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Planktonic Mussel Larvae, Mussel Spat Settlement, and Bio-fouling: a Perspective on Recent Spat Collection Problems at Mussel Culture Farms in Newfoundland

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PLANKTONIC MUSSEL LARVAE, MUSSEL SPAT SETTLEMENT, AND BIO-FOULING: A PERSPECTIVE ON RECENT SPAT COLLECTION PROBLEMS AT MUSSEL CULTURE FARMS IN NEWFOUNDLAND

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TABLE OF CONTENTS

LIST OF TABLES

1. Proportion of horse mussels 14
2. Abundance of planktonic mussel veligers 15
3. Statistical comparison of mussel veliger length 16
4. Statistical comparison of mussel veliger length 17
5. Depth distribution 19
6. Density of settled spat 20

LIST OF FIGURES

ABSTRACT

Populations of planktonic larvae, settled spat, and the occurrence of bio-fouling were monitored from 1989-91 at Thimble Bay Farm, a commercial mussel and scallop farm on the northeast coast of Newfoundland. These data are analysed in relation to spat collection problems experienced at this site, and similar problems reported by mussel farmers at many other farms in Notre Dame Bay, in 1991 and 1992 (1990 and 1991 spat year classes). Abundance of planktonic veligers was high, particularly in 1991, but the occurrence of settlement stage veligers was delayed. Settled spat sampled through the autumn months were also much smaller in shell length compared to 1989. For both the 1990 and 1991 year classes, the density of initial spat settlement on the collectors was acceptable but, by the following June, only about 20-30% of collectors held spat in 1991 and, in 1992, virtually all the spat from the 1991 year class had disappeared. Bio-fouling by various algal species, particularly the brown alga, _Ectocarpus sp._ in the late summer and autumn and the red alga, _Polysiphonia flexicaulis_ during the autumn and winter, was extensive on the collectors for both the 1990 and 1991 spat year classes.

The annual spring warm-up in water temperature was delayed in 1990 and 1991 compared to previous years. Unseasonably low nearshore, water temperatures in the Spring of 1990 and 1991 delayed the appearance of settlement stage veligers causing settled mussel spat to be unusually small in the following Autumn. The small size of the spat and low water temperatures apparently provided ideal conditions for extensive growth of algal bio-fouling which displaced the settled mussel spat and resulted in widespread collection failure. Possible initiatives by industry to mitigate the severity of the impact of future recurrences of such unpredictable environmental events on commercial operations are suggested.

RÉSUMÉ

Entre 1989 et 1991, on a surveillé les populations de larves planctoniques, le naissain fixé et l'encrassement biologique à la Thimble Bay Farm, une installation d'élevage commercial des moules et des pétoncles située sur la côte nord-est de Terre-Neuve. Ces données ont été recueillies à la suite des problèmes de collecte de naissain signalés par cette entreprise et de problèmes similaires qui ont affecté maintes exploitations de la baie Notre Dame en 1991 et en 1992 (naissain des classes de 1990 et de 1991). Le nombre des larves véligères planctoniques était élevé, particulièrement en 1991, mais le stade de la fixation des larves a été tardif. La

longueur des coquilles du naissain fixé prélevées au cours des mois d'automne a été de beaucoup inférieure à celle du naissain de 1989. Tant en 1990 qu'en 1991, la densité du naissain initialement fixé sur les collecteurs était acceptable; pourtant, en juin suivant, seulement quelque 20 à 30 p. cent des collecteurs abritaient toujours du naissain en 1991, tandis que le naissain de la classe de 1991 avait presque entièrement disparu en 1992. L'encrassement biologique par diverses espèces d'algues, en particulier l'Ectocarpus sp. (une algue brune) à la fin de l'été et en automne, et la Polysiphonia flexicaulis (une algue rouge) en automne et en hiver, était considérable sur les collecteurs des classes de 1990 et de 1991.

Par rapport aux années précédents, le réchauffement printanier de la température de l'eau a été tardif en 1990 et en 1991. La température exceptionnellement basse de l'eau près des côtes aux printemps 1990 et 1991 a retardé l'arrivée du stade de fixation des larves véligères, si bien que le naissain de moules fixé a été anormalement petit l'automne suivant. La petitesse du naissain et la froideur de l'eau semblent avoir créé des conditions de croissance idéales pour les algues, entraînant un encrassement biologique qui a déplacé le naissain de moules fixé et provoqué les maigres récoltes observées un peu partout. On suggère divers mesures pour réduire l'impact d'écarts environnementaux aussi imprévisibles sur l'industrie.

INTRODUCTION

The mussel culture industry in Newfoundland is quite young, with most of the 50-70 currently active farms having been started since 1986. The majority of mussel farms are located in bays along the northeast coast of the island, with the greatest concentration in Notre Dame Bay (see Figure 1). Annual production from these farms is still small by world standards with production output of about 150 metric tons in 1992. Most of these farms are owner-operated sites with all aspects of culture, from spat collection to final harvesting carried out at the same site. Only a few site owners utilize separate sites for spat collection and growout, and only recently have there been any sales of spat between different site owners or companies. All mussel farms in Newfoundland currently use the longline culture method with mussels collected on vertically hung rope collectors, suspended from a horizontal longline supported by plastic floats. Spat are stripped from the rope collectors into plastic sleeving material and resuspended from the same longlines for growout to commercial size.

Unlike Prince Edward Island where mussel spat are socked in the same year as they are collected, mussel spawning is relatively later (usually July and August) and the spat are still too small by late Autumn for socking at most sites in Newfoundland. Most mussel farmers therefore wait until the following June, or sometimes even later depending upon local growth rates, before they sock their mussels.

Successful collection of mussel spat on an annual basis is a leading determinant of long term financial stability on mussel farms. Any factor which unexpectedly reduces the amount of spat collected in any year is, therefore, of concern to mussel farmers. In this report, data on larval mussel populations and spatfall at one site in Notre Dame Bay, Newfoundland, are discussed in light of the widespread deficiencies in spat collection experienced by many mussel farmers throughout the area (box insert in Figure 1) in 1991 and 1992.

METHODS

As part of a multi-year study of biological and bio-technical aspects of mussel (*Mytilus edulis*) culture in Newfoundland, research into larval mussel populations and spat settlement dynamics began in 1989. The study site chosen was a commercial scallop and mussel farm, Thimble Bay Farm Ltd., located in Charles Arm, Notre Dame Bay, on the northeast coast of Newfoundland (see Figure 1).

In 1990 and 1991, populations of planktonic mussel larvae were collected at approximately weekly intervals from June through to late Autumn. The sampling gear consisted of a plankton net (23 cm mouth diameter and 80 μm mesh) towed horizontally at 1 m depth for 5-10 minutes. A flowmeter (General Oceanics Ltd. Model 2030) was mounted in the mouth of the net to record water flow rates for calculation of water volumes filtered during each tow (Smith and Richardson, 1977). Plankton samples were preserved in 7% buffered formalin. On three occasions in 1990 and four times in 1991, depth stratified series of horizontal tows were carried out (1, 3, 5, 7, and 9 meters depth in 1990 and 1, 3, 5, and 7 meters in 1991).

In the laboratory, each sample was subsampled using a Folsom plankton splitter (1990 samples) or Stempel pipette (1991 samples). Numbers of larvae were recorded, and their length and width measured using an ocular micrometer and stereo microscope. Length and width axes in the larvae were defined as the axis parallel to the hinge line and the axis perpendicular to the hinge line respectively (de Schweinitz and Lutz, 1976). In 1990, mussel larvae were identified to species, based on the descriptions of Fuller and Lutz (1989) and de Schweinitz and Lutz (1976), and the presence of other bivalve molluscan species was noted. In 1991, the larvae were not identified to species and were recorded simply as mussel larvae, consisting of unknown proportions of Modiolus modiolus, the horse mussel, and Mytilus edulis, the common blue mussel. This was done for logistical reasons due to the difficulty in separating larval stages of the two species.

Series of spat collectors were placed on site in each of the three years from 1989 to 1991, approximately 1 week before the estimated time of maximum occurrence of settlement stage spat. Collectors were hung from longlines strung from shore to shore and suspended at approximately 0.5 m depth. Plastic floats were placed at intervals sufficient to maintain the longline's desired depth in the water. The spat collectors included four different mesh sizes (three replicates of each) of Vexar plastic cut into strips approximately 15 cm width by either 2 m or 0.5 m in length, and similar lengths of 8 mm (5/16 inch nominal size) polypropylene rope. Small concrete weights were fastened to the bottom of each collector to maintain its vertical position in the water column. In 1991, additional collector lines were sunk to greater depths (maximum 12 meters) at 10 day intervals from the time initial spat settlement on the collectors was first observed.

During the Autumn of each year and again at socking time, in June of the following year, randomly selected collectors of each type were retrieved from the water. Subsamples of mussels on each collector were counted and measured using an ocular micrometer mounted on a stereo microscope. Large individuals were measured with calipers. Samples of major bio-fouling species were returned to the laboratory for identification. Each year class of mussel spat from 1989-91 was sampled at least three times.

RESULTS AND DISCUSSION

Planktonic Veligers: Abundance, and size

In 1990, the first plankton samples were collected in late June. Mussel veligers were already present in high numbers, in excess of 40 per liter at one meter depth (Figure 2). It can be inferred these were from a recent spawning since their length frequency distribution indicates all were in the 75-100 μm range (Figure 3, first panel), a range consistent with the earliest known shell lengths reported for Mytilus edulis, the common blue mussel (Loosanoff *et al.* 1966; de Schweinitz and Lutz 1976; Fuller and Lutz 1989). Two further distinct peaks in abundance were recorded, in mid-July and early August (Figure 2), but both were under 20 veligers per liter. Both these peaks were also different from the earlier peak abundance of late June in that the latter two peaks were mostly comprised of veligers 250 μm or greater in length (Figure 3, panels 3, 6, and 7). This length approximates that at which Mytilus veligers are ready to settle out of the water column (see Loosanoff and Davis 1963). The abundance of mussel veligers remained low for the rest of the year.

The rate of development of mussel larvae is known from laboratory rearing trials and varies with water temperature. Data reported by Bayne (1976) indicates the expected time from fertilization to the settlement stage to be 20-35 days at water temperatures normally experienced in our area during the early summer. Using this information, it can be inferred that the settlement sized veligers which comprised the mid-July peak were from the same group observed as small veligers on June 23. Similarly, the settlement sized veligers comprising the early August peak were probably from the same group as those small veligers which comprised the mid-July peak. This interpretation leads to a conclusion that , in 1990, most mussels spawned about the third week of June while some spawning continued into early July. Since few small veligers were observed after the middle of July, it can be inferred that spawning had ceased by this time. It should be noted, however, that peaks of reproductive activity do not necessarily correlate with subsequent settlements (Hickman, 1992).

In 1991, the first plankton samples were collected in mid-June. However, unlike 1990, large numbers of veligers were not observed until August (Figure 2). A peak of approximately 200 veligers per liter was recorded on August 12, comprised mostly of small veligers (Figure 4). A second peak, comprised almost entirely of settlement sized veligers (and probably from the same group observed as small veligers in the early August peak) occurred in early September. This situation is notably different from 1990 in that the occurrence of mussel veligers was much later but, when they did occur, their abundance was much higher. It can be inferred, therefore, that mussels did not spawn at Charles Arm in 1991 until late July and early August. By pinpointing the time of occurrence of large numbers of settlement sized veligers from plankton samples, a mussel farmer can determine the optimum time to set out his spat collectors.

These abundances in both 1990 and 1991 compare favorably with those reported elsewhere for areas which support commercial mussel culture. The peak abundance observed in 1991 is high compared to any published records. Waterstrat *et al.* (1980) reported a peak of 152 veligers per liter in an enclosed inlet in the State of Washington on the Pacific coast. Judson and Bernard (1990) reported peak veliger abundances <25 per liter in estuaries of Prince Edward Island where commercial mussel spat collection has been successful. These data support the conclusion that larval mussel abundances were sufficiently high to support commercially adequate spat collection at Charles Arm in both these years.

The timing of peak abundance of settlement size veligers appears to be atypical compared to long term records at Charles Arm (T. Mills, pers. comm.). Peak availability of settlement size veligers was estimated to usually occur in mid-July in previous years. Yet, in 1990, the peak abundance of such veligers was delayed until early August and, in 1991, didn't occur until early September.

The seasonal warming in inshore Newfoundland waters usually picks up in May. The 1989 continuous temperature records from Charles Arm (Figure 16) are typical of the trend. However, the data from 1990 and 1991 indicate that the seasonal warming of water temperatures in that period was considerably delayed compared to 1989. For example, by the end of May, 1989, water temperatures at 4 meters (approximately the depth of the headropes) were in the 12-14°C range. In 1990 and 1991, the end of May temperatures were only about 6-8°C. Also in both these years, summer water temperatures tended to be lower than 1989 and the long term norm. In 1991, summer water temperatures were particularly reduced. Water temperatures along the entire northeast coast of Newfoundland were atypically low in 1990 and 1991. The annual Spring warmup in both these years was later than in any year of the preceding decade (Narayanan, pers. comm.). These low temperatures delayed mussel spawning and may also have negatively impacted on the development and condition of the planktonic mussel veligers.

In 1990, veligers of the horse mussel, <u>Modiolus modiolus</u>, were identified from the plankton tow samples. Horse mussels are present at Charles Arm, but constituted <20% of the veliger population at all times (Table 1). Their time of peak occurrence coincided with that of <u>Mytilus</u> veligers, indicating <u>Modiolus</u> has a spawning time similar to that of <u>Mytilus</u>.

Planktonic Veligers: Depth distribution

Mussel veligers were not homogeneously distributed, in terms of abundance, by depth on any of the seven occasions sampled in 1990 and 1991. Although mussel farmers in Newfoundland have often observed that successful spat collection occurs in the top three meters of the water column (this also occurs at Charles Arm), the maximum abundance of mussel veligers did not occur in the near-surface depths on any of the seven sample dates (Table 2). Rather, maximum abundances more typically occurred at depths from 5-9 meters. On some occasions, the differences in abundance between different depths on the same sample date were quite large.

At times, there were also significant differences in the length frequency distributions of veligers at different depths. On August 18, 1990, the veligers present were a mixture of pre-settlement sized veligers and those of settlement size. Settlement sized veligers predominated at all depths (Figure 5). The mean length of veligers differed significantly with depth (Table 3, panel 1) but there was no obvious pattern of changing length with depth. On August 29, 1990, those veligers present were predominately pre-settlement sized (Figure 6). On October 21, 1990, those veligers present were predominately pre-settlement sized but with some settlement sized veligers included (Figure 7). On both these latter sample dates, there was no significant overall difference between the mean lengths of veligers at the various depths (Table 3, panels 2 and 3) as determined by ANOVA. Some heterogeneity in length distributions with depth did occur, as indicated by the significant pairwise T tests.

On July 20, 1991, those veligers present were mostly pre-settlement sized (Figure 8). On August 25 and September 8, most veligers present had reached the settlement size (Figures 9 and 10), while on September 29, a mixture of both size groups occurred (Figure 11). There were significant (ANOVA) overall depth related differences in mean length of veligers on the first three sample dates in 1991 (Table 4). On July 20, there was a significant increase in veliger length with depth. However, On August 25 and September 8, the pattern was reversed with a decreasing mean length with depth (Table 4, panels 2 and 3). The ANOVA on September 29 was not significant but a trend to decreasing length with depth is apparent.

While these data are somewhat confusing to interpret, they confirm extreme variability in depth distributions of planktonic mussel veligers does occur. Mussel veligers are not passively drifting particles in the water. Bivalve veligers are known to be capable of active swimming both horizontally and vertically (Isham and Tierney, 1953; Lough and Gonor, 1971), even in areas with significant water currents (Wood and Hargis, 1971). It is interesting to note that, in those two samples where the mean length of veligers was >250 μm (settlement sized), there was a clear pattern of increasing mean length of veligers from bottom to top of the water column (Table 4, panels 2 and 3).

If the differences in mean length with depth are considered somewhat differently by dividing the veligers into two groups, those greater than or less than 250 μm, a clearer picture regarding relationships between depth and veliger length begins to emerge (Table 5). The Chi square statistic indicates a significant depth relationship to proportion of veligers >250 μm on all seven sample dates. On five of the seven dates, the proportion of veligers >250 μm increases from bottom to top of the water column.

This might be an indication of increasing affinity for near surface depths by settlement sized larvae and might offer an explanation for the apparent discrepancy between observations that the highest overall abundance occurs in sub-surface depths while most actual settlement on spat collectors occurs near the surface. Bayne (1964a) and Cragg and Gruffydd (1975) showed bivalve veligers react both positively and negatively to light, gravity, and hydrostatic pressure.

In laboratory experiments, Bayne (1964a) found that settlement sized veligers responded negatively to light, a situation which he interpreted as encouraging a downward tendency for veligers when they are ready to settle. However, in Charles Arm, downward drift of settlement sized veligers would take them into a silty, muddy bottom, an environment which is clearly not conducive to their survival. An upward affinity in settlement sized veligers, as was found in this study, would appear to be most adaptive for Mytilus veligers since the natural adult habitat for mussels is in the shallow, rocky shoreline areas.

Settled Mussel Spat: Abundance, size, and overwintering

On each sample date, the variability in density of spat settlement between adjacent collectors at 1m depth was quite high (Table 6). Adjacent longlines, strung from shore to shore, were only about 10-20 meters apart. However, the density of spat settlement would often vary from quite dense (visual estimation) to almost none at all between collectors just a few meters apart on the same longlines. There was no apparent reason for this patchy distribution. In both 1989 and 1990, the mean density of spat on the collectors at 1m depth varied between 10-15 spat per cm^2 of collector in the autumn, a density which compares favorably to other locations in eastern North America (Incze *et al.* 1978). In 1991, the autumn spat settlement density was much lower (Table 6) compared to the preceding two years. Spat collectors placed at various depths from 3-9 meters in 1990 did not collect any mussel spat.

The length frequency distributions of the settled mussel spat recorded from the autumn samples were quite different among years. In 1989, settled spat were already well established on the collectors in August (Figure 12) and, by mid-November had grown to a mean length of 5.08 mm. By comparison, in 1990 and 1991, the settled spat had only reached a mean length of <1 mm by November (Figures 13 and 14). The reduced size (and probably abundance as well) of these spat compared to 1989 appears to be the result of their delayed appearance as planktonic veligers in the Summer, which in turn may have been caused by the unusually low water temperatures recorded in the Spring-Summer period (Figure 16) in both these years.

These differences continued through into the overwintered spat the following Spring of each year. In June of the year following their collection, the 1989 and 1990 year classes were still abundant on the collectors (Table 6), although the variation in settlement density between adjacent collectors was quite high. Typically, mussel spat were heavily concentrated on the upper 1-2 meters of the collectors (water depth <3 meters) and totally absent from sections of collector below that. This shallow depth distribution of settled spat may only be typical of sheltered sites like Charles Arm since the depth distribution of spat at more exposed locations has been reported to exceed 10 meters (Sutterlin *et al.* 1981). By June, 1990, the 1989 year class had reached a mean length >10 mm (Figure 15, first panel). However, about 20-30% of all collectors on the site had virtually no spat remaining on them in June, 1990. Socking of mussel spat from the remaining collectors yielded a mean sock:collector ratio of 2.60.

In comparison, by June, 1991, the 1990 year class, although numerically abundant on some collectors, had barely reached a mean length of 1 mm (Figure 15, second panel). Many collectors (approximately 70-80%) had virtually no mussel spat remaining on them at all. Those that did showed a similar depth pattern as in 1990 ie. heavy spat concentration in the top 2 meters and none below that. The 1991 year class spat failed to overwinter on the collectors and by June, 1992, had virtually disappeared.

Settled mussel spat: the occurrence of bio-fouling

In all three years, those areas of the collectors which contained no spat were heavily fouled with algae. The occurrence of bio-fouling organisms on spat collection gear is not unique to Newfoundland. Some areas of Prince Edward Island have experienced bio-fouling with a species of hydroid, Tubularia laryna, which displaces spat from the collectors (Judson and Bernard 1990). At Charles Arm in the August through October period of each year, the most abundant bio-fouling species was the brown alga, Ectocarpus sp. Throughout this period, mussel spat were observed to be present in heavy concentrations, apparently attached to the algae, not to the collector material.

This condition has been observed with mussel spat elsewhere (Bayne, 1964b, 1976; Bøhle, 1971; Davies, 1974). Davies (1974) reported that mussels which initially settled on algae subsequently moved onto the collector material when they reached 1-2 mm in size. Bayne (1964b, 1976) suggested the occurrence of a two-stage settlement process for mussels, initial or primary settlement taking place on algae with a subsequent detachment and secondary settlement at another site on new, hard substrate. This secondary site might be physically removed some distance from the place of primary settlement. During conditions unfavorable for secondary attachment, mussel spat may overwinter on the algae (Dare 1976).

By November of each year, a new flora of algae had appeared on the collectors. Its luxurious growth continued through the winter and, by June of each successive year, the growth of algae was very extensive, sometimes exceeding a meter in length and covered many collectors from top to bottom. No mussels were found growing amongst these algae. The main constituent species, which accounted for a visually estimated minimum of 95% of the total algae present, was the red alga, Polysiphonia flexicaulis. Another red alga, Ceramium rubrum, also commonly occurred, but its biomass was insignificant compared to the Polysiphonia.

Growth of algae in the water column is strongly related to available light. However, sinking the collector lines down to 12 meters depth in 1991 had no noticeable effect on the growth of Polysiphonia. Maximum water depth at Charles Arm is only 12-15 meters. Although the collector lines were sunk as far as possible, all spat were gone by the following June. Sinking of the collector lines may be more successful at sites where greater water depths are available.

While the failure of mussel spat to overwinter on the collectors is clearly associated with the presence of bio-fouling algae, it is more difficult to interpret their exact relationship. After seeing the luxurious growth of Polysiphonia on the collectors in June and with the knowledge that dense aggregations of mussel spat had been present the previous Autumn, it is tempting to conclude that the Polysiphonia displaced the settled mussel spat over the winter months. It is possible this may have been an act of simple physical displacement, the Polysiphonia outcompeting the spat for space. The extensive growth of Polysiphonia might also actively interfere with the growth of mussel spat by affecting their water filtering capacity and hence feeding success. It is also possible that biochemical factors may have played a part since Polysiphonia is one of many algal species which excrete bromine-based organic chemicals which are probably toxic to bivalve molluscs.

Other factors may have also played a part in the failure to overwinter on the collectors. The brown alga, Ectocarpus was observed on collectors in the Summer and Autumn and the newly settled spat were observed to be attached to the algal filaments. It is possible that, when the Ectocarpus died out with the onset of winter, the mussel spat were not successful in migrating onto the collector material itself. Rather, they were dispersed elsewhere.

This possibility suggests that the timing of spat collector gear placement each year should be closely matched to the availability of settlement size veligers. By doing so, the opportunity for algal growth on the collectors prior to spat settlement is reduced. However, the settlement of spat on algae in 1990 and 1991 at Charles Arm did not seem to be a result of inaccurate estimation of the appropriate time to set out the collector gear. The collectors were only set out after pinpointing the availability of settlement size veligers in the plankton. As well, in 1990, experimental collector lines set out at weekly intervals from June through October all showed heavy algal growth and reduced spat settlement success. No relationship between date of initial collector placement and spat retention was found.

The unusually small size of the settled spat in the Autumn of both 1990 and 1991 may have also been a factor and may help explain the success the algae enjoyed in displacement of the spat from the collectors. The small spat size, in the absence of an offsetting increase in spat density, effectively increased the amount of open space on the collectors, relative to 1989, offerring increased opportunities for algal attachment. Had spawning and the development of planktonic veligers not been delayed by low water temperatures during the preceding Spring, the mussel spat may have been sufficiently large to successfully resist displacement.

The same environmental conditions which resulted in the small size of the mussel spat may have also had a negative impact upon other molluscs , crustaceans, etc. which normally graze upon algae. This absence of predators might have contributed to the the extensive growth of the algae. As well, Polysiphonia is a cold water species which normally reaches its maximum growth during the winter months, then dying back when the temperature exceeds 10°C. The cold temperatures of 1990 and 1991 may actually have been ideal for Polysiphonia.

Impact on Industry Development

While an exact cause and effect relationship between the algal growth, delayed mussel spawning, mussel veliger development, and overwintering success is hard to establish, it is obvious that, in 1990 and 1991, environmental conditions contributed to a failure of commercial spat collection over a wide area of Notre Dame Bay. However, reports from other growers in nearby areas such as New World Island and farther along the northeast coast of Newfoundland indicate no similar spat collection problems occurred. Further comparative studies in these areas seem warranted.

From an industry perspective, a key observation from the events of 1990 and 1991 is that spat collection success along the northeast coast can be expected to vary considerably from year to year. The occurrence of unfavorable environmental conditions is a largely unpredictable event. Such events may have a dramatic effect on potential commercial success. Some sites, which initially seem good for spat collection, may turn out to be too unreliable for commercial purposes.

In 1991 and 1992, spat collection at Charles Arm was far less than expacted. A similar situation occurred at farms throughout a larger area of Notre Dame Bay. Successful marketing of aquaculturally produced seafood is strongly linked to reliability of production which, in turn, is largely dependent upon the spat collection process. Customers want and demand stable levels of supply on a continuous basis. A failure to collect spat translates into a production shortfall of market size mussels, an event which might lead to loss of market position, loss of the customer base, and severe cash flow problems for the producer. Even assuming an alternate source of mussel spat could be found, a spat collection failure results in duplication of costs since the producer must pay the costs of his own failed spat collection efforts as well as the cost of purchasing spat from other producers.

Periodic spat collection failures, sometimes over a wide geographical area, are not unusual in molluscan shellfisheries. On an industry wide scale, one practical solution to the problem might be found in greater cooperation between site owners or greater diversification in production between sites. One example demonstrating the effective utility of such systems has been reported for the green mussel industry in New Zealand where farmers successively maintained their spat supply, despite a two year failure of local spat collection, by transferring spat from sites over 600 km away (Hickman, 1989). Overall production in the industry might be both stabilized and maximized by identification of the best spat collection areas. Production at such sites could become specialized for spat collection with subsequent transfer of spat to growout sites at socking time. This could be accomplished either by company ownership of several sites, some for spat collection and others for growout, or by some growers specializing in spat collection for subsequent resale and transfer to other sites. For this to occur, the present industry members in Newfoundland will have become more cohesively linked together.

This situation is not without precedent. The mussel culture industry in Prince Edward Island, which has become the most successful in eastern Canada, already utilizes such a diversified system. Although growout sites are distributed throughout most of the sheltered areas on the island, about 70% of all market size mussels produced on the island are still collected as seed in a single bay, St. Peter's Bay (Judson and Bernard 1990).

On individual farm sites, several modifications to current spat collection procedures could potentially improve spat collection reliability. Firstly, few mussel farmers currently engage in larval monitoring. This is relatively easily carried out and could benefit the farmer greatly by providing information on size and numbers of spat available, thus allowing spat gear to be set out at optimum times. Secondly, use of specialized, fibrous ropes which offer greater surface area for spat settlement and mimic filamentous algae might also improve spat retention. Indeed, the apparent preference of mussel spat to settle on filamentous algae has been put to great practical advantage by mussel farmers. Elsewhere in the world, farmers utilize a variety of coarsely fibred, hairy ropes with improved spat catching and seed retention characteristics for spat collection (Nie 1991). Thirdly, on deepwater sites, spat collection gear might be sunk to greater depths in the autumn, after spat have set, to discourage the growth of fouling algae. Algal growth depends on light from the surface which quickly drops in intensity with increasing depth. Although this was tried at Charles Arm, the shallow water depth (~ 12-15 meters) was too shallow to make an appreciable difference.

ACKNOWLEDGEMENTS

I wish to thank all the members of the Mills and Jewer families of Botwood who contributed their time and effort towards collecting the samples which made this document possible. Their support and perseverance over the last four years was indispensable. I also wish to thank Bob Hooper, of the Biology Department at Memorial University, who identified the species present in the samples of algae. Claude Morris and Sharon Kenny spent long hours identifying, counting, and measuring mussel veligers in the plankton samples. Constructive reviews of an earlier draft were provided by Dr. Pat Dabinett of Memorial University and Vern Pepper DFO, St. John's. Funding support was provided jointly by the Department of Fisheries and Oceans, Science Branch, and the Canada/Newfoundland Inshore Fisheries Development Agreement.

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Table 1. Proportion of horse mussels, Modiolus modiolus, planktonic veligers (expressed as a per cent of all mussel veligers present) taken in plankton tows at 1 m depth in Charles Arm, 1990.

Sample Date	% Modiolus	Sample Date	% Modiolus
June 23	1.9	August 25	0
		29	0
July 2	16.8		
13	14.2	September 7	0
21	7.6	17	0
27	6.6	22	0.7
August 5	1.6	October 2	4.8
10	0	6	0
16	0	14	0
18	0	21	0

Table 2. Abundance of planktonic mussel veligers at various depths in the water column at Charles Arm during 1990 and 1991.

August 18, 1990		August 29, 1990		October 21, 1990	
Depth (m)	Abundance (#/liter)	Depth (m)	Abundance (#/liter)	Depth (m)	Abundance (#/liter)
1	4.0	1	5.7	1	0.16
3	23.9	3	3.6	3	0.05
5	33.1	5	2.2	5	0.12
7	13.8	7	8.2	7	0.11
9	6.6	9	3.5	9	0.21

July 20, 1991		August 25, 1991		September 8, 1991	
Depth (m)	Abundance (#/liter)	Depth (m)	Abundance (#/liter)	Depth (m)	Abundance (#/liter)
1	1.9	1	52.4	1	55.6
3	11.6	3	178.0	3	44.2
5	26.2	5	155.7	5	96.9
7	10.3	7	245.5	7	20.3

September 29, 1991	
Depth (m)	Abundance (#/liter)
1	19.2
3	24.6
5	21.7
7	2.5

Table 3. Statistical comparison of mussel veliger length versus depth from depth stratified plankton tows at Charles Arm in 1990. The F values and their probabilities refer to ANOVA on the main effects model of length vs. depth. Within table results are pairwise T tests of mean mussel length vs. depth. Asterisks denote P<0.05; NS is not significant.

Aug. 18/90

F= 4.94
P< 0.01

Depth (m)	1	3	5	7	9	Mean Length (μm)
1		NS	*	NS	NS	253.8
3			*	NS	NS	241.7
5				NS	NS	215.1
7					NS	257.1
9						259.2

Aug. 29/90

F= 1.12
P> 0.05

Depth (m)	1	3	5	7	9	Mean Length (μm)
1		NS	NS	*	NS	145.7
3			NS	NS	NS	135.9
5				NS	NS	140.1
7					NS	132.8
9						139.3

Oct. 21/90

F= 1.54
P> 0.05

Depth (m)	1	3	5	7	9	Mean Length (μm)
1		*	NS	NS	NS	215.2
3			NS	NS	NS	203.4
5				NS	NS	213.6
7					NS	207.6
9						206.6

Table 4. Statistical comparison of mussel veliger length versus depth from depth stratified plankton tows at Charles Arm in 1991. The F values and their probabilities refer to ANOVA on the main effects model of length vs. depth. Within table results are pairwise T tests of mean mussel length vs. depth. Asterisks denote $P<0.05$; NS is not significant.

July 20/91 ($F=32.45$, $P< 0.01$)

Depth (m)	1	3	5	7	Mean Length (μm)
1		NS	NS	*	111.4
3			NS	*	121.7
5				*	120.6
7					180.4

Aug. 25/91 ($F=14.56$, $P< 0.01$)

Depth (m)	1	3	5	7	Mean Length (μm)
1		*	*	*	304.3
3			NS	*	272.0
5				*	277.6
7					251.0

Table 4. Continued

Depth (m)	1	3	5	7	Mean Length (μm)
1		NS	*	*	297.1
3			*	NS	283.0
5				NS	262.8
7					268.8

Sept. 8/91

F= 4.73
P< 0.01

Depth (m)	1	3	5	7	Mean Length (μm)
1		NS	NS	NS	245.6
3			NS	NS	229.9
5				NS	224.0
7					220.3

Sept. 29/91

F= 1.28
P> 0.05

Table 5. Depth distribution of settlement sized planktonic mussel veligers, Prop>250 μm, expressed as a percent of all veligers present. The χ^2 statistic indicates the strength of the linear association between Prop>250 and depth ($P<0.05$ is significant).

August 18, 1990 χ^2= 6.24, P<0.05		August 29, 1990 χ^2= 4.52, P<0.05		October 21, 1990 χ^2= 7.52, P<0.05	
Depth (m)	Prop>250 (%)	Depth (m)	Prop>250 (%)	Depth (m)	Prop>250 (%)
1	63.5	1	7.4	1	16.7
3	60.9	3	3.9	3	7.8
5	47.4	5	3.8	5	4.9
7	73.7	7	0	7	6.8
9	71.1	9	2.6	9	3.8

July 20, 1991 χ^2= 4.92, P<0.05		August 25, 1991 χ^2= 11.42, P<0.05	
Depth (m)	Prop>250 (%)	Depth (m)	Prop>250 (%)
1	1.8	1	100.0
3	0	3	80.0
5	1.8	5	90.7
7	8.9	7	73.7

September 8, 1991 χ^2= 5.20, P<0.05		September 29, 1991 χ^2= 5.37, P<0.05	
Depth (m)	Prop>250 (%)	Depth (m)	Prop>250 (%)
1	89.1	1	60.0
3	82.4	3	50.9
5	69.6	5	35.7
7	74.5	7	41.8

Table 6. Density of settled spat at Charles Arm, 1989-92, combined for both Vexar and poly rope collectors. Mean and standard deviations are of four mesh sizes of Vexar and one size of poly rope.

Year Class	Collection Date	Mean Density ($\#/cm^2$)	Standard Deviation
1989	Aug. 23	11.19	8.64
	Sept. 21	13.78	11.55
	Nov. 10	14.07	8.44
	June 21/90	7.89	2.94
1990	Oct. 1	10.81	15.17
	Oct. 21	9.86	3.98
	June 14/91	15.97	11.31
1991	Sept. 27	7.49	2.05
	Nov. 2	5.56	5.06
	June 15/92	*	

* No spat survived on experimental collectors

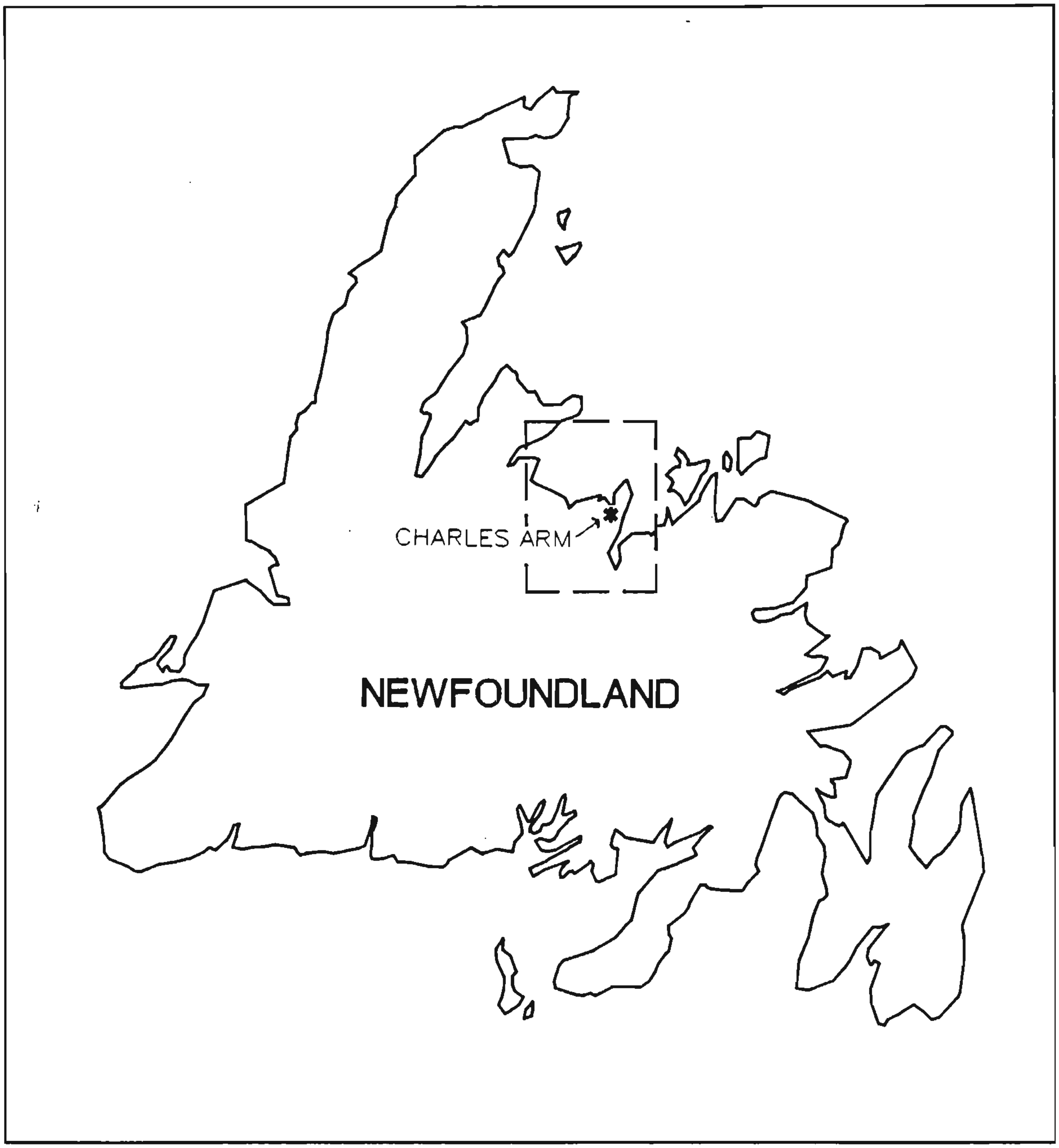
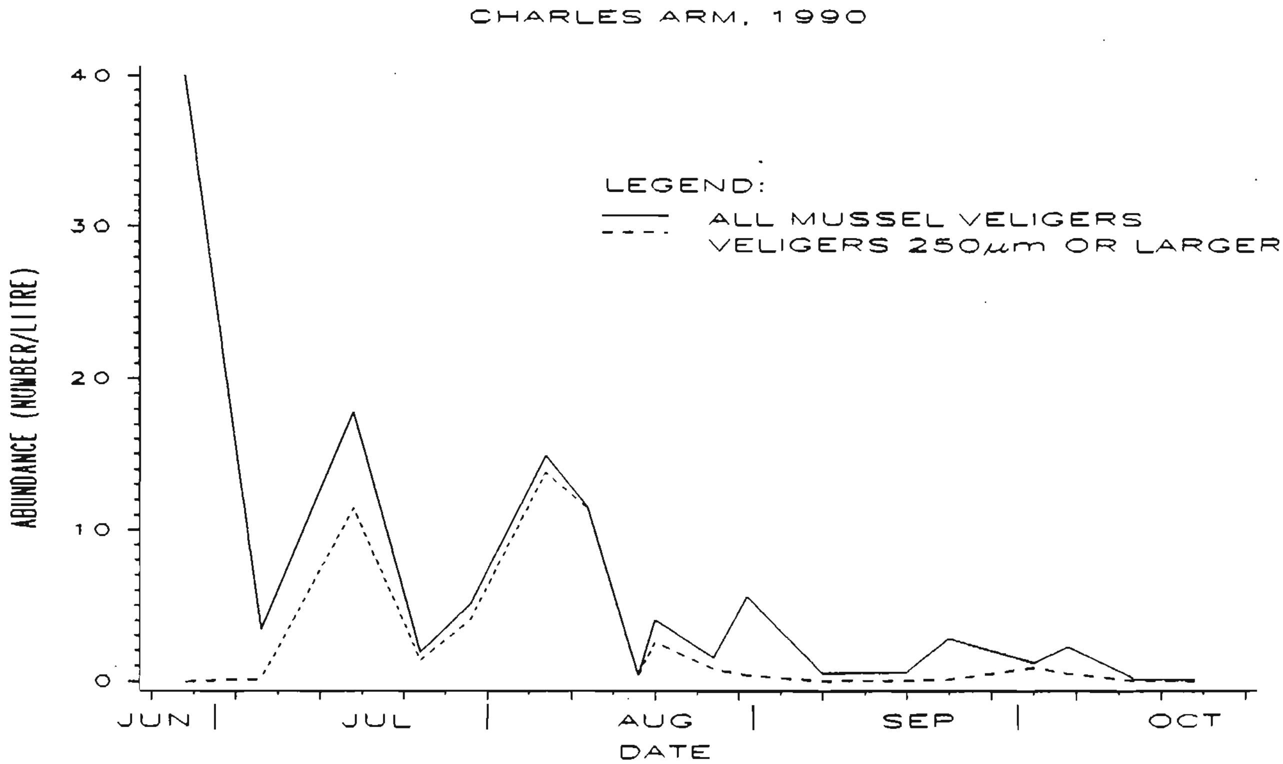


Figure 1. The island of Newfoundland showing the study site and the main area reporting spat collection problems (box insert) in 1991 and 1992.



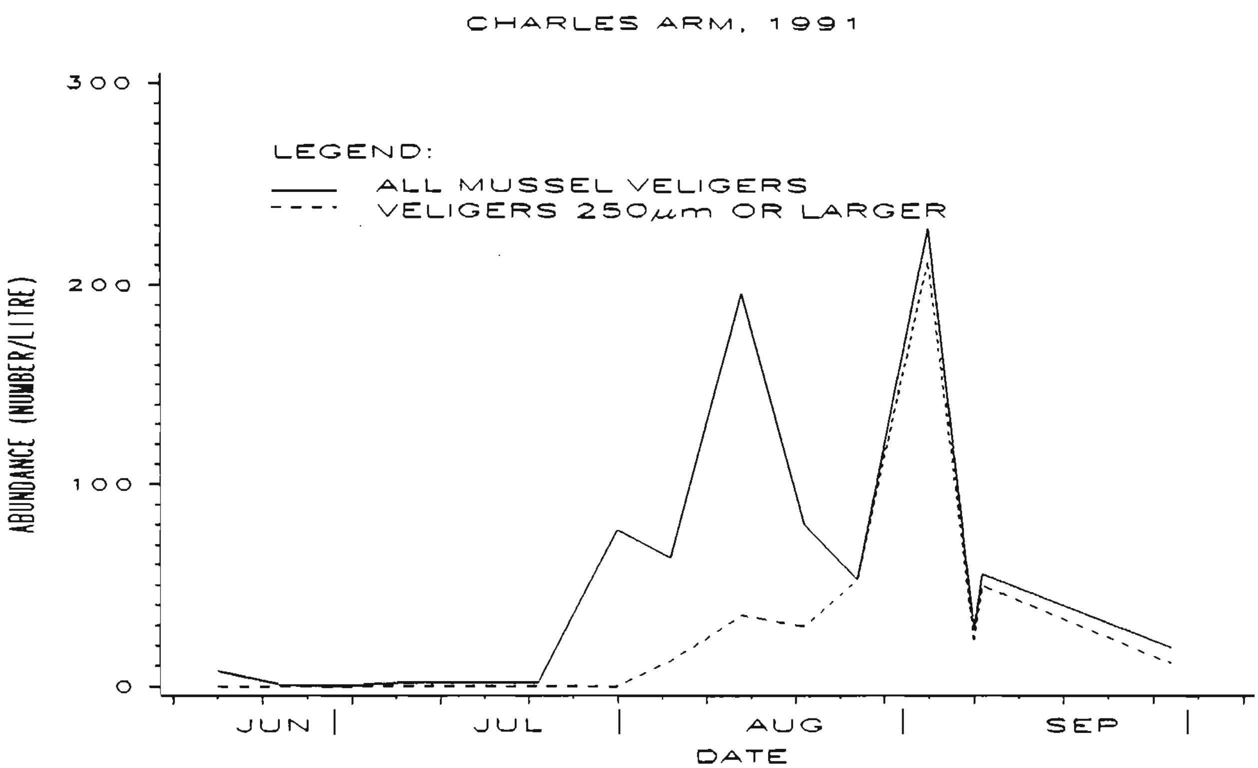


Figure 2. Abundance of planktonic mussel veligers at a depth of 1 m during the Spring to Autumn period, 1990 and 1991.

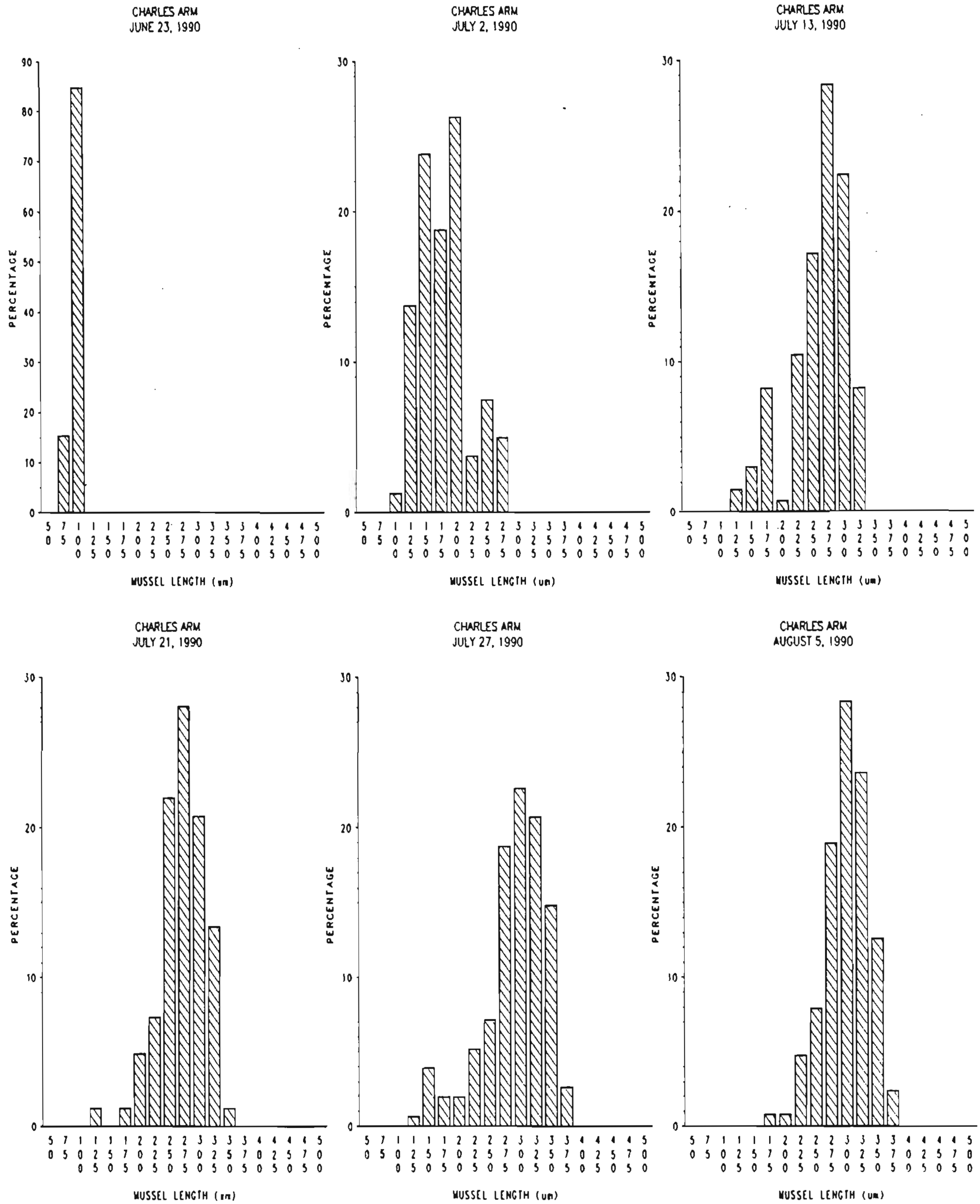


Figure 3. Length frequencies of planktonic mussel veligers at a depth of 1 m during the Spring to Autumn period, 1990.

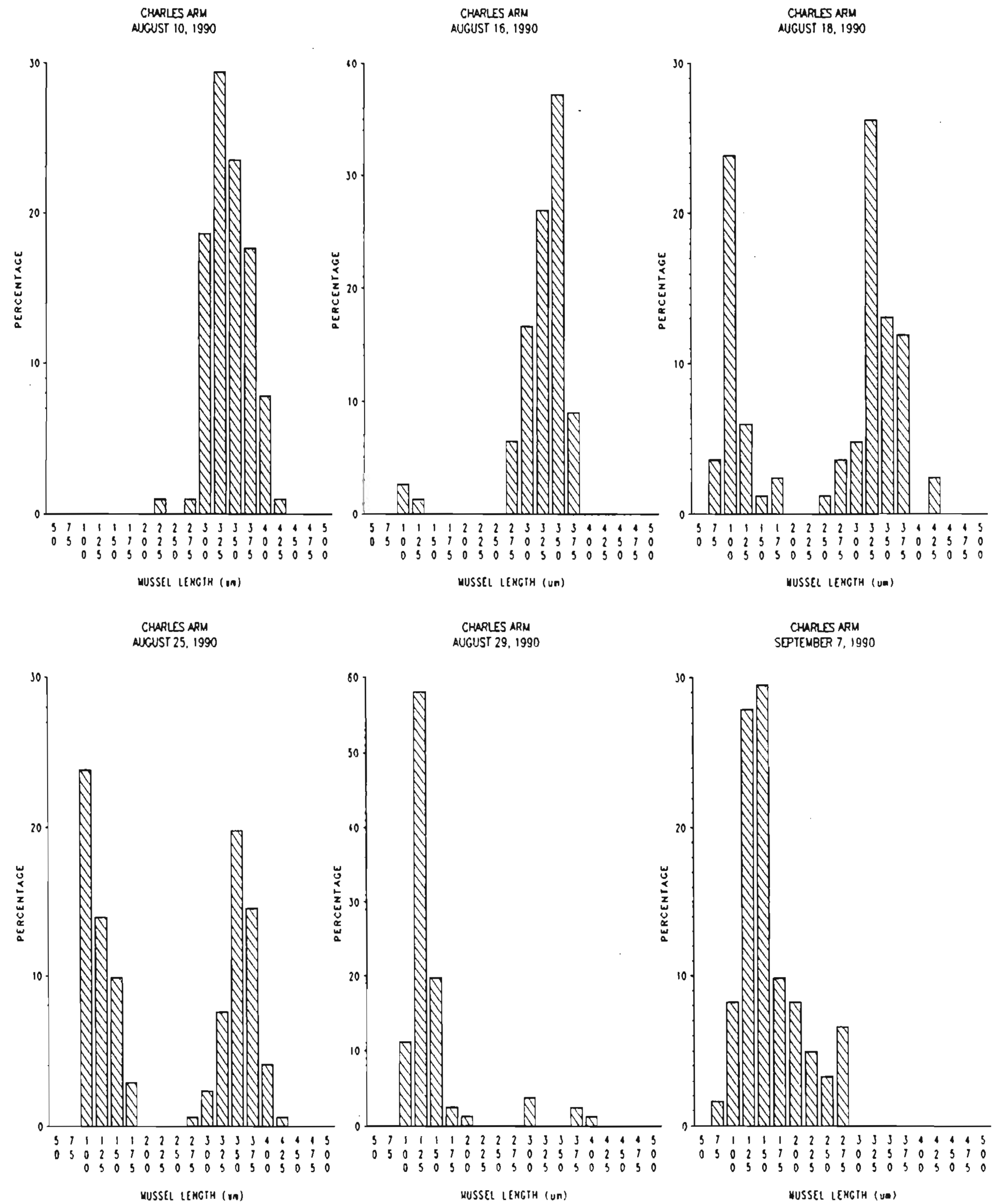


Figure 3 continued.

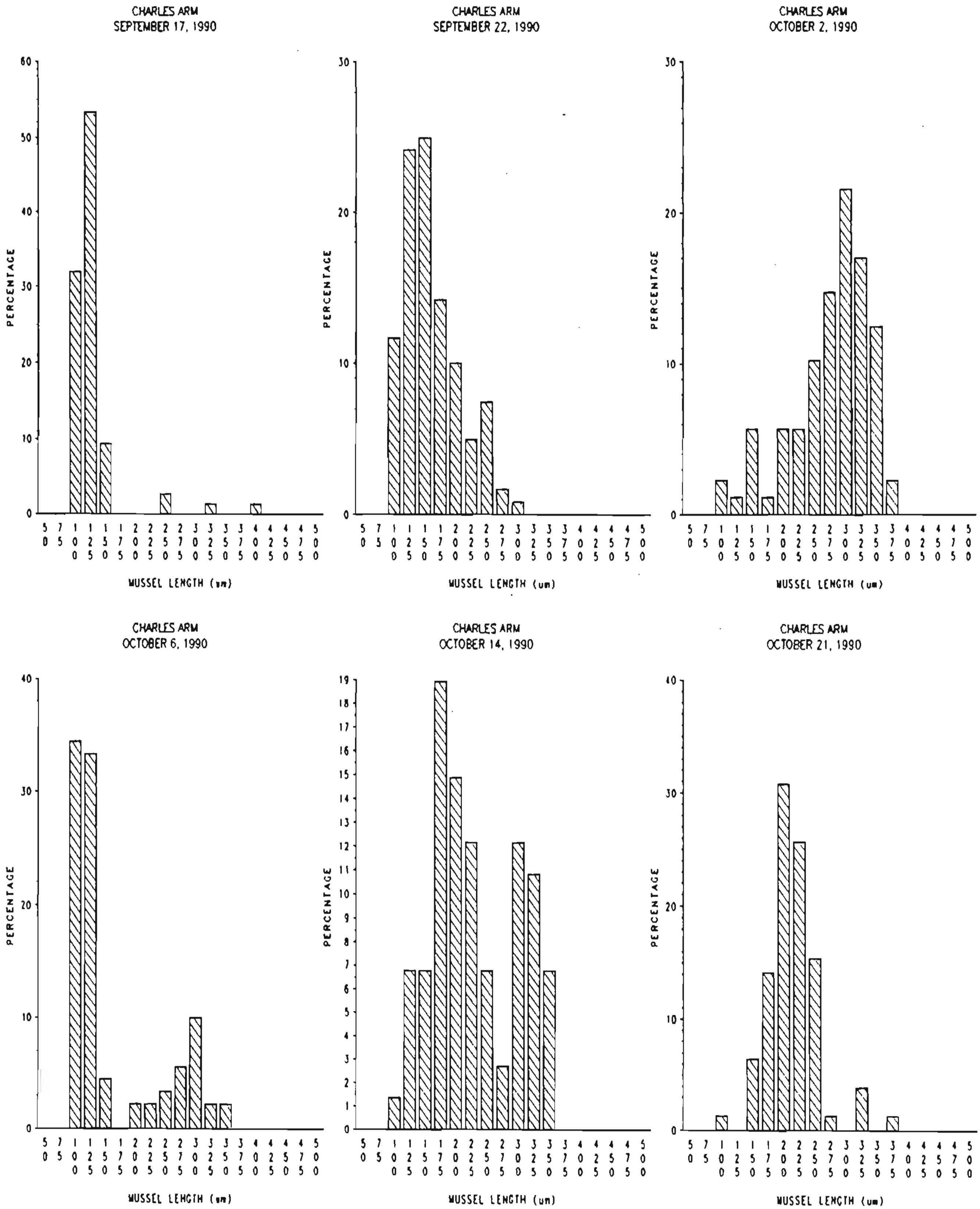


Figure 3 continued.

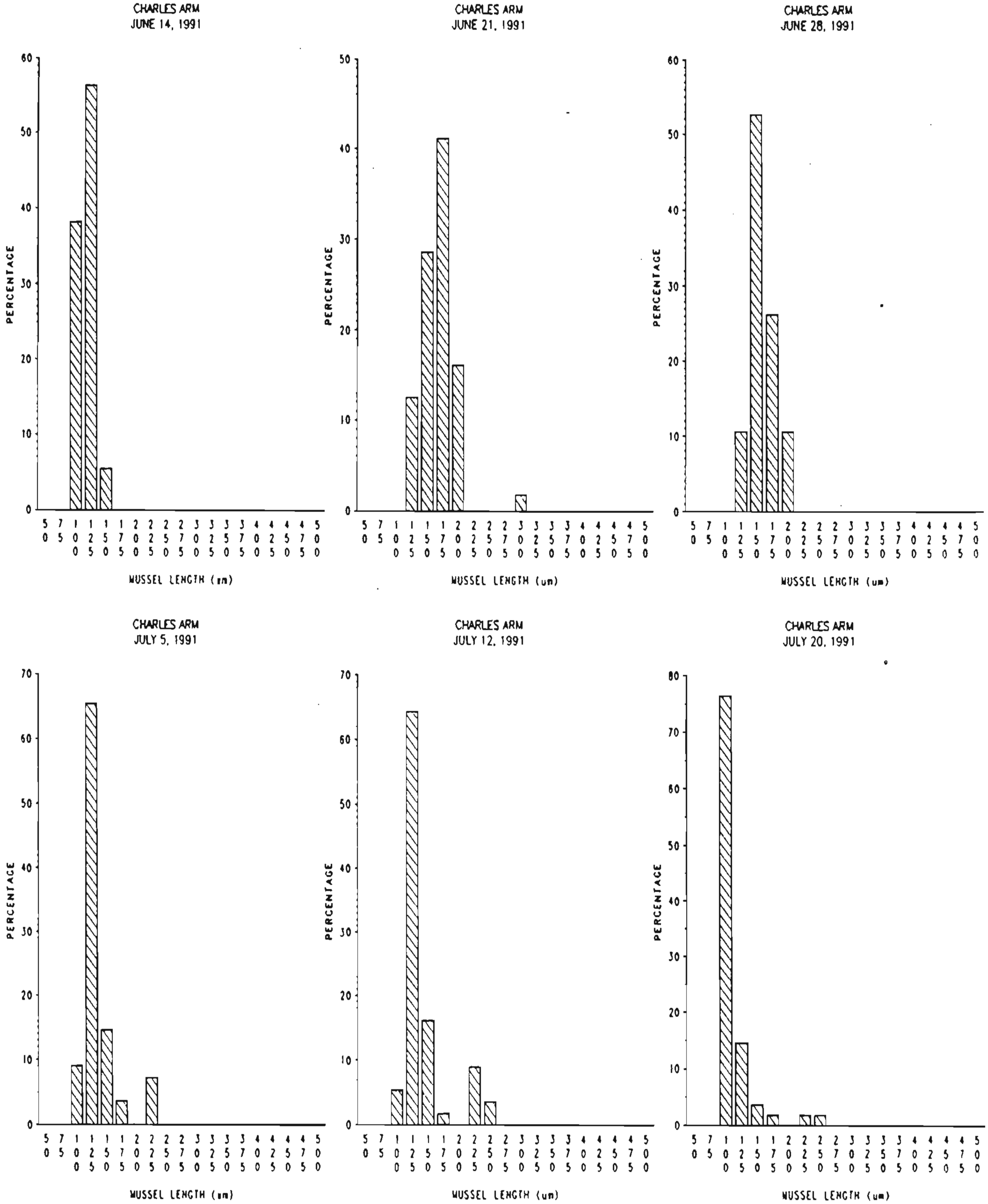
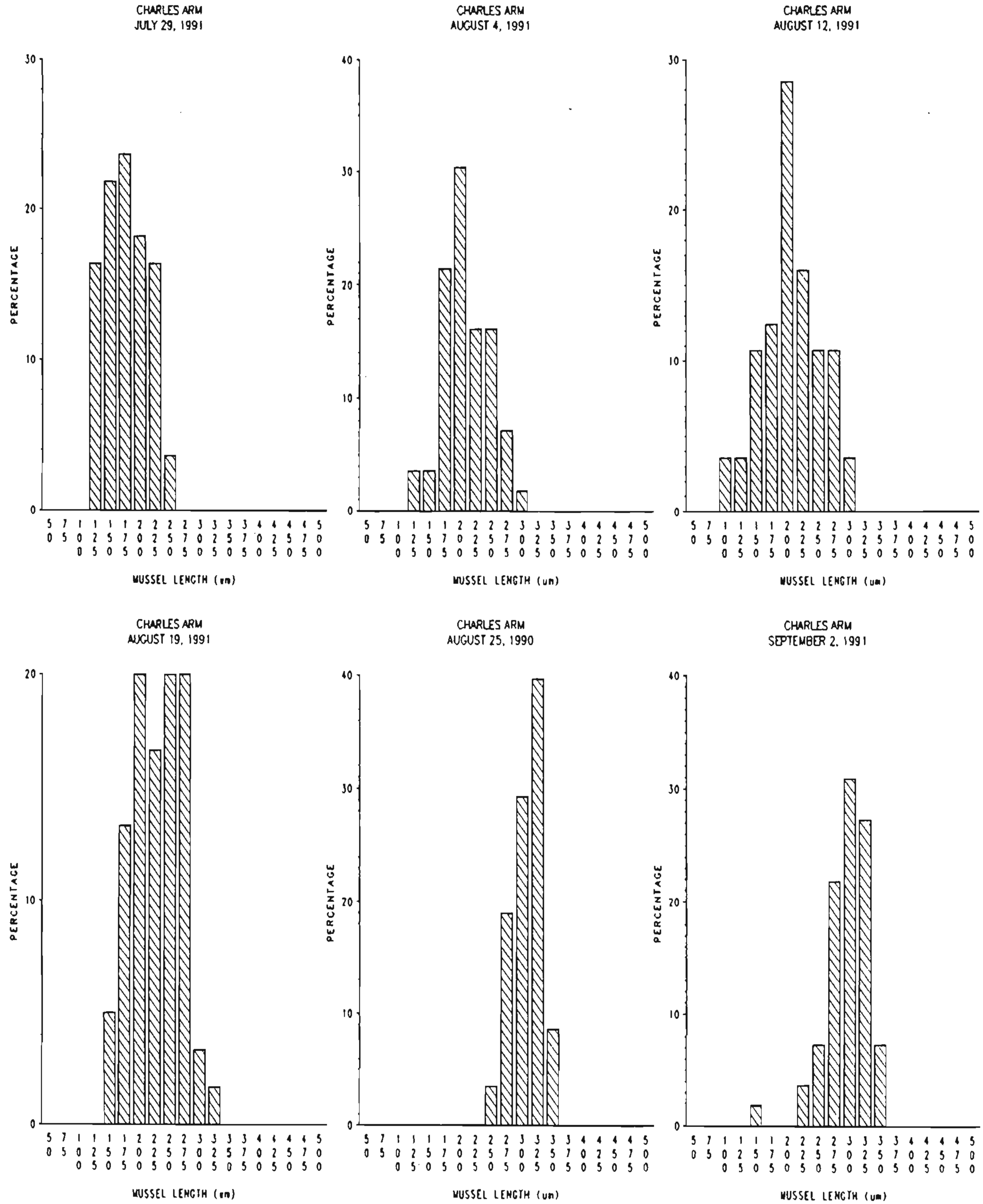


Figure 4. Length frequencies of planktonic mussel veligers at a depth of 1 m during the Spring to Autumn period, 1991.



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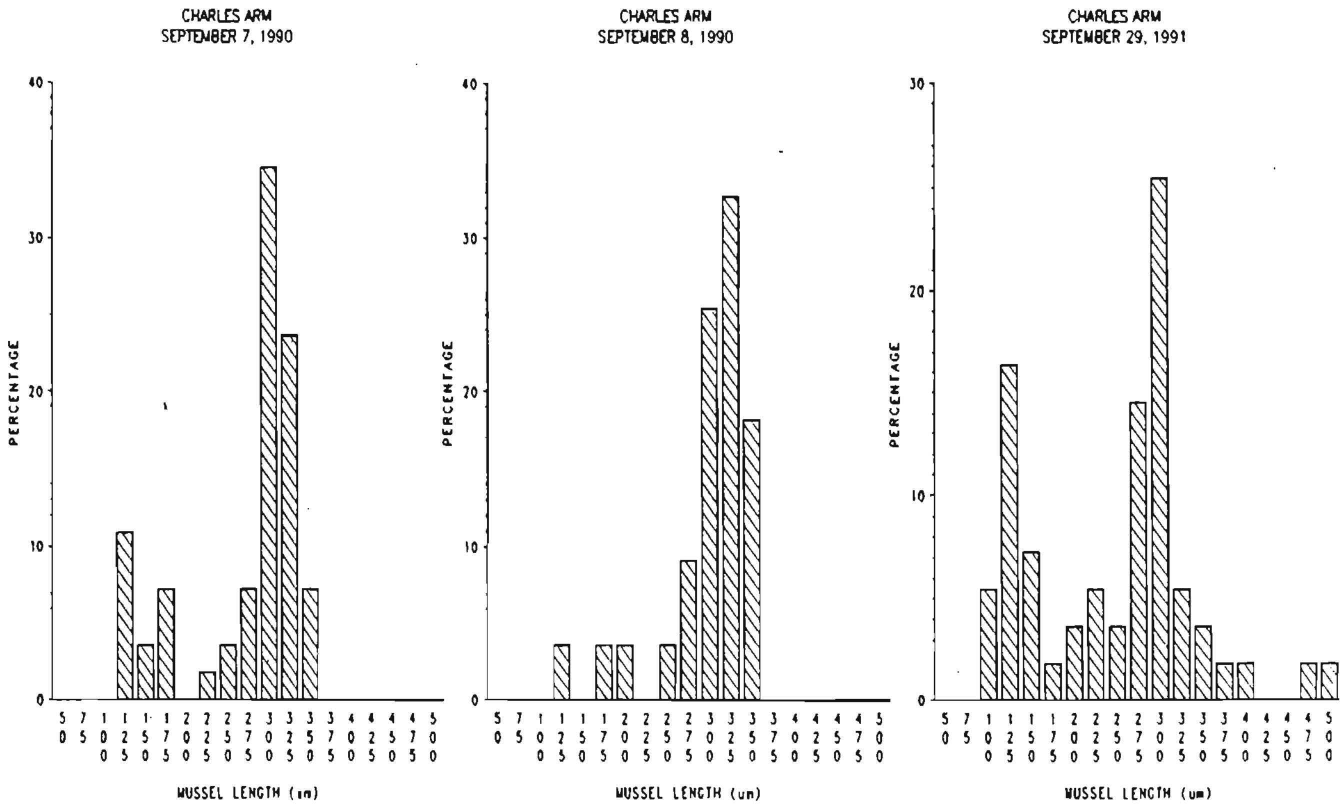

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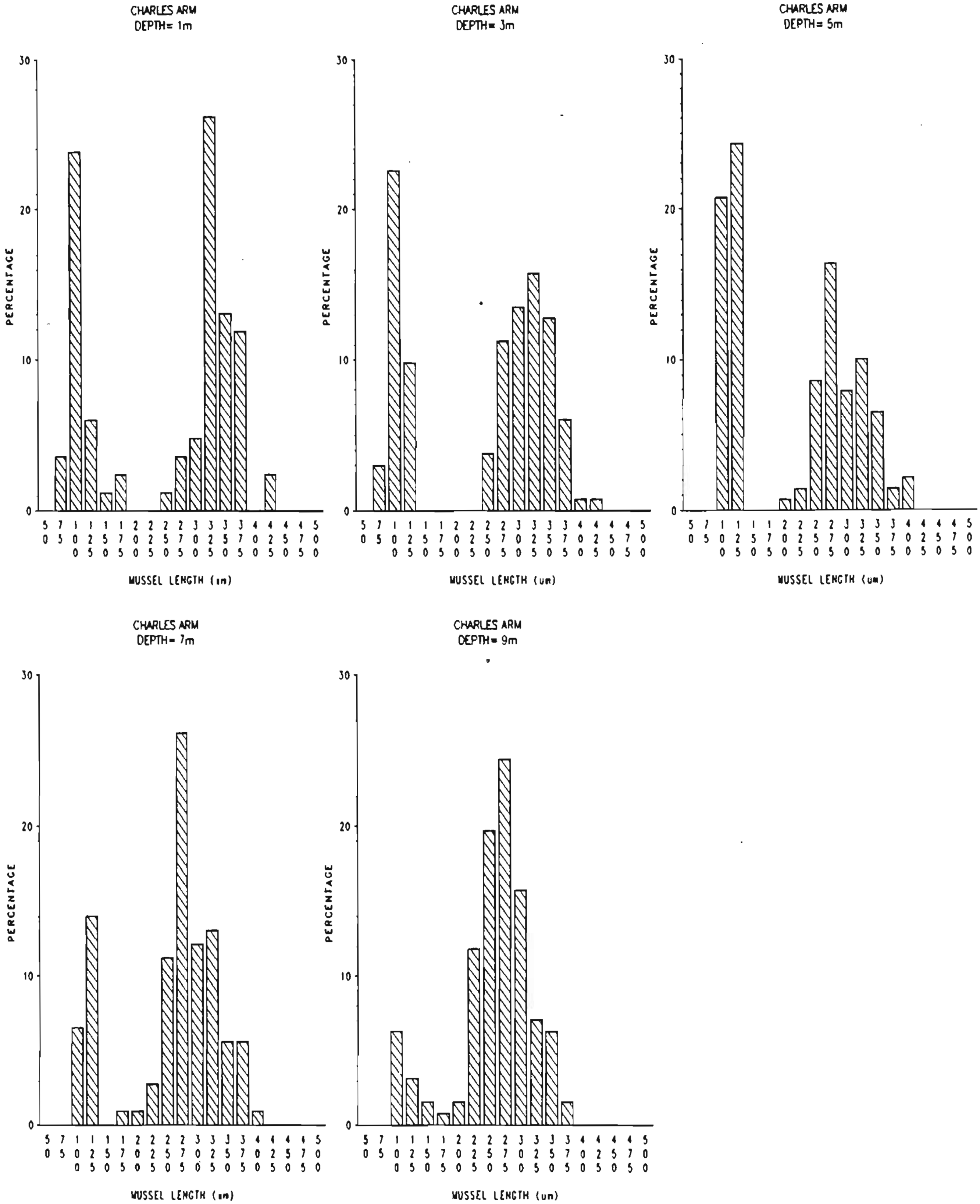


Figure 5. Length frequencies of planktonic mussel veligers at various depths in the water column on August 18, 1990.

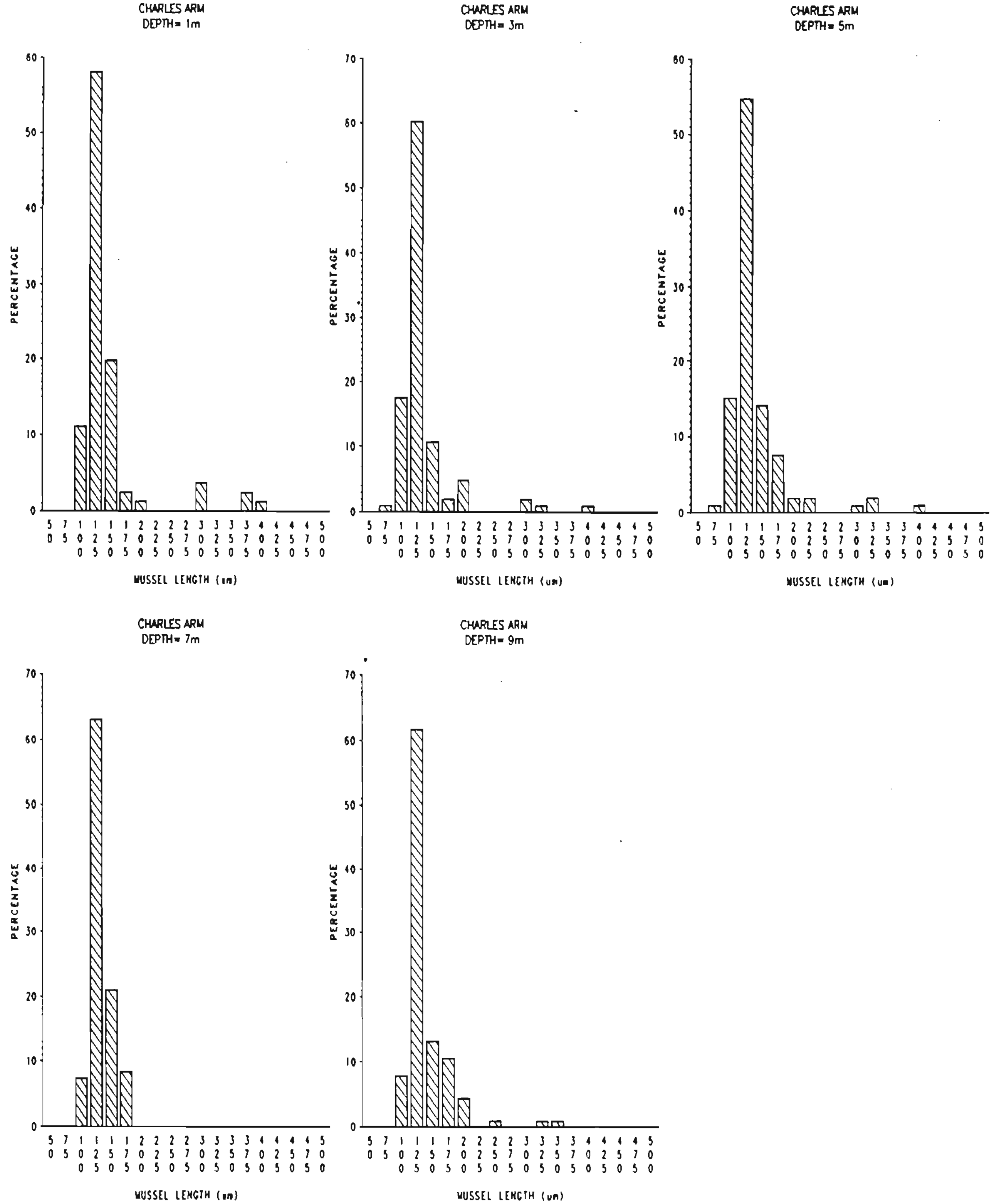


Figure 6. Length frequencies of planktonic mussel veligers at various depths in the water column on August 29, 1990.

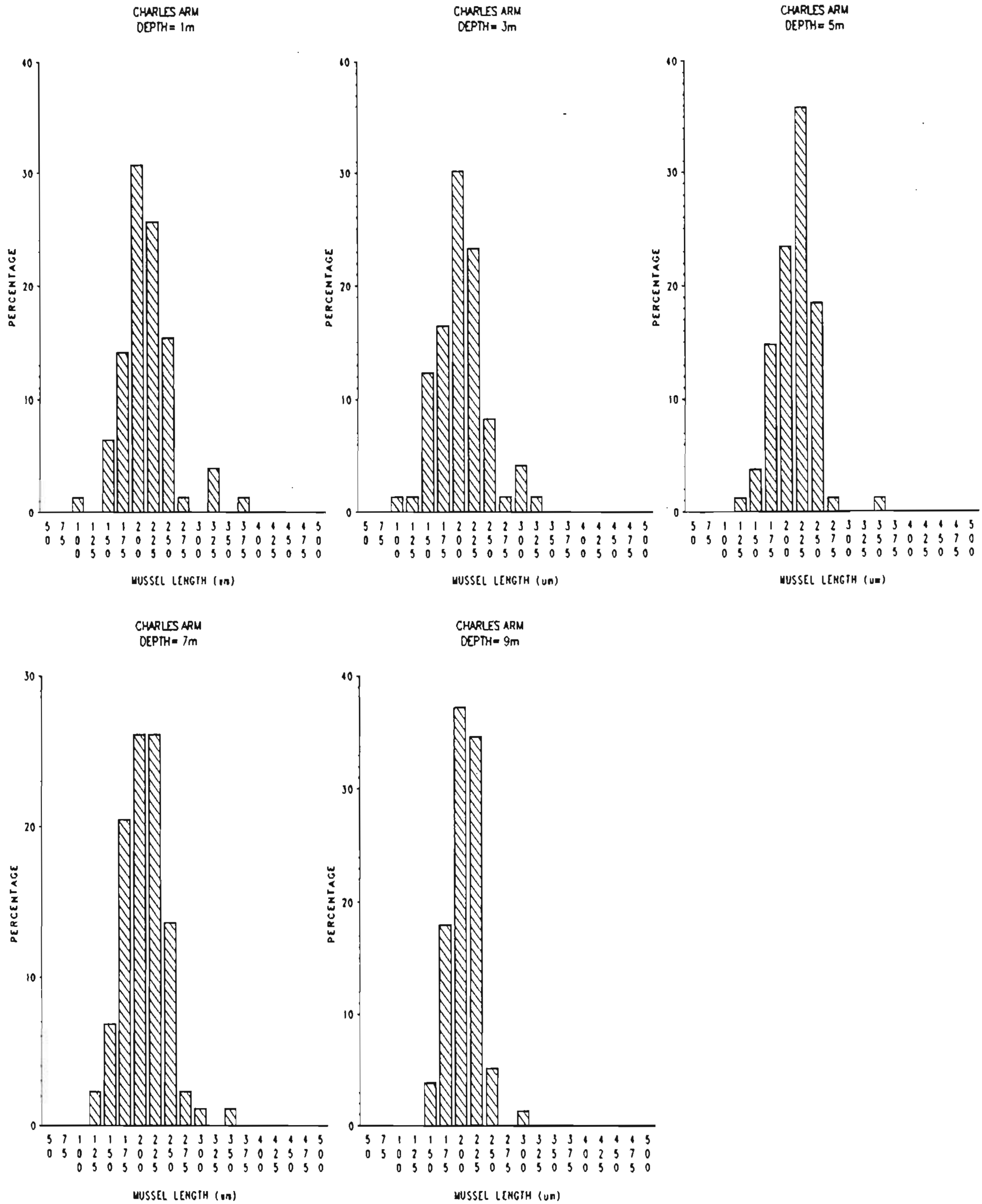


Figure 7. Length frequencies of planktonic mussel veligers at various depths in the water column on October 21, 1990.

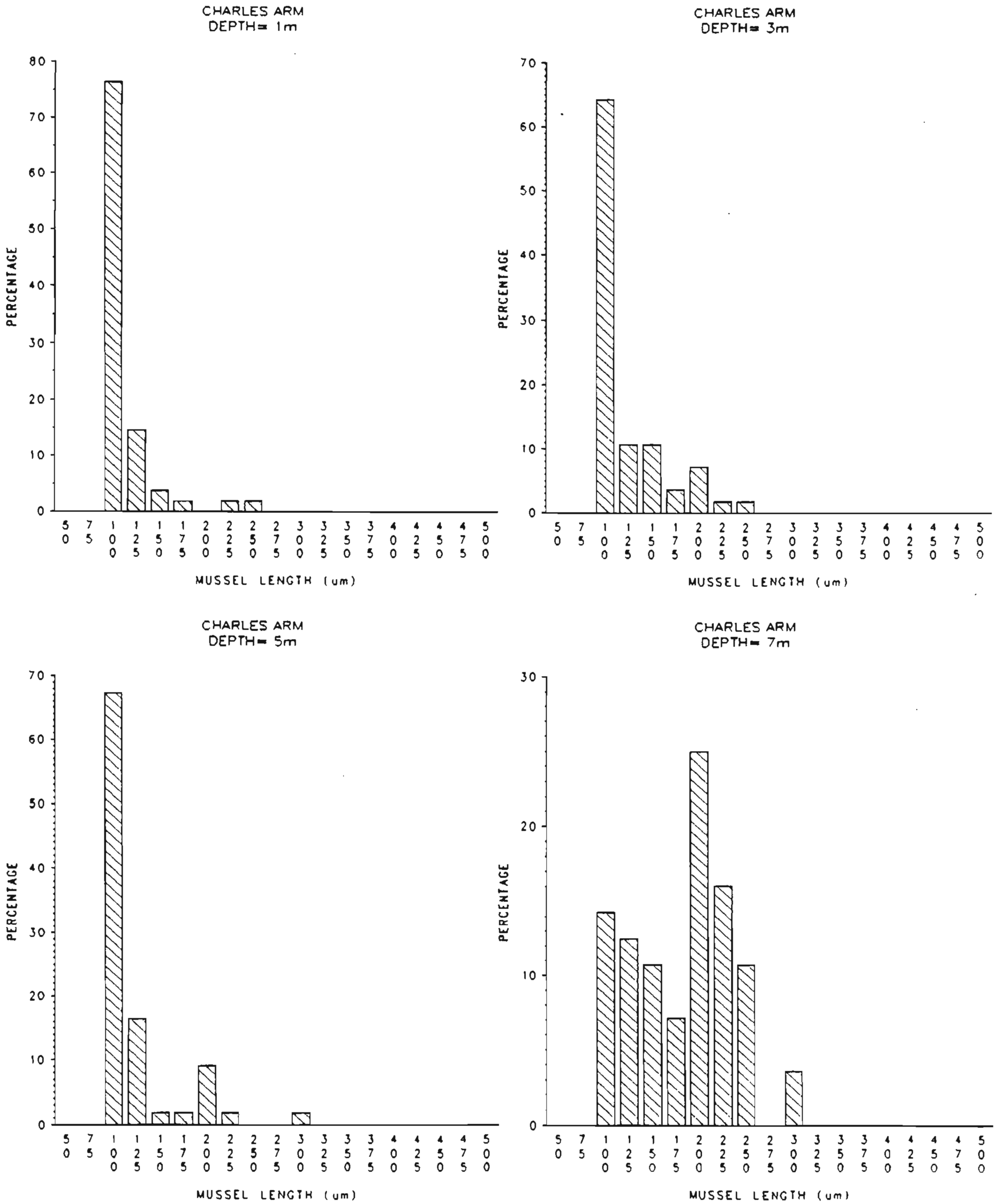


Figure 8. Length frequencies of planktonic mussel veligers at various depths in the water column on July 20, 1991.

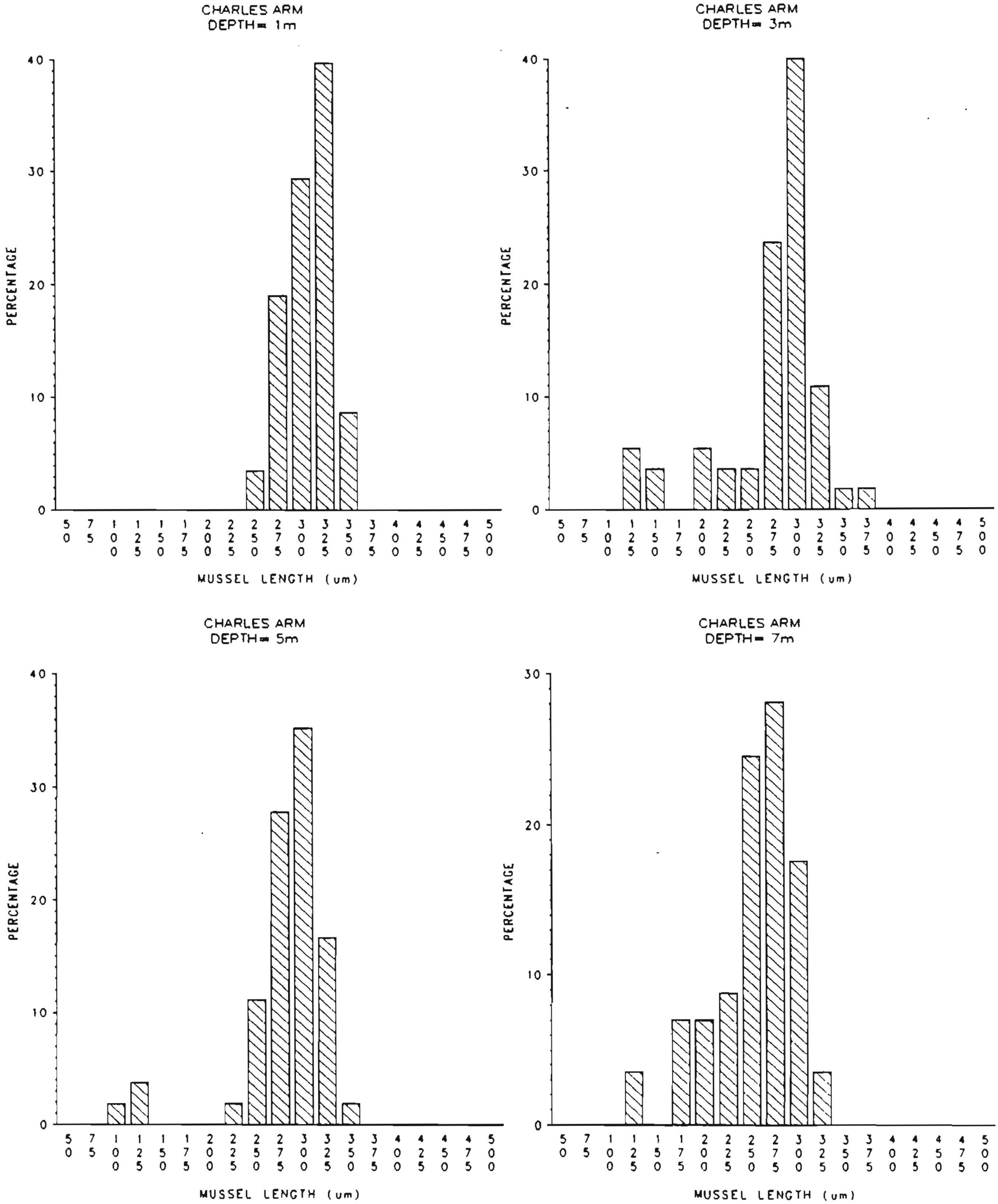


Figure 9. Length frequencies of planktonic mussel veligers at various depths in the water column on August 25, 1991.

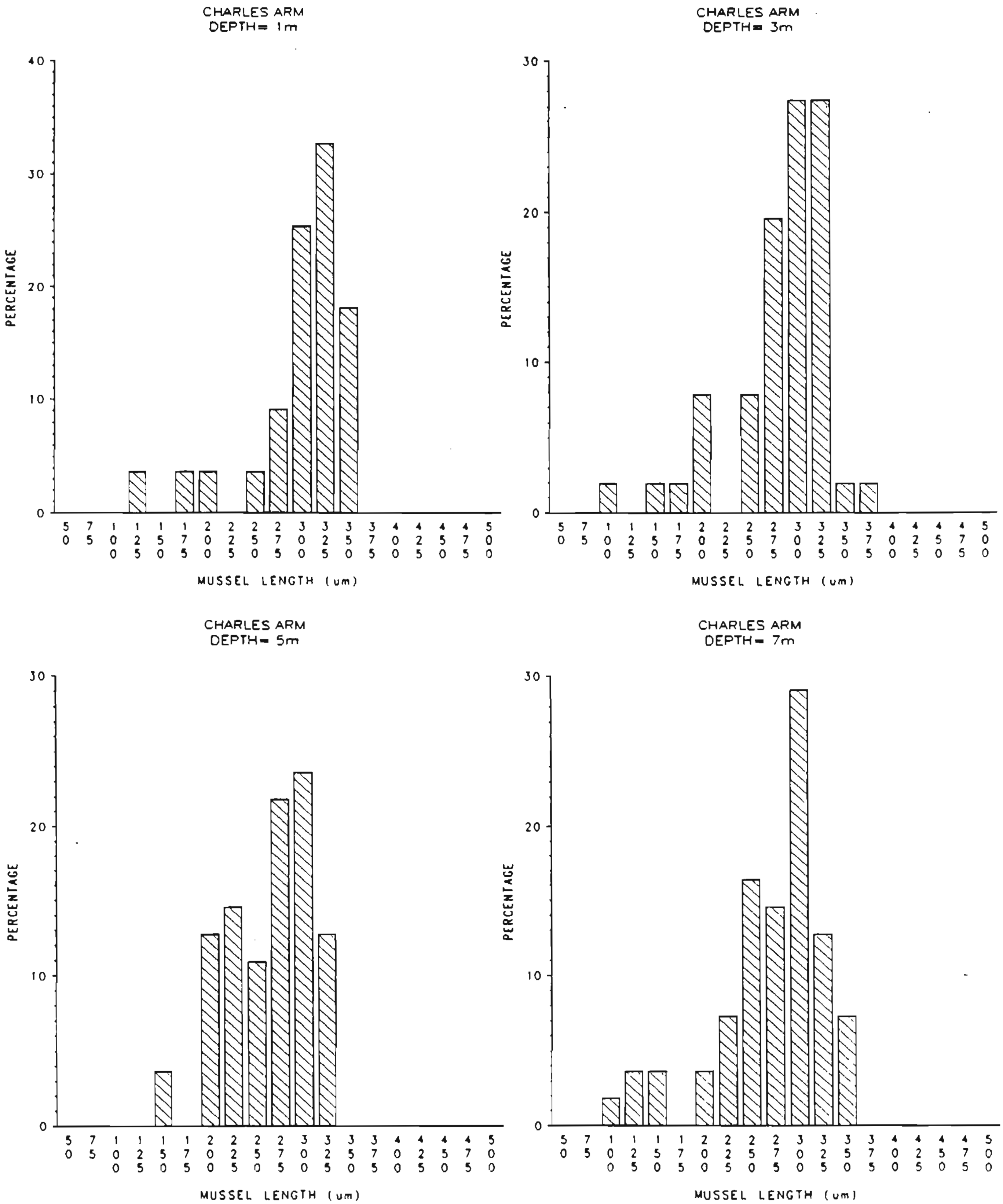


Figure 10. Length frequencies of planktonic mussel veligers at various depths in the water column on September 8, 1991.

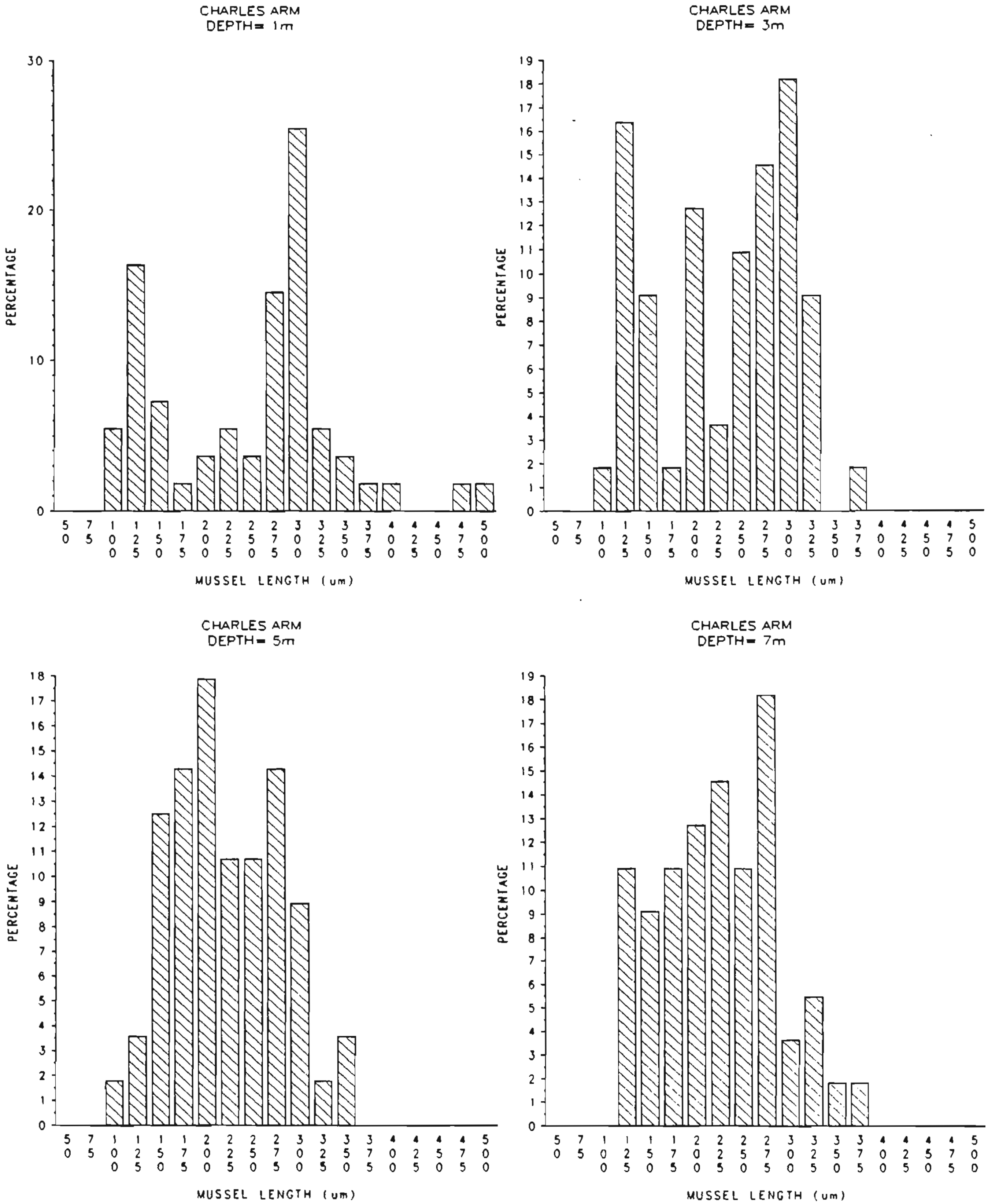


Figure 11. Length frequencies of planktonic mussel veligers at various depths in the water column on September 29, 1991.

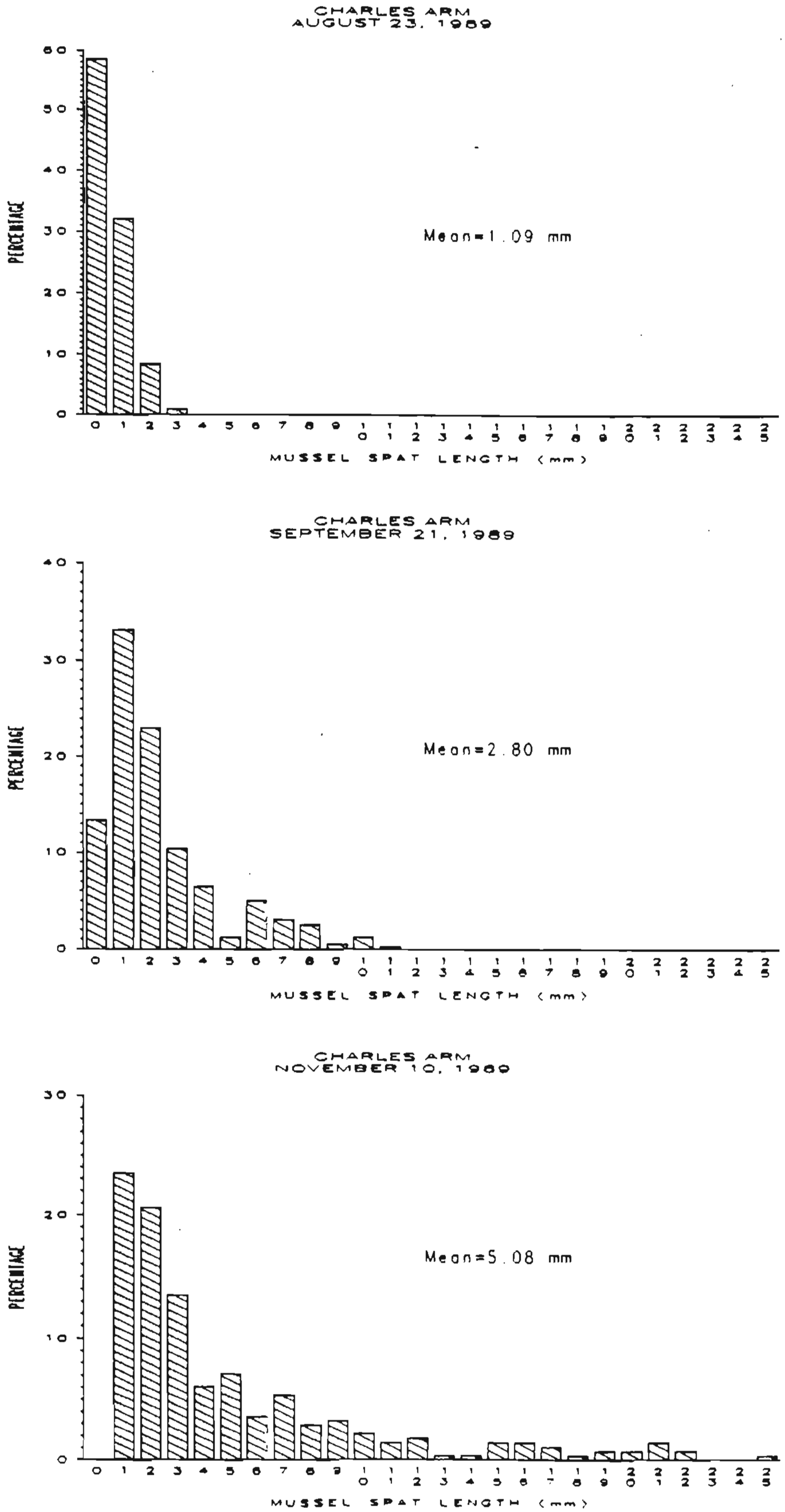
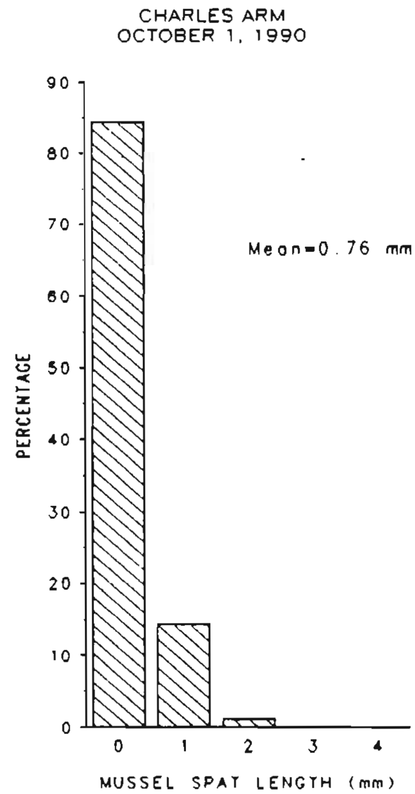


Figure 12. Length frequencies of settled mussel spat, Autumn, 1989, combined for Vexar and poly rope collectors.



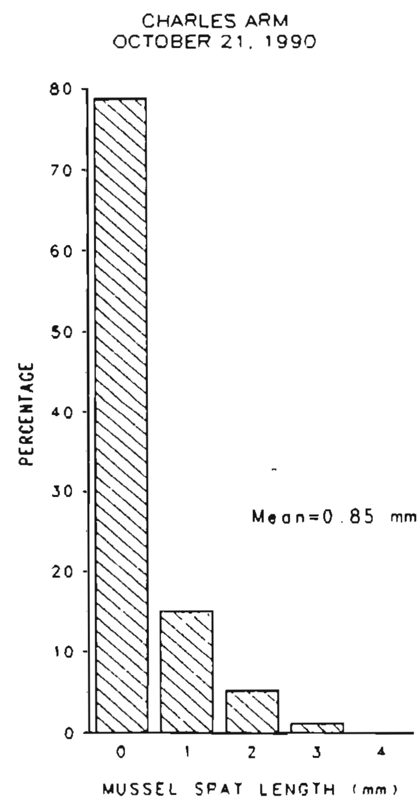
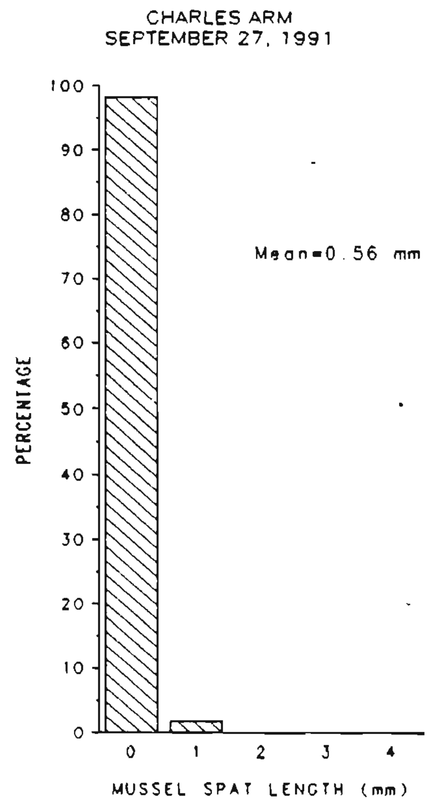


Figure 13. Length frequencies of settled mussel spat, Autumn, 1990, combined for Vexar and poly rope collectors.



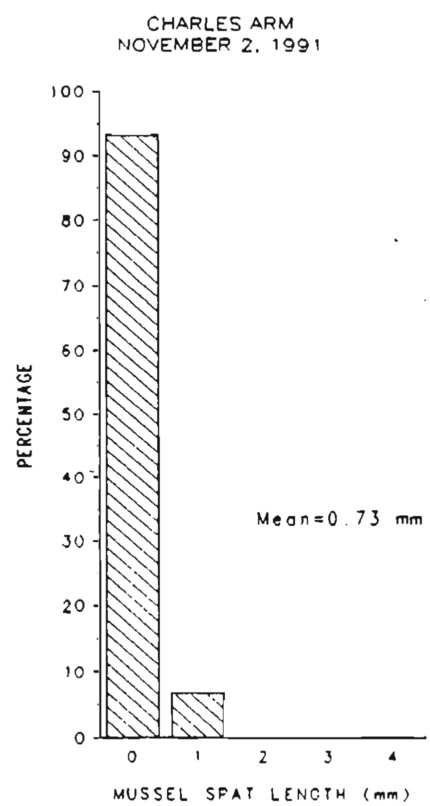
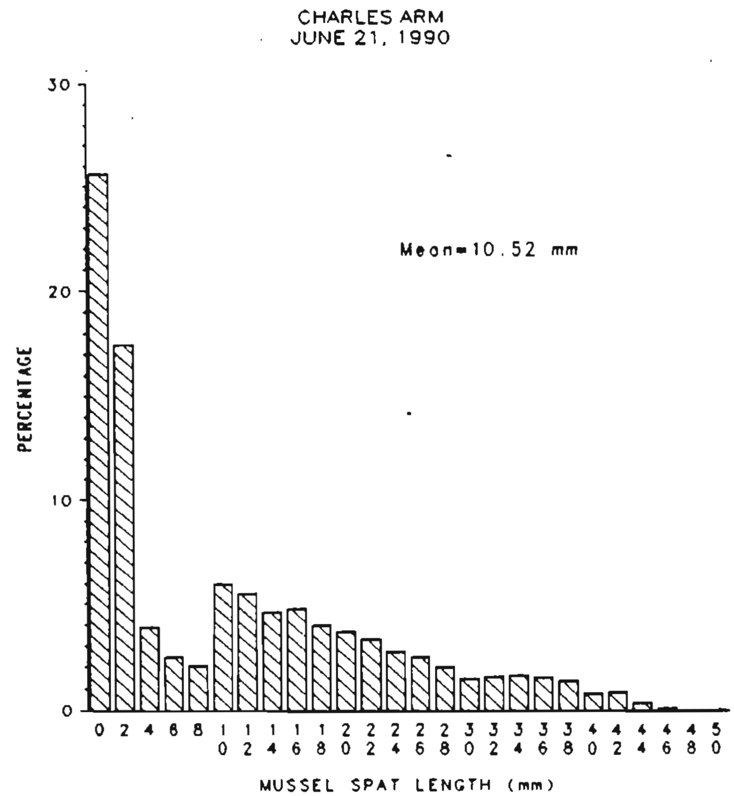


Figure 14. Length frequencies of settled mussel spat, Autumn, 1991, combined for Vexar and poly rope collectors.



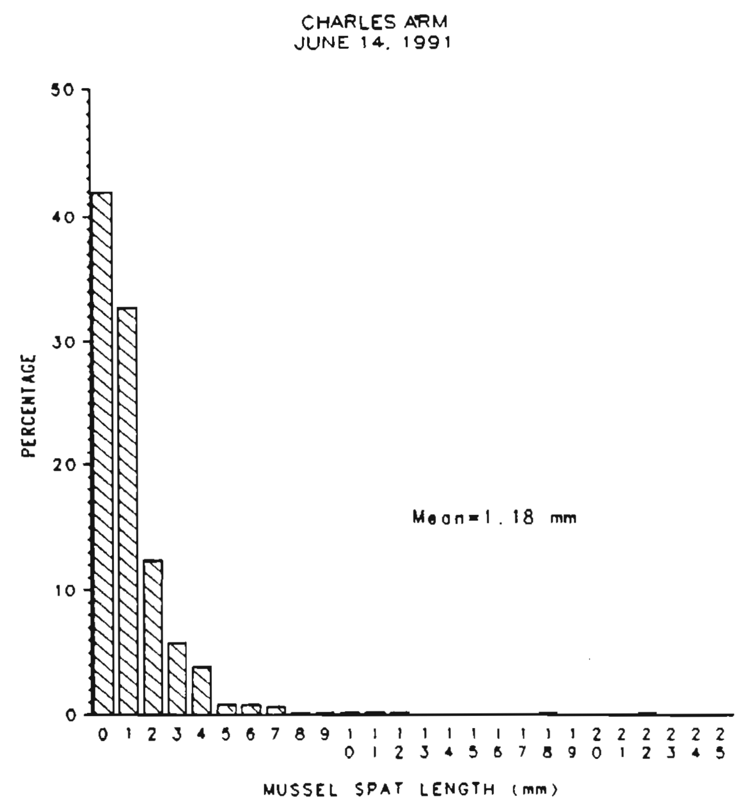


Figure 15. Length frequencies of overwintered mussel spat, Spring, 1990 and 1991, combined for Vexar and rope collectors.

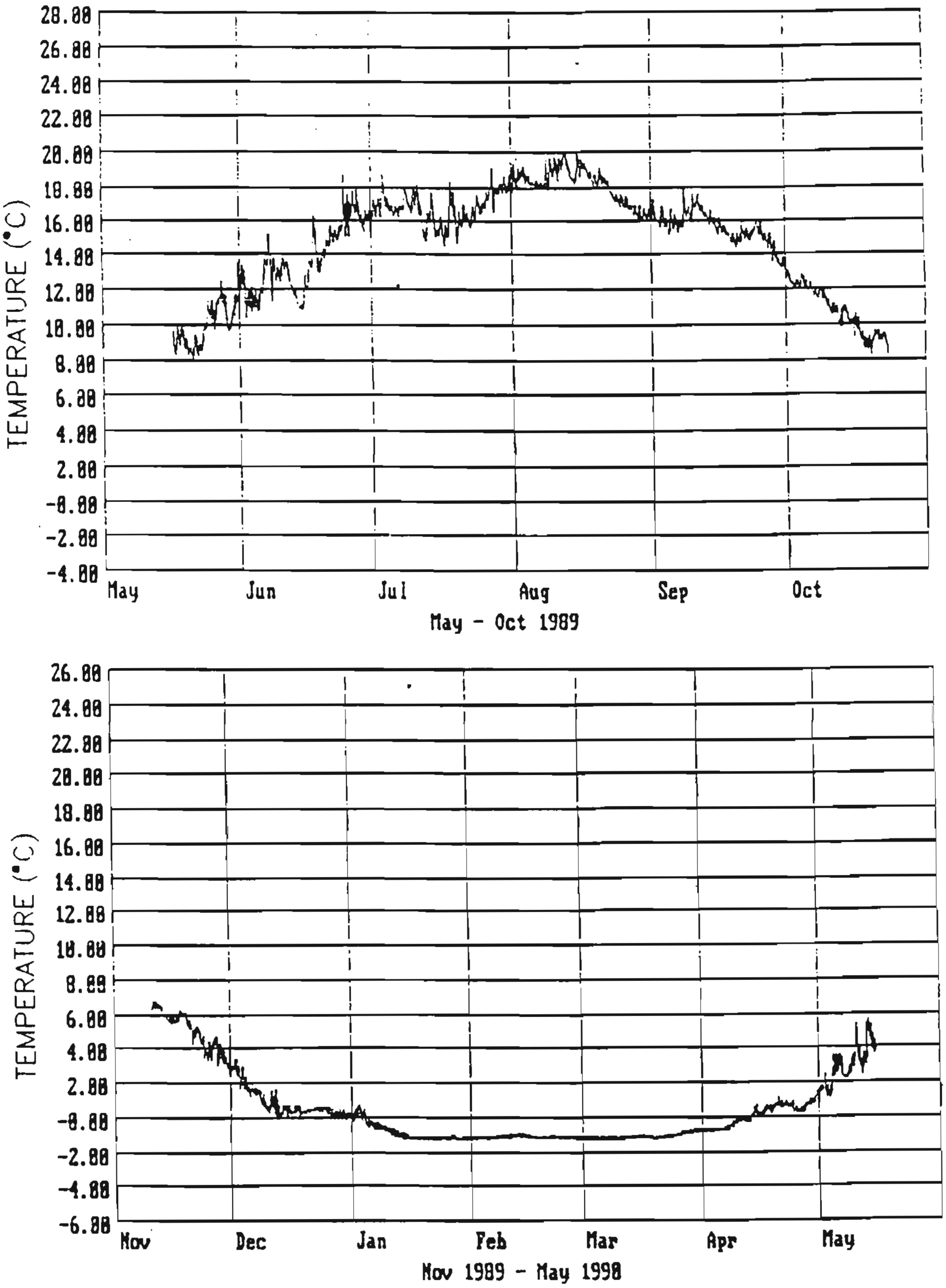


Figure 16. Water temperatures recorded by Huygren thermographs placed at 4.5m depth (on the headrope) in Charles Arm, May 1989 to May 1992.

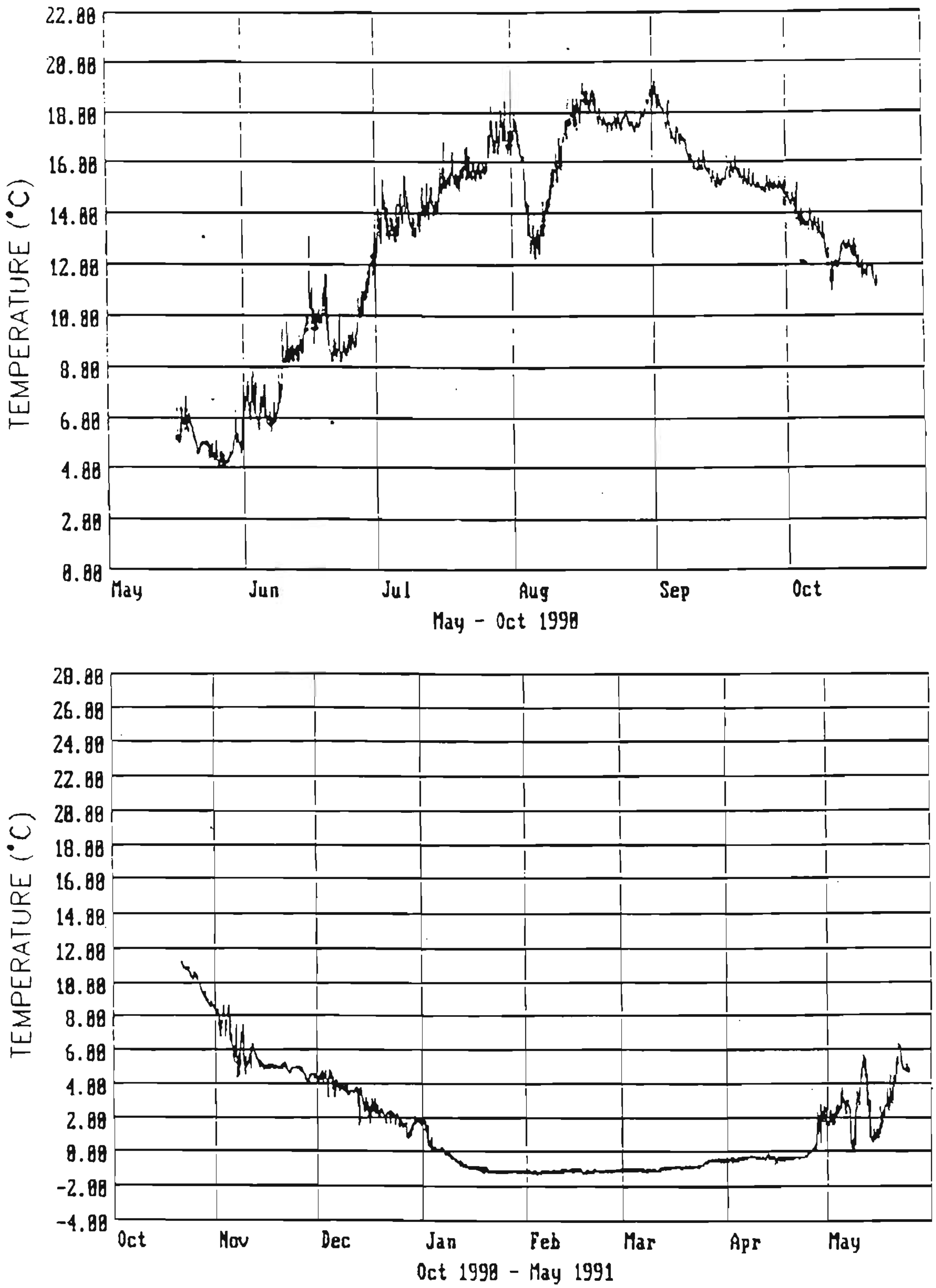


Figure 16. continued

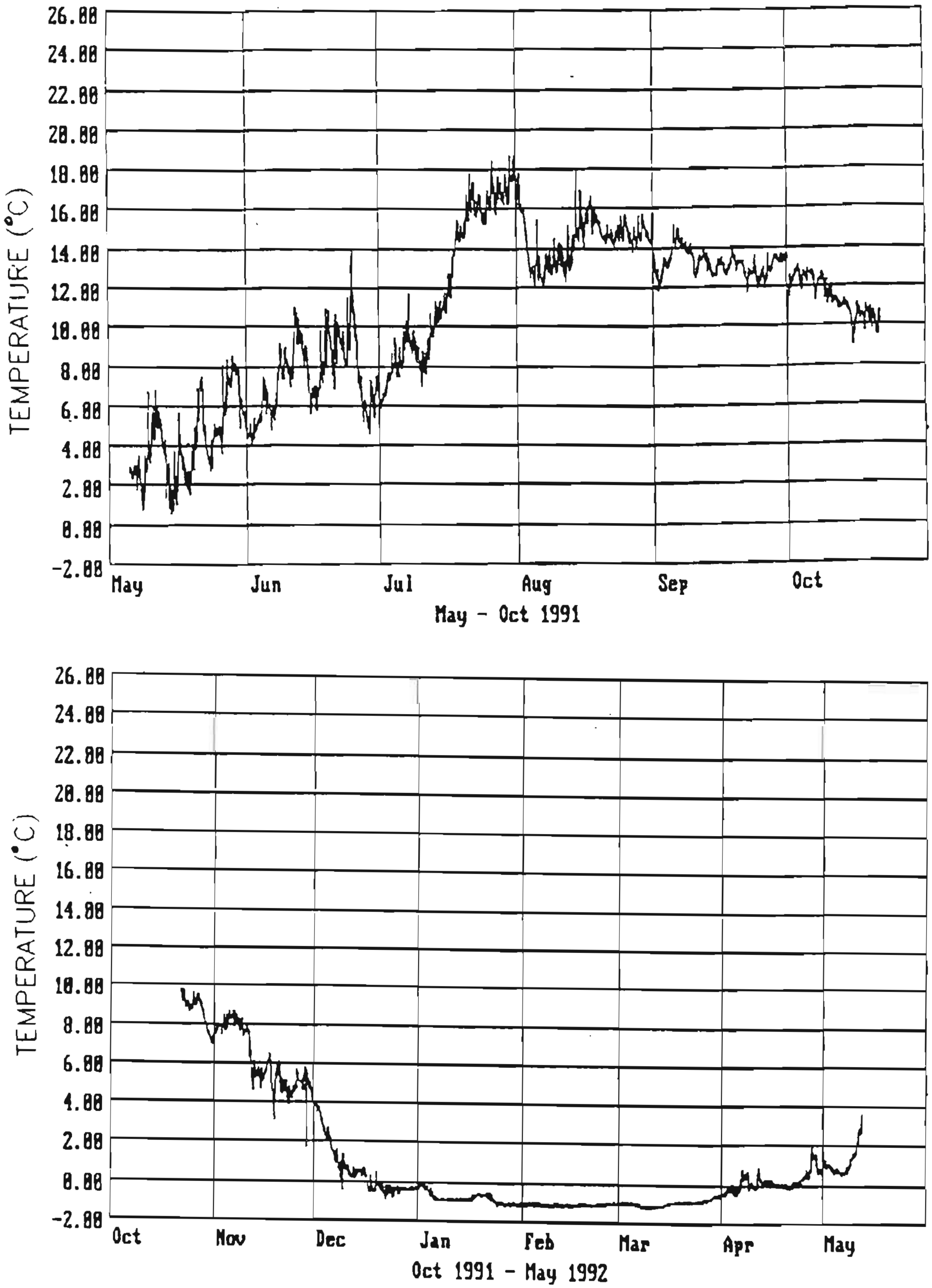


Figure 16. continued