellan 0,5 och 2,5 m djup (ca 10 000 - 15 000 per 0,1 $m^2$), och antalet musslor minskade med djupet. Några större skillnader i fastsättning mellan de två lokalerna kunde ej påvisas. På de uppruggade banden hade fyra gånger fler musslor satt sig fast än på de obehandlade banden, och 65 % av musslorna var längre än 1 mm jämfört med 15 % för de obehandlade banden.

Förflyttning av små blåmusslor studerades i en serie experiment, där bitar av band med nyligen fastsatta musslor användes. Den dominerande förflyttningsriktningen var uppåt; 65 % rörde sig uppåt, 2,5 % rörde sig nedåt eller horisontellt då utrymme erbjöds.

Flytmigration observerades i laboratoriet i de fall då samlarbandens överdel var i kontakt med vattenytan.


Omslag: Musselband från Grebbestad efter ca 1,5 månader 1982 (foto Rutger Rosenberg).

INTRODUCTION

Cultivation of the blue mussel, *Mytilus edulis*, started in Sweden in 1975 with experimental suspended long-line cultures on the northern part of the west coast. Today this kind of mussel culture yields about 2000 tons of living mussels a year, and this figure is expected to increase five- to tenfold over the next ten years. Cultivation of *Mytilus* in Sweden occurs only in the relatively sheltered and saline waters between Gothenburg and the Norwegian border (Fig. 1). The suspended cultures are mostly situated in sheltered areas of the coastal archipelago where the current is sufficiently strong. The Swedish west-coast archipelago is characterized by tidal amplitudes less than 20 cm and a salinity fluctuating at the surface between 17 and 34 $^{o}/oo$. In summer, water temperatures between 15-20$^{o}$C are normal but during the winter temperatures are low and sea-ice is common in coastal waters.

To reach an optimum yield from a mussel cultivation it is necessary to catch and retain sufficient spat in areas where growing conditions are good. At the same time, it is important to avoid predators and the settlement of other organisms competing for space and food.

Much work has been done on the problems of collecting and transplanting young mussels to be used for bottom cultures (Dare & Edwards, 1976) and the biology of mussels living in tidal areas is well studied (Bayne, 1976). There is, however, very little material available relating to the behaviour of mussel larvae and young mussels in areas like the Swedish west coast, where tidal movement is small. Two Norwegian studies have been published dealing with the settlement of blue mussels on suspended collectors (Böhle, 1968; 1971).

In order to minimize labour costs, Swedish mussel cultivation relies on mussel spat being settled and grown at the same site and on the original collectors. The design and location of the collectors is therefore critical if maximum settlement is to be acheived with a minimal presence of competitors and predators. This study was carried out in the Tjärnö archipelago between 1978-1980 (Fig. 1). It's purpose was to gain a better understanding of the settlement and subsequent dispersion of *Mytilus edulis*. The study is in two parts; a field study concerning settlemnt, and some laboratory experiments concerning the dispersion of the juveniles.

The study is part of a wider ecological research programme concerned with the culture of mussels in Sweden (Loo and Rosenberg, in MS; Rosenberg and Loo, in MS). It was supported by The Bank of Sweden Tercentenary Foundation.

## MATERIAL AND METHODS

The collectors used in both the field and the laboratory studies were made of flat polypropylene threads (approximately 2 mm in width) woven into 5 cm-wide bands. The same type of collector-bands are also used by commercial mussel farmers.

The field study was carried out at 2 different sites in the archipelago near the Tjärnö Marine Biological Laboratory. The site at Styrsö was more exposed to waves and wind than the protected site at Tenskär (Fig. 1).

The collector bands used were 6 m in length and hung well off the bottom. When in the water, the collectors orientated themselves parallell to the current flow. In order to accurately record the density of settlement at different times of the year and at varying depths, new collectors were suspended each week during the summer months over a three-years period 1978-1980. In the first year collectors were sampled after first seven and then thirty days, but the following years samples were taken every two weeks. Three random samples of 5 cm each were taken at three succesive depth strata (0-2, 2-4 and 4-6 m). The samples were preserved in 96 % ethanol or immersed in sea water and brought directly to the laboratory for counting under a stereoscopic microscope. When counting, the samples were divided into 1 $cm^2$ squares (5 x 5 cm) and the number of mussels in each square was recorded. Counts of mussle spat were made for comparison on both sides of the band and no statistical difference was found. Consequently, the mussels were counted on one side of the sample only and then doubled to show the density of mussels on both sides per meter, which is equal to 0.1 $m^2$.

During the summer of 1979 an experiment was carried out using collectors which had been roughened with a steel-brush. The collectors were suspended at the end of July at the Tenskär site and samples taken after four weeks. Six samples of 5 cm were taken every 20 cm from the surface downwards and treated in the same way as the other samples.

Mussel larvae were collected in 1979 with a plankton net (mesh size 63 $\mu$m) in a 7 m vertical tow and also with a net (mesh size 25 $\mu$m) towed 20 m at the surface. The larvae were measured in a stereoscopic microscope at both Tenskär and Styrsö, during the summers of 1978/79. Current speeds were measured each week at four different depths. A gelatin pendulum was used. At Tenskär, temperature and salinity were recorded at the same intervals and depths.

In the experiments with dispersion, 10 l aquaria and 15x15x15 cm cages made from 0.5 $mm^2$ nylon mesh were used. Sea water was taken from a depth of 2 meters and supplied directly at a rate of 0.5 l/min by means of a centrifugal pump. During the course of the experiments, water temperature remained constant at 17.0$^{o}$C, whereas salinity varied between 22.0 and 29.0 $^{o}$/oo. At the start of the experiment the mussels on the collectors were between 5-6 weeks old, with a length of about 7-8 mm.

Horizontal dispersion was tested using 10 cm collectors suspended horizontally in the aquaria. With 5 cms of each collector cleaned of all mussels. After 14 days a current was induced close to the collectors and then removed again after an-other 14 days. The current, 0.5 l/min, was directed along the collectors starting from the cleaned end.

When testing vertical dispersion, collectors with the upper or the lower 5 cm cleaned from mussels were suspended vertically in cages in a 2 $m^3$ basin. Upward migration was tested in one aquarium exposed to light and one in darkness.

To test floating migration, individual 10 cm collectors were placed inside a cylindrical mesh (Ø 10 cm, length 10 cm) in aquaria with no water movement. One of the collectors was in contact with the water surface. The mussels that had migrated to the outer mesh were collected and counted every day for 14 days.

Mortality studies were done on the collectors both in cages in the field and in 3 l aquaria with a water flow of 0.5 l/min. Three densities were used, 100, 300 and 500 ind./5 cm, and the number of dead mussels were recorded after 20 days. The length of the mussels at the start of the experiment was about 2.0 mm.

## RESULTS

### Currents

The two differently exposed sites for settlement studies had different current velocities, as shown in Table 1. The Styrsö site had stronger currents at all depths.

### Settlement

The settlement periods for the two sites during the summers of 1978 and 1979, and at the Tenskär site in 1980 are shown in Fig. 2. The main peak of settlement occurred during a short period. This period varied over the years from early to late June. No difference in timing can be seen between the two sites. At both sites settlement declined as depth increased (Fig. 2).

## Size of larvae

The size-distribution of the planktonic mussel larvae collected near Tenskär in the summer of 1979 is shown in Table 2. Only larvae larger than 175 µm were measured. An increase in mean length up to 317 µm could be seen between the samplings of 4 June and 26 June. The larvae settling in mid June were between 300-600 µm with an average length of about 400 µm. This corresponds to what Bayne (1964 a) called early-stage plantigrades (250-300 µm) at time of settlement.

## Surface structure

The experiment with the roughened collector-surface was carried out after the main settlement period. A significantly ($p<0.05$) higher settlement was recorded on the rougher surface (Table 3). A difference in size-distribution of the spat was also observed between the two kinds of collector surfaces (Table 3). The roughened collectors produced a higher proportion of larger mussels than the smooth collectors.

## Laboratory experiments

The results from the dispersion experiments are shown in Table 4. The dominating migratory movement was upward, while horizontal migration, with no current present, was negligible A similar frequency of upward migration was registered in both darkness and light.

A current was induced close to the cleared and of the horizontally-orientated collectors. After ten days a slow migration started as about 5 % of the mussels moved diagonally up towards the cleared end. On removal of the current a more rapid, vertical migration started towards the upper edge of the collector and subsequently along the upper edge towards the cleared area. Two days after the removal of the current, 70-80 % of the mussels had moved upwards and 20-35 % had moved horizontally along the upper edge.

Floating migration was observed in the experiments, but only when the collectors were in contact with the water surface. After 14 days about 6 % of the mussels were found to have migrated from the collectors.

The mortality of the mussels on collectors protected in cages was found to be less than 2 %, both in the field and the laboratory.

## DISCUSSION

### Time of settlement

The period of settlement of early-stage mussel plantigrades at the Tjärnö archipelago on the Swedish west coast during the period 1978-1980 occurred mainly in June. The main period of settlement lasted for a few days only. In Oslofjord, Norway, a settlement period of about four weeks has been observed with settlement-density reaching a peak between 4-10 June and again between 19-25 June (Böhle, 1971). The small variation in time of peak settlement was probably related to the spring water temperatures that influence the onset of spawning (Böhle, 1971; Seed, 1969).

In 1978 and 1979 no second settlement period was found at Tjärnö, but in 1980 some settlement was noted at the end of July. Böhle (1971) found a second settlement peak at the end of July in Oslofjord. In the Menai Straits, Wales, two main settling periods were also registered: one in June and one in July after several spawnings in the spring (Bayne, 1964 a). In southern European waters two settlement periods can take place: one in the spring and one in the autumn (Mason, 1972).

The short settlement period recorded at Tjärnö in 1978-1980 makes it important to suspend the collectors at the right time. It should be possible to relate the beginning of settlement to the size of the larvae found in the waters. Metamorphosis and settlement can occur when the mussel larvae reach a size of 250-300 µm (Bayne, 1964 a). Both in Oslofjord (Böhle, 1971) and in this study an equation was found between the increased incidence of large larvae and the onset of settlement. The polypropylene collectors need, however, a couple of days in water to "mature"; *i.e.* to obtain a layer of bacteria and micro algae, before settlement will take place. The collectors should therefore be set out about a week before settlement is likely to begin. At the raft cultures in Spain the collectors are suspended about one month before the settlement period is known to commence (Mason, 1972).

## Numbers settled

About the same amount of mussel spat settled in each of the years studied: *i.e.* about 10 000 - 15 000 per meter collector-band (0.1 $m^2$) on the upper meters. This is less than the maximum amount recorded in the Oslofjord on polystyrene plates and synthetic fibre ropes, where 24 000 - 60 000 mussels settled per 0.1 $m^2$ (Böhle, 1968; 1971). In England maximum densities of plantigrades attached to mussel beds have been recorded in numbers of 15 000 - 32 000 per 0.1 $m^2$ (Dare, 1976). The amount of mussels settled in Sweden, however, has so far shown to be sufficient to ensure an adequate harvest.

## Settlement in relation to depth

The settlement in the Galician rias in Spain take place only in the surface waters (Mason, 1972). The settlement behaviour recorded by Bayne (1964 a ) showed that the mussel larvae become positive geotactic and negative photoactic when ready to settle. In this study settlement was observed to decline with increased depth at both sites in 1978 and 1979. The highest settlements were found between 0.5-2.5 m in 1979. There the highest current velocities were also recorded. No stratification of the waters down to 6 m depth was found at that time. The same year, in a soft-bottom bay in Gullmarsfjord (Abrahamsson & Loo, 1980) about 60 km south of Tjärnö, the incidence of juvenile *Mytilus* was found to be ten-times greater at a depth of 0.5-2 m than at 2-6 m. Similarly, the highest density of spat was found at 1-1.5 m in the Oslofjord (Böhle, 1968).

Mussel larvae are known to be capable of keeping their vertical position even at high current velocities (Bayne, 1976). A possible preference by the larvae to settle in waters with higher current velocities, together with the fact that the pediveligers in their crawling stage, when in contact with the substrate, become negative geotactic and crawl upwards (Bayne, 1964 b), could explain the observed concentration of settled mussels on the upper 2 meters of the collectors. The blue mussel can in this way occupy areas of considerable physical stress like the 'splash-zone' or bottoms that become partly exposed, thus avoiding competition from other organisms less tolerant to exposure.

## Structure of collector band and secondary settlement

Roughened bands, suspended together with the smoother bands during August, gave a significantly ($p<0.05$) higher settlement at that time, when the main settlement period was over. The increase, however, mainly involved mussels with a length of more than 1 mm. It is likely that these larger mussels migrated as late plantigrades from other bands, a behaviour observed in the experiments. Small mussels could also have crawled down from the ropes to which the bands were attached, but such downward dispersion was not observed in the experiments, neither were planktonic late plantigrades observed. Planktonic late plantigrades and secondary settlement have been noted in British waters (Nelson, 1928; Bayne, 1964 a). According to Seed (1969), late plantigrades require niches, grooves and crevices for settlement, which the rough-surface collectors in our field experiment provided to a greater extent than the smoother collectors. The spontaneous settlement of larger larvae on the rougher bands and the migration from the smooter variety could prove to be an advantage, effectively thinning out the mussel growth and providing a larger end-product.

## Dispersion

Bayne (1964 a) observed that recently settled larvae crawled upwards. When secondary settlement occurs, plantigrades have been found to migrate from algae onto existing mussel-beds (Bayne, 1964 a). Planktonic plantigrades were found in plankton hauls both by Nelson (1928), Bayne (1964 a) and Böhle (1971). Plantigrades were observed by Nelson (1928) to attach to the water surface film under laboratory conditions and Sigurdsson (1976) described a bysso-pelagic dispersion by *Mytilus*. This floating migration was also found to occur in this study, when the collector bands had contact with the surface. Probably a more important way of migrating, according to Bayne (1964 a), is the protruding ciliated foot of the plantigrades, enabling them to be transported by water currents even at low velocities. As discussed earlier, it is possible that this migratory behaviour, together with the observation of higher densities of larger (> 1 mm) mussels on roughened bands, indicates the existance of secondary settlemnt in Swedish waters.

Dare (1973) and Dare & Davies (1974) found that groundspat (1-1.5 mm), which had settled early in the year, become mobile in spring before the growing season started, and moved about for some weeks. This horizontal movement was not observed in mussels of 7-8 mm on the vertically placed collectors in this study. Dare & Davies (1974) found that spat always swarmed upwards when collectors were stored vertically in seawater tanks, a characteristic that was confirmed in this study. This behaviour does not seem to be effected by light conditions. However, if an earlier induced current was switched off an upward migration immediately started.

CONCLUSIONS

- One short period of settlement was found during the period of the study, 1978-1980, to occur each year in the month of June.

- The densities of mussel spat were highest in the upper four meters, where the currents reached higher velocities.

- The mobility of young mussels was high even several weeks after settlement. Direction of movement was predominantly upwards.

- Floating migration was observed in the laboratory, and this, together with the higher densities of larger spat found on the rougher bands, indicates the existance of secondary settlement in Swedish waters.

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Table 1. Mean and maximal current velocities measured at four depths at the two sites Tenskär and Styrsö, the summers 1978 and 1979.

| Depth (m) | Site | Mean value (cm/s) | Maximal (cm/s) |
|---|---|---|---|
| 0.5 | Tenskär | 0.6 | 4.0 |
| | Styrsö | 8.2 | 28.5 |
| 2.0 | Tenskär | 0.4 | 2.0 |
| | Styrsö | 8.0 | 20.0 |
| 4.0 | Tenskär | 0.2 | 1.5 |
| | Styrsö | 3.0 | 11.0 |
| 6.0 | Tenskär | 0.3 | 2.5 |
| | Styrsö | 2.7 | 11.6 |

Table 2. Mean and maximum length (μm) of planktonic blue mussel larvae found in the Tjärnö archipelago in June and July 1979.

| Date | Mean length | S.D. | Maximum length | No. measured |
|---|---|---|---|---|
| 4 vi | 205 | 21 | 260 | 94 |
| 12 vi | 251 | 32 | 320 | 106 |
| 19 vi | 298 | 46 | 380 | 86 |
| 26 vi | 317 | 43 | 400 | 200 |
| 3 vii | 326 | 51 | 440 | 174 |
| 10 vii | 305 | 64 | 440 | 61 |

Table 3. Number of spat of *Mytilus edulis*, and percentage spat larger than 1 mm on smooth (original) and roughened collectors suspended at Tenskär between July 31 and August 28, 1979.

| Collector surface | Tot. No. | Mean No. | S.D. | % > 1 mm |
|---|---|---|---|---|
| A. Smooth | 92 | 15 | 9 | 14 |
| B. Smooth | 123 | 20 | 14 | 15 |
| Total | 215 | 18 | 12 | 15 |
| C. Roughed | 361 | 60 | 20 | 65 |
| D. Roughed | 439 | 73 | 36 | 65 |
| Total | 800 | 67 | 28 | 65 |

Table 4. Experiments with vertical and horizontal migration of newly settled *Mytilus edulis*. The columns show: part of collector cleaned from mussels, type of water renewal, density on area not cleaned from mussels at start of experiment, percentage mussels that had migrated onto cleaned area, and duration of experiment.

| 'pe of migration | Clean area | Water exchange | Start density/5 $cm^2$ | % migrators/5 $cm^2$ | Days |
|---|---|---|---|---|---|
| ›wnwards | lower 5 $cm^2$ | 0.5 l/min | 400<br>200 | 0<br>2 | 7 |
| ›wards | upper 5 $cm^2$ | " | 400<br>200 | 68<br>62 | 7 |
| ›wards with light | " | every 42 hr | 100 | 32 | 1 |
| ›wards with dark | " | " | 100 | 34 | 1 |
| ›rizontal | right 5 $cm^2$ | " | 500<br>300 | 1<br>3 | 14 |

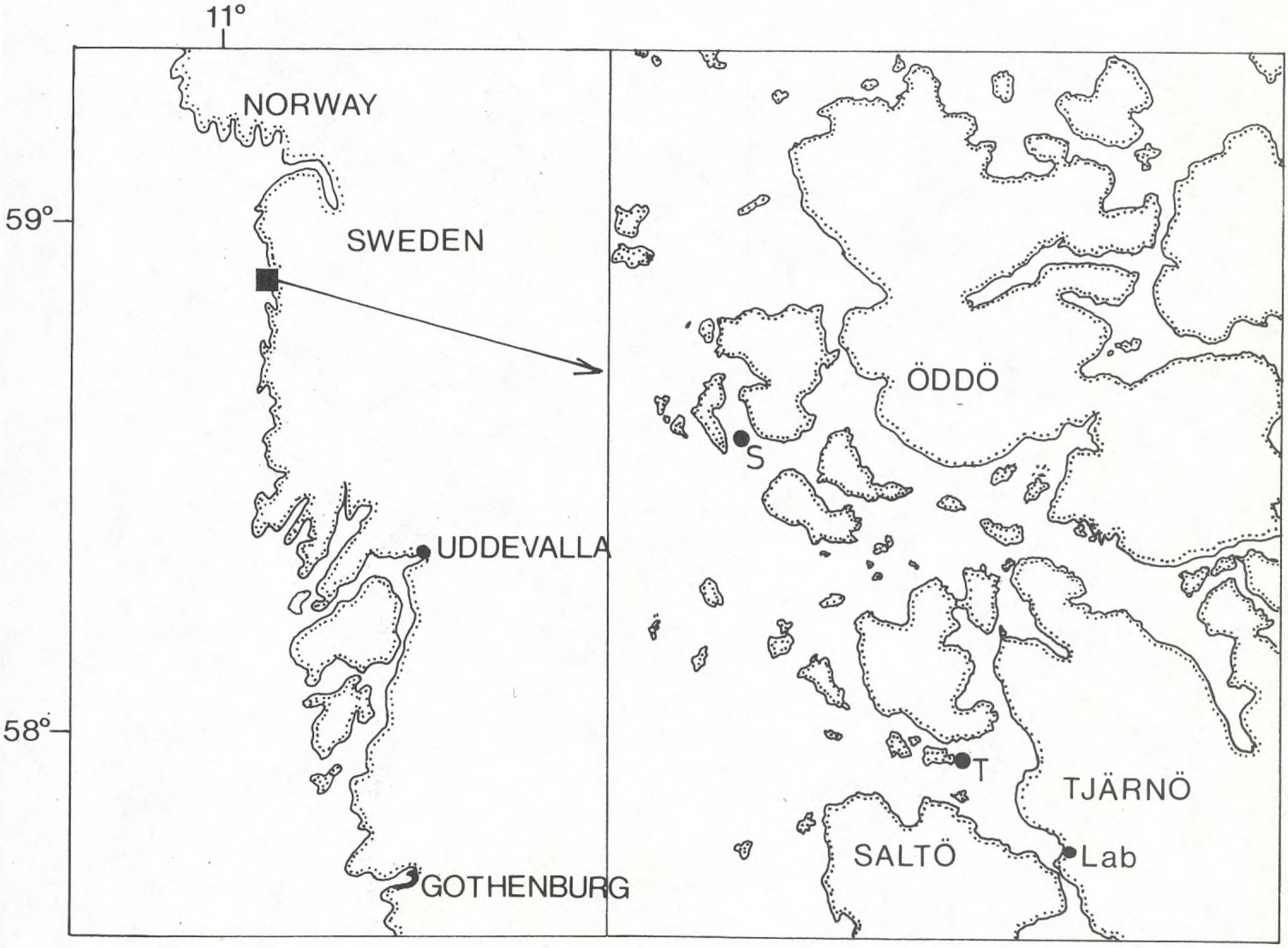


Fig. 1. Map of the area for settlement studies. Styrsö (S) was the exposed station and Tenskär (T) the protected station.

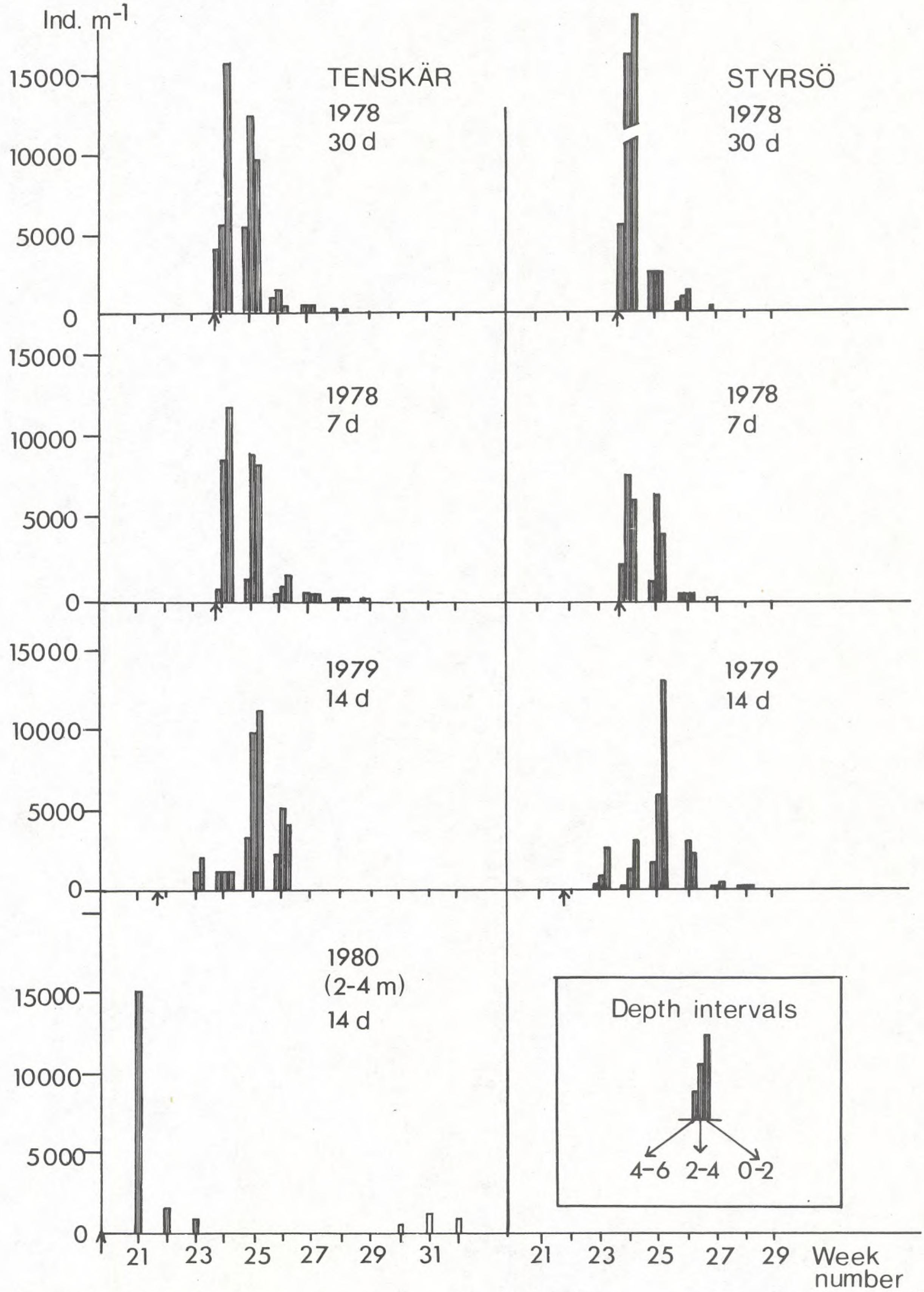


Fig. 2. Number of spat of *Mytilus edulis* per meter collector at three depth intervals (see lower right corner) Fresh collectors were suspended each week at two sites, Tenskär and Styrsö, during the summers of 1978, 1979 and 1980. The exposure time varied between 7 and 30 days. The arrow indicates first registration. Week-numbers, when collectors were suspended, are given at the abscissa. In 1978, 1979 and 1980 week 21 began on May 22, 21 and 19 respectively.