CHANGES IN SEDIMENT TYPES AND INVERTEBRATE FAUNA IN THE INTERTIDAL MUDFLATS OF THE BAY OF FUNDY BETWEEN 1977 AND 1994

by

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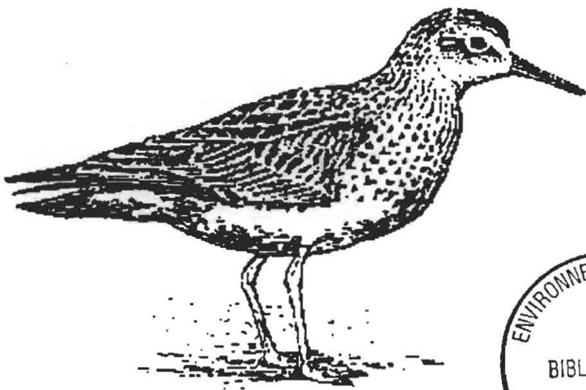

TECHNICAL REPORT SERIES NO. 237
ATLANTIC REGION 1995
CANADIAN WILDLIFE SERVICE
ENVIRONMENTAL CONSERVATION BRANCH

Issued under the Authority of the
Minister Environment
Canadian Wildlife Service

Ministry of Supply and Services Canada 1994
Catalogue No. CW 69-5/237E
ISBN 0-662-23607-6
ISSN 0831-6481

Copies may be obtained from:
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ABSTRACT

In 1977-1979, ten intertidal mudflats in Minas Basin and Chignecto Bay were studied to determine the invertebrate species composition and species' abundances on each flat as well as differences in sediment types (substrate particle sizes) which might account for the variations found between the mudflats. The same investigations were carried out in 1994 and the findings were compared to the results obtained in 1977-1979 in order to confirm qualitative observations that considerable changes had occured in substrate types which might be associated with observed reductions in invertebrate abundances.

In Chignecto Bay, the water content of the sediments in 1994 was nearly double that of 1977 - 1979 (34.5% vs 19.2%), a statistically significant increase. Overall, for sediments in both Minas basin and Chignecto Bay, the relative amounts of fine and very fine sands changed significantly: fine sands had increased by 6.5% in 1994 while very fine sands decreased by 8.9%.

Changes in invertebrate abundances were quite localized and substantially different between Chignecto Bay and Minas Basin. In Chignecto Bay in 1994, densities of *Corophium volutator* were significantly lower at Grande Anse and Peck's Cove. In Minas Basin, densities of polychaetes were significantly greater at Evangeline Beach and Starrs' Point Sandbar in 1994.

Overall, in 1994, the water content of the sediments in the upper Bay of Fundy increased, Chignecto Bay became siltier while Minas Basin became slightly sandier and there were fewer infaunal organisms in Chignecto Bay but more in Minas Basin.

GENERAL INTRODUCTION

Of all taxa of North American migratory birds, shorebirds (plovers and sandpipers of the Families Charadridae and Scolopacidae) perform some of the longest non-stop migrations. Many of the western hemisphere shorebird species nest in the Canadian Arctic and spend the winter in Central and South America. Along their migration routes, they stop to rest and feed at a few key coastal and interior wetlands where food is very abundant. Unfortunately, since the arrival of Europeans, more than a third of all North American wetlands have disappeared. Because there are few of these key stopover sites which can support large portions of the shorebird populations in North America and since human disturbance continues to encroach on wetland habitats, conservation of the remaining sites is vitally important (Myers *et al.* 1987). Since migratory birds do not honour political borders and conservation efforts can only be successful if all countries in the Americas collaborate. In 1985, the Western Hemisphere Shorebird Reserve Network (WHSRN) was created as a network of reserves linking key wintering, staging and breeding areas used by North American shorebird populations.

In the Bay of Fundy, the southern bight of the Minas Basin in Nova Scotia and Shepody Bay in New Brunswick were designated as separate portions of the Bay of Fundy Western Hemisphere Shorebird Reserve in 1987 and 1988. Sites are designated as hemispherically important only if they support at least 500,000 birds or more than 30% of the world population of a shorebird species. The Bay of Fundy itself supports as many as 2 million shorebirds during the southward migration, including between 50 to 95% of the world population of the Semipalmated Sandpiper *Calidris pusilla* in any single year (Mawhinney *et al.* 1993, Hicklin 1987). The migrants depend on invertebrates that inhabit the Bay's vast mud and sand flats as a source of food in preparation for the long migration to the wintering grounds (Boates and Smith 1989, Hicklin 1987, Hicklin and Smith 1984, Hicklin and Smith 1979). Several species of resident and migratory fish feed on the same invertebrate species (Imrie 1979, Yeo 1978). Therefore, any changes in the unique Bay of Fundy ecosystem could potentially have an impact of global importance on Semipalmated Sandpiper populations and other species of shorebirds as well as waterfowl and fish.

Many researchers have concluded that the distribution of the invertebrate fauna in intertidal habitats is correlated with sediment type (Hicklin and Smith 1984, Deans *et al.* 1982, Fenchel *et al.* 1975, Meadows 1964, Wieser 1959). *Corophium volutator* is a tube-dwelling amphipod which dominates the invertebrate fauna in much of the Bay of Fundy (Hicklin 1981, Gratto 1979) and is the primary food source of Semipalmated Sandpipers (Hicklin and Smith 1979). Hicklin (1981) found that the distribution of *C. volutator* in Minas Basin was significantly positively correlated with the amount of very fine sands but not with any other sediment particle sizes. Other researchers examining mudflats in other countries (Deans *et al.* 1982, Fenchel *et al.* 1975, Meadows 1964) have found a positive correlation between *C. volutator* abundances and the proportions of silt and clay as well as very fine sands. *C. volutator* relies on the sediments to constuct stable burrows and use as a substrate for food such as surface diatoms and bacteria attached to sediment grains (Murdoch *et al.* 1986, Hawkins 1985, Deans *et al.* 1982, Fenchel *et al.* 1975). Any changes occurring in the sediments of the Bay of Fundy may therefore result in changes to the invertebrate populations such as those of *C. volutator*.

Furthermore, a comprehensive field study on the use of invertebrate fauna and associated substrates by migrant shorebirds in the Bay of Fundy was undertaken by Hicklin in 1976-1977 in the southern bight, Minas Basin (Hicklin 1981). Data on the particle sizes of sediments and the invertebrate abundances and species composition of several mud and sand flats were collected in Minas Basin in 1977 and in Chignecto Bay in 1979 to explain the presence of migrant shorebirds on particular flats. Data were also collected on the water contents of sediments in Chignecto Bay.

In 1992 and 1993, Philippa Shepherd studied invertebrate and shorebird populations in Minas Basin (Shephard 1994). And in 1993, two German graduate students (Ralph Schieke and Svenja Timm) conducted similar field studies at Grande Anse in Chignecto Bay. Both studies uncovered changes in the abundances and distributions of the invertebrate populations in specific mudflats when they compared their findings to those of earlier field studies in the Bay of Fundy (Boates and Smith 1989, Hicklin 1987, Hicklin and Smith 1984, Hicklin 1981, Boates 1980). And in recent years, Hicklin (pers. comm.) and others have made qualitative field observations which suggested that shorebird foraging behaviours and the invertebrate communities of the Bay of Fundy mudflats appeared to have changed considerably. It was proposed that changes in the sediments of the Bay of Fundy may have occurred and that such changes would account for the differences in invertebrate abundances and, consequently, shorebird foraging behaviours.

All of the above factors contributed to the initiation of this investigation into possible changes in the sediments and invertebrate populations of the Bay of Fundy from 1977-79 to 1994.

PART I. SEDIMENTS

INTRODUCTION

The Bay of Fundy is a unique macrotidal estuary and its sediment dynamics have been well studied since the early 1970s (see Amos 1984). The two main portions of the bay, Minas Basin and Chignecto Bay (Figure 1.0), have different sediment history characteristics. Minas Basin is a sandy estuary with intermediate exposure to wave action which is the primary cause of erosion of the cliffs dominating the shoreline. The water column contains much silt. Silt concentrations are derived mainly from reworking of the sea bed sediments but due to strong currents, deposition is low and restricted to sheltered areas.

Chignecto Bay is a muddy estuary with higher exposure to ocean swells and increased wave action which causes erosion of the siltstone, shale cliffs and the sea bed. These sediments are transported primarily in suspension, resulting in a suspended sediment concentration that is an order of magnitude greater than in Minas Basin (Amos *et al.* 1992, Paterson and Daborn 1991, Amos 1987, Amos 1984, Amos and Asprey 1981).

The mud and sand flats in Minas Basin and Chignecto Bay are vitally important to the food chain of the Fundy estuary providing important habitats for many species of plants, invertebrates, fish and birds. It is therefore necessary to understand the mechanisms controlling the stability of these flats to better understand the system as a whole and to make accurate predictions of the effects of both natural and anthropogenic changes in the system (Faas *et al.* 1992, Amos *et al.* 1988).

The level of stability of an intertidal mudflat is influenced by the erosion, transport and deposition of sediments (Paterson and Daborn 1991, Amos 1990). And these result from i) physical factors such as waves, tide, wind, sun, currents, gravity and ice, ii) biological factors such as diatoms and other primary producers, benthic invertebrates, fish, and other fauna and iii) chemical factors such as salinity and pollutant levels that might affect sediment flocculation. Incorporating all of these factors into models of sediment behaviour is a complex and difficult process which argues strongly for the use of field experiments to determine the behaviour of sediments under natural conditions (Paterson and Daborn 1991, Amos 1990).

The objective of this study was to use *in situ* methods to determine whether there were any significant differences in the intertidal sediments of the Bay of Fundy between 1977-79 and 1994. This study was designed to determine whether any changes in the sediments of the Bay of Fundy have occurred and, if so, whether they are due to anthropogenic influences.

Water content and particle size, two of the principal variables that affect sediment stability (Trask and Rolston 1950), were originally investigated by Hicklin (1981) and Hicklin and Smith (1984) to characterize the habitats available to invertebrates and shorebirds in the Bay of Fundy. In the present study, the same two variables were used as indicators of change between 1977-79 and 1994. Although it was not possible to collect data on all of the oceanographic, atmospheric, sedimentological, and biological factors which may have contributed to any changes in the sediments, we make predictions about them based on the sediment data and suggest areas for further research.

MATERIALS AND METHODS

Sampling transects were established on ten intertidal mudflats in the upper Bay of Fundy in 1994 and positioned as close as possible to those sampled by Hicklin (1981) in 1977 in Minas Basin and by Hicklin *et al.* (1980) in 1979 in Chignecto Bay. Eight of the flats were sampled on the same dates and two were sampled one day after the sampling dates in Hicklin (1980, 1981); the latter was simply due to problems with weather. The following mudflats were sampled on the following dates: Mary's Point N.B. on 16 June (one day late), Porter's Point and Kingsport N.S. on 20 June, Avonport N.S. on 21 June, Starrs Point mudflat and Starrs Point sandbar N.S. on 22 June, Evangeline N.S. on 23 June, Minudie N.S. on 27 June (one day late), Peck's Cove N.B. on 4 July, and Grande Anse N.B. on 5 July. Sampling stations were established every 100 meters along each transect for the purpose of collecting invertebrate samples (see Part II). Three to four sediment samples (depending on the length of the transect) were collected at the bottom, middle, and top of each transect at the same stations where similar samples were collected in 1978 and 1979 (Hicklin (1981); Hicklin *et al.* (1980)). For a detailed description of the study area and transects in Minas Basin see Hicklin (1981) and for those in Chignecto Bay see Hicklin *et al.* (1980).

Samples were collected with a circular core measuring 5.2 cm (diameter) by 8.7 cm (depth). One sample was collected at each station. Each sample was placed into a labelled plastic bag, returned to the laboratory and frozen. The procedure for analysis was taken from Royce (1970) as described in Hicklin (1981).The field procedures were identical to those described in Hicklin (1981).

Samples were thawed and wet weights were measured to the nearest 0.01g using a Sartorius electronic balance. Each sample was then treated with 30 ml of 30% H_2O_2 to remove all organic matter. The sediment was placed onto a pre-weighed aluminium pie plate and dried to a constant weight (for a minimum of 24 h) at 60°C in a vaccuum oven. Any shells found in the samples were removed and weighed and these weights were subtracted from the total sediment dry weight. The dry sediment samples were then washed through a U.S. Standard Sieve No. 230 to remove the silt and clay fraction. Once the water passing through this sieve became clear, the remaining sediment was rinsed with distilled water and placed in a Proctor-Silex blender with a 0.01 M sodium oxalate solution, an antiflocculent. The samples were then mixed in the blender for 10 minutes and then returned to the vaccuum oven (again at 60°C) to be dried to a constant weight. The dry samples were once again weighed and the differences between both dry weights constituted the weight of silt and clay lost by sieving. Each sample was then passed through a stack of sieves mounted in order of decreasing mesh size from top to bottom on a Fisher Scientific Shaker which ran for 5 minutes. The sieves used were U.S. Standard Sieves numbers 10, 18, 35, 60, 120 and 230 (Table 1). Sediment recovered from each sieve was removed and weighed and the dry weights of each particle size class were then converted to a percentage of the whole sample.

Water content data from Chignecto Bay in 1994 were compared to those found by Hicklin *et al.* (1980) in 1979. Hicklin did not collect water content data in Minas Basin in 1977 so it was not possible to compare the 1994 water content data to corresponding data for that area. The particle size class percentages calculated for the 1994 samples were also compared to those found by Hicklin (1981) in 1977 and Hicklin *et al.* (1980) which were computed for the samples collected in 1979. Since only one sample was analyzed from each station in each year, it was not possible to conduct quantitative statistical analyses because of the low sample size. Instead, graphical qualitative comparisons were made between stations. Samples were lumped together (overall) by area (Minas Basin and Chignecto Bay) and by location on the flat (upper, middle, and lower) and then compared statistically. The data on overall percent very fine sands were distributed normally so comparison were made using a paired t-test. Water content and all other particle size classes in all groups (overall, by area and by location) were compared using Wilcoxon Signed Ranks tests since they violated assumptions of normality (even after transformations) and/or lacked adequate sample sizes for parametric tests. Because of the difficulties associated with comparisons of multinomial proportional data (i.e. the fact that changes in one size class proportion will cause some change in the other size class proportions thereby creating a false impression of change or confounding real changes) weighted particle size means were compiled for each station and these were then log-transformed, lumped as above, and put through the same statistical tests as outlined above. All statistical tests were run using SYSTAT Statistical Software.

RESULTS

The mean water content of the Chignecto Bay sediment samples in 1994 was 34.5% $\pm$ 3.5

SD. This was nearly double what it had been in 1979 (19.1% ± 1.8 SD). The data were distributed normally but since the sample size was only 14, a non-parametric Wilcoxon Signed Ranks test was used to compare the water content data of 1979 and 1994; the differences were found to be statistically significant ($p=0.001$). Qualitative station-by-station comparisons of water content all consistently showed that values were higher in 1994 than they were in 1979 (see Figures 1.1- 1.4).

Data on the water contents of the Starrs Point Sandbar sediments were collected by J. S. Boates in 1979 (Boates 1980). We averaged the 10 sediment samples he collected (from 20 minutes after exposure to 3 hours and 20 minutes after exposure) and arrived at a mean water content value of 17.8% for this flat in 1979. This can be compared with the 1994 value of 22.4% for the same flat. Like the flats in Chignecto Bay, water content in 1994 was higher than in 1979 but only by 4.61%. This represents about a 20% increase in water content for Minas Basin as opposed to the near-doubling found in Chignecto Bay (Figure 2).

There was no statistically significant difference between the percentages of silt and clay found on Bay of Fundy mudflats in 1977-79 versus those in 1994 (WSRT $p=0.584$). This reflects the fact that the net change was a gain of only 0.8% (Table 2). When the data were separated into areas (Chignecto Bay and Minas Basin) and/or locations on the flat (upper, middle, and lower), again no statistical differences were found. When the qualitative data were examined, there did appear to be a small net gain of 3.2% in Chignecto Bay and a net loss of 2.4% in Minas Basin with some flats exhibiting more change than others (Table 2 and Figures 3.1 and 3.2). Figures 4.1 to 4.10 show the flat-by-flat, station-by-station changes in percent silt and clay; it is apparent that certain stations on certain flats have undergone more change than others but there does not appear to be a common trend in these differences.

Fine sands and very fine sands showed highly statistically significant differences ($p<0.005$) between 1977-79 and 1994 when comparisons were made using the percentage values. Levels of fine sands increased from 7.2% of the sediment in 1977-79 to 13.7% in 1994 and very fine sands decreased from 22.3% of the sediment in 1977-79 to 13.4% in 1994. But because of the proportional nature of the data, the changes in the percentages of very fine sands may be due to the concurrent changes in fine sands or vice versa. There was also a slight increase in percent granules from 0.50% in 1977-79 to 0.53% in 1994 that was statistically significant ($p=0.047$) but this may also simply be due to the proportional nature of the data. When the weighted means of all the particle sizes for 1977/79 and 1994 were compared, statistical differences between years were not found ($p=0.68$)

Even though Minas Basin is typically a sandy estuary and Chignecto Bay a muddy one, the increases in percent fine sands and the decreases in percent very fine sands between 1977 and 1994 were both found to be statistically significant when the data were separated by area (Table 3). The slight increases in percent granules were only found to be significant in Minas Basin. Again, when the comparisons between 1977/79 and 1994 for each area were made using the weighted means instead of the percentage values, no statistical differences were found.

When the data were separated by location on the flat (lower, middle, and upper), neither percentage or weighted mean comparisons revealed any statistically significant changes in sediment from 1977/79 to 1994 at either the upper or lower ends. The middle portions of the flats did appear to reveal significant changes in fine sands, very fine sands and granules when the comparisons were made using percentages but not when they were made using the weighted means. These trends remained apparent when the data were grouped by both location and area.

Figures 5.1 through 5.33 show the 1977/79 and the 1994 particle size compositions of each station sampled at each flat. Those stations showing interesting changes will be discussed in relation to invertebrate densities in the General Discussion.

DISCUSSION

Significant changes have occurred in the intertidal sediments of the Bay of Fundy between 1977-79 and 1994 . In this discussion we will attempt to explain these differences and to propose possible proximate and ultimate causes for them. We will also propose areas of future research into the sediment dynamics of the Bay of Fundy that might provide concrete answers to the questions raised by this study.

The mudflats in Chignecto Bay experienced **significant increases in water content** from 1979 to 1994 probably resulting in reduced cohesion and resistance to erosion and thereby decreasing sediment stability (Heinzelmann and Wallisch 1991, Amos *et al.* 1988). The sediments at Starrs Point Sandbar in Minas Basin also had a higher water content in 1994 although the increase was less than a quarter of that seen in Chignecto Bay. The increases in water content at all mudflats confirms qualitative observations that the surface texture of the flats, especially at Grande Anse, had changed and had become more "soupy" since 1977/79.

The increased water content in Chignecto Bay was likely due to increased sediment deposition and/or a lower rate of consolidation. This in turn is likely due to an increase in the amount of suspended sediment in concentration (SSC) in the waters of the bay since particle settling increases in proportion to SSC (Amos *et al.* 1992). The amount of SSC is an order of magnitude higher in Chignecto Bay than it is in Minas Basin (Amos *et al.* 1991, Amos 1984, Amos and Asprey 1981) so if an increase in SSC is one of the proximate causes of increased water content, it is not surprising that at the Starrs Point sandbar (the one Minas Basin mudflat for which we have data) water content is only 20% higher in 1994 than it was in 1979. Water content data were also collected at Starrs Point across both the mudflat and the sandbar by Amos *et al.* (1992) in 1989 and 1990. They determined the water content to be between 30 and 40 percent at that time, so it appears the change in water content at Starrs Point occurred before 1989.

The possible decrease in very fine sands in the absence of a decrease in silt and clay is counterintuitive, since one would expect that any oceanographic forces that would cause the resuspension and export of the larger particles would similarly affect the smaller ones. As explained in the results section, this decrease may not be significant but if it is and the increase in the larger fine sand particles also proves to be significant, these may be the result of a change in the particle sizes of the sediments in suspension. This in turn may reflect changes in the particle sizes of sediments at the source as discussed below.

Baseline data for Chignecto Bay were collected between 1978 and 1980 (Amos *et al.* 1991, Amos and Tee 1989) and used to construct models of sediment dynamics. Data collected in the future using the same methodology would be particularly useful for comparison since both of these baseline studies occurred at the same time as Hicklin *et al.*'s (1980) field studies. It would also be important to collect water samples in Chignecto Bay to determine the concentrations and particle sizes of sediments in suspension at present and compare them to the baseline data obtained by Amos et al. (1991) and Amos and Tee (1989).

The major sources for an increase in SSC in the Bay of Fundy are cliff line erosion, seabed reworking and river input (Amos and Tee 1989, Amos 1987). As mentioned above, if the increase in the larger fine sand particles proves to have occurred, it may be that the particles being eroded from the cliffs along the shoreline are changing with time as erosion removes layers of sediment (Amos, pers. com.). In addition to collecting data on the concentrations and particle sizes of sediments in suspension, data on total suspended mass would also be essential since Amos and Tee (1989) found that this variable remained constant over two years despite changes in SSC. This data would help to ascertain whether changes in water content are due to a net increase in erosion throughout the Bay or whether these increases are localized. Pinpointing areas of higher SSC would facilitate the search for sediment sources. As well, a comparison of recent aerial photos and/or Landsat Imagery with those from 1977-79 could be used to determine the magnitude of cliff line erosion. Qualitative observations by longtime residents of Dorchester Cape are that as much as 150 feet of cliffs in some areas have eroded into Shepody Bay since 1945 (Tom Johnson pers. com.).

There are many possible causes of increased erosion and seabed reworking which result in decreased sediment stability all of which likely play some part in the changes we have seen in the sediments of the Bay of Fundy. Although it is beyond the scope of this study to assign proportional responsibility to each of these possible factors, we describe them below and attempt to relate them to the results herein.

Physical factors such as waves, wind, currents, tide, sun and ice play an important part in determining the level of stability of the sediments in the Bay of Fundy (Amos in prep., Amos *et al.* 1992, Amos *et al.* 1991, Daborn 1991, Amos and Tee 1989, Amos *et al.* 1988, Amos and Mosher 1985, Amos 1984, Greenberg 1984, Dalrymple et al. 1975). Waves may be very important to mudflat stability since they play a major role in the release of fine sands and silt through cliff line erosion and in reworking and resuspending seabed sediments (Amos *et al.* 1991). Minas Basin is subject to intermediate levels of wave activity while Chignecto Bay, which is oriented parallel to the dominant northeast-southwest winds, is subject to greater wave attack (Amos 1984). In order to see whether differences in wave activity might help to explain the increase in water content found in this study, we compared wind data in the year leading up to 1979 when Hicklin et al. (1980) sampled Chignecto Bay, with wind data in the year leading up to 1994. Increased wave activity would keep more particles from settling and thereby result in decreased water content. We used wind levels as an indicator of wave height/strength since wave data was not accessible. The data were obtained from the Canadian Atmospheric Environment Service station at Fort Lawrence at the head of Chignecto Bay. There did not appear to be significant differences in wind speeds between 1978-79 and 1993-94 (it appeared to be slightly higher in 1978-79) so this does not explain the increases in water content we found in 1994. Without actual wave data this is largely conjectural, and, in any case, Amos (in prep.) found the effects of waves on tidal flats to be largely unpredictable.

Strong tidal currents have been found to be eroding previously-deposited muddy sediments in Chignecto Bay (Amos *et al.* 1991) and may be a factor in the increases in water content found in 1994. As well, relatively small waves superimposed on strong tidal currents can have a significant effect on sediment stability (Amos 1984). Tidal currents are much stronger in Minas Basin than in Chignecto Bay (Greenberg 1984) which may be related to a net loss of sediment in Minas Basin as opposed to a gain in Chignecto Bay. The direction of currents in both Minas Basin and Chignecto Bay might explain some of the qualitative differences found in percent silt and clay (Table 2). All of the flats in Minas Basin from Avonport through to Porter's Point have lost silt and clay while Kingsport gained considerable amounts. The tidal currents in the Basin circulates from Avonport around to Kingsport and then out into the Bay of Fundy perhaps dropping off some silt and clay at Kingsport on the way. In Chignecto Bay, currents move along the coast down from the Petticodiac

River to Mary's Point where a slower current occurs which might lend itself to deposition. Minudie is located in an area where relatively strong currents move down the coast taking sediments out into the Bay of Fundy. Grande Anse also receives sediment from the Petticodiac River and, as well, there is a great deal of circular movement of slower currents at this site and at Peck's Cove. Peck's Cove also has two stronger circular currents on either side of it which might tend to trap sediments there (Greenberg 1984). We do not expect the 18-year nodal cycle of the Bay of Fundy tides to have had an effect on our results since there were between 15 and 17 years between Hicklin's studies and the present study and therefore our studies occurred at similar points on the cycle.

Increased subaerial exposure has been found to increase the resistance to erosion of fine-grained sediments (Amos *et al.* 1988, Amos and Mosher 1985). In fact, Amos *et al.* (1988) found that subaerial exposure was more important to sediment strength than oceanographic or biological conditions. It would be useful to obtain data on rain and cloud cover to compare with data on time of low tide for both 1977-79 and 1994 to see whether any differences in exposure to the sun exists between years which might explain sediment differences.

Each winter, ice removes the surface 10 cm of the intertidal flat and is therefore a major cause of erosion (Amos *et al.* 1992). It is thought that flats recover from ice turbation during the spring and summer months and that material eroded by ice and subsequently deposited are approximately in balance (Amos and Tee 1989). Unfortunately, since very little is known about this process it is difficult to assess its role in the changes we have found in Bay of Fundy sediments.

Biological organisms such as diatoms, benthic invertebrates, fish and birds also play a part in determining the level of stability of the sediments. Many researchers have found that benthic diatoms have a profound influence on sediment stability (Madsen *et al.* 1993, Daborn *et al.* 1993, Faas *et al.* 1992, Paterson *et al.* 1990, Paterson 1989, Grant and Gust 1987, Holland *et al.* 1974). Faas *et al.* (1992) recorded a three-fold increase and Paterson (1989) recorded a 200% increase in the stability of sediments inhabited by diatoms compared to those without diatoms. Certain species of diatoms release mucopolysaccharides as part of their locomotion mechanism. Diatoms migrate up through the sediment at low tide for photosynthesis and then migrate back down to avoid resuspension (Paterson 1989). These mucopolysaccharides decay upon flooding but some residual stability remains after a full tidal inundation. This results in increased consolidation and decreased resuspension of sediments which ultimately affects their rate of final deposition (Holland *et al.* 1974).

One of the reasons for increased water content in Chignecto Bay sediments might be a decreased rate of consolidation due in part to a decrease in populations of diatoms which release mucopolysaccharides. Bothwell *et al.* (1994) found that solar ultraviolet radiation (UVR) can reduce photosynthesis and growth in benthic diatom communities in shallow freshwater and Vincent and Roy (1993) predicted subtle community-level responses to ozone depletion that could affect photosynthetic production and ultimately impact on higher trophic levels. It is therefore possible that solar UVR might be affecting benthic diatom communities and hence sediment stability in the Bay of Fundy. Prouse *et al.* (1984) discusses studies by Schwinghamer (1981) who measured benthic diatom biomass at Peck's Cove and Gordon *et al.* (unpublished data) who measured chlorophyll content in surface sediments of Minas Basin. These studies were done at the same time as Hicklin *et al.*.'s (1981) and Hicklin's (1980) field studies and could be used as baseline data for comparison with similar data to be collected next year. At a minimum, this would provide some indication of whether changes have occurred in diatom populations that may partially explain the changes we have found in sediment stability. Ideally, since all mud and sandflats in the Bay of Fundy are exposed to solar UVR and since the effects of ozone depletion on intertidal communities are unknown, a comprehensive study should be initiated.

Burrowing intertidal organisms increase bioturbation of the sediment thereby increasing water content and decreasing sediment stability. At the same time, many species release carbohydrates while burrowing and these act as adhesives which in turn increase sediment stability. When the density of these intertidal organisms in the sediment is low, the former effect is predominant. At most flats in the Bay of Fundy however, invertebrate densities are likely high enough that the net effect of their presence is an increase in sediment stability (Heinzelmann and Wallisch 1991, Rhoads and Young 1970). Meadows *et al.* (1990) and Meadows and Tait (1989) found that water content decreased with increasing densities of both *C. volutator* and *Nereis diversicolor*. They also found that shear strength (the ability of a flat to resist erosion), which is negatively correlated with water content, increased with increasing densities of both species and that *C. volutator* had a proportionately larger effect than did *N. diversicolor*. The significant decreases in *C. volutator* and polychaete densities at Grande Anse, Peck's Cove, and Starrs Point Sandbar (see Part II) may therefore have contributed to the decreases in water content of the sediments.

However, Jumars and Nowell (1984) found that under high transport rates, the effects of benthic organisms on sediment erodibility were overridden by the effects of the suspended sediment load. Unfortunately, they did not determine the transport rates at which organism effects were overridden. Also, Amos *et al.* (1988) found that the effects of evaporation and drainage overshadowed bioturbation, so further study will be required to determine the effects of intertidal invertebrate populations on the stability of sediments in Chignecto Bay.

Fish that feed in the estuary and migratory shorebirds that feed on the intertidal flats may also have an effect on sediment stability. Grant (1983) found that benthic-feeding fishes caused sediment bioturbation that he estimated to be important relative to other biogenic sources but still only about 1% of the disturbance produced by tidal reworking of sediments. The large numbers of migrant shorebirds (between 1 and 2 million) that use the Bay of Fundy's intertidal habitat each year affect sediment stability in at least two ways. They compact the surface while they search the flats for *C. volutator* which they consume in large numbers thereby reducing the predation on diatoms (one of *C. volutator*'s preferred prey) which increase sediment stability as described above (Daborn *et al.* 1993, Paterson and Daborn 1991).

Some of the physical factors that may have contributed to decreases in sediment stability, such as cliff line erosion and sea bed sediment reworking especially in Chignecto Bay, are undoubtedly natural. Still, anthropogenic input such as causeways, construction, dredging, channelling, amenity development, baitworm harvesting, CFCs and other pollutants also likely play a part in determining the level of stability of the sediments by altering processes that determine the level of erosion and the transport and deposition of sediments (Shepherd 1994, Paterson and Daborn 1991, Amos 1984). The magnitude of the effects of each of the anthropogenic inputs outlined above are unknown although they are thought at present to be outweighed by cliff line erosion and seabed reworking (Amos, *pers. com.*). In order to determine the proportional responsibility of natural and human-made influences on the sedimentology of the Bay of Fundy, further research targeting specific questions must be initiated.

Summary

There do appear to be some significant changes in the intertidal sediments of the Bay of Fundy between 1994 and 1977-79. **The sediments of all Chignecto Bay flats as well as Starr's Point in Minas Basin experienced a significant increase in mean water content from 1979 to 1994** potentially resulting in reduced cohesion and resistance to erosion and thereby decreasing sediment stability. The increased water content in Chignecto Bay was likely due to increased sediment deposition and/or a lower rate of consolidation. This in turn is likely due to an increase in the amount of suspended sediment in concentration (SSC) in the waters of the bay. The major sources for an increase in SSC in the Bay of Fundy are cliff line erosion, seabed reworking and river input. There are many possible causes of increased erosion and seabed reworking resulting in decreased sediment stability, all of which likely play some part in the changes we have seen in the sediments of the Bay of Fundy. Physical factors such as waves, wind, currents, tide, sun and ice, biological organisms such as diatoms, benthic invertebrates, fish and birds, and anthropogenic input such as causeways, construction, dredging, channelling, amenity development, baitworm harvesting, CFCs and other pollutants, all play a part in determining the level of stability of the sediments in the Bay of Fundy. In order to determine the proportional responsibility of natural and human-made influences on the sedimentology of the Bay of Fundy, further research targeting specific questions should be initiated.

PART II. INVERTEBRATE ABUNDANCES

INTRODUCTION

The amphipod *Corophium volutator* (Pallas) is a keystone species in the ecosystem of the intertidal mudflats of the upper Bay of Fundy. It is the primary food of the Semipalmated Sandpiper *Calidris pusilla* (Hicklin and Smith 1984, Boates 1980), a species of shorebird which migrates between arctic nesting grounds and wintering areas in South America. During this extensive southward migration each year, between 1 and 2 million of sandpipers stop in the Bay of Fundy during July and August (Mawhinney, Hicklin and Boates 1993) to feed on *Corophium* in the mudflats of Chignecto Bay and Minas Basin. They interrupt their southward flight to feed in order to gain the energy reserves required to undertake the final leg of the long journey over the Atlantic Ocean from the Maritime Provinces to Suriname and the Guianas in northeastern South America (Gratto-Trevor and Dickson 1994). Several species of fish in the Bay of Fundy also depend on *C. volutator* for food.

In 1976-1977, Hicklin (1981) studied the distribution of *C. volutator* to better understand its abundance and distribution and its relative importance as a prey species for migrating shorebirds in Minas Basin. He also examined various aspects of its breeding cycle and quantified the impact of shorebird predation on *Corophium* populations in Chignecto Bay (Hicklin *et al.* 1980; Peer *et al.* 1986). These and other studies (*e.g.* Boates 1980; McCurdy 1979) indicated that abundant *C. volutator* populations were available to the shorebirds. Observed changes in the foraging behaviours of the Semipalmated Sandpiper in 1993 (Hicklin, pers. comm.) raised questions as to the continued availability of these birds' important food species. Therefore, a study was undertaken for the purpose of determining whether there was quantitative evidence to support the qualitative observations of changes in *C. volutator* abundances.

In our study design, we attempted to control as many variables as possible by duplicating the transects, stations and methods as well as the sampling dates listed and described in Hicklin (1981) and Hicklin *et al.* (1980).

The population dynamics of *C. volutator* are such that its densities vary considerably within a year. *C. volutator* in the Bay of Fundy is known to have at least two generations a year (Peer *et al.* 1986; Gratto 1979; Matthews *et al.* 1992): an overwintering cohort which reproduces in early June and its offspring which, in turn, reproduce in late summer to produce the next overwintering generation. Thus there is a cyclic pattern of sharp increase in numbers of *C. volutator* as the first broods are released from early June to early July followed by a drop in July as the older overwintered adults die off and another burst in August as the young of the summer generation are released (Peer *et al.* 1986, Gratto 1979, Matthews *et al.* 1992). Fish and Mills (1979) postulated a lunar rhymicity to the breeding cycles of *C. volutator* in Englandwhich determined when young were released.

In addition to life-cycle trends, there are predictable changes to *C. volutator* populations due to the effects of predation. The population cycles and abundances of *C. volutator* in the Bay of Fundy are intertwined with those of its predators which follow their own annual rhythms. *C. volutator* is the primary diet of the Semipalmated Sandpiper (Hicklin, 1981; Boates, 1980; Hicklin and Smith, 1984) and is a preferred food item of some species of fish such as the tomcod, *Microgadus tomcod* (Wilson, 1989). Large numbers of migrating shorebirds first arrive at the Bay of Fundy in mid- to lateJuly to store up reserves for the long 4,000 km non-stop flight to South America (Hicklin 1987; Mawhinney *et al.* 1993) and prey heavily upon *C. volutator* (Hicklin and Smith 1979; Hicklin and Smith 1984).

There are also factors such as weather which affect *C. volutator* abundances and the timing of their breeding season which are more difficult to predict. It has been found that temperature also influences the timing of the reproductive cycle of *C. volutator* (McLusky 1968). Weather (particularly rainfall) would affect the salinity of the substrate which McLusky (1968) found to be a factor in the reproductive success of *C. volutator*.

The purpose of this study was to determine whether there have indeed been changes in the distribution and abundances of *C. volutator* in the Bay of Fundy over the past 16-17 years as qualitative observations have suggested.

MATERIALS AND METHODS

Sampling

We duplicated as closely as possible the sampling procedures used by Hicklin in 1977 and 1978 (see Hicklin *et al.* 1980, Hicklin 1981). Table 4 lists the transects, stations and dates when the transects were sampled. In all the transects except at Starrs' Point Sandbar, the first station of each transect was positionned 50 meters from the beach and all subsequent stations were spaced 100 meters apart. For more details, including maps of the mudflats showing the locations of the transects, see Hicklin (1981) for Minas Basin and Hicklin *et al.* (1980) for Chignecto Bay.

Two samples, spaced approximately 1 meter apart, were taken randomly at each station with a 11.3 cm diameter (100-cm^2-area) core sampler to a depth of approximately 10 cm.

Where possible, samples were sieved in the field with a Standard Tyler Sieve No. 20 (0.85mm mesh) and put into ambient water in 100 ml jars. When it was not possible to sieve the samples in the field, the samples were transported to the laboratory and sieved there.

In the laboratory, approximately 20 ml of methanol was added to each jar to preserve the invertebrate specimens. The specimens were later sorted into major invertebrate groups (*C. volutator*, polychaetes, pelecypods, gastropods, and "other"), counted and preserved in 70% ethanol. Some polychaete specimens were sent to the Huntsman Marine Science Centre in Saint Andrews, New Brunswick, for identification. Due to the unexpectedly large volume of tiny polychaetes and an unfortunate decomposition problem in some of the samples (in which primarily the polychaetes were affected), we had to estimate the polychaete counts. In those cases, we estimated the numbers of polychaetes by volume (i.e. we compared the volume of worms and tubes to that in one sample in which the larger worms and intact tubes had been counted). The resulting counts and corresponding density figures for polychaetes are, therefore, approximate.

Statistical Analysis

Invertebrate densities (no.organisms/m^2) were estimated by multiplying the numbers recovered from each sample (100 cm^3) by 100. For each location, year, sampling station and group (*C. volutator*, polychaetes, pelecypods, gastropods, and "other"), the mean density per transect (*i.e.* the mean of the averages of the replicate samples at each station along each transect), was used for all subsequent analysis. Hence, the density for an invertebrate group at a station refers to the average of the duplicate samples. Since the objective of the study was to compare the 1994 invertebrate profiles (particularly those of *C. volutator*) to those obtained in 1977 and 1978, the analysis was concentrated on year-to-year comparisons within each flat.

Tests for normality (Lilliefors test and normal probability plots) of the station average densities of *C. volutator* for each location indicated lack of fit to normal distributions in almost all cases as one would expect because the large numbers of counts which were zero. The few exceptions were the Grande Anse and Peck's Cove transects in 1978, the Avonport and Starrs Point Sandbar transects in 1977 and the Starrs Point Flats transect in 1994. However, the corresponding data used for comparison were not normally distributed. Therefore, distribution-free tests (Wilcoxon signed ranks test, Fisher sign test, Friedman one-way analysis of variance, and notched box plots) were used for comparisons in all cases. SYSTAT Version 5.03 was used for all analysis and figures (Wilkinson 1990).

In such highly skewed distributions as these, the median is often a better indicator than the mean to represent the population. Table 6 lists the overall median (*i.e.* the median of the station avertages) for each transect and each year. As the medians for 1977 and 1978 were not included in Hicklin (1981) and Hicklin et al. (1980), we calculated them from the available raw data. For most of the samples, the medians were smaller than the means and not infrequently zero which reflects the high numbers of zero counts. The median was close to the mean in those samples which, as stated above, could be considered normally distributed.

The median densities of*C. volutator* were zero for i) Evangeline Beach in both years, ii) Kingsport and Porter's Point in 1977, and iii) for Grande Anse and Starrs Point Sandbar in 1994. In other words, more than half of the stations sampled at those locations in those years had no *C. volutator*.

RESULTS

The densities of *C. volutator* at the ten sites which were sampled in 1977-78 and 1994 are shown in table 5.

At the Grande Anse and Peck's Cove flats in Chignecto Bay, *C. volutator* was significantly less abundant in 1994 than in 1978 while at the Starrs Point Flats in Minas Basin there were significantly more *C. volutator* in 1994 than in 1978. In addition, the Wilcoxon test indicated a marginally significant increase in *C. volutator* densities over the years at Mary's Point (Chignecto Bay) and at Porter's Point (Minas Basin). At Porter's Point, *C. volutator* was not found there in 1978 and only three *Corophium* were found in the 1994 samples.

Figures 6.1 and 6.2 show the species composition by mudflat in Minas Basin and Chignecto Bay in 1977-78 and 1994. In 1977-78, although both sides of the Bay of Fundy supported biota of approximately the same magnitude, the species composition was quite different (Figure 6.1). *Corophium* was more abundant in Chignecto Bay than in Minas Basin while polychaetes dominated in Minas Basin. In 1994, densities of *Corophium* were much lower in Chignecto Bay and considerably greater in Minas Basin (Figure 6.2). These trends in relative abundances were due primarily to a) decreases in *C. volutator* densities at Grande Anse and Peck's Cove (Figures 7.1& 8.1), b) increases in polychaete densities at Evangeline and Starrs Point Sandbar (Figure 7.2) and c) increases in densities of *C. volutator* at Avonport and Starrs Point Flats (Figure 8.2). Grande Anse and Peck's Cove used to be important areas for *C. volutator* in 1977-78 and their numbers there were comparable to those at Avonport and Starrs Point Flats (Figures 8.1, 6.1). However, the abundances of *C. volutator* at Grande Anse and Peck's Cove had decreased considerably by 1994 thus increasing the relative importance of Avonport and Starrs

Point Flats to *C. volutator* by this time (see Figures 6.2 & 8.2).

Below are descriptions of the changes which occurred over the 16-17 year period at each mudflat which are graphically illustrated in Figures 9.1- 9.10 and 10.1-10.10.

Grande Anse

There were significantly fewer *C. volutator* in 1994 than in 1978 (Figure 9.1). The decreases in *C. volutator* contributed most to the overall decline in the total benthic invertebrate population as shown in Figure 10.1. And as shown in Figure 9.1, the distribution of the amphipods along the transect on the Grande Anse mudflat in 1978 was essentially bell-shaped with the greatest numbers of *Corophium* in the middle of the flat. But in 1994, *C. volutator* was nearly absent from the mudflat except for 2 of these amphipods at Station 1 and 47 at Station 9 (Figure 9.1). In streambed-like fissures in the substrate in the vicinity of Station 9, "pockets" of *C. volutator* concentrations were visible but rarely anywhere else. *C. volutator* were concentrated in these microhabitats. Additional samples which we collected in areas where *C. volutator* appeared most concentrated, contained 59 and 201 of the crustaceans. If the extra samples had been part of the transect, this would have represented an average density of 13,000 *C. volutator* per m^2 at that station. Instead, the 47 *C. volutator* collected in one random sample (which happened to have been taken from a stream) and the zero *C. volutator* in the other replicate at that station (which happened to have been taken in the mud) combine to give an estimate of 2350 *C. volutator*/m^2 for that station.

Mary's Point

The overall mean and median densities of*C. volutator* were slightly (though not statistically significantly) higher in 1994 than in 1978. As Figure 9.2 indicates, most *C. volutator* were found close to shore in 1978 and densities declined seaward. By contrast, there were much larger concentrations of *C. volutator* in the uppermost portions of the flat in 1994 but with very low numbers from the middle of the flat to the water's edge. Our samples at Mary's Point were all taken from the mud but we noticed, in the course of sampling at this site, that *C. volutator* were more concentrated in standing pools. Figure 10.2 shows that at this site there was a decline in the number of bivalves and a slight decline in the numbers of worms from 1978 to 1994.

Minudie

The overall mean densities of *C. volutator* at Minudie were similar in 1994 and 1978 (Figure 9.3). *C. volutator* were fairly evenly distributed across the mudflat in 1994 while in 1978 the higher densities were more "clumped" in the upper (stations 2 & 3) and lower portions (stations 7 & 8) . Polychaete abundances were considerably lower in 1994 than in 1978 (Figure 10.3).

Peck's Cove

In 1994, Peck's Cove had significantly fewer *C. volutator* than in 1978 (see Figure 10.4). *C. volutator* abundances were greater in the upper third of the mudflat in 1994 and lower elsewhere whereas in 1978 most of the *C. volutator* were found at the middle stations of the transect (Figure 9.4). As shown in Figure 10.4, all the invertebrate groups, dominated by *C. volutator* and polychaetes, declined between 1978 and 1994. At Peck's Cove, as at Mary's Point and Grande Anse, we noticed a difference in the abundances of *C. volutator* in the mud in relation to the puddles. We deliberately took additional samples in the pools from Stations 2 to 6, which, as Figure 9.4 shows, were the stations with the highest *C. volutator* densities. And in these temporary pools, we found *C. volutator* densities in the order of 5000 animals/m^2, not much different from the results from our random samples (one of the regular random samples (#3B) was taken in a puddle by chance).

Avonport

As shown in Figure 9.5, it appears that the distribution of *C. volutator* changed dramatically at Avonport with increasing densities from 1977 to 1994 although the Wilcoxon signed ranks test did not indicate statistical significance (the Wilcoxon test is an indicator of how often values from one population are larger than values from another population; as Figure 9.5 shows, at some Avonport stations there were more *C. volutator* in 1977 than in 1994 while at others the opposite was true). Instead of being rather evenly spread across the mudflat and peaking in the middle reaches as in 1977, the populations in 1994 were concentrated in the lower third of the transect. *C. volutator* was the dominant organism in 1994 at Avonport (see Figure 10.5).

Evangeline

There was no significant difference between the 1977 and 1994 distributions and abundances of *C. volutator* at Evangeline Beach. Populations in both years were low and concentrated almost entirely halfway down the flat. As shown in Figure 9.6, it appears that the area of high density was larger in 1994 than in 1977. The dominant invertebrates at Evangeline are polychaetes. Since the Evangeline samples in this study (1994) were those most affected by the worm-counting problems (volume and decomposition), we are unable at this time to substantiate the apparent dramatic increase in worms from 1977 to 1994 shown in Figure 10.6. We did, however, notice the high abundances of polychaetes and tubes when we performed the sampling.

Kingsport

Densities of*C. volutator* were low at Kingsport in 1977 and concentrated close to shore.

By contrast, virtually all of the *C. volutator* in 1994 were found in the middle/lower part of the flat as shown in Figure 9.7. The Kingsport transect is short; it consists of only 5 stations from the sand/mud interface to the low water line. The four main invertebrate groups (*Corophium*, polycaetes, pelecypods and gastropods) were more abundant and better represented throughout the transect at Kingsport than at the other locations studied (see Figure 10.7).

Porter's Point

There were no *C. volutator* extracted from the Porter's Point samples in 1977 and only one was recovered at each of the first three stations in 1994 (see Figure 9.8.). Thus, Porter's Point does not appear to be an important location for *C. volutator*. It is a short transect which primarily hosts polychaetes (Figure 10.8).

Starrs Point Flats

There were significantly more *C. volutator* at Starrs Point Flats in 1994 than in 1977. In 1977, the animals occurred in the lower half of the transect and especially in the middle of the lower half. But in 1994, they were spread fairly evenly across the entire flat including the first 200 meters where none had been found earlier by Hicklin (Figure 9.9). While *C. volutator* was the most dominant invertebrate group there in 1977, its dominance was more pronounced in 1994 as shown in Figure 10.9.

Starrs Point Sandbar

C. volutator was found in small numbers at the Starrs Point Sandbar in 1977. In 1994 however, the sandbar was almost devoid of the amphipod (Figure 9.10) but contained large populations of polychaetes (Figure 10.10). While the actual polychaete counts for these samples are approximate, large numbers of polychaetes were very noticeable when we took the samples and most likely represent substantial increases since 1977.

DISCUSSION

The results indicate that there were significantly fewer *C. volutator* at the Grande Anse and Peck's Cove mudflats in Chignecto Bay in 1994 than in 1978. These findings confirm speculation from field observations at these major feeding grounds of migrating shorebirds in Chignecto Bay that the sediments and invertebrate communities in that portion of Fundy's intertidal zone were undergoing change (Hicklin, personal observation). Concurrently, there were also substantial increases in the numbers of*C. volutator* at the Starrs Point Flats and Avonport Beach, two important shorebird feeding areas in Minas Basin where qualitative observations similarly suggested that changes were taking place in those areas (J.S.Boates, pers. comm.).

It is difficult to make claims about trends based on a single sampling dates at each location because the abundances of *C. volutator* vary dramatically throughout the year. Rather than comparing the results obtained from our single sampling dates to average densities obtained from many sampling dates in other studies, we compared our findings to those for a single comparable date whenever possible. This minimized the confounding effect of life-cycle stages and other factors which affect *C. volutator* populations on specific schedules even though it may reduce the statistical discrimination power.

Many other researchers have studied *C. volutator* in Minas Basin over the past 20 years but data on *C. volutator* in Chignecto Bay are less abundant. Listed in Table 7 are densities of *C. volutator* that other researchers have reported at the same mudflats on similar dates.

The observation that there were higher concentrations of *C. volutator* in puddles on some flats in Chignecto Bay has also been reported elsewhere. Peer *et al.* (1986) noted that there were more *C. volutator* burrows in the shallow pools at Peck's Cove (p. 361). Since only averages for June and July are available from graphs in Peer *et al.* (1986), it is difficult to discern whether their numbers reflect dates so different that the life-cycles are not at comparable stages. Because they used a finer mesh size than we did (0.25 mm vs 0.70 mm) to capture the small newly-released broods, their densities are higher than ours.

The overall mean *C. volutator* densities reported in Gratto (1979) and McCurdy (1979) (same data used in both studies) for 1977 differed from those those reported in Hicklin (1981) at several sites. Theirs were greater at Avonport, slightly greater at Evangeline and Kingsport and less at Starrs Point Flats but the standard deviation calculated for the Hicklin data and the ranges given for the Gratto and McCurdy data suggest that the differences were not statistically significant. At all four flats, the Gratto/McCurdy densities for 1977 are lower than our 1994 densities but the differences are significant only for Starrs Point. The densities which Gratto and McCurdy calculated are much higher for 1978 than for 1977, significantly greater than Hicklin's 1977 data except at Starrs Point and significantly different from our 1994 data at Evangeline Beach. Since Gratto and McCurdy used a smaller mesh to sieve some of their samples, one would expect their numbers to be higher than if all samples had been sieved with the larger mesh. Thus, their estimates of *C. volutator* abundances in 1977 are considered to be comparable to Hicklin's and the increase seen at Starrs Point Flats in 1994 is significant. Gratto and McCurdy concentrated on seasonal variations and did not remark on the substantially larger population estimates they found in 1978 compared to 1977 which were particularly striking at Avonport and Evangeline.

Although our 1994 mean density figure for *C. volutator* at Starrs Point Flats is statistically significantly higher than Hicklin's 1977 estimate, neither is significantly different from Boates' 1979 figure (Boates, 1980) which is intermediate between the two. However, at the Sandbar, Boates found *C. volutator* in numbers one to two orders of magnitude larger than either ours or Hicklin's (1981). Boates sampled a different transect in 1979 than did Hicklin in 1977. Boates took 15 core samples, 25 meters apart, in a grid within 100m x 100m plots spaced about 500 meters apart through the centre of the flat and the sandbar (Boates 1980, DuBois-Laviolette 1985) whereas Hicklin (1981) took two cores, one meter apart, at stations spaced every 100 meters along a more easterly transect on the flat and a perpendicular transect across the sandbar. Since benthic organisms such as *C. volutator* are patchily distributed (Murdoch *et al.* 1986), it would be more likely that field studies using Boates' sampling scheme would find larger densities because of the larger number of samples collected at each mudflat.

Gratto and McCurdy used a shorter and more northerly transect than did Hicklin (1981) or Boates (1980). They collected three cores every 150 meters (Gratto 1979, McCurdy 1979, DuBois-Laviolette 1985) while Gilliland's (1992) and Shepherd's (1994) transects were more like Boates' (1980) and their sampling methods were yet different . Since all the densities for *C. volutator* at Starrs Point Flats from different researchers and years all fall within the same general range but the estimates obtained from the Sandbar differ so greatly, it appears that *C. volutator* are somewhat evenly distributed across the Starrs Point Flats and very patchily distributed on the adjoining Sandbar. Shepherd postulated that the declines in *Corphium volutator* abundances in the southern bight were due to disturbance to the sediment caused by baitworm harvesters (Shepherd, 1994).

Wilson (1989), Gilliland (1992) and Shepherd (1994) all sampled in the lower part of the Avonport mudflat where we found large numbers of *C. volutator*. Wilson (1989), however, used a much finer mesh size and his data indicate that in his June 16 samples almost all of the *C. volutator* were under 1 mm in length and in his July 7 samples, most of the *C. volutator* were 4 mm or smaller (*i.e.* newly-released juveniles which are part of the population explosion seen in late June; see Wilson, 1989),

Nasution (1992) sampled at Porter's Point by taking five cores in front of each of his fish-traps at low water and sieving them with a 0.6-mm mesh. Thus, his study differed from ours both in where he sampled and in the size distribution of the animals he collected.

The changes in polychaete abundances suggest directions for further research into the ecology and populations of the mudflats of the Bay of Fundy. Wilson (1988) studied interactions at Avonport Beach between *C. volutator* and several species of polychaete and found that, while adult *C. volutator* and adult polychaetes did not exclude each other, adult polychaetes could inhibit juvenile *C. volutator* from establishing. In a separate study in Maine, Wilson (1984) examined competition between various spionid polychaetes (some of which occur in Minas Basin) and concluded that characteristics of the sediment may be more important than the presence of other species in determining benthic invertebrate distributions (Wilson, 1984).

Summary

The purpose of this study was to determine whether the distributions and abundances of benthic invertebrates in the upper Bay of Fundy, in particular the amphipod *Corophium volutator*, had changed between the late 1970s and early 1990s. The results indicate that there were significantly fewer *C. volutator* at the Grande Anse and Peck's Cove mudflats in Chignecto Bay in 1994 than in 1978. And in the same period, there were also substantial increases in *C. volutator*densities at Starrs Point Flats and Avonport Beach in Minas Basin.

In 1977 and 1978, the mudflats on both sides of the Bay of Fundy supported invertebrate populations of approximately the same size though of different species composition while in 1994, there were, overall, fewer organisms in Chignecto Bay and more in Minas Basin. This trend appears to consist primarily of a) a decrease in *C. volutator* at Grande Anse and Peck's Cove, b) an increase in polychaetes at Evangeline Beach and Starrs Point Sandbar in Minas Basin, and c) an increase in *C. volutator* at Avonport and Starrs Point Flats.

GENERAL DISCUSSION

Both qualitative and quantitative changes in the intertidal sediments and associated invertebrates in the Bay of Fundy have clearly occurred in the period between 1977 and 1994. Although there was no significant universal relationship between the changes in the biotic (invertebrates) and abiotic (sediments) parameters of this intertidal ecosysytem, we did find some interesting trends.

At the stations in Chignecto Bay where noticeable changes had occurred in both sediments and invertebrates, changes in invertebrate densities were negatively correlated with changes in the percent silt and clay. Conversely, at the stations in Minas Basin where noticeable changes had occurred in both sediments and invertebrates, the changes in invertebrate densities were positively correlated with changes in percent silt and clay. The primary sedimentological difference between Chignecto Bay and Minas Basin is that the former is considered a "muddy" estuary (84-87% silt and clay, Table 3), while the latter is considered a "sandy" one (52-56% silt and clay, Table 3). Since sandy sediments are better drained, this difference between both portions of the bay is also reflected by the fact that the average water content in Minas Basin in 1994 was lower in Minas Basin (26%) than in Chignecto Bay (35%).

C. volutator is known to prefer a combination of silt and clay and very fine sands to larger grain sizes but can also adjust to a wide range of grain sizes (Murdoch *et al.* 1986, Hawkins 1985, Deans *et al.* 1982, Fenchel *et al.* 1975, Meadows 1964). Since, overall, there is less silt and clay in Minas Basin than in Chignecto Bay and that *C. volutator* requires silt and clay, it is clear why *Corophium* densities in the Bay of Fundy vary with the relative amounts of silt and clay in the sediments. Perhaps the opposite trend in Chignecto Bay is due to both the high percentages of silt and clay in the sediments as well as the substantial increases in water content which, in combination, create an unstable "soupy" sediment unsuitable for the construction of burrows by *Corophium* . As well, if diatom populations are lower (see Part 1), *C. volutator* may be required to reduce its intake of this main food resource and filter-feed in order to make up for the difference (Fenchel *et al.* 1975). Since Chignecto Bay has higher concentrations of suspended sediment than Minas Basin (Amos *et al.* 1991), filter-feeding would be expected to be less successful there than in Minas Basin.

C. volutator densitieswere significantly lower in 1994 at Grande Anse and Peck's Cove in Chignecto Bay. The only significant change in the sediments which might explain this is the increase in water content due perhaps to increased deposition of fine sediments on the flats. Since water content also increased at both Mary's Point and Minudie where no significant decrease in *C. volutator* was found, there are likely other factors involved of which we are not aware.

C. volutator densities increased at Starrs Point Flat and especially at the nearshore stations. As well, *C. volutator* densities at the Starrs Point Sandbar were slightly down from Hicklin's (1981) numbers and significantly down from those densities shown in Boates (1980). Baitworm harvesters thoroughly dug over the Starrs Point Sandbar and the outer flat (beyond the study transect) for eight years leading up to this study (Shepherd 1994). In doing so, harvesters probably caused a decrease in the densities of *C. volutator* and impacted their intertidal habitat by i) digging over burrows, ii) loosening fine sediments and iii) increasing the likelihood of its resuspension and transport seaward. Perhaps the shift in *C. volutator* distributions seen at Starrs Point is due, in part, to baitworm harvesting activities.

All flats where polychaete densities were significantly higher in 1994 experienced concurrent decreases in the percentages of silt and clay in the sediments. All mudflats experienced increases in the percentages of silt and clay in the sediment except for Avonport where polychaete densities were significantly lower in 1994. Avonport experienced a decrease in both polychaete abundances and relative amounts of silt and clay, possibly because intensive baitworm harvesting has been ongoing there for the past few years. Consequently, it appears that polychaete distribution is inversely related to the amount of silt and clay and perhaps also to *C. volutator* densities in the sediment.

The significant decreases in *C. volutator* densities at Grande Anse also reflected observed changes in the foraging behaviours of migrant Semipalmated Sandpipers. Peter Hicklin, Reid McManus, Ralph Schieke, Svenja Timm and Philippa Shepherd have all observed that the peeps at Grande Anse are no longer following the tide all the way down the flat and then spreading out to forage as was more typically the case in 1977-1978 (Hicklin, unpublished information). They now appear to be concentrating their foraging activities nearshore at about the 1 km mark (about halfway down the mudflats), the only areas where *C. volutator* are now found. As well, they spend more time flying around the flat in small groups, foraging for a while and then leaving again. The birds have also been observed in salt marshes up the Memramcook River where they were rarely seen before in large numbers and may be supplementing their diet more than in previous years. A study of the foraging behaviours, habitat use, diets, rates of weight gain and length of stay of the shorebirds at Grande Anse would be necessary to quantitatively assess the effects of decreased densities of *Corophium volutator* on migrant shorebirds.

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Further research into possible changes in SSC (Suspended Sediment in Concentration) and the particle sizes of those sediments would be a first step towards finding the causes of changes in Bay of Fundy sediment composition. Baseline data for Chignecto Bay were collected between 1978 and 1980 (Amos et al. 1991, Amos and Tee 1989) and used to construct models of sediment dynamics. Data collected in the future using the same methodology would be particularly useful for comparison since both of these baseline studies occurred at the same time as Hicklin *et al.*'s (1980). At a minimum, it would be important to collect water samples in Chignecto Bay to determine the concentration and particle sizes of sediments in suspension and compare them to the baseline data in Amos et al. (1991) and Amos and Tee (1989).

2. In addition to collecting data on the concentrations and particle sizes of sediments in suspension, data on total suspended mass should also be collected since Amos and Tee (1989) found that this variable remained constant over two years despite changes in SSC. This data would help to ascertain whether changes in water content are due to a net increase in erosion throughout the Bay or whether these increases are localized. Pinpointing areas of higher SSC would facilitate the search for sediment sources. As well, aerial photos and/or Landsat Imagery could be used to determine the magnitude of cliff line erosion since 1977-79.

3. Continuous data on wave magnitude and activity and on current strength should be collected near study flats. It would also be useful to obtain data on rain and cloud cover and to collate them with data on time of low tide for both 1977/79 and 1994 to see whether there were any differences in exposure to the sun between years. Finally, further research into the effects of ice scouring on sediments is required since so little is known about this process. Together, this information would provide a means of assigning the relative importance of some of the physical factors which affect Bay of Fundy sediment dynamics.

4. Prouse *et al.* (1984) discussed studies by Schwinghamer (1981) who measured benthic diatom biomasses at Peck's Cove and Gordon et al. (unpublished data) who measured the chlorophyll content in surface sediments in Minas Basin. These studies were done around the time of Hicklin *et al.*'s (1980) and Hicklin's (1981) field studies and could be used for comparison with similar data to be collected in future.This would provide some indication of whether changes have

occurred in diatom populations that may partially explain the changes observed in sediment stability. Ideally, since all mud and sandflats in the Bay of Fundy are exposed to solar UVR and since the effects of ozone depletion on intertidal communities and especially benthic diatoms are unknown, a comprehensive study of the effects of UV on these communities should be initiated.

5. The magnitude of the effects of anthropogenic input such as causeways, construction, dredging, channelling, amenity development, baitworm harvesting, CFCs and other pollutants into the Bay of Fundy ecosystem are not well-known and have never been integrated. In order to determine the relative importance of the human influences on the sediment dynamics of the Bay of Fundy, further research targeting specific questions must be initiated and all of the data integrated into a holistic analysis.

6. The literature on the particle-size preferences by *C. volutator* has largely focused on situations in which the percentages of silt and clay are low. Further research into the diet and foraging behaviour of *C. volutator* and its preferred sediment grain sizes and relative water content for burrow construction in the Bay of Fundy, especially in Chignecto Bay where the silt and clay content is high, must be initiated in order to properly manage this species' intertidal habitat.

7. It appears that there have been significant changes in the densities of polychaetes in Minas Basin. In addition, previous studies differ substantially in their polychaete species lists as well as their abundances and distributions. Therefore, it is necessary that a comprehensive study be done to characterize the polychaete distributions in Chignecto Bay and Minas Basin.

8. Wilson (1988) postulated inhibitory interactions between *C. volutator* and other invertebrates. Further research is required in order to understand the interspecies interactions among *C. volutator*, polychaetes and other invertebrates as they relate to sediments.

9. Patchiness is a particular problem when studying the distributions of organisms. Statistical analysis using spatial autocorrelation techniques would aid toward a better understanding of the incidence of *C. volutator* and other important species and to identify population trends.

10. Other filter and deposit-feeding invertebrates inhabiting the intertidal zone may also be affected by changes in sediment grain sizes and water content in the intertidal mudflats of Bay of Fundy. Studies similar to those proposed for *C. volutator* would be required to determine such effects.

11. A study of the foraging behaviours, diets, rates of weight gain and movement of the fish predators at these mudflats is necessary to assess the effects of a decreases in preferred prey on fish stocks.

12. A study of the distribution, foraging behaviours, habitat use, diets, rates of weight gain, and lengths of stay of the Semipalmated Sandpiper at Grande Anse is necessary to assess the effects of a decrease of preferred prey on migrating shorebirds.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of the Acadia Centre for Estuarine Research with special thanks to Jamie Gibson. We are very grateful to Keir Daborn, Ken Meade, Steve Mockford,Trent Oldford and Grazyna Prozynska for sorting invertebrate samples. We are grateful to Dr. Carl Amos and Dr. Graham Daborn for their willingness to share ideas and information and to the Atlantic Reference Centre of the Huntsman Marine Science Centre for identifying polychaetes. Richard Elliot and Eric Hiscock provided useful reviews of the manuscript.

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TABLES

Table 1.Comparison of sieve numbers, particle size grade scales and their corresponding class limits (taken from Hicklin (1981) and adapted from Royce (1970)).

U.S. Standard sieve number	phi (0)	mm	description
5	-2	4	--------------------
			granule gravel
10	-1	2	--------------------
			very course sand
18	0	1	--------------------
			coarse sand
35	1	1/2	--------------------
			medium sand
60	2	1/4	--------------------
			fine sand
120	3	1/8	--------------------
			very fine sand
230	4	1/16	--------------------
pan fraction	>4	<1/16	silt and clay

Table 2.Net overall changes in percent silt/clay from 1977/79 to 1994 at each of the ten mudflats studied in the upper Bay of Fundy. Separate group totals for the Chignecto Bay flats and the Minas Basin flats are also included.

CHIGNECTO BAY:

Location (# Stations)	Silt/Clay
Mary's Point (4)	+ 1.85%
Minudie (3)	- 3.25%
Peck's Cove (3)	+ 12.30%
Grande Anse (4)	+ 2.02%
TOTAL (14)	+ 3.23%

MINAS BASIN:

Location (# Stations)	Silt/Clay
Porter's Point (3)	- 2.87%
Kingsport (2)	+ 11.98%
Avonport Beach (4)	- 5.19%
Starrs Point Flat (4)	- 5.20%
Starrs Point Bar (3)	- 8.45%
Evangeline Beach (4)	- 4.76%
TOTAL (20)	- 2.42%

CHIGNECTO BAY AND MINAS BASIN:

Location (# Stations)	Silt/Clay
GRAND TOTAL	+ 0.81%

Table 3.Differences in percent particle size class between Minas Basin and Chignecto Bay flats.

Particle Size	Minas Basin (1977/1994)	Chignecto Bay (1979/1994)
Silt/Clay	55.88/52.35	83.73/86.78
Very fine sand	28.12/17.05	13.87/8.12
Fine sand	11.17/21.20	1.51/3.02
Medium sand	2.08/4.63	0.66/1.61
Course sand	1.67/2.69	0.15/0.41
Very course sand	0.43/1.20	0.09/0.05
Granule	0.85/0.89	0.00/0.01

Table 4.Sampling scheme for benthic invertebrates in the present study and Hicklin (1981) and Hicklin *et al.* (1980)

Location	Area	# of Stations	1977/8	1994
Mary's Point	Chignecto Bay	19	June 15, 1978	June 16
Minudie	Chignecto Bay	9	June 26, 1978	June 27
Peck's Cove	Chignecto Bay	9	July 4, 1978	July 4
Grande Anse	Chignecto Bay	12	July 5, 1978	July 5
Porter's Point	Minas Basin	6	June 20, 1977	June 20
Kingsport	Minas Basin	5	June 20, 1977	June 20
Avonport Beach	Minas Basin	9	June 21, 1977	June 21
Starrs Point Flats	Minas Basin	9	June 22, 1977	June 22
Starrs Point Sandbar	Minas Basin	6	June 22, 1977	June 22
Evangeline Beach	Minas Basin	20	June 23, 1977	June 23

Table 5. Results of Wilcoxon Signed Ranks Test comparison of *C. volutator* mean densities in 1977/8 and 1994, by location (significance at 95% confidence level).

Location	1977/8 Overall Mean ± Std. Dev.	1994 Overall Mean ± Std. Dev.	Wilcoxon Signed Ranks Test	p-value
Grande Anse	5162.5 ±3476.3	204.2 ± 676.4	significant	0.002
Mary's Point	415.8 ± 569.9	726.3 ± 849.9	not significant	0.115
Minudie	1081.3 ± 1264.3	1333.3 ± 1103.7	not significant	0.338
Peck's Cove	2761.1 ± 1987.1	738.9 ± 969.1	significant	0.008
Avonport	2788.8 ± 2789.7	9283.3 ± 10,695.2	not significant	0.314
Evangeline	47.9 ± 149.4	92.5 ± 192.1	not significant	0.765
Kingsport	222.6 ± 343.0	1540.0 ± 2303.1	not significant	0.674
Porter's Point	0.0 ± 0.0	25.0 ± 27.4	not significant	0.083

Table 5 (cont'd)

Starrs Point Flats	4202.9 ± 5773.9	9111.1 ± 2976.9	significant	0.051
Starrs Point Sandbar	367.4 ± 447.1	91.7 ± 224.5	not significant	0.173

Table 6. Median densities of *C. volutator* in 1977-78 and 1994

Location	1977/8 Overall Median (# *C.v.* / m^2)	1994 Overall Median (# *C.v.* / m^2)
Grande Anse	5275	0
Mary's Point	150	200
Minudie	525	1500
Peck's Cove	2450	350
Avonport	2314	1800
Evangeline	0	0
Kingsport	0	200
Porter's Point	0	25
Starrs Point Flats	1001.5	9350
Starrs Point Sandbar	223	0

Table 7. Mean densities of *C. volutator* reported in other studies in the Bay of Fundy.

Researcher	Location	Year	Sieve mesh size	# *C. volutator*/m^2
Peer et al. (1986)	Grande Anse	1979	0.25 mm	200 (June) - 5,200 (July)
	Mary's Point			1,000 (June) - 8,000 (July)
	Minudie			1,000 (June) - 6,000 (July)
	Peck's Cove			500 (June) - 3,000 (July)
Gratto (1979), McCurdy (1979)	Avonport	1977	0.45 mm & 0.85 mm	7,000 (June 21)
		1978		17,500 (June 20)
	Evangeline	1977		75 (June 23)
		1978		2,200 (June 21)
	Kingsport	1978		500 (June 19)
	Starrs Point Flats	1977		1,800 (June 20)
		1978		6,200 (June 22)
Boates (1980)	Starrs Point Flats	1979	0.85 mm	7,300 (June 23, 29)
	Starrs Point Sandbar			13,200 (June 23, 29)
Wilson (1989)	Avonport	1985	0.25 mm	44,700 (June 16) - 51,900 (July 7)
Gilliland (1992)	Avonport	1990	0.85 mm	24,400 (July - August)
		1991		21,200 (July - August)

Table 7 (cont'd)

	Evangeline	1990		2,000 (July - August)
		1991		2,800 (July - August)
	Starrs Point Flats	1990		4,100 (July - August)
		1991		12,800 (July - August)
Nasution (1992)	Porter's Point	1991	0.6 mm	4,700 (June 28)
Shepherd (1994)	Avonport	1993	0.85 mm	20,700* - 33,800** (mid-July - August)
	Starrs Point Flats			0 - 2,000 (avg. 1,000) (mid-July - August)
	Starrs Point Sandbar			0 (mid-July - August)

* dug by baitworm harvesters

** not dug by baitworm harvesters

FIGURES

Figure 1.1

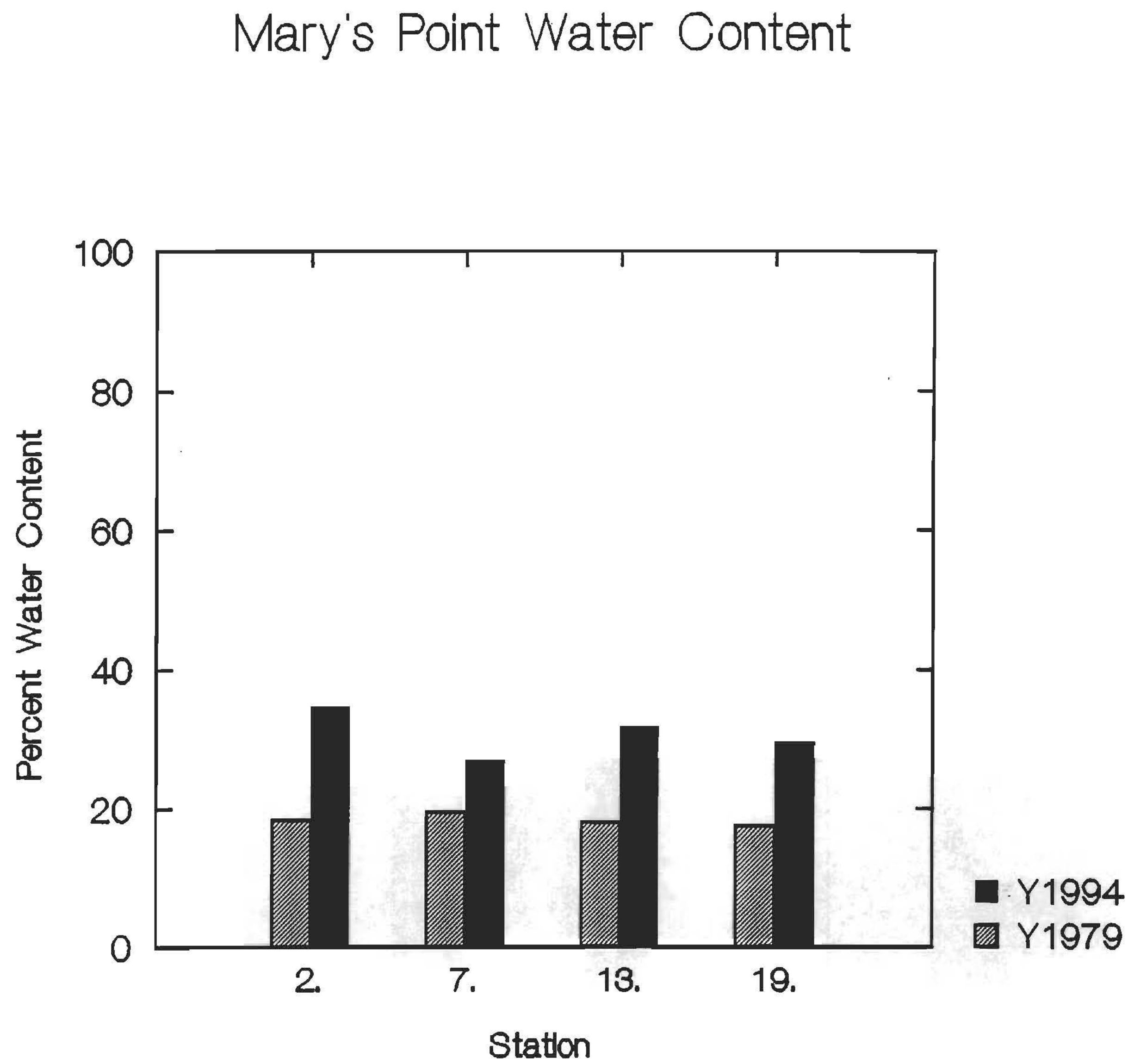
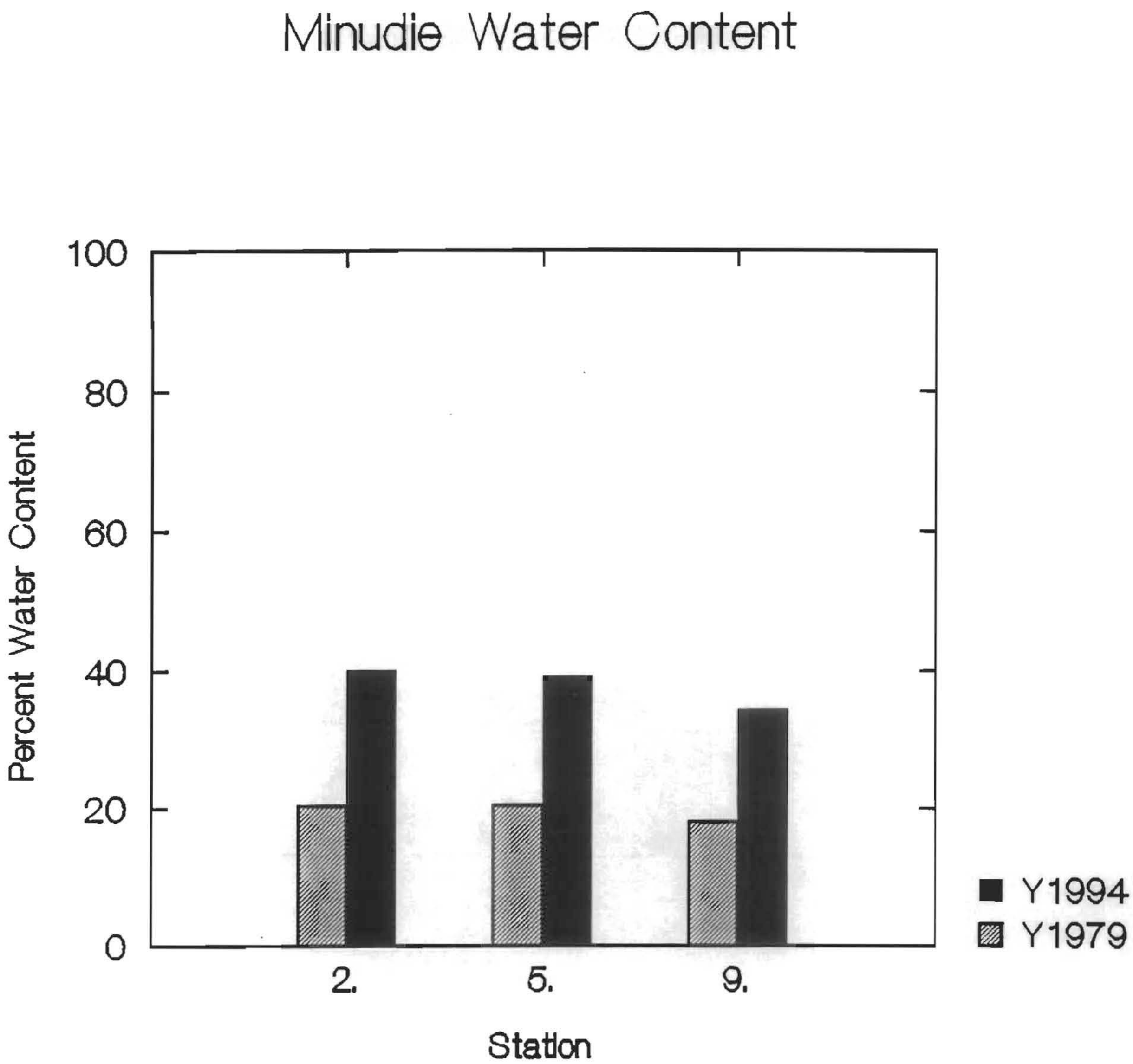

Mary's Point Water Content
100
80
60
40
20
0
Percent Water Content
2.
7.
13.
19.
Station
Y1994
Y1979

Figure 1.2



Minudie Water Content
100
80
60
40
20
0
Percent Water Content
2.
5.
9.
Station
Y1994
Y1979

Figure 1.3

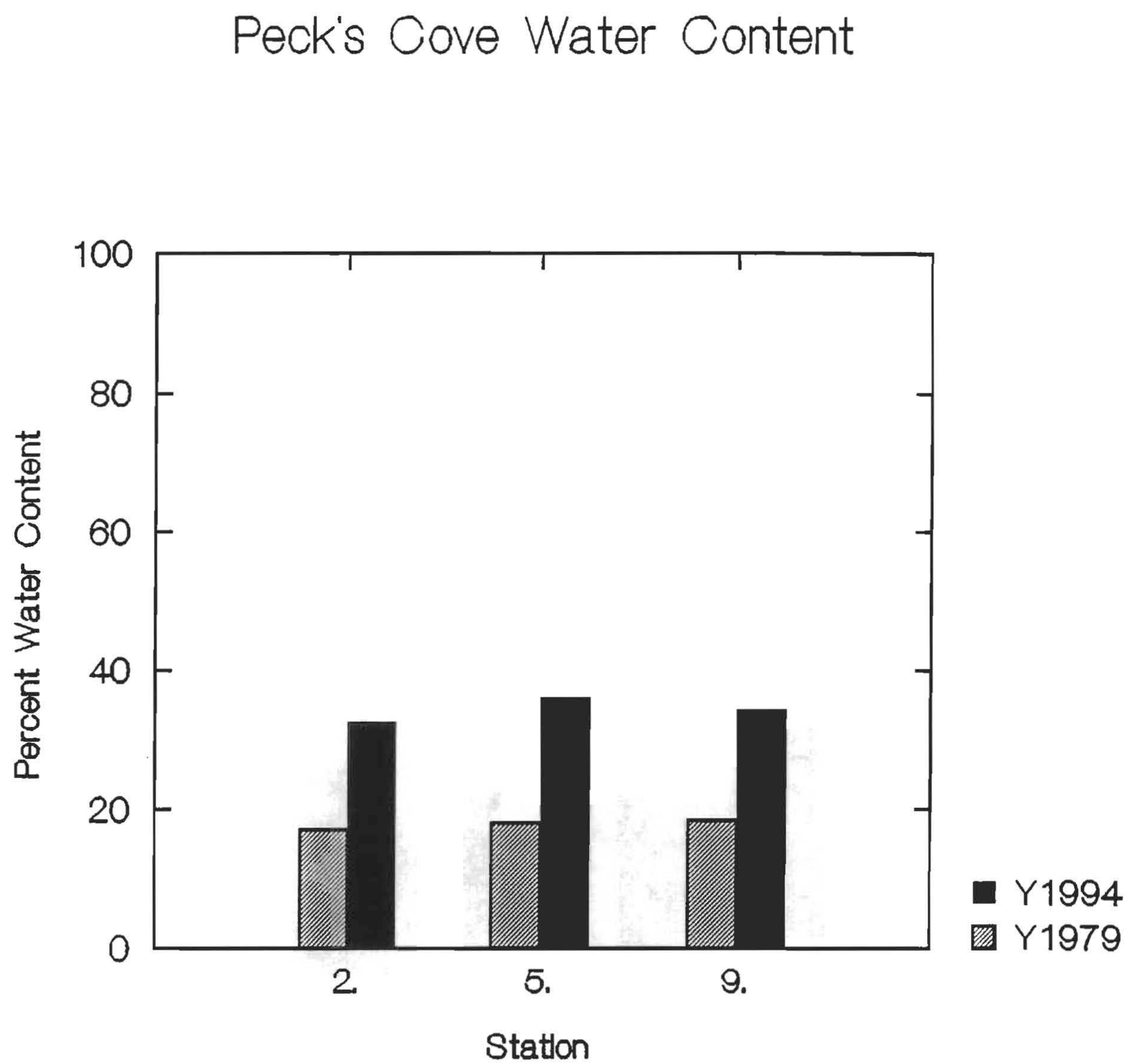

Peck's Cove Water Content
100
80
60
40
20
0
Percent Water Content
2.
5.
9.
Station
Y1994
Y1979

Figure 1.4

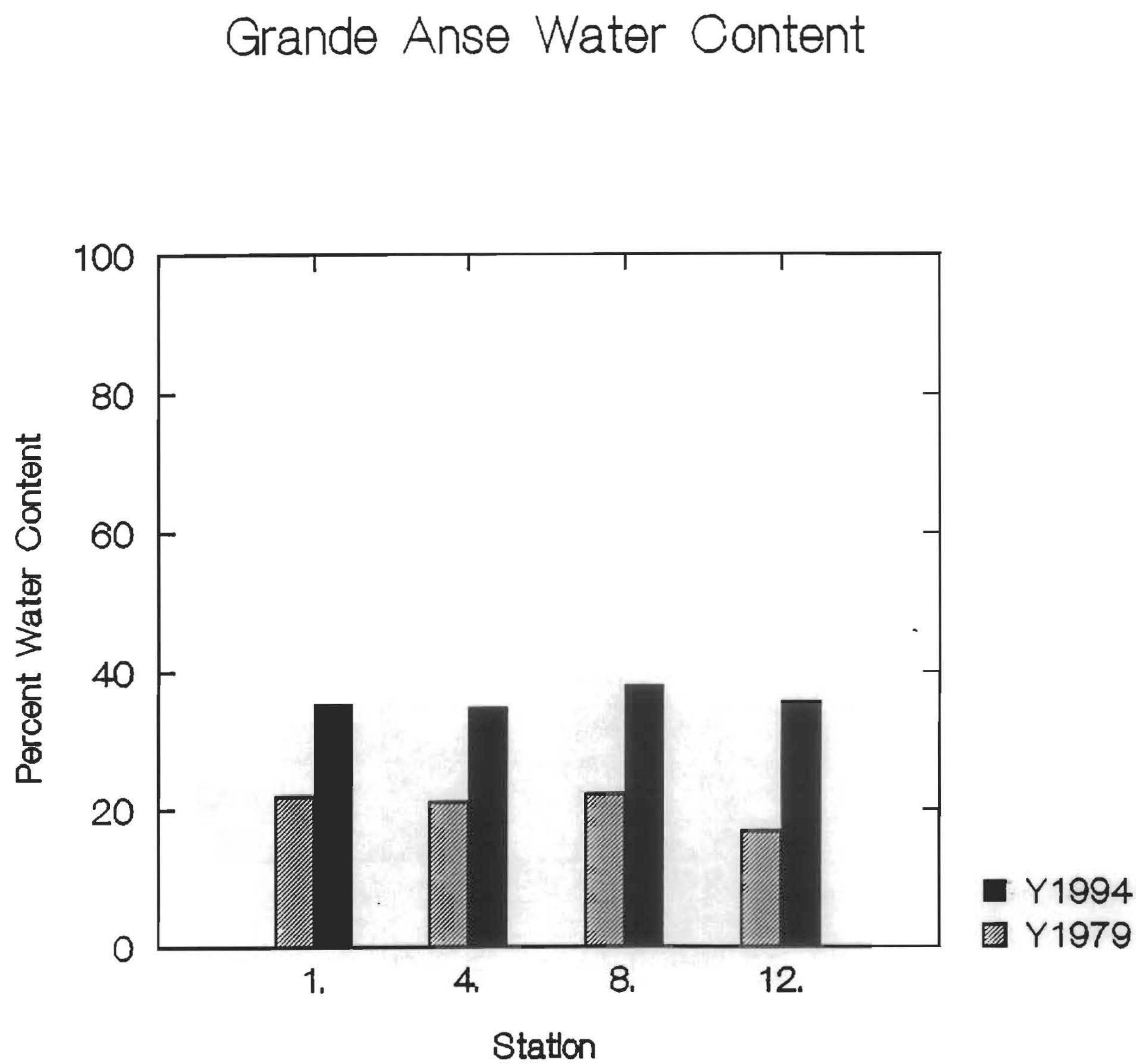

Grande Anse Water Content
100
80
60
40
20
0
Percent Water Content
1.
4.
8.
12.
Station
Y1994
Y1979

Figure 2

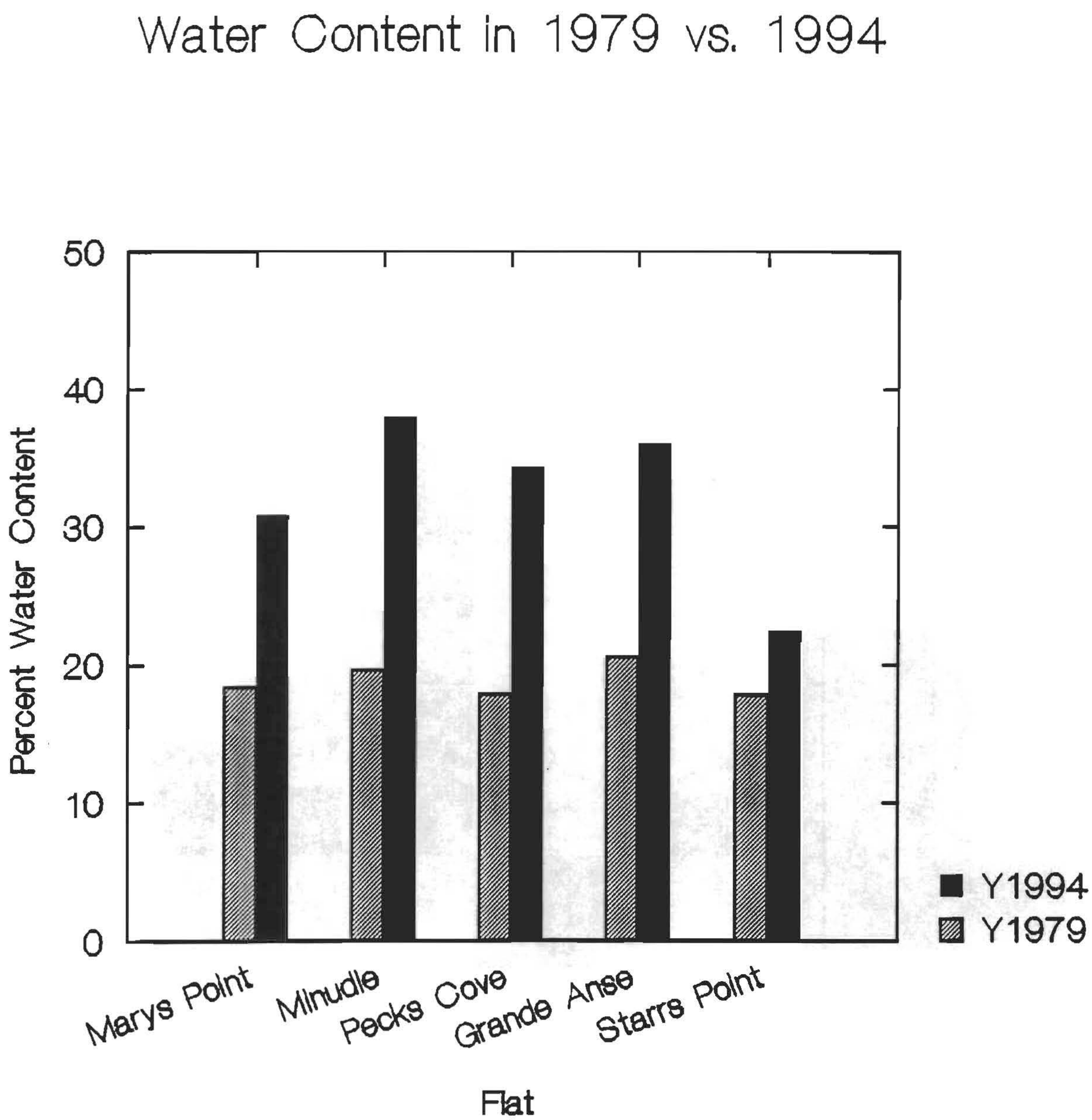

Water Content in 1979 vs. 1994
Percent Water Content
50
40
30
20
10
0
Marys Point
Minudie
Pecks Cove
Grande Anse
Starrs Point
Flat
Y1994
Y1979

Figure 3.1

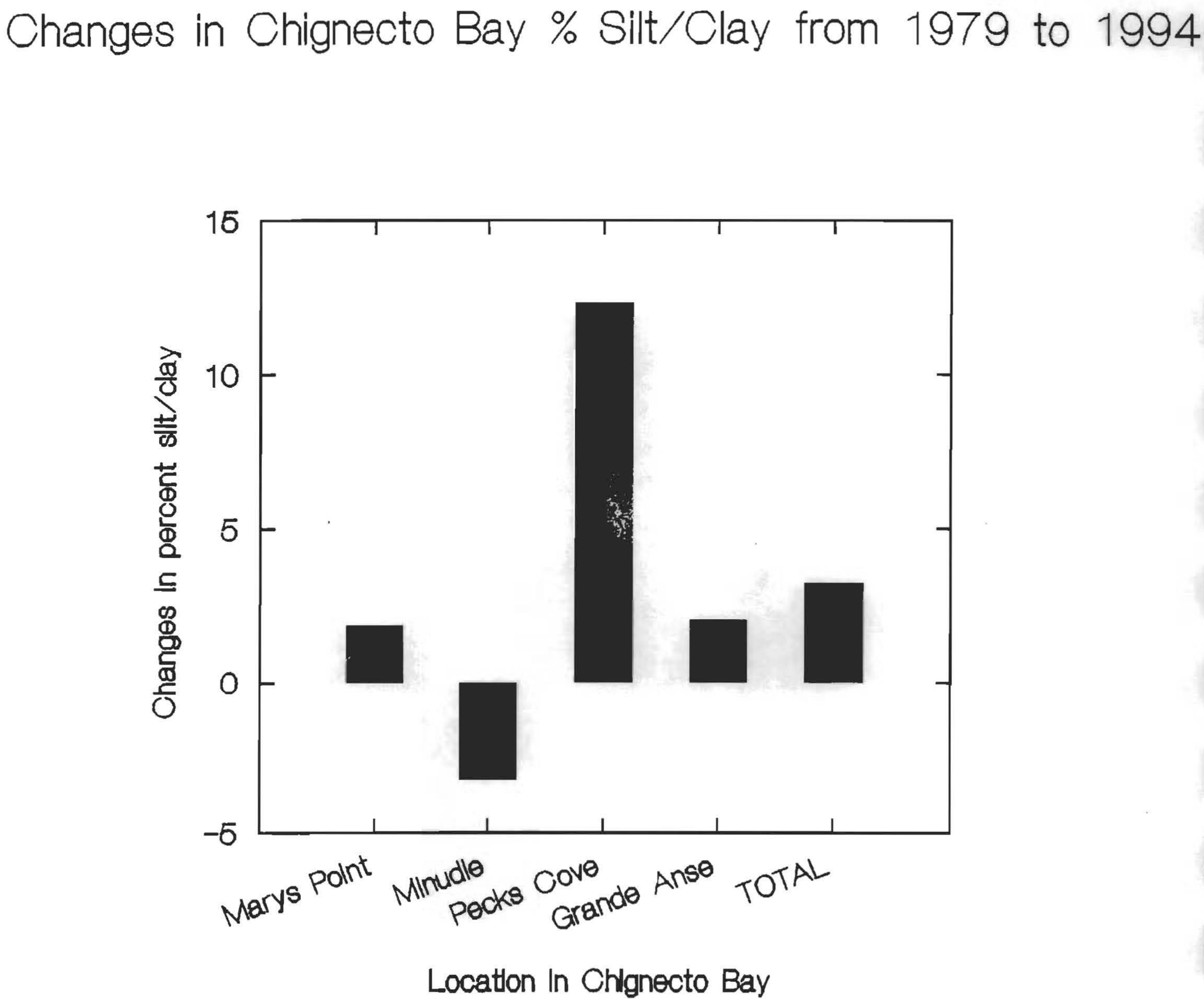
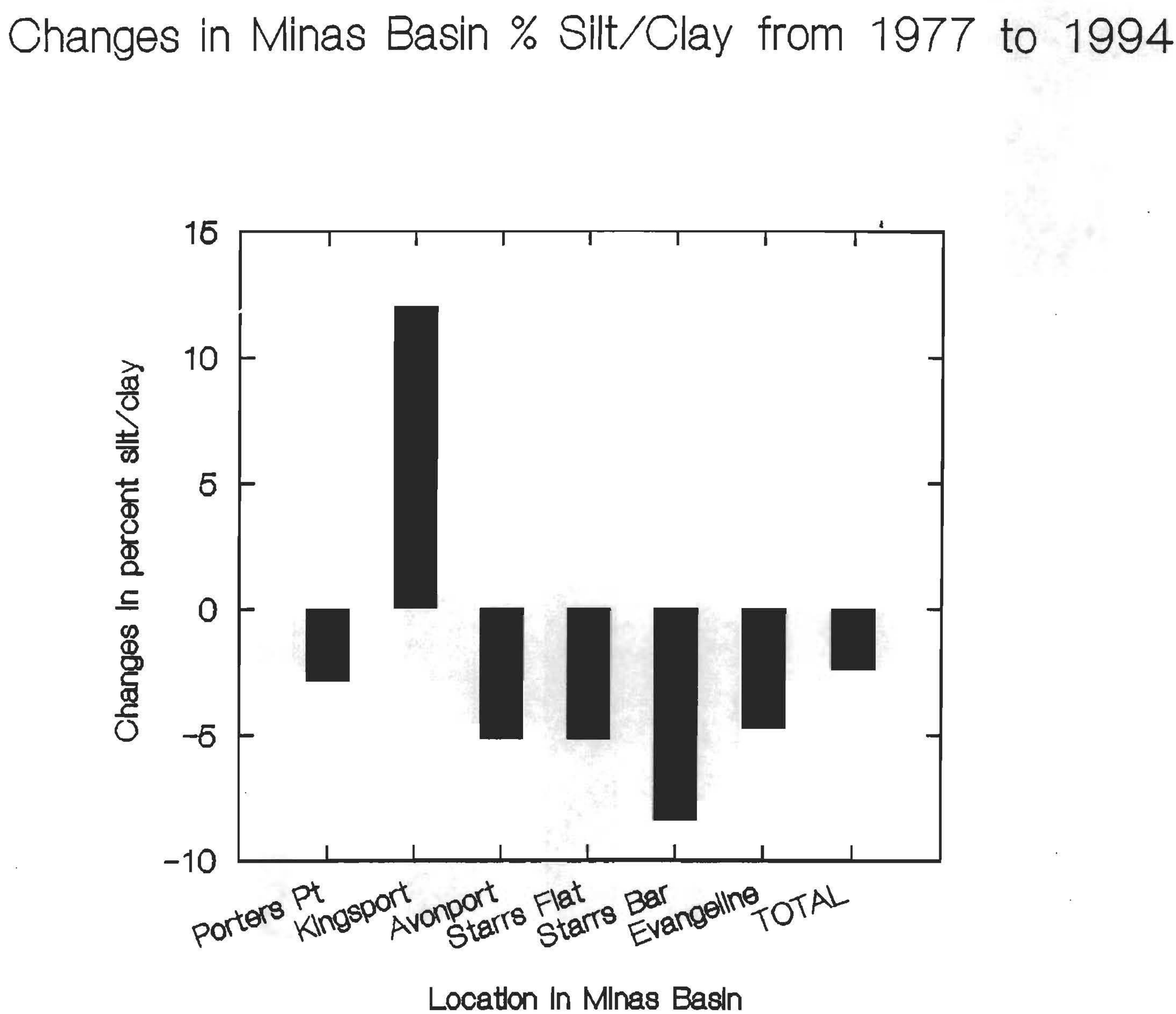

Changes in Chignecto Bay % Silt/Clay from 1979 to 1994
15
10
5
0
-5
Changes in percent silt/clay
Marys Point
Minudie
Pecks Cove
Grande Anse
TOTAL
Location in Chignecto Bay

Figure 3.2



Changes in Minas Basin % Silt/Clay from 1977 to 1994
Changes in percent silt/clay
15
10
5
0
-5
-10
Porters Pt
Kingsport
Avonport
Starrs Flat
Starrs Bar
Evangeline
TOTAL
Location in Minas Basin

Figure 4.1

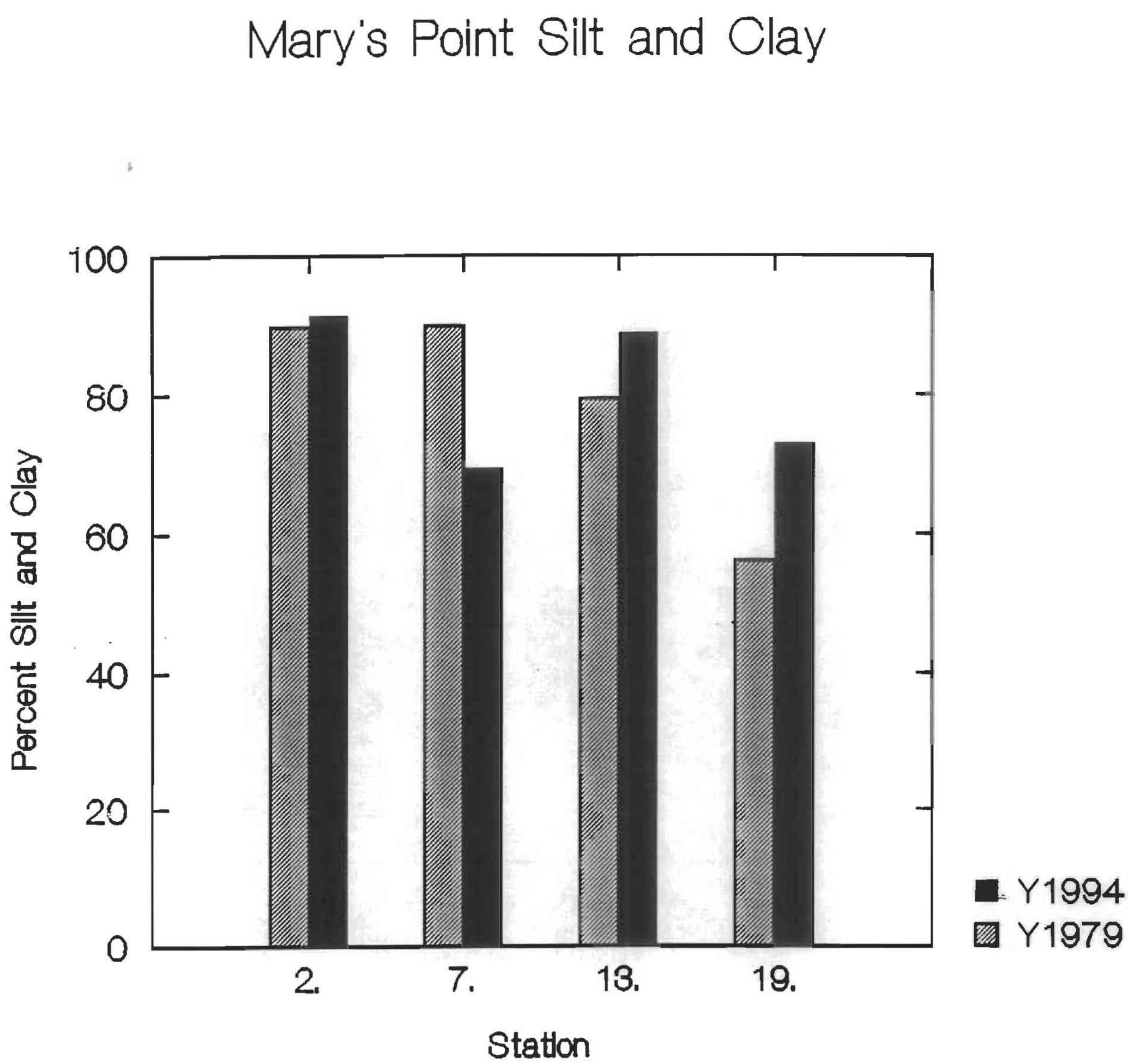
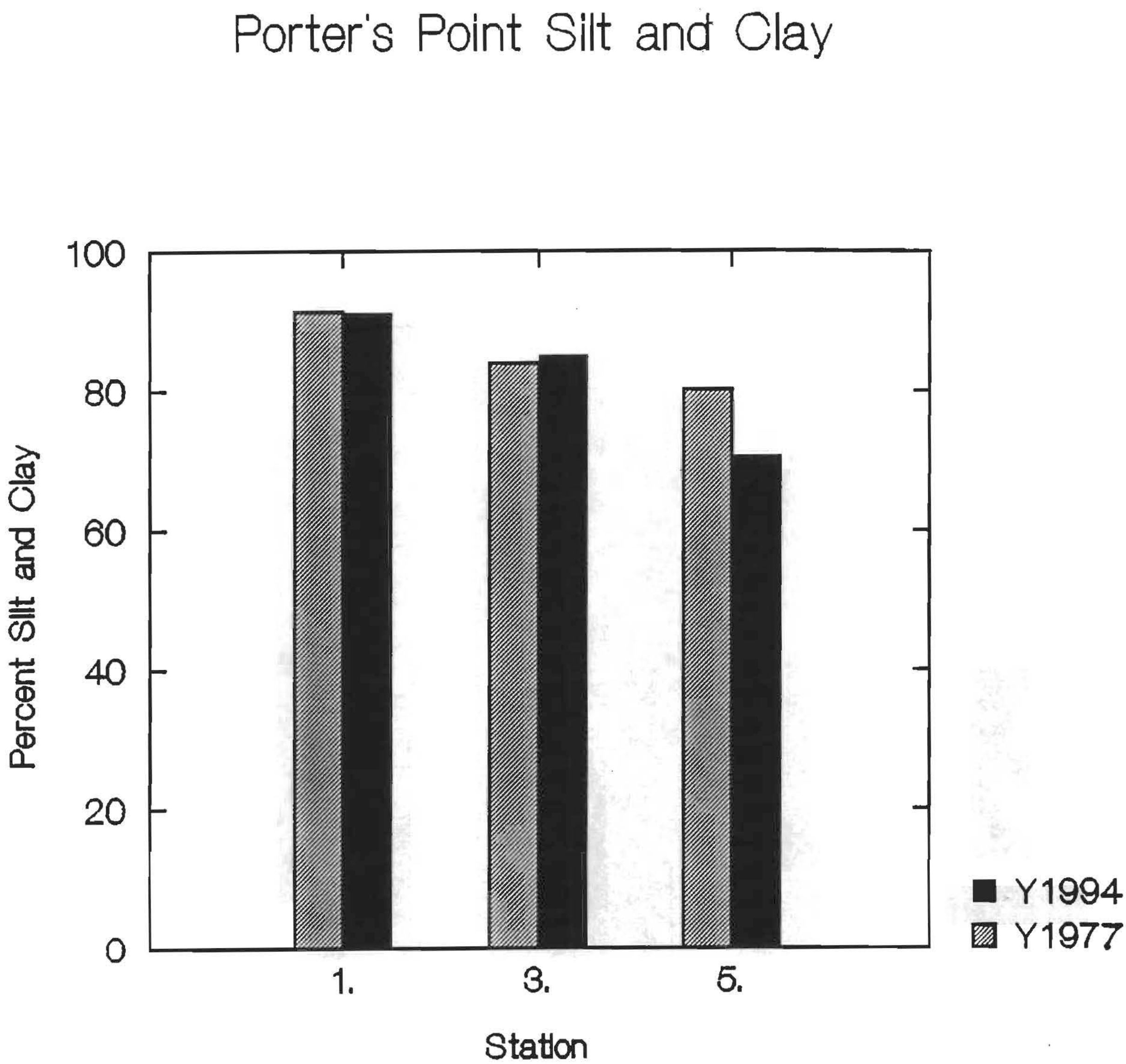

Mary's Point Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
2.
7.
13.
19.
Station
Y1994
Y1979

Figure 4.2



Porter's Point Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
1.
3.
5.
Station
Y1994
Y1977

Figure 4.3

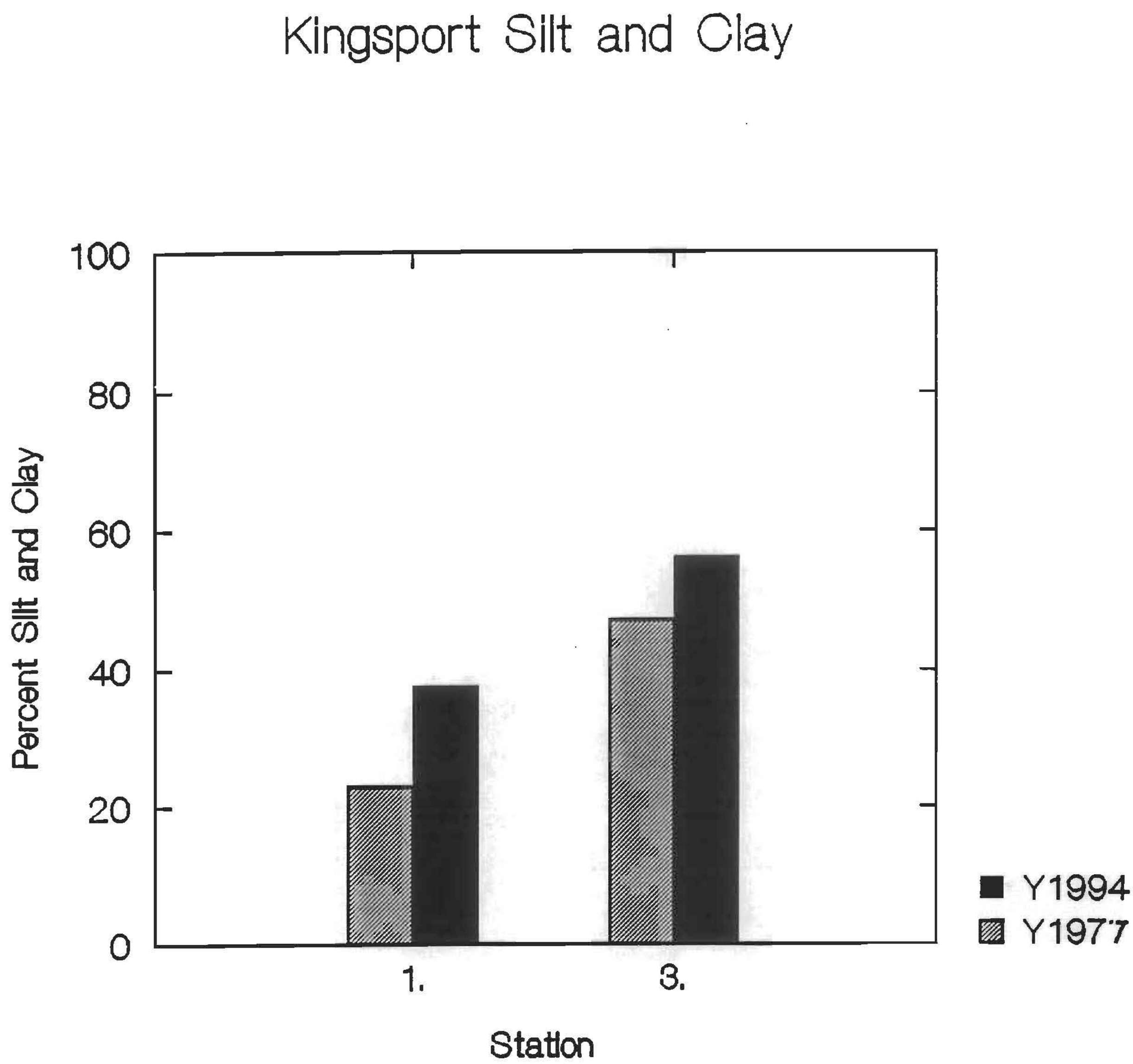

Kingsport Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
1.
3.
Station
Y1994
Y1977

Figure 4.4

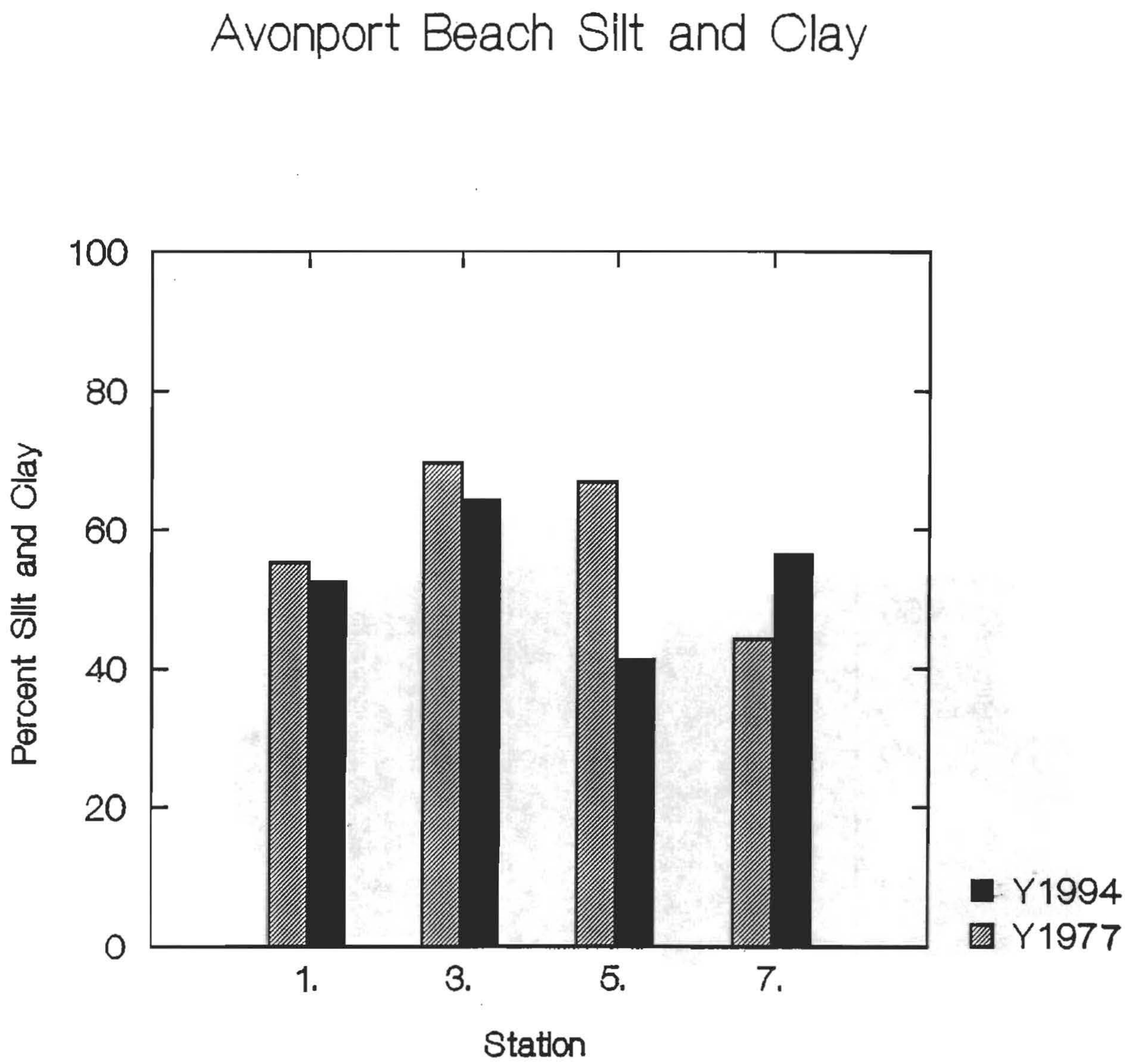

Avonport Beach Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
1.
3.
5.
7.
Station
Y1994
Y1977

Figure 4.5

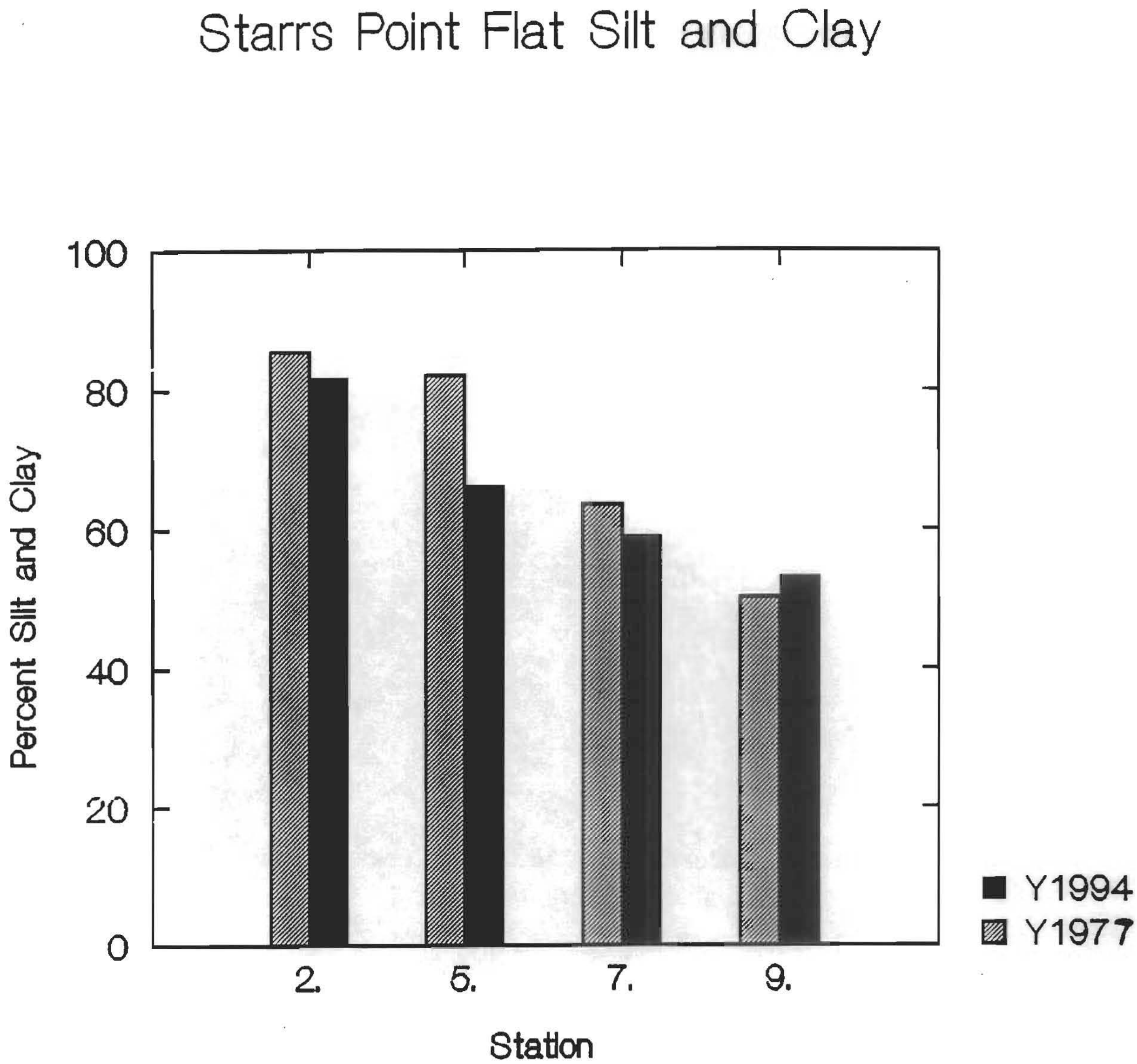
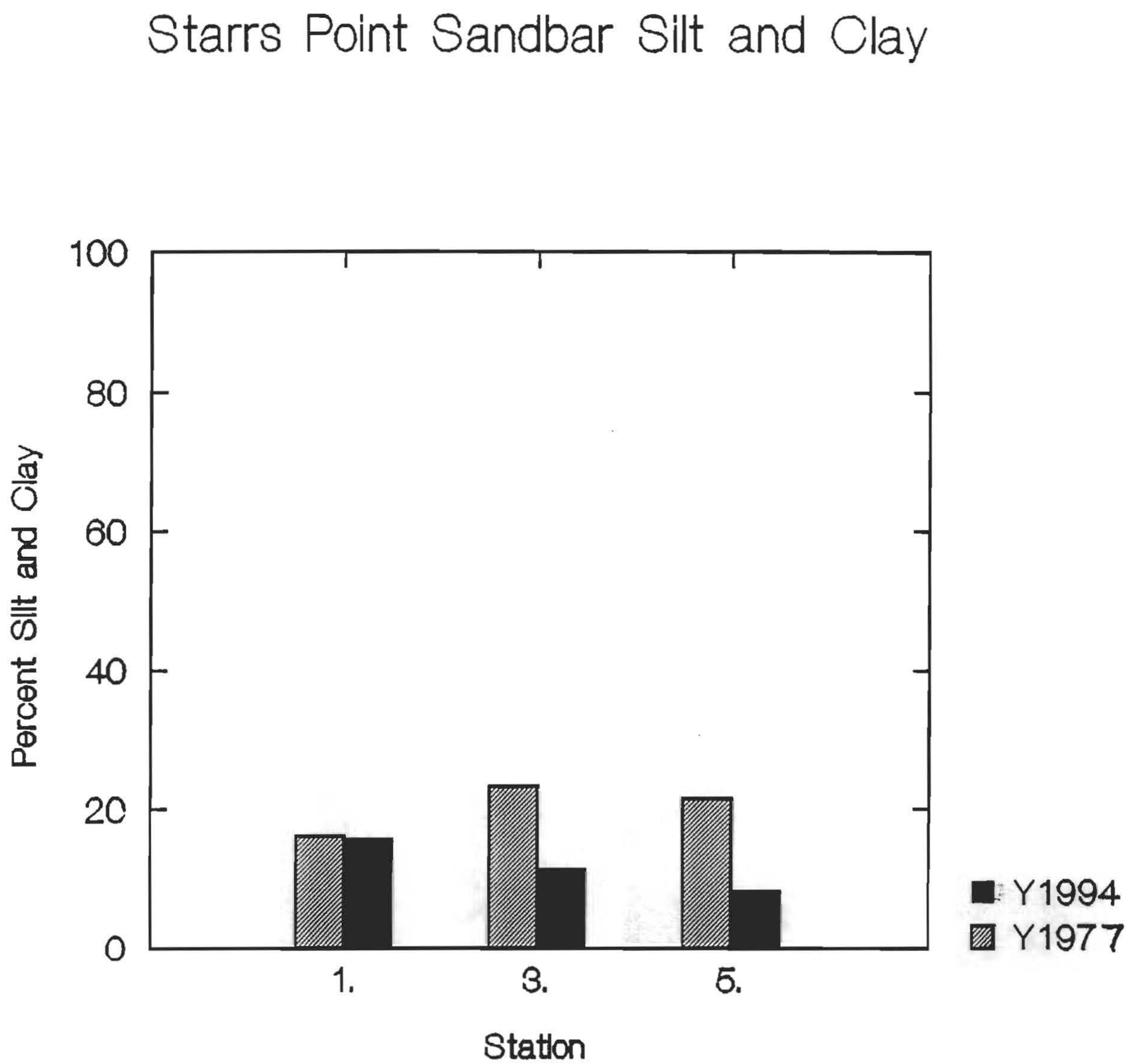

Starrs Point Flat Silt and Clay
Percent Silt and Clay
100
80
60
40
20
0
2.
5.
7.
9.
Station
Y1994
Y1977

Figure 4.6



Starrs Point Sandbar Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
1.
3.
5.
Station
Y1994
Y1977

Figure 4.7

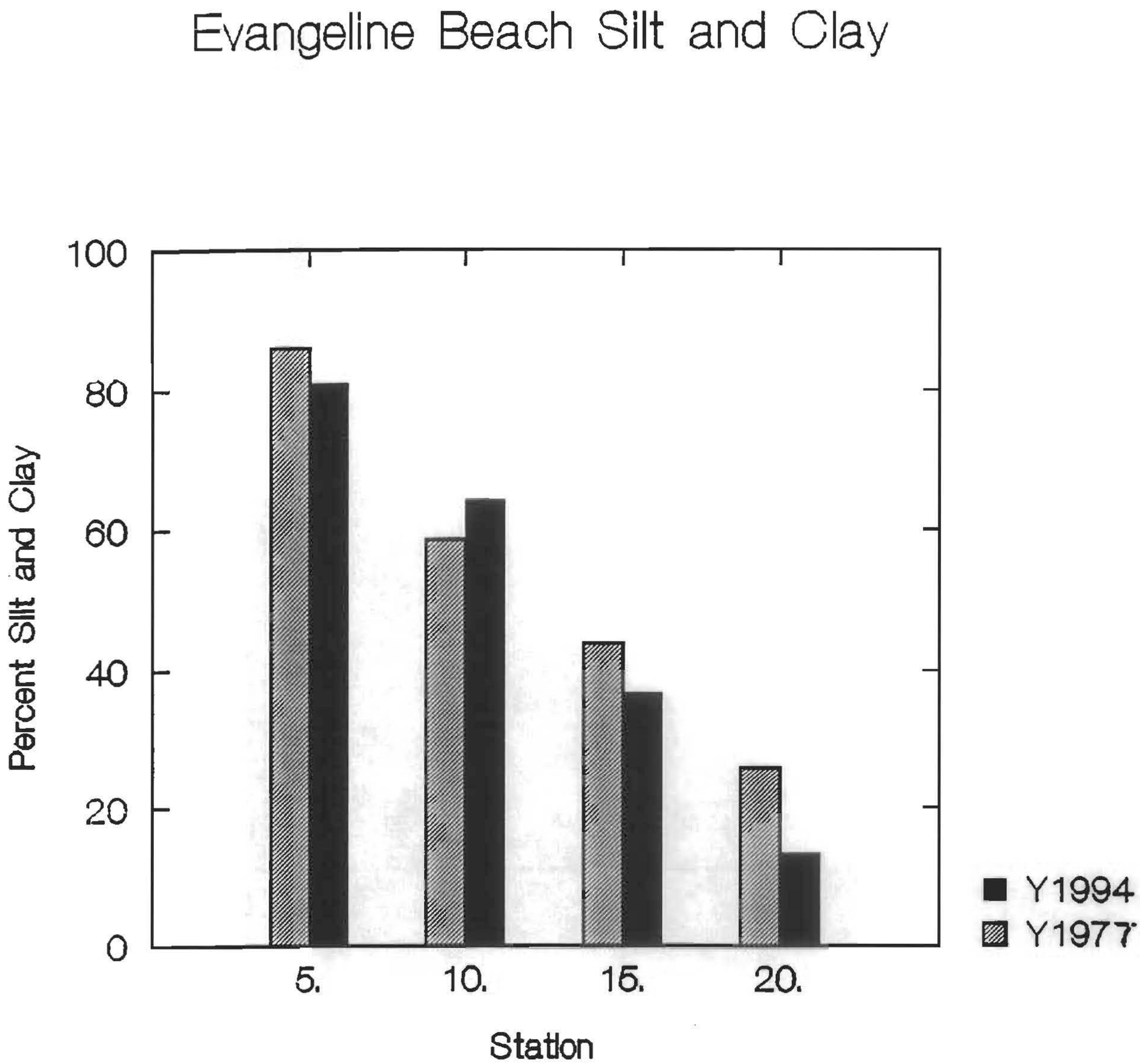
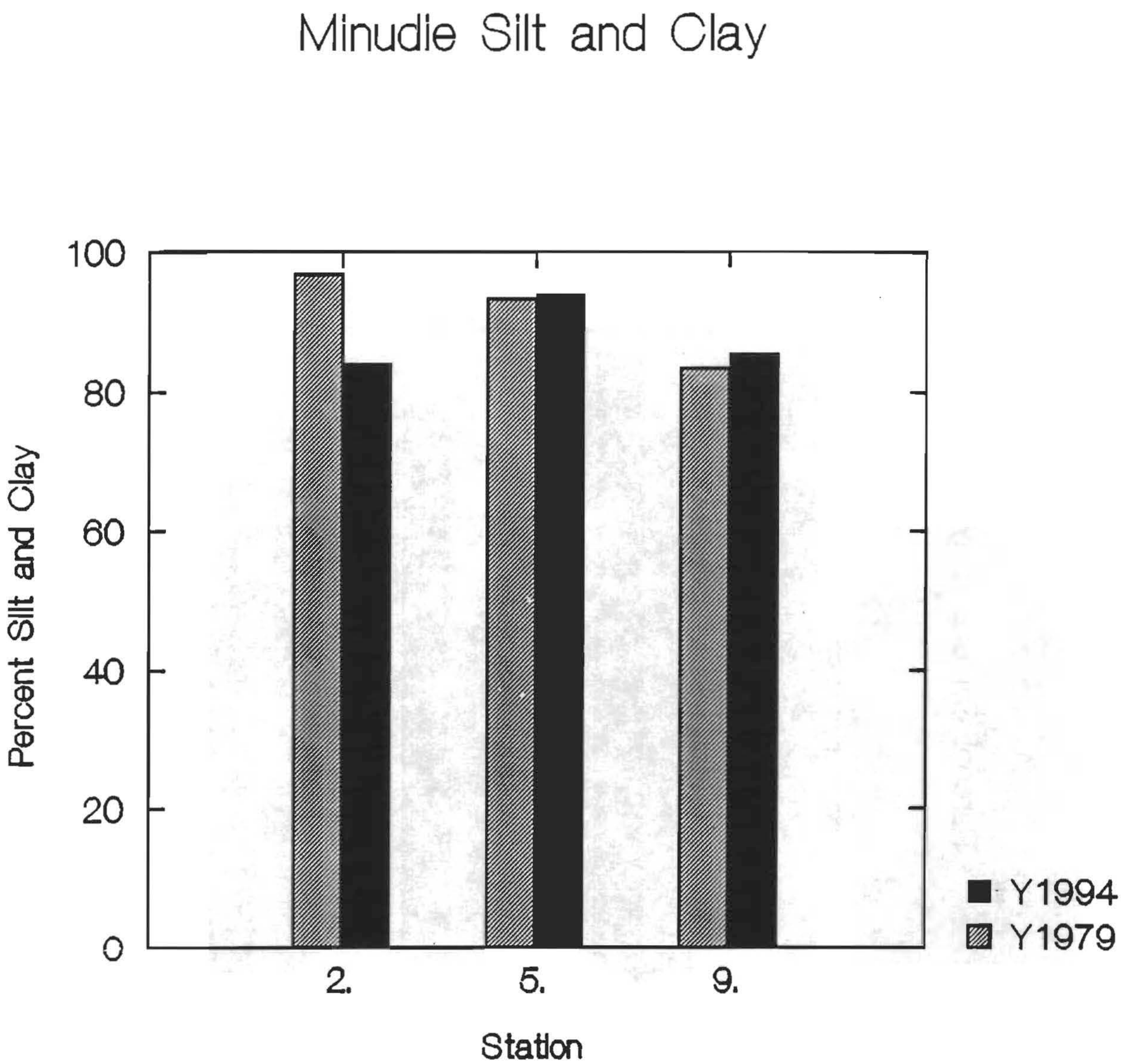

Evangeline Beach Silt and Clay
Percent Silt and Clay
100
80
60
40
20
0
5.
10.
15.
20.
Station
Y1994
Y1977

Figure 4.8



Minudie Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
2.
5.
9.
Station
Y1994
Y1979

Figure 4.9

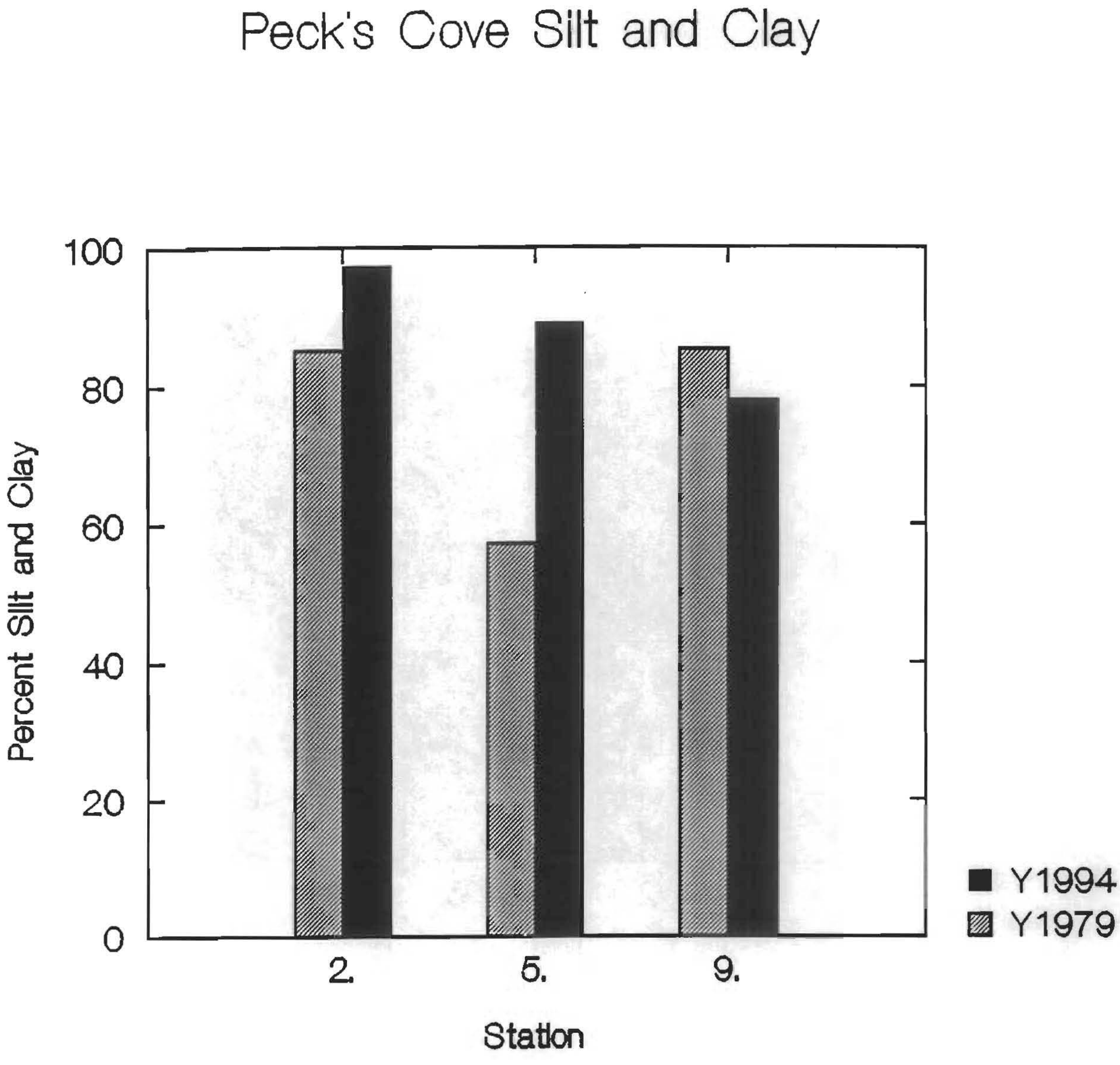

Peck's Cove Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
2.
5.
9.
Station
Y1994
Y1979

Figure 4.10

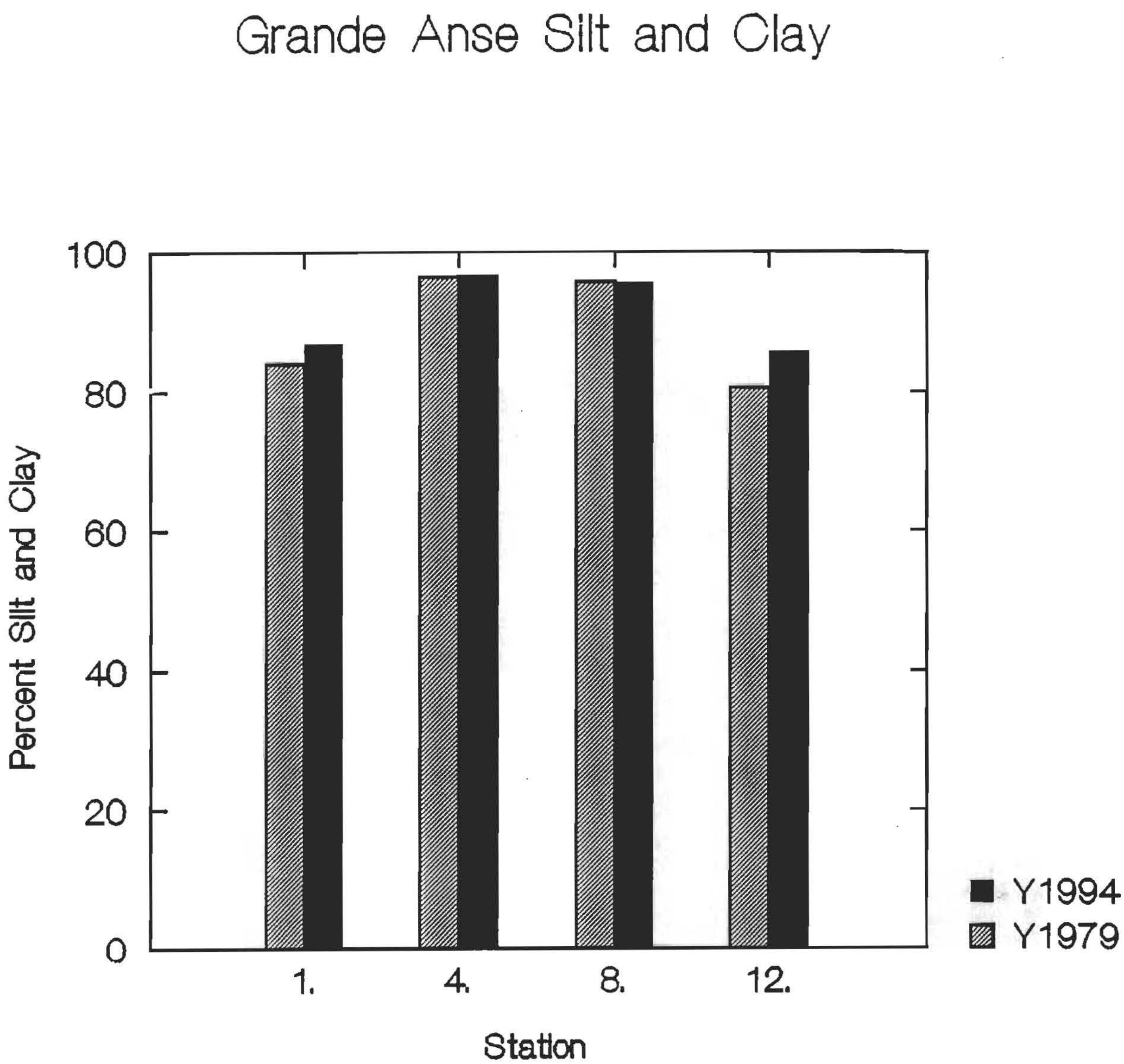

Grande Anse Silt and Clay
100
80
60
40
20
0
Percent Silt and Clay
1.
4.
8.
12.
Station
Y1994
Y1979

Figure 5.1

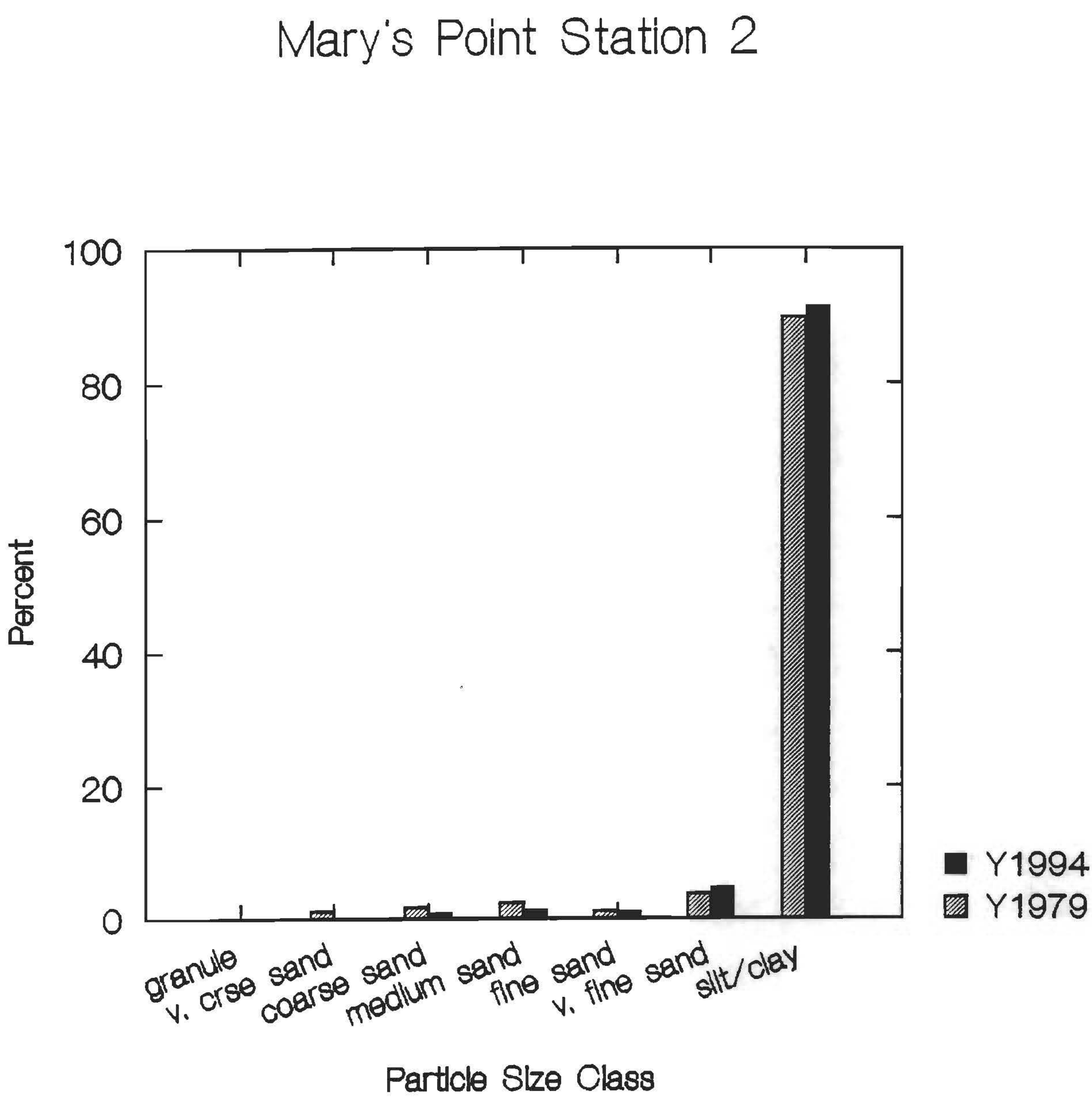

Mary's Point Station 2
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.2

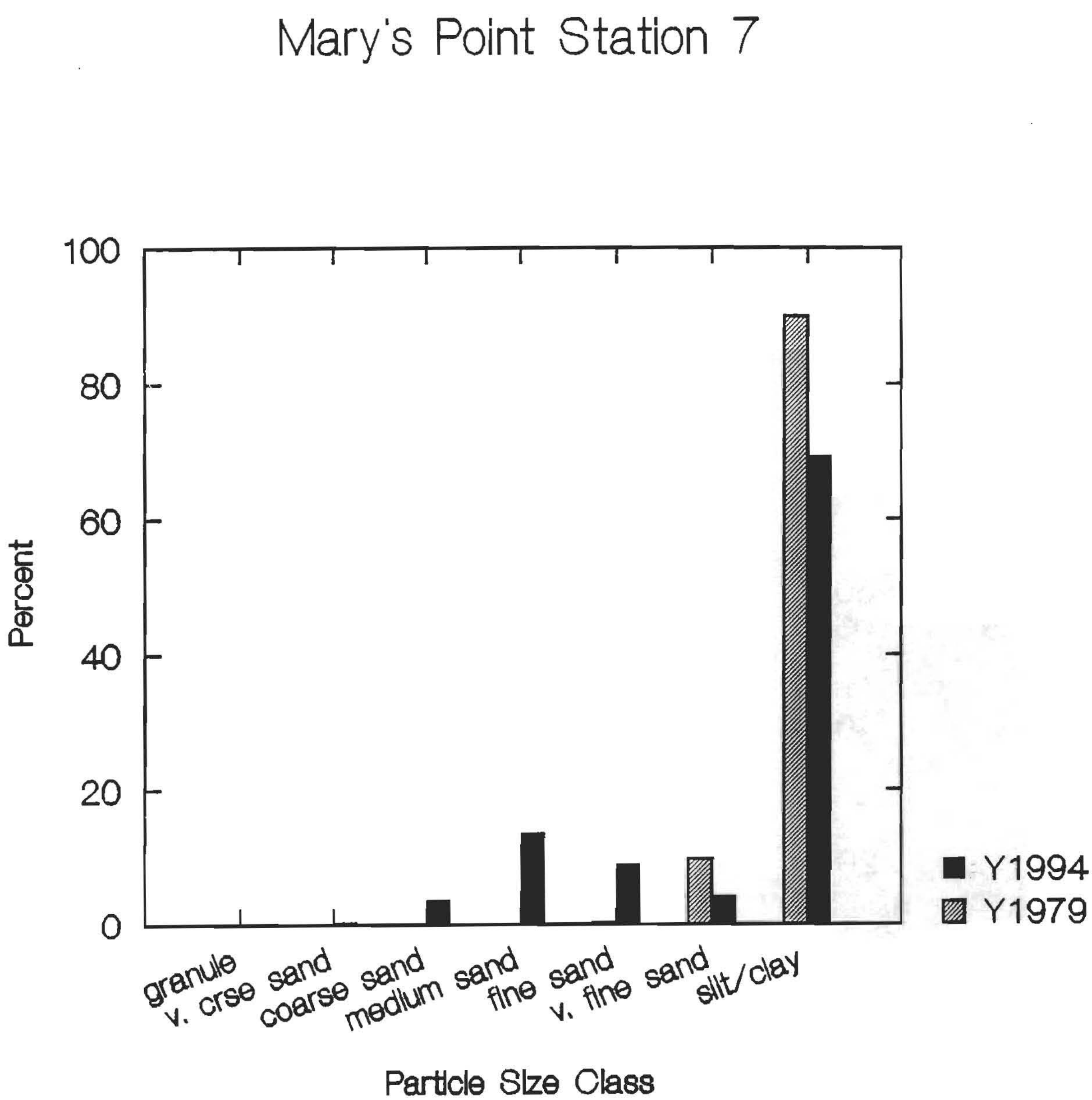
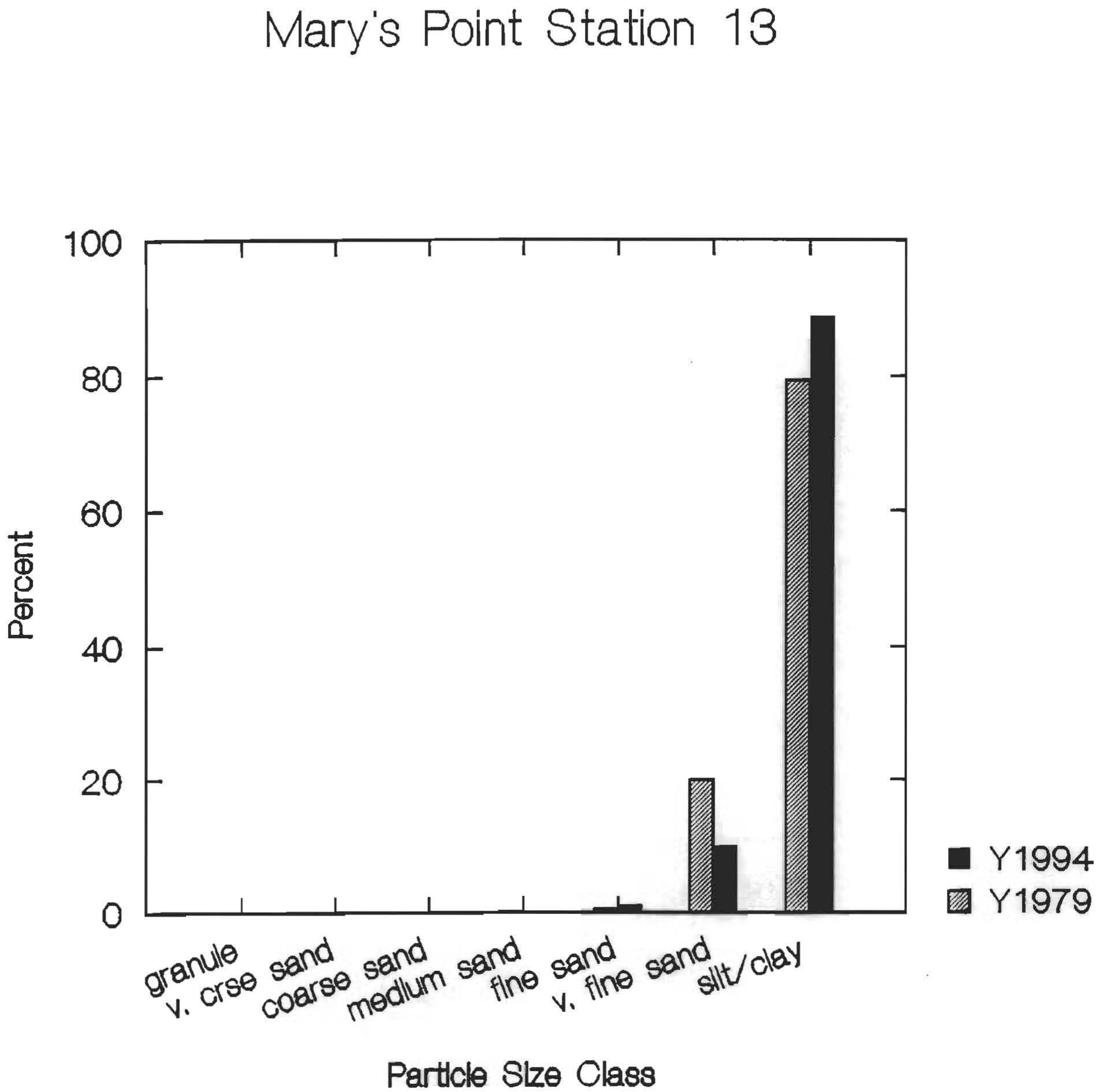

Mary's Point Station 7
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.3



Mary's Point Station 13
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.4

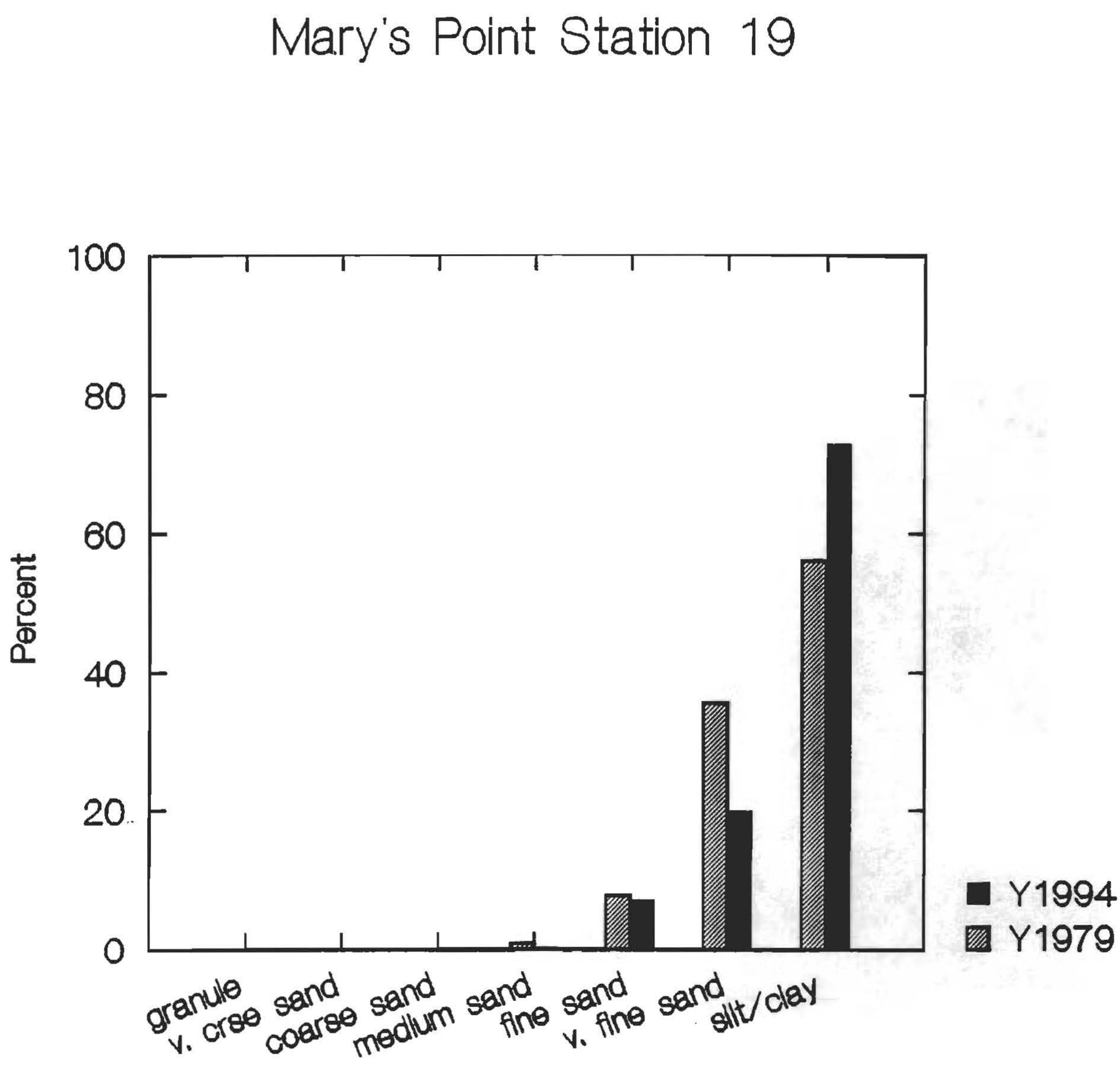

Mary's Point Station 19
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.5

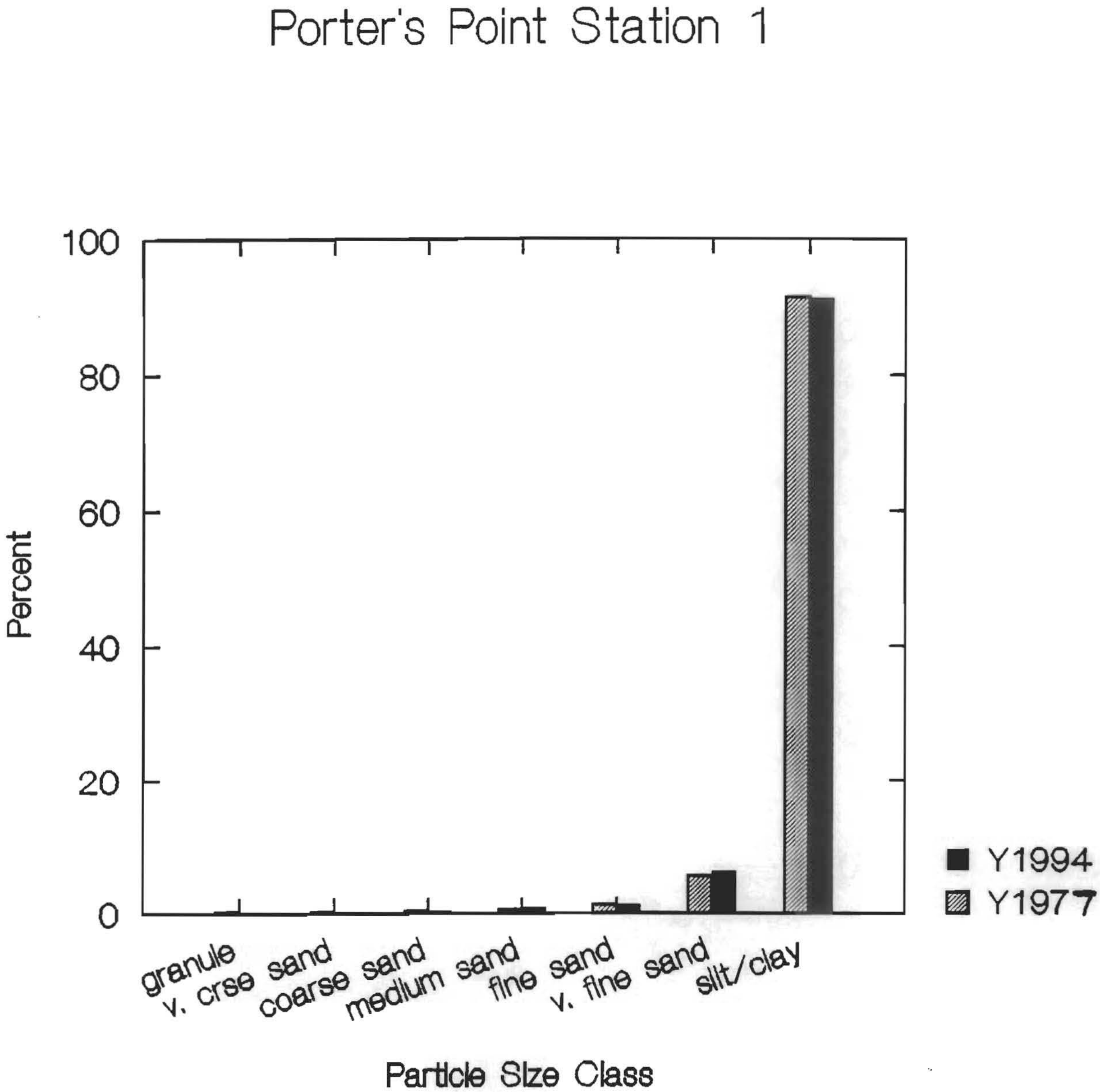
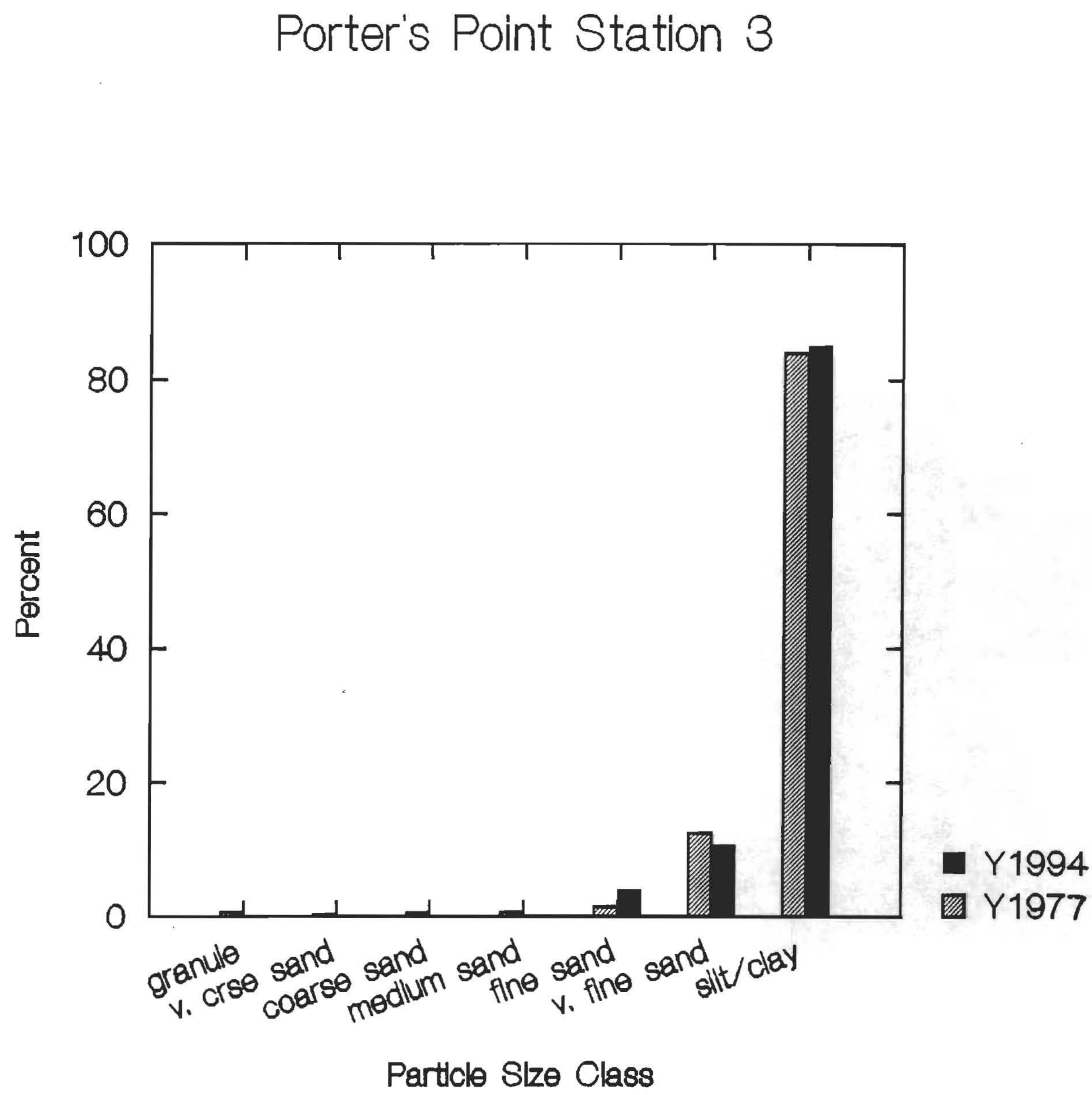

Porter's Point Station 1
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.6



Porter's Point Station 3
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.7

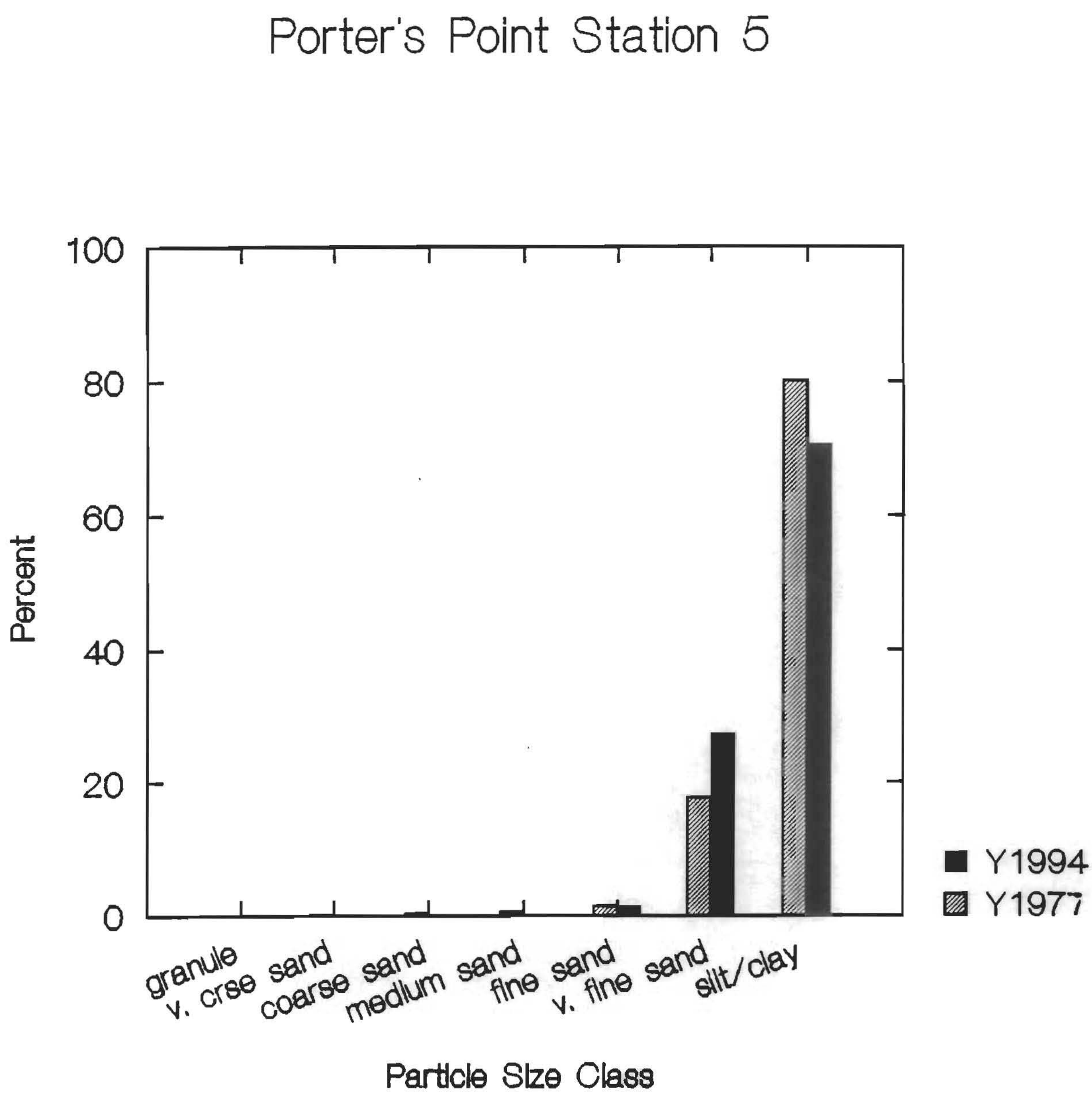
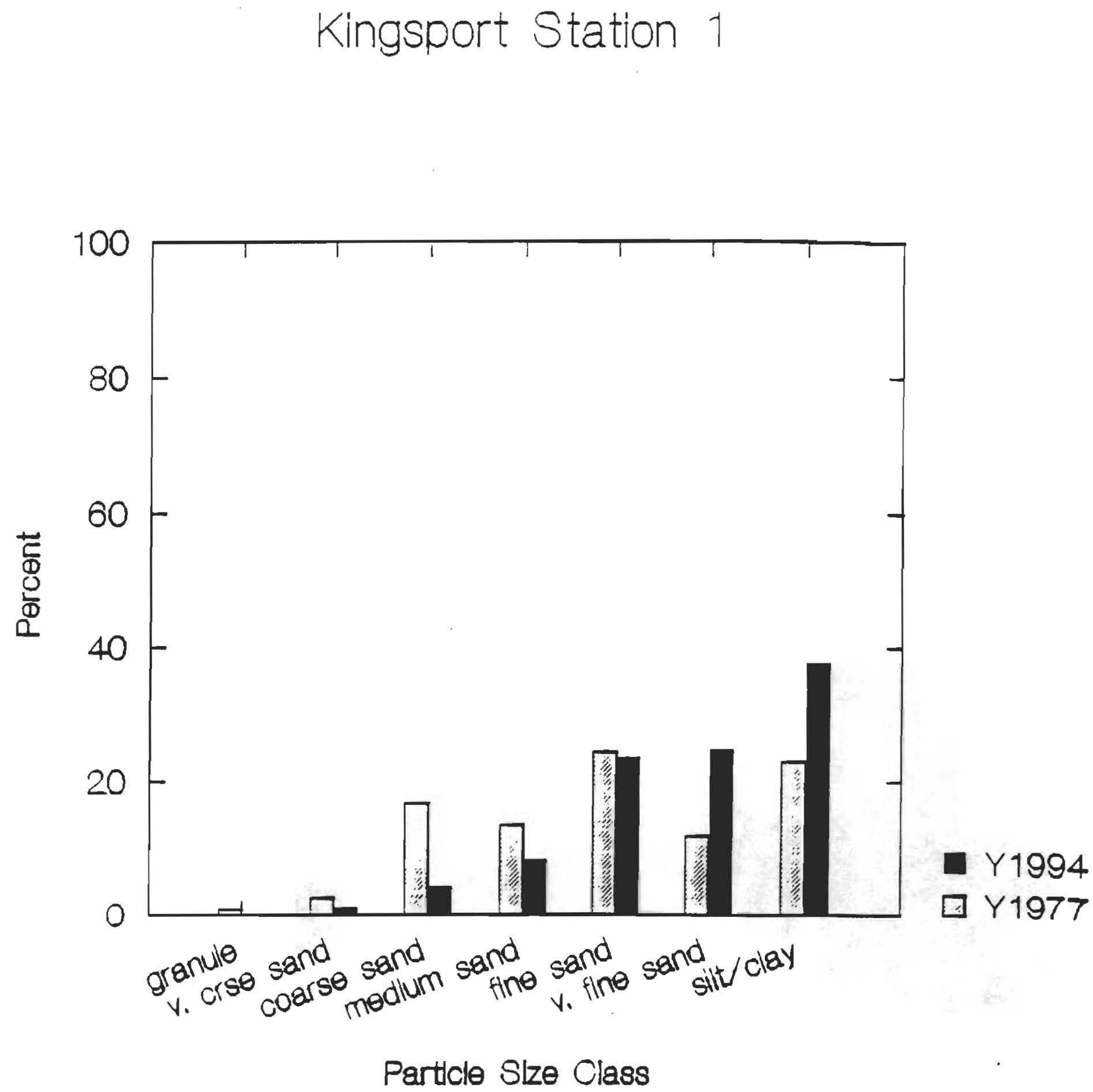

Porter's Point Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.8



Kingsport Station 1
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.9

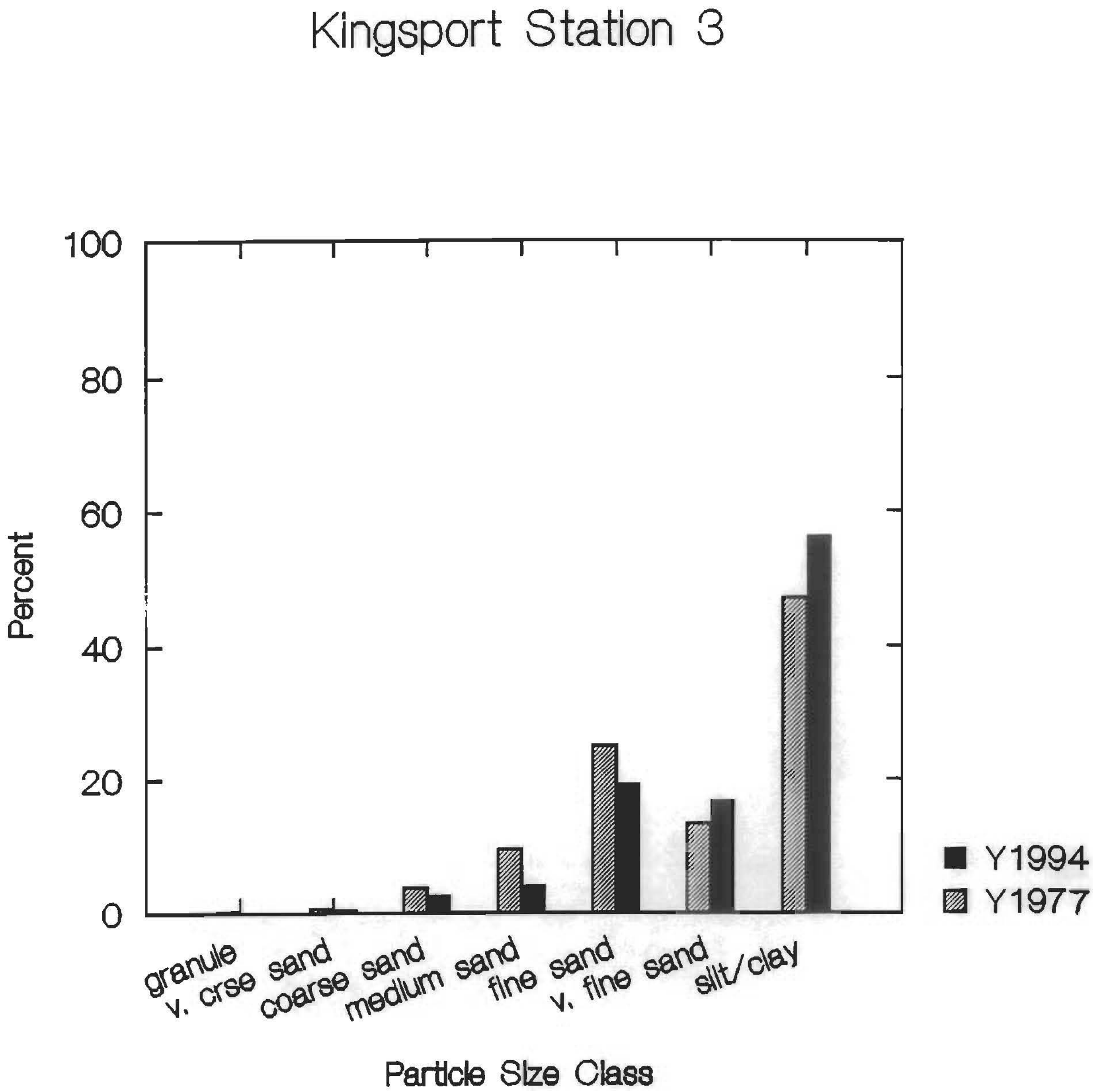

Kingsport Station 3
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.10

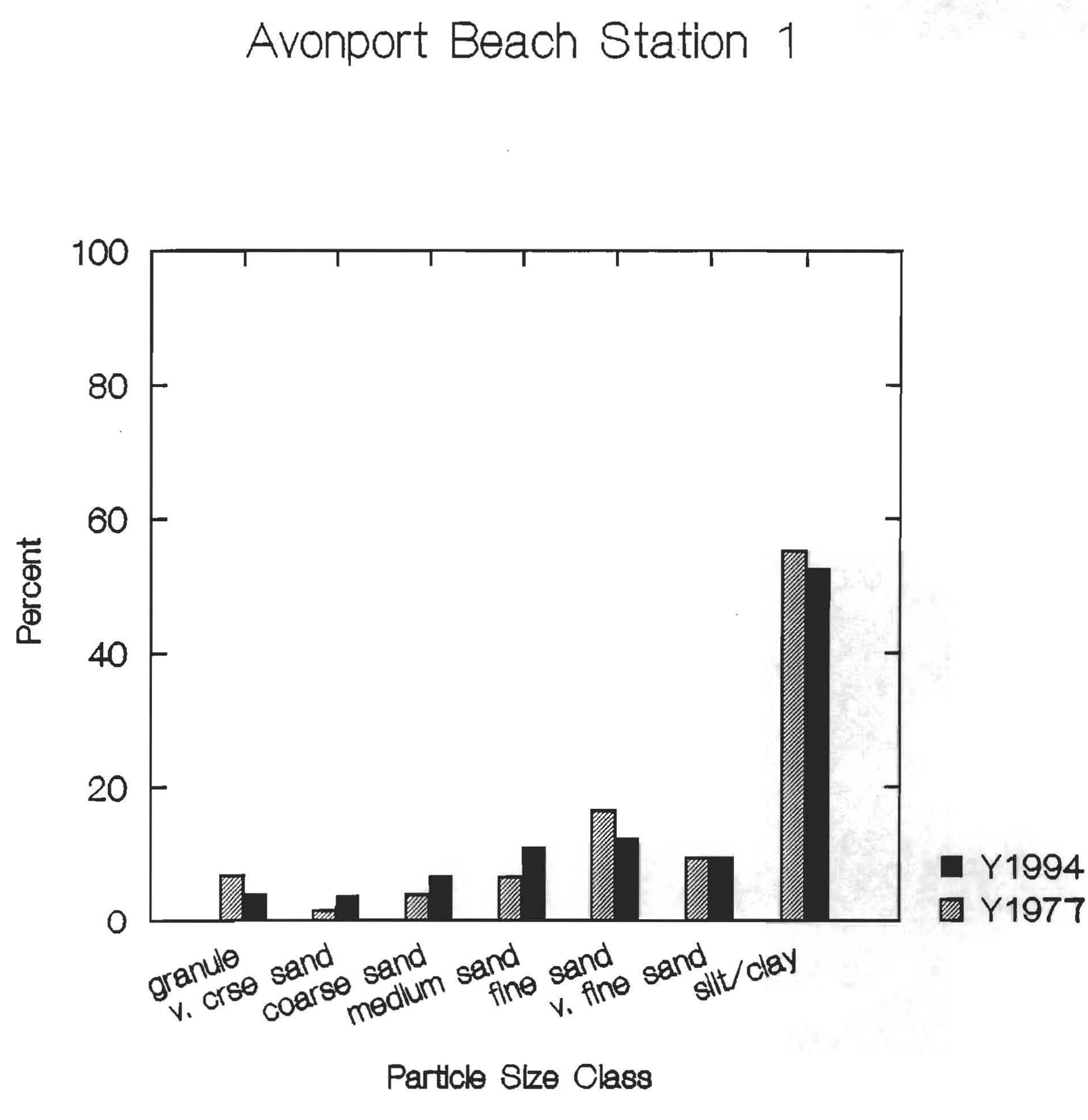

Avonport Beach Station 1
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.11

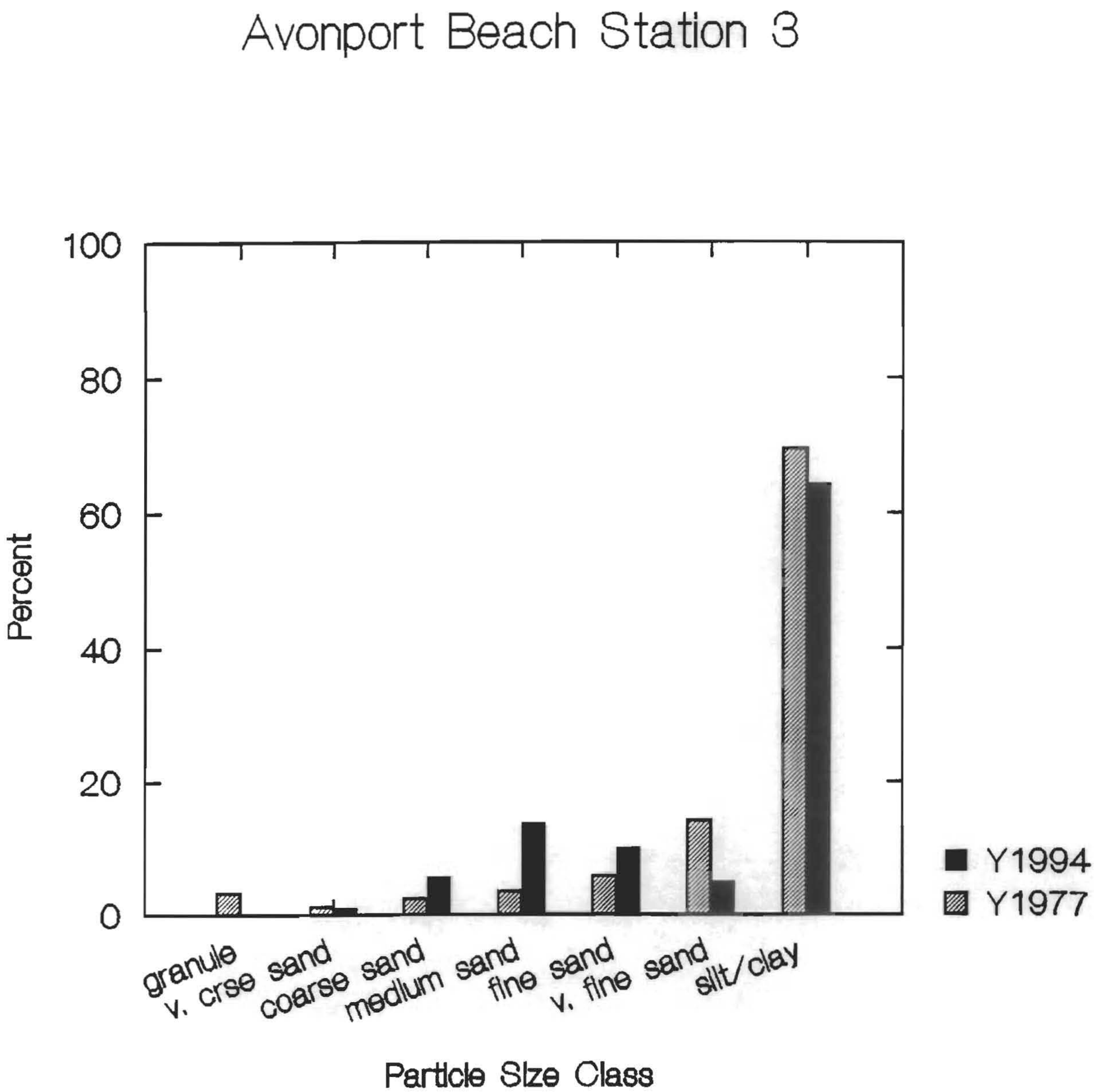

Avonport Beach Station 3
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.12 (a)

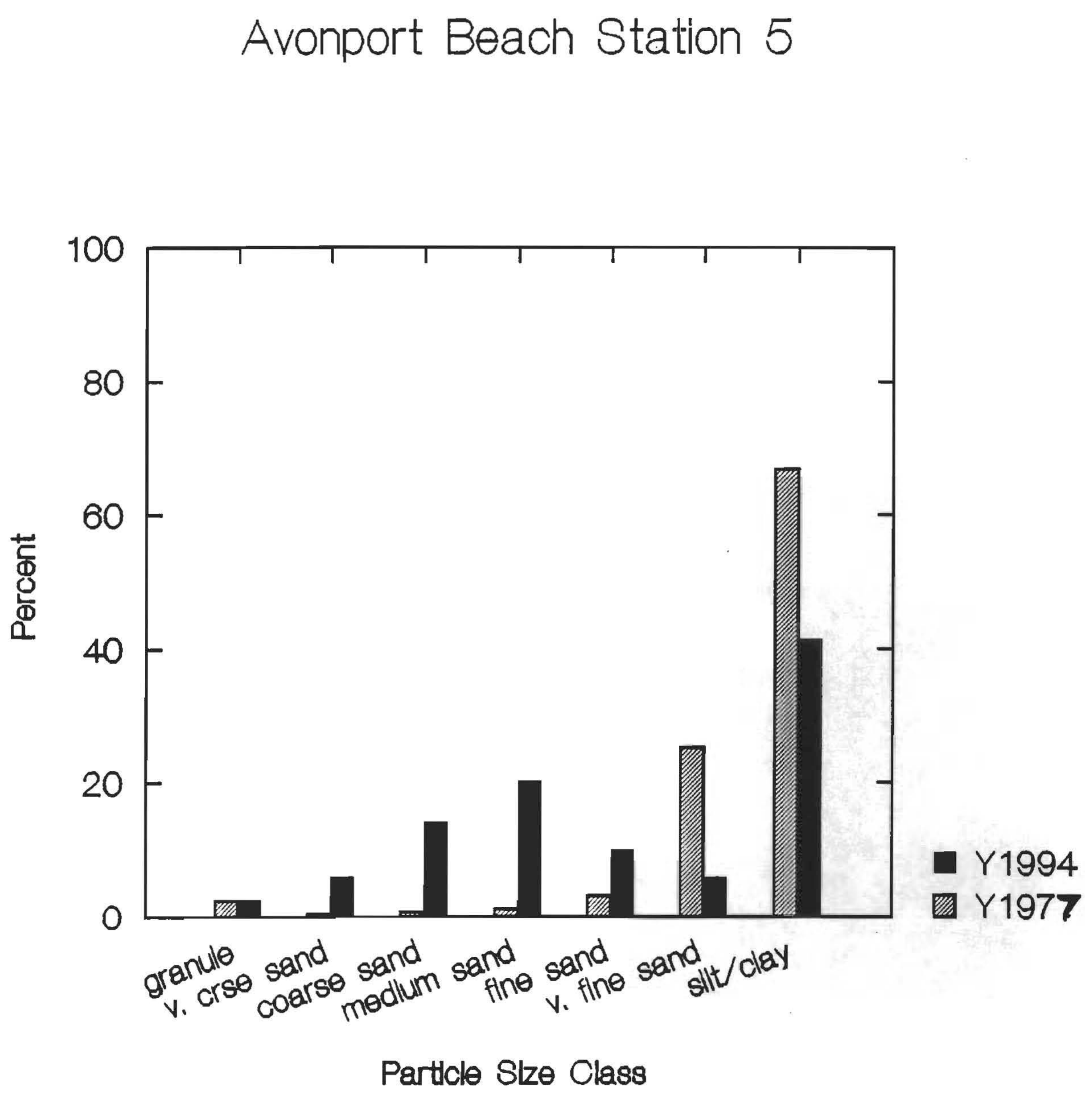
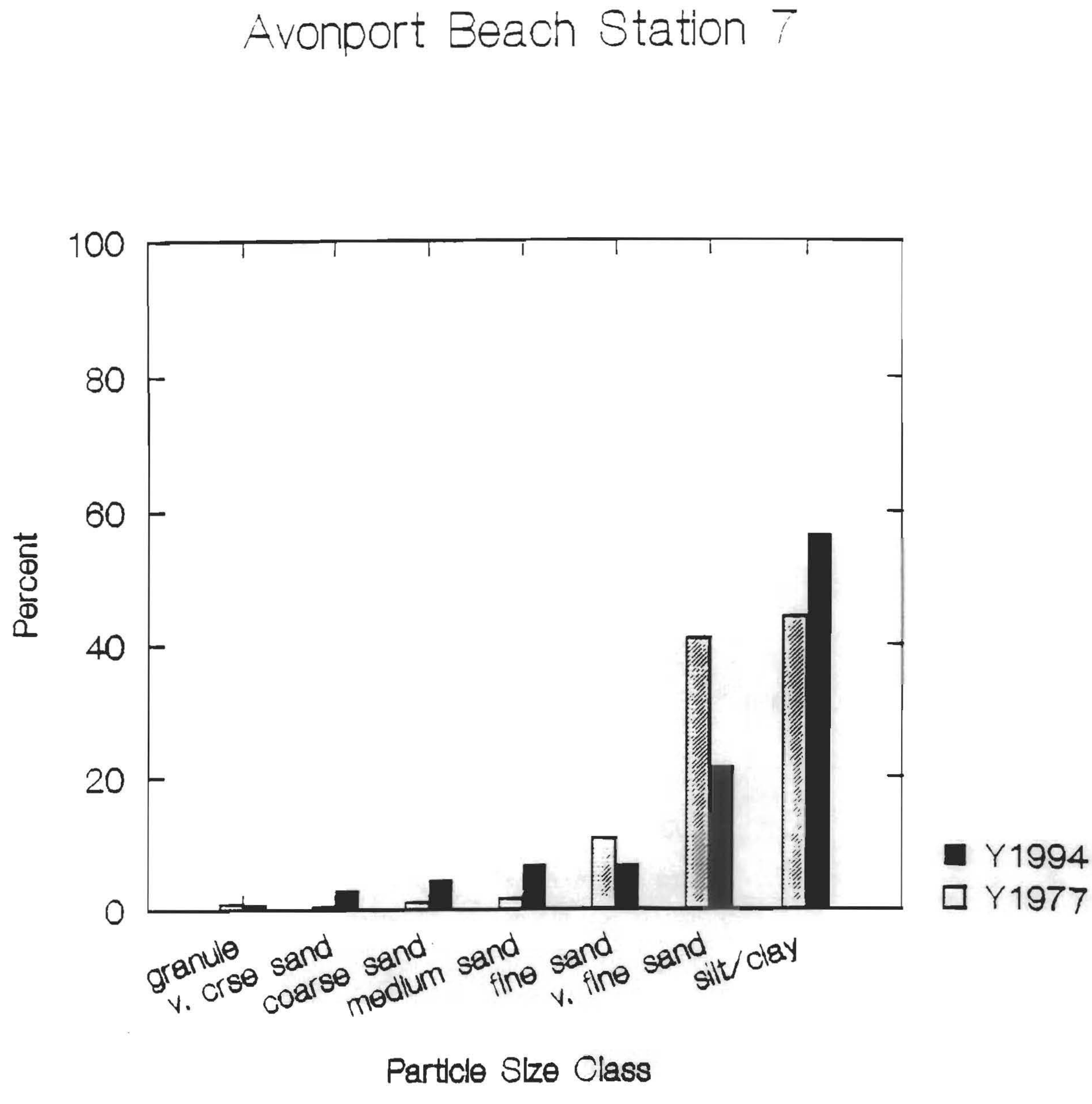
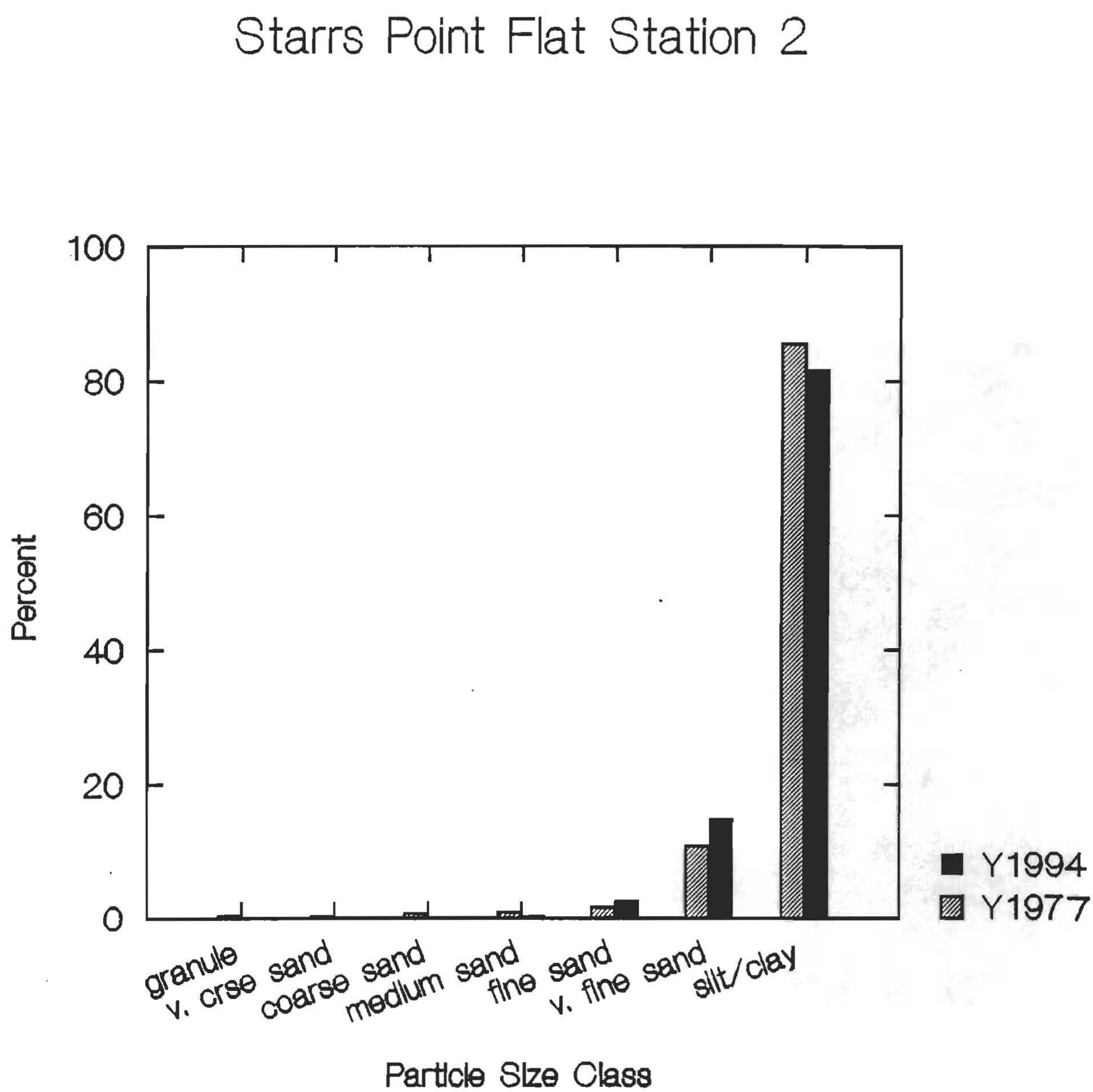

Avonport Beach Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.12 (b)



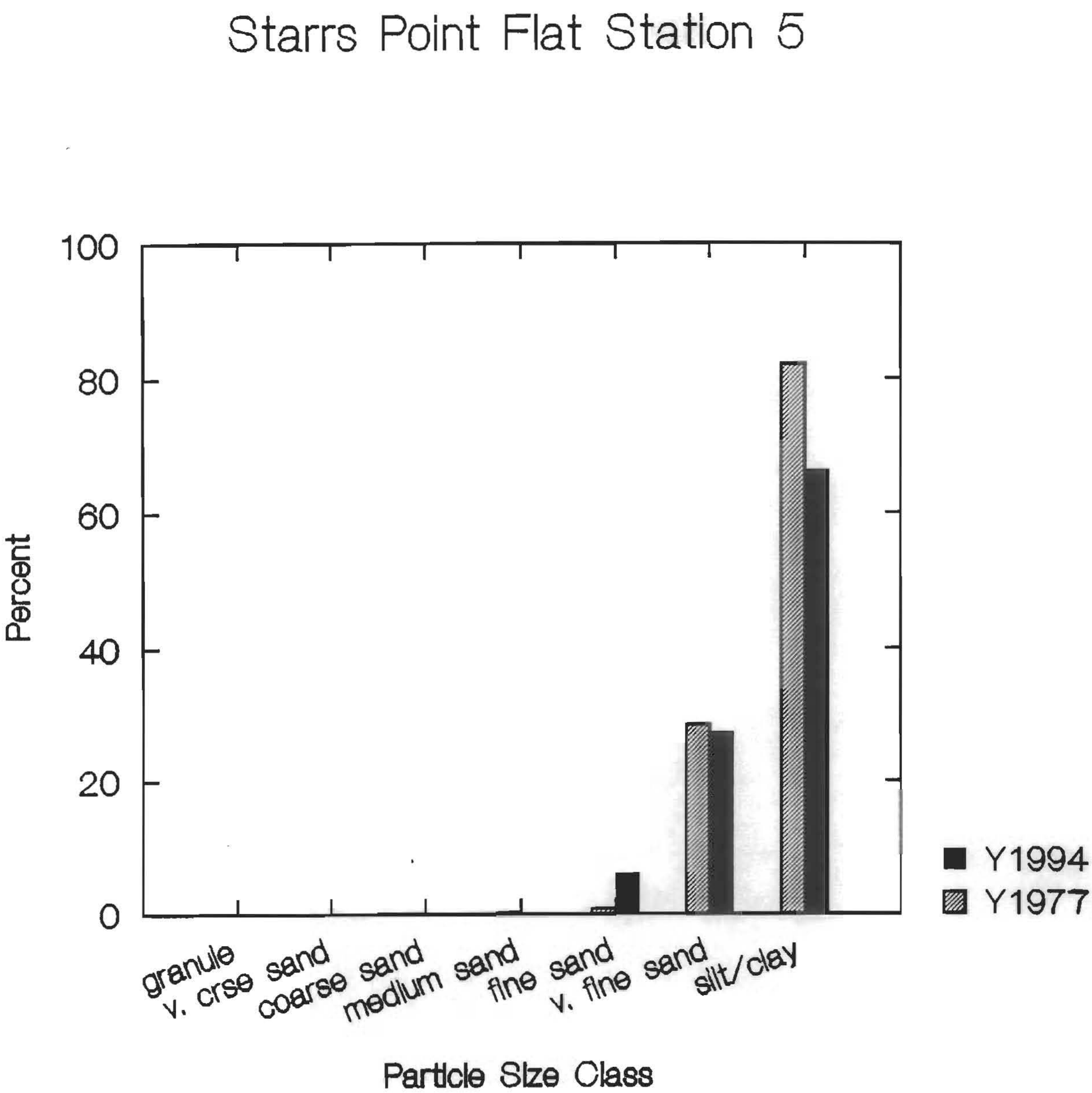
Avonport Beach Station 7
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.13



Starrs Point Flat Station 2
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.14



Starrs Point Flat Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.15

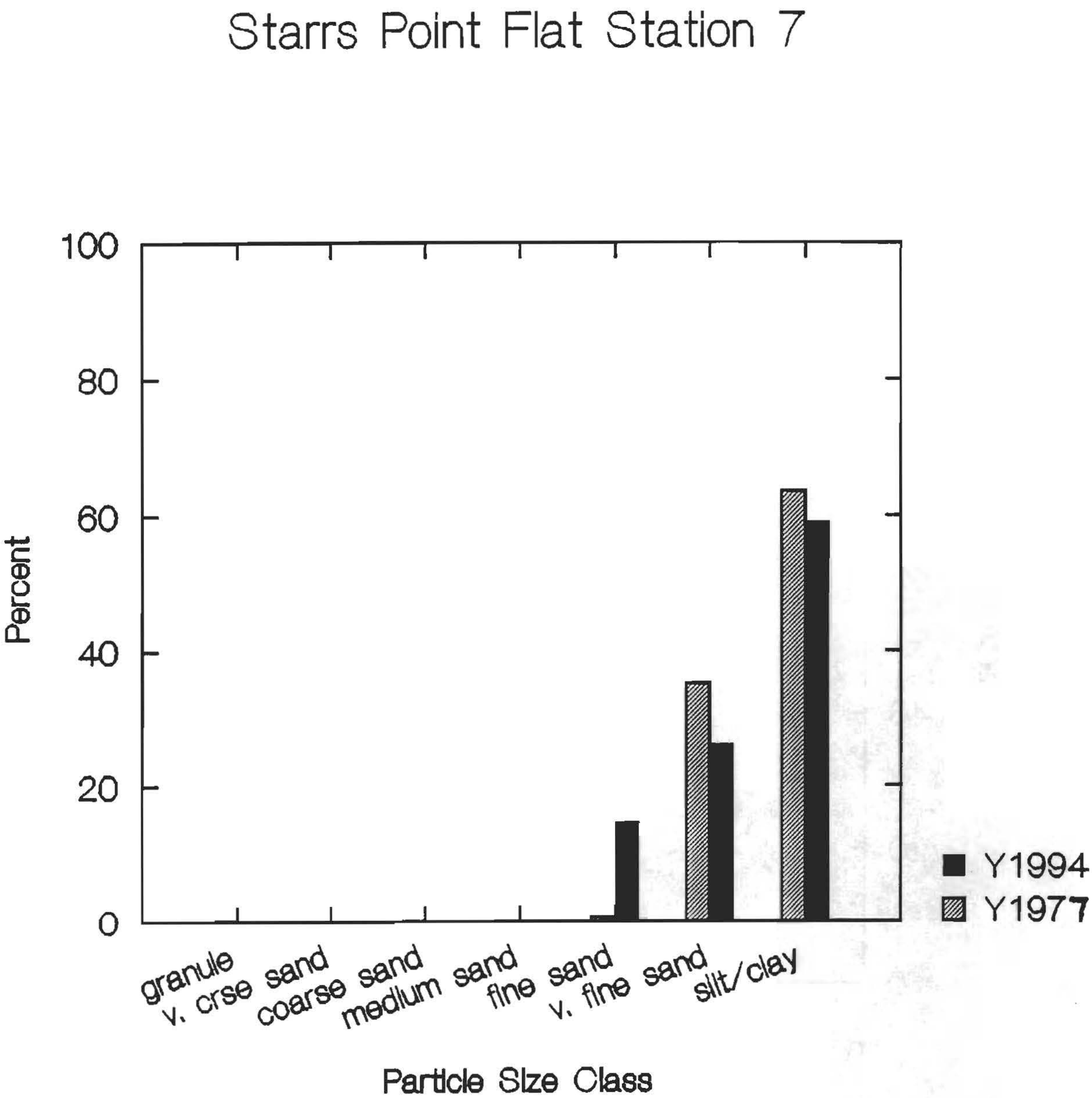

Starrs Point Flat Station 7
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.16

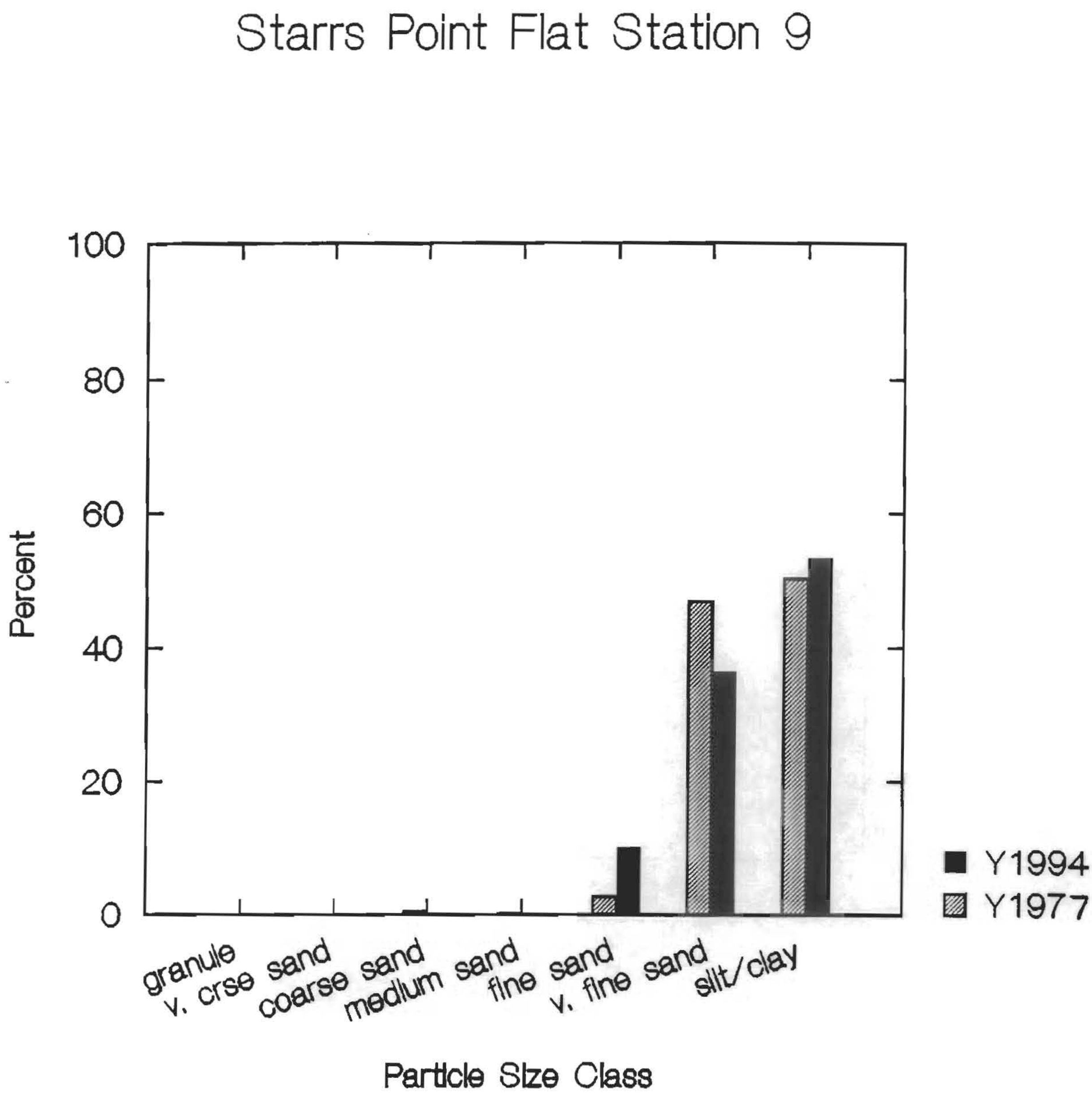
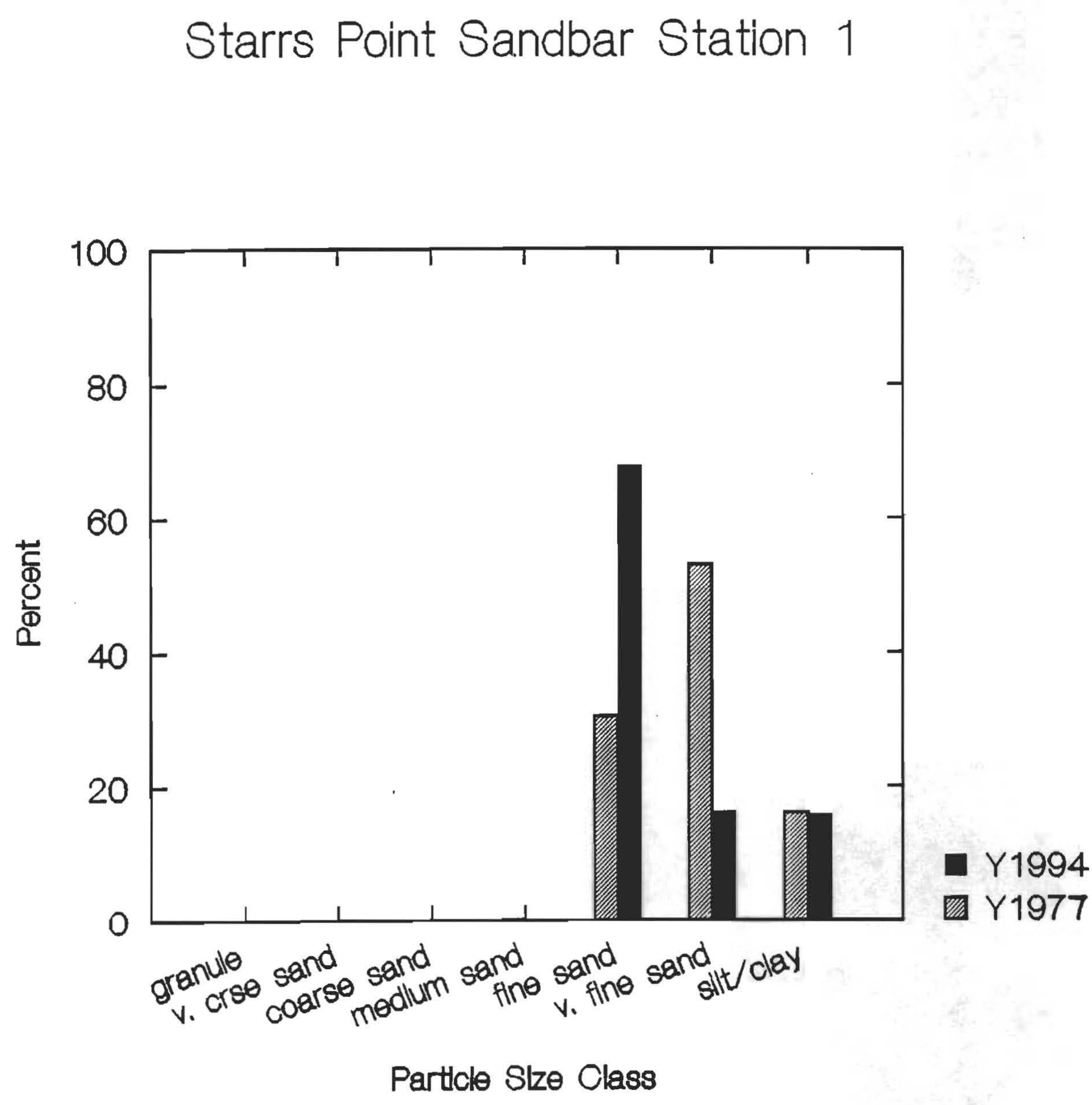
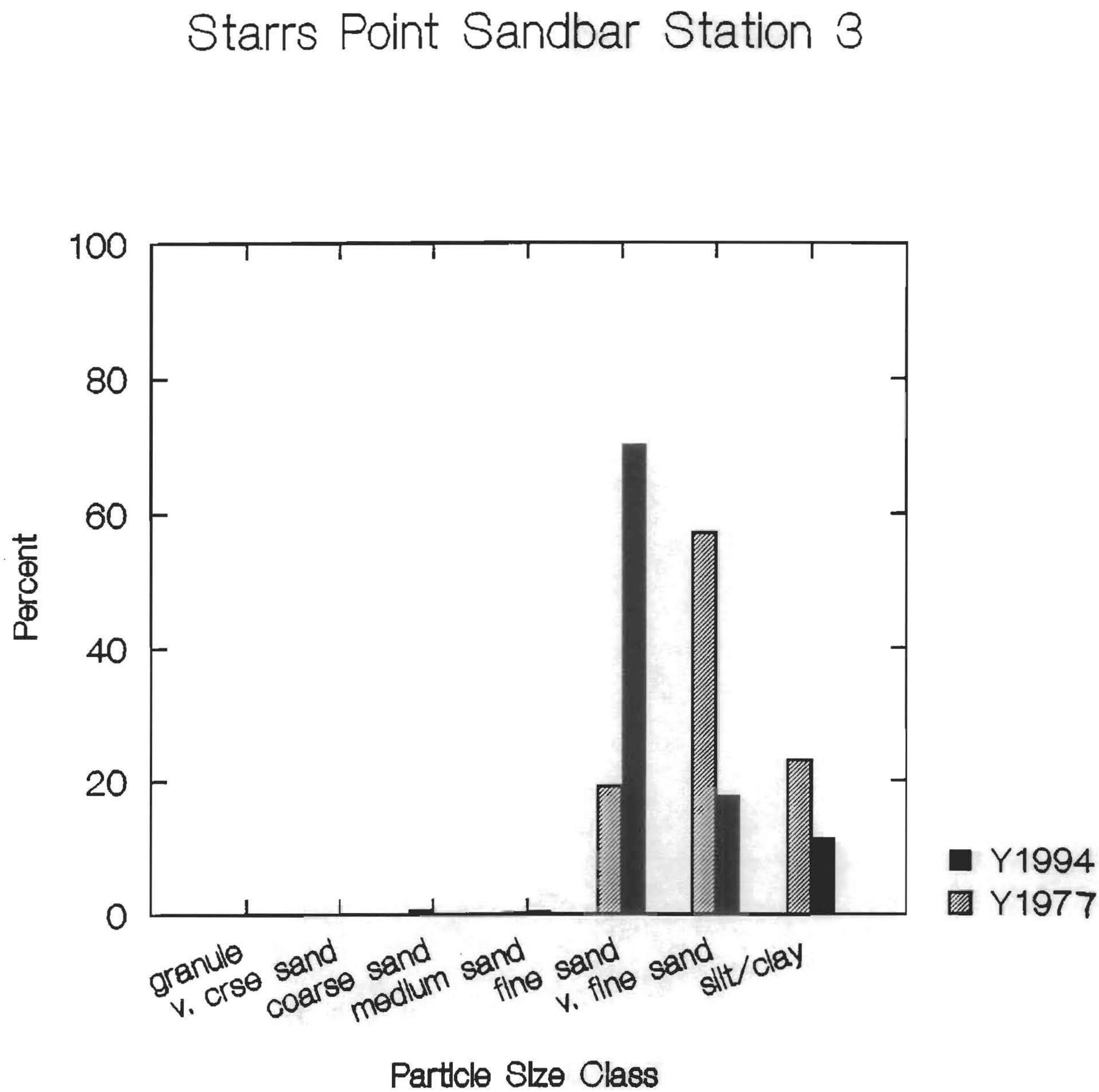

Starrs Point Flat Station 9
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.17



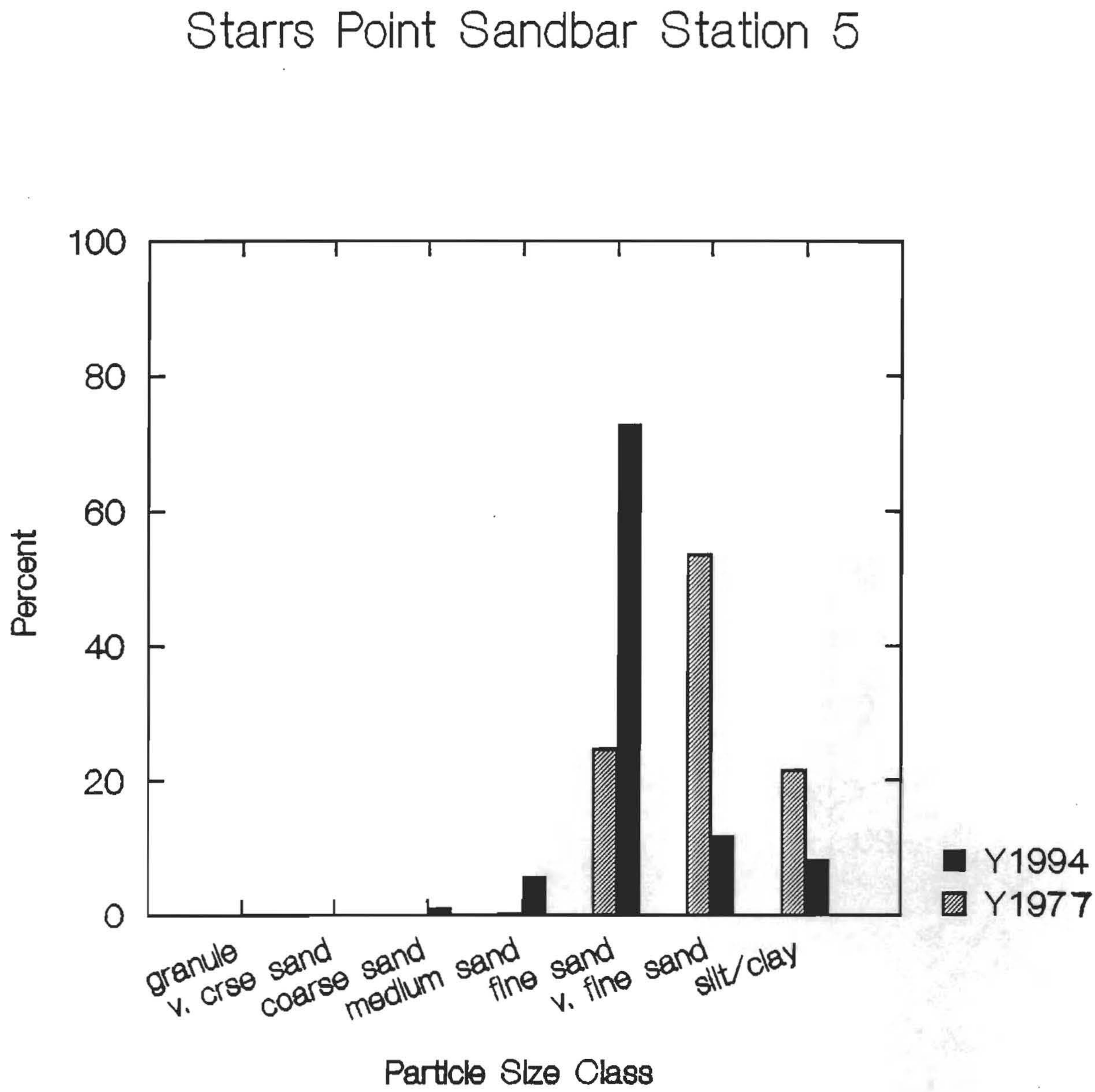
Starrs Point Sandbar Station 1
Percent
100
80
60
40
20
0
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.18



Starrs Point Sandbar Station 3
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.19



Starrs Point Sandbar Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.20

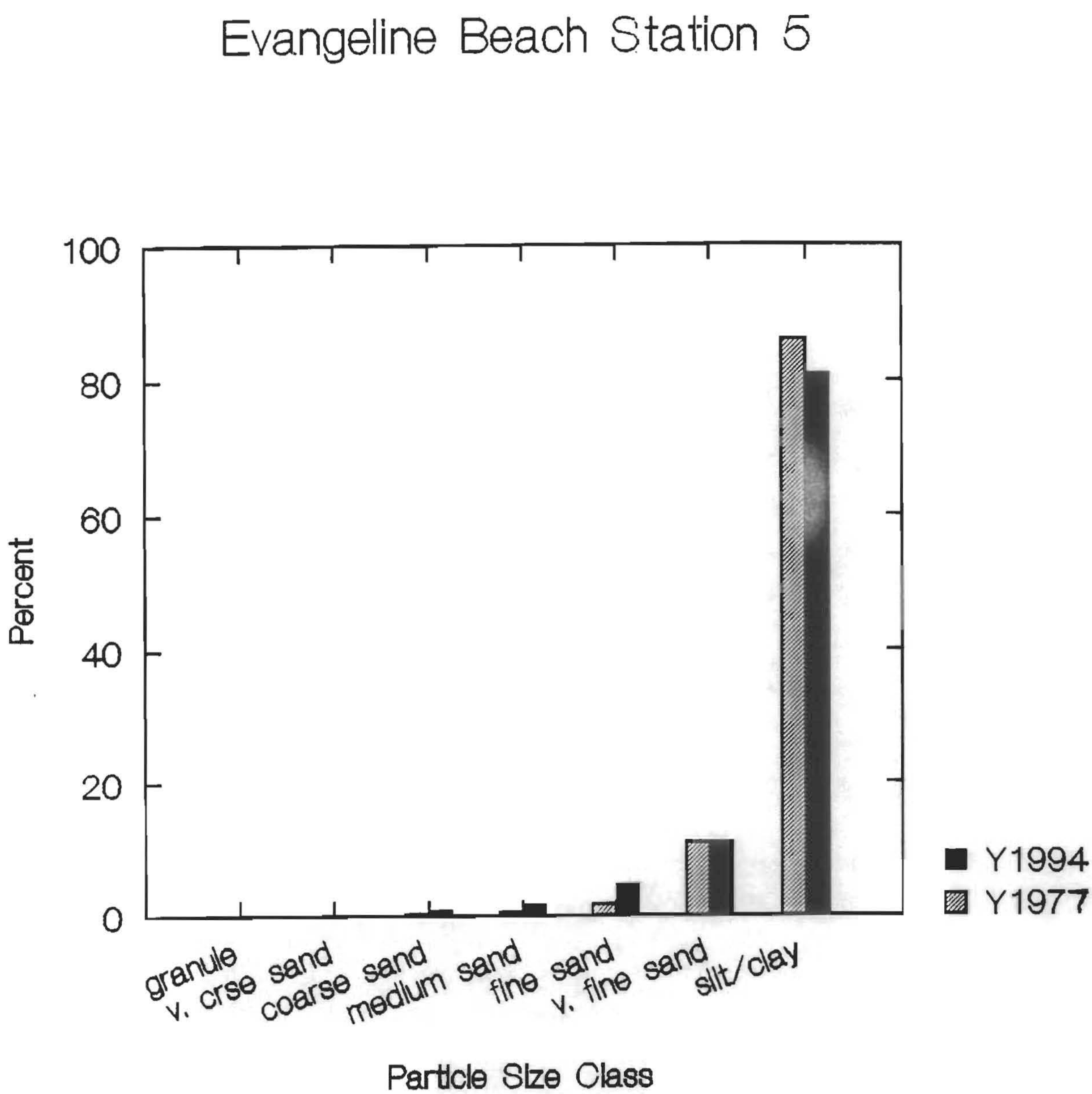

Evangeline Beach Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.21

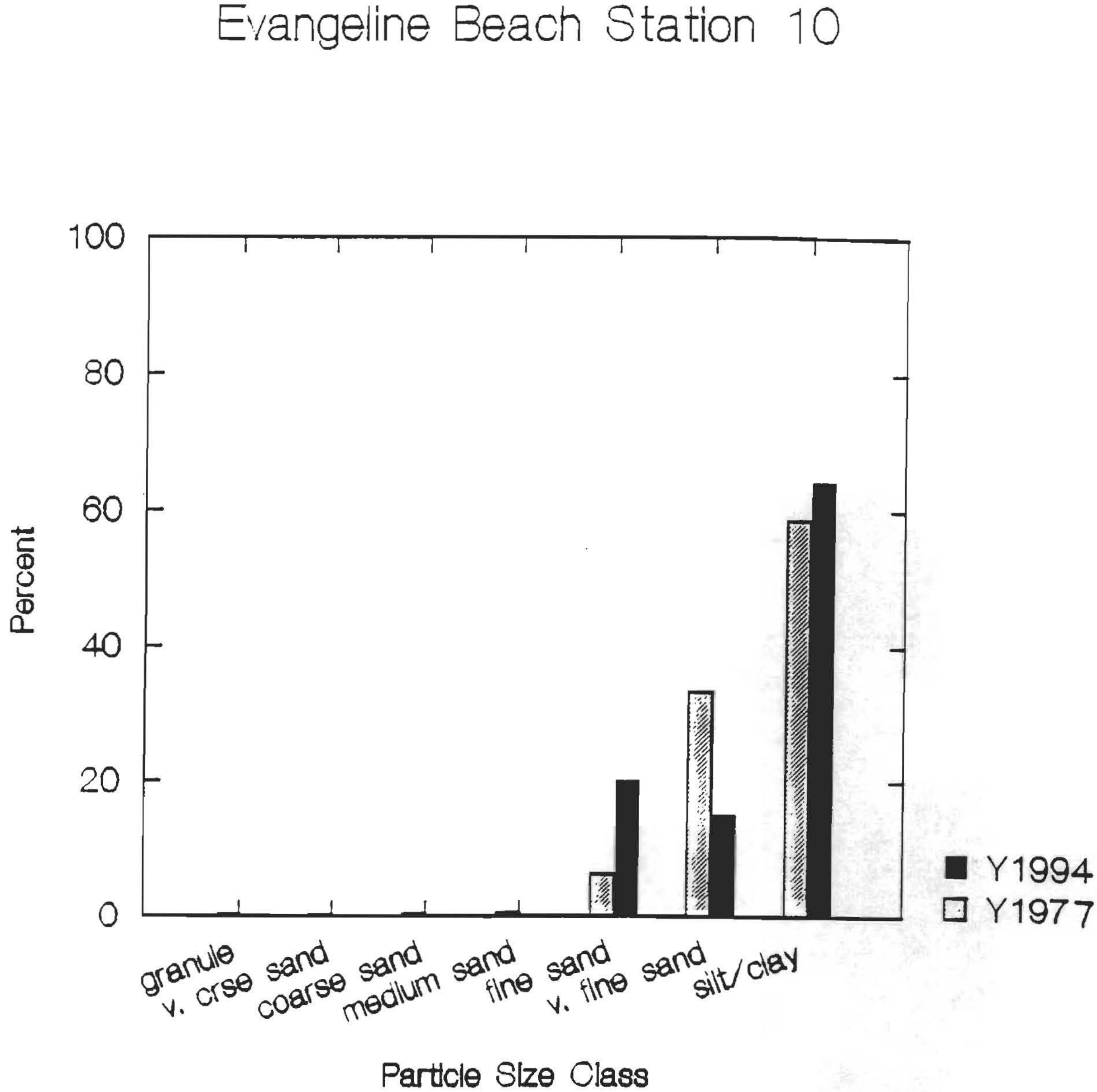
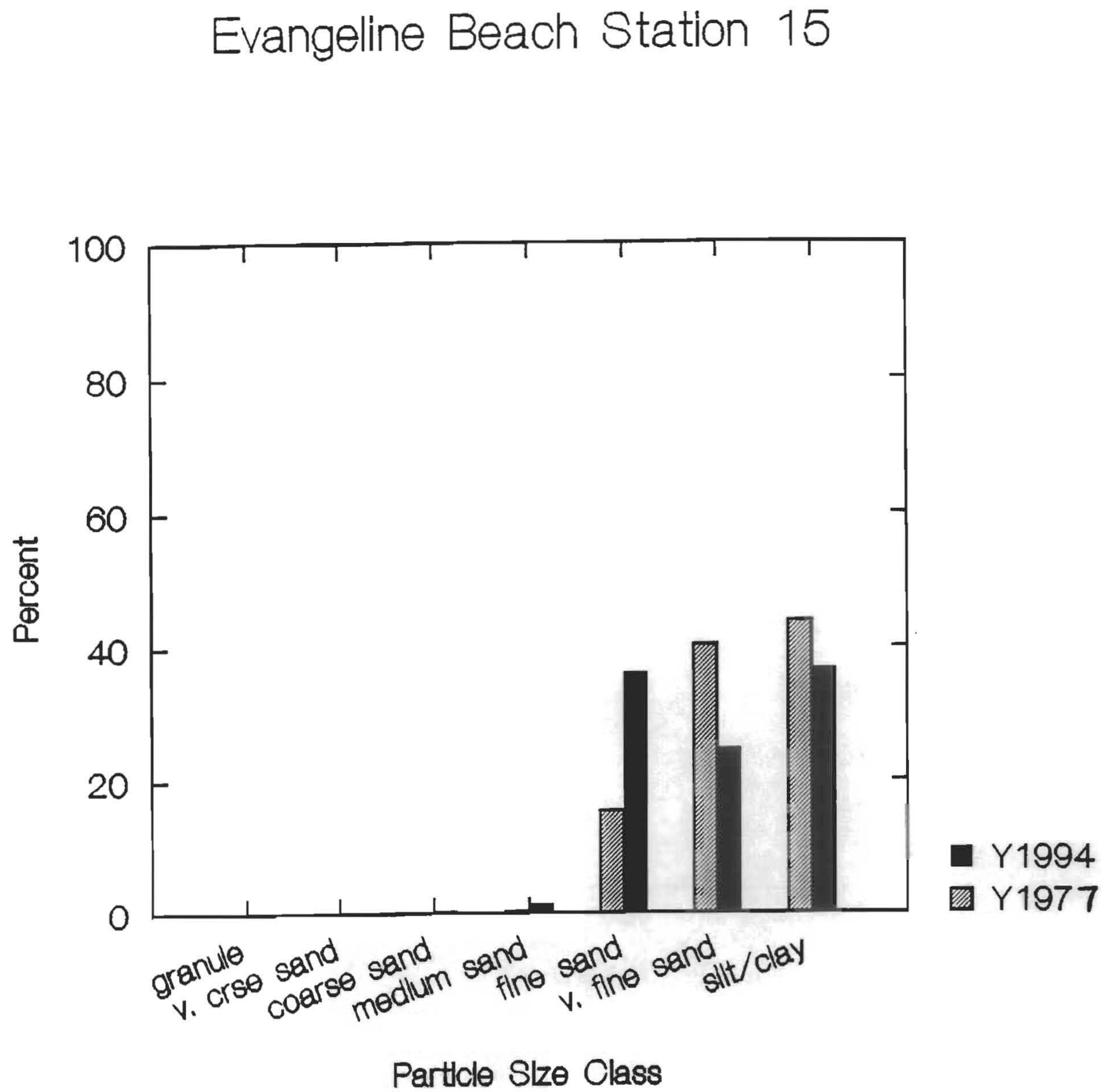
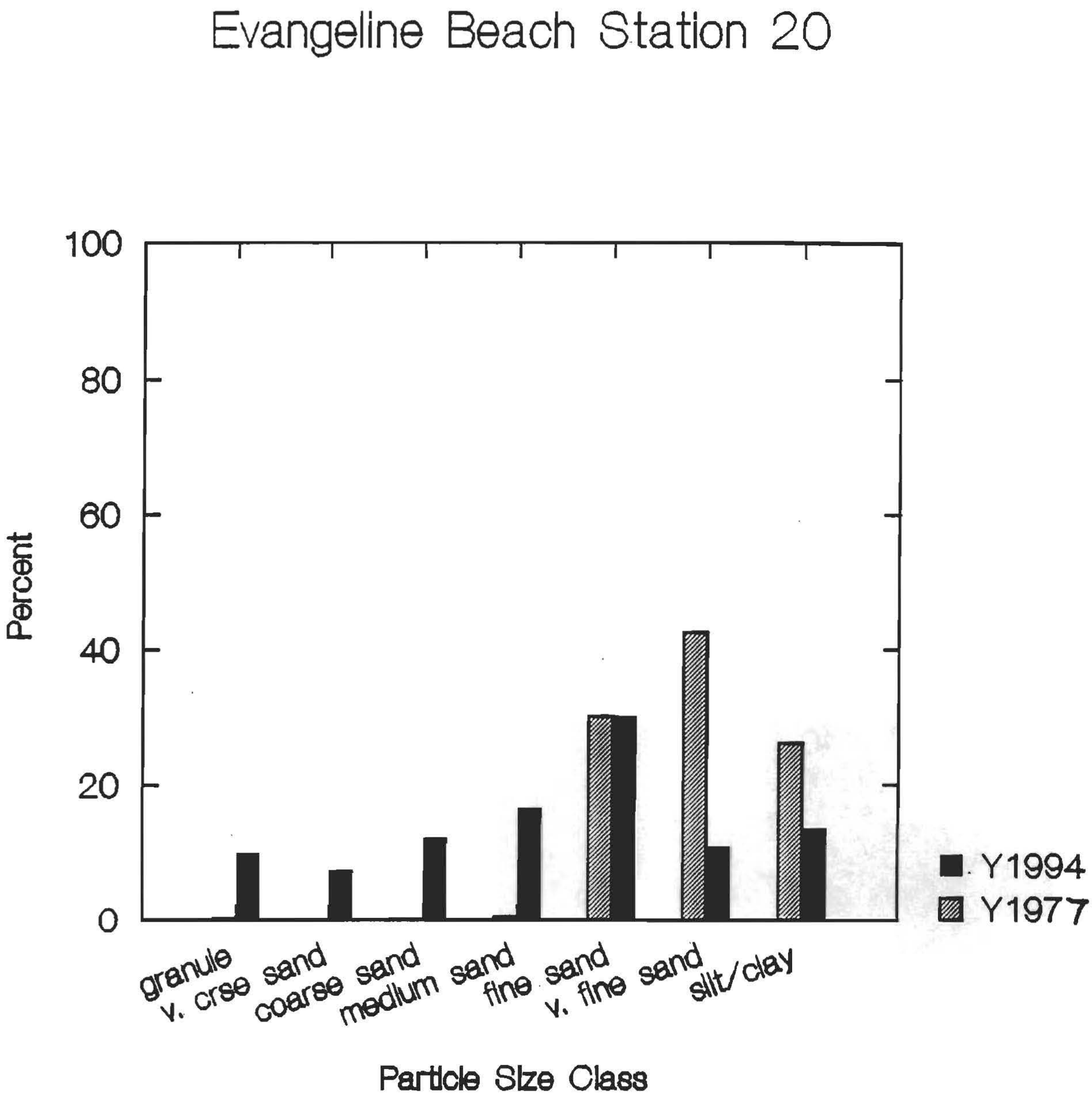

Evangeline Beach Station 10
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.22



Evangeline Beach Station 15
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.23



Evangeline Beach Station 20
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1977

Figure 5.24

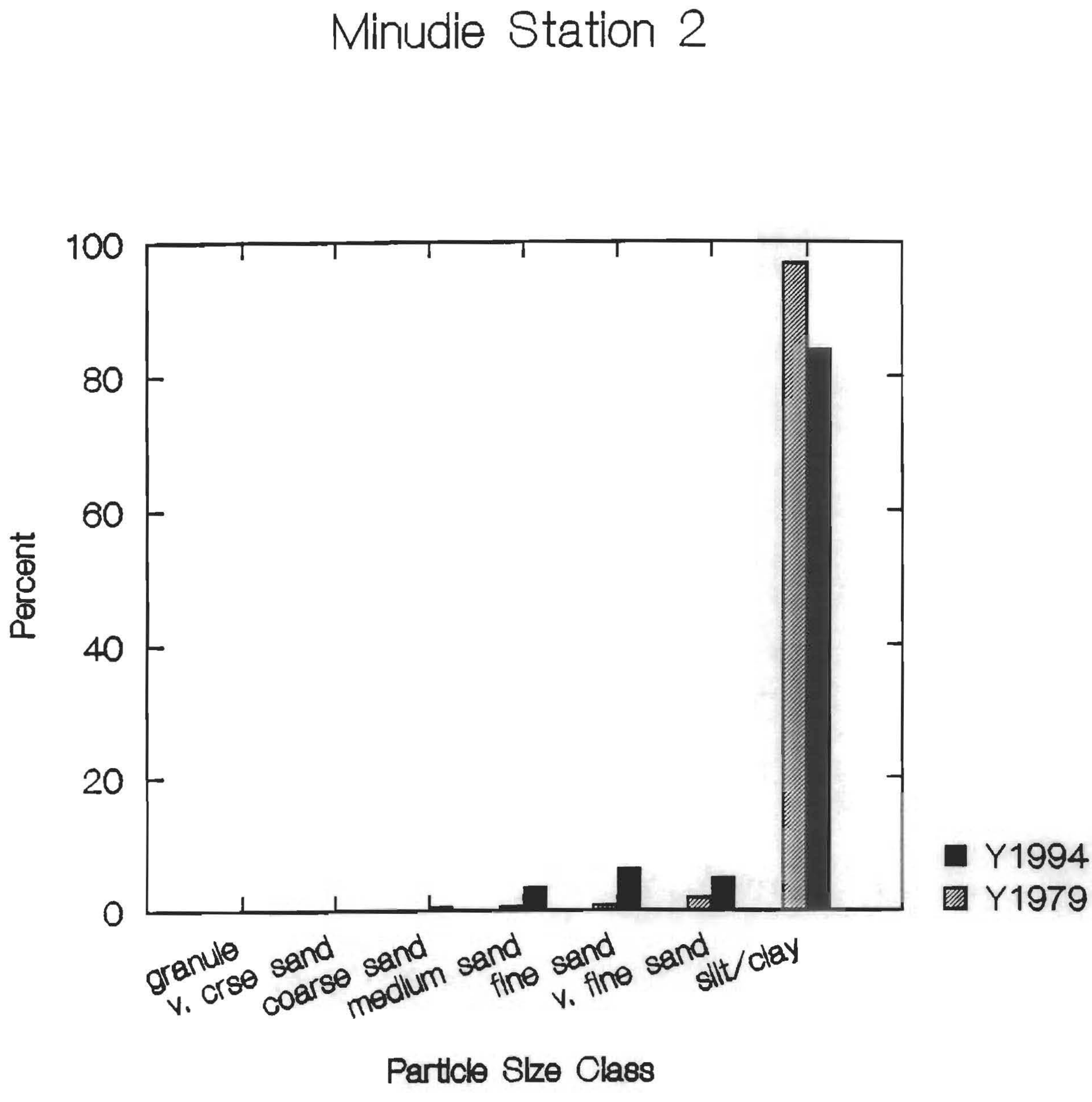
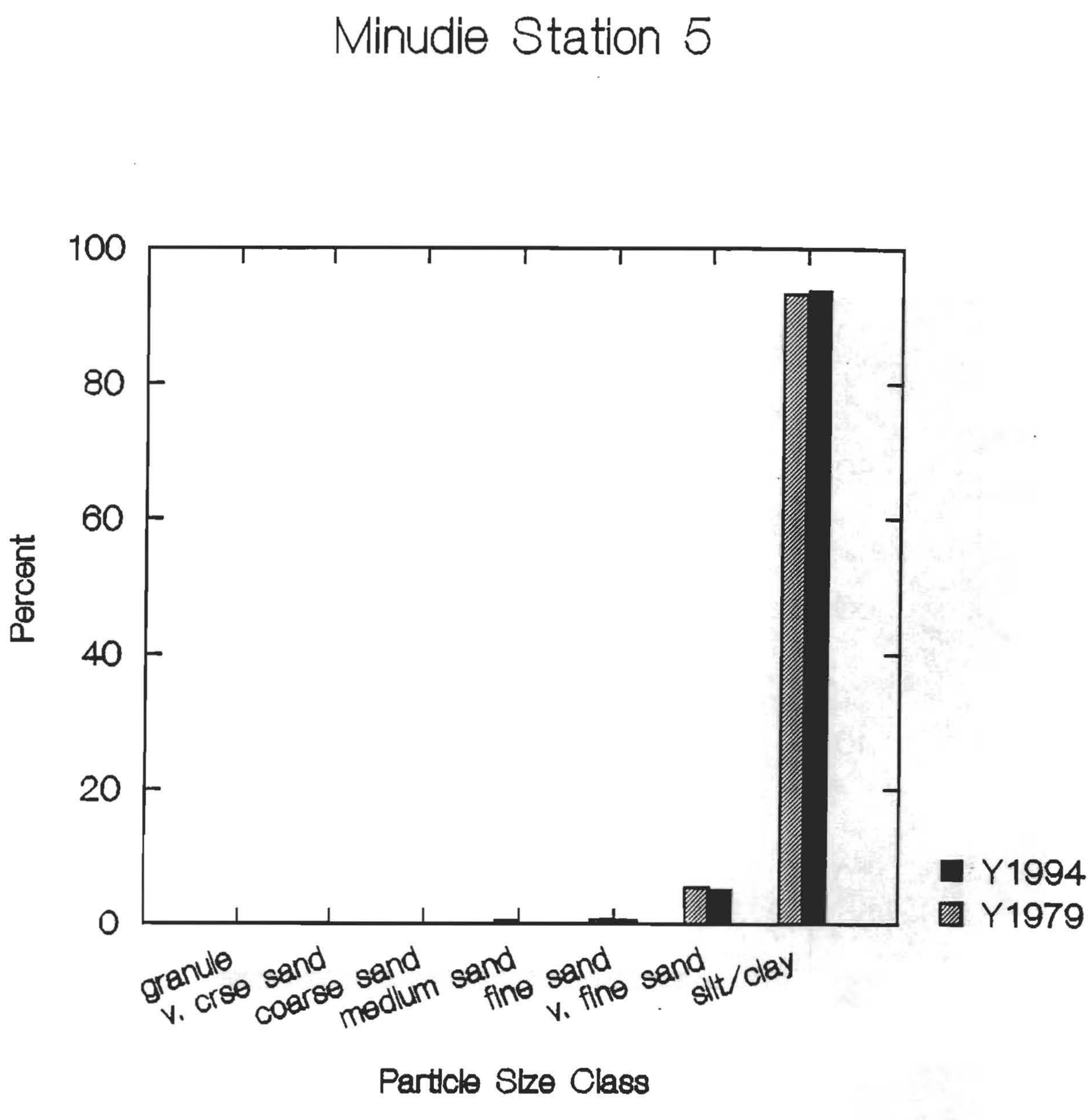

Minudie Station 2
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.25



Minudie Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.26

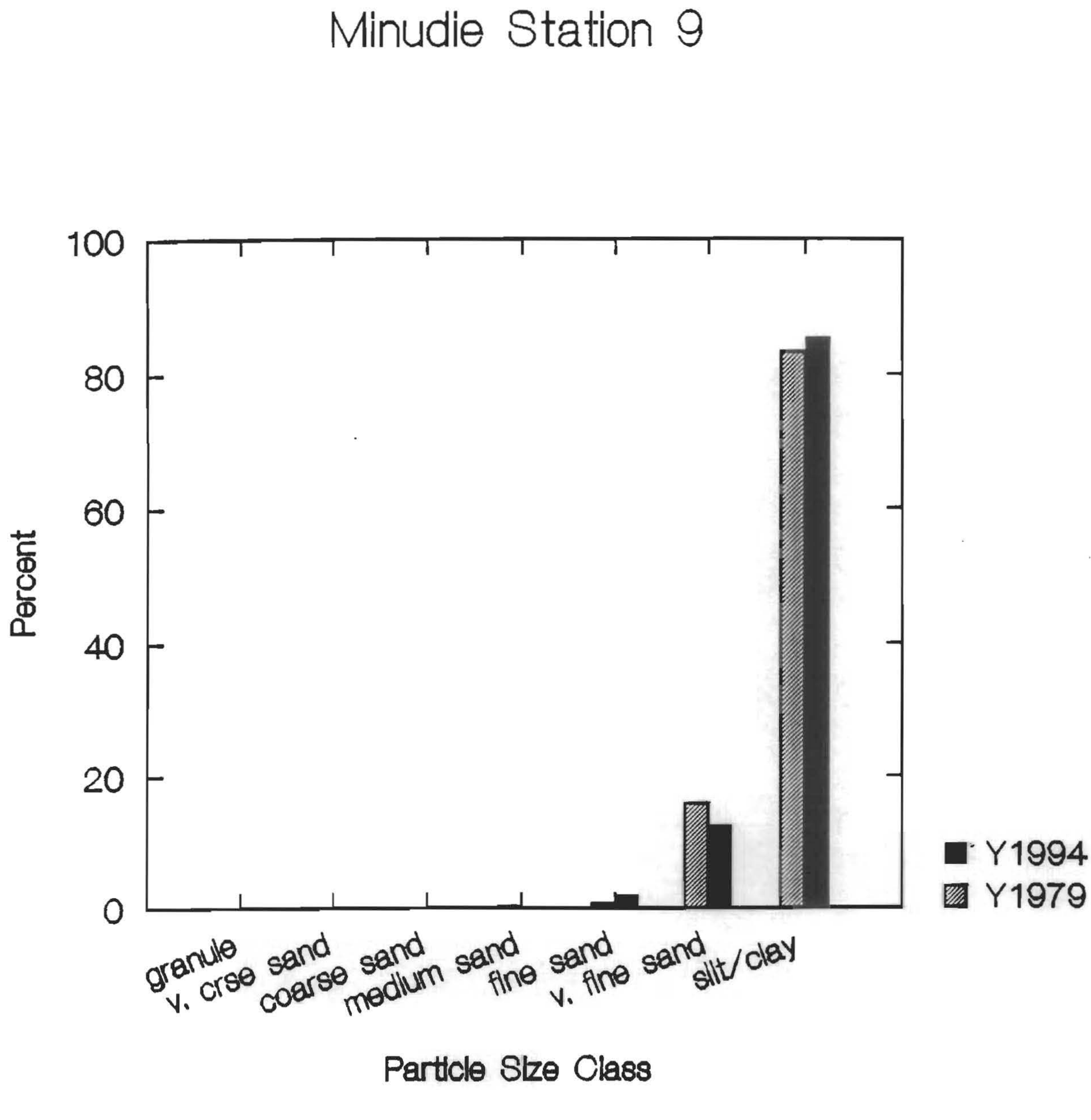

Minudie Station 9
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.27

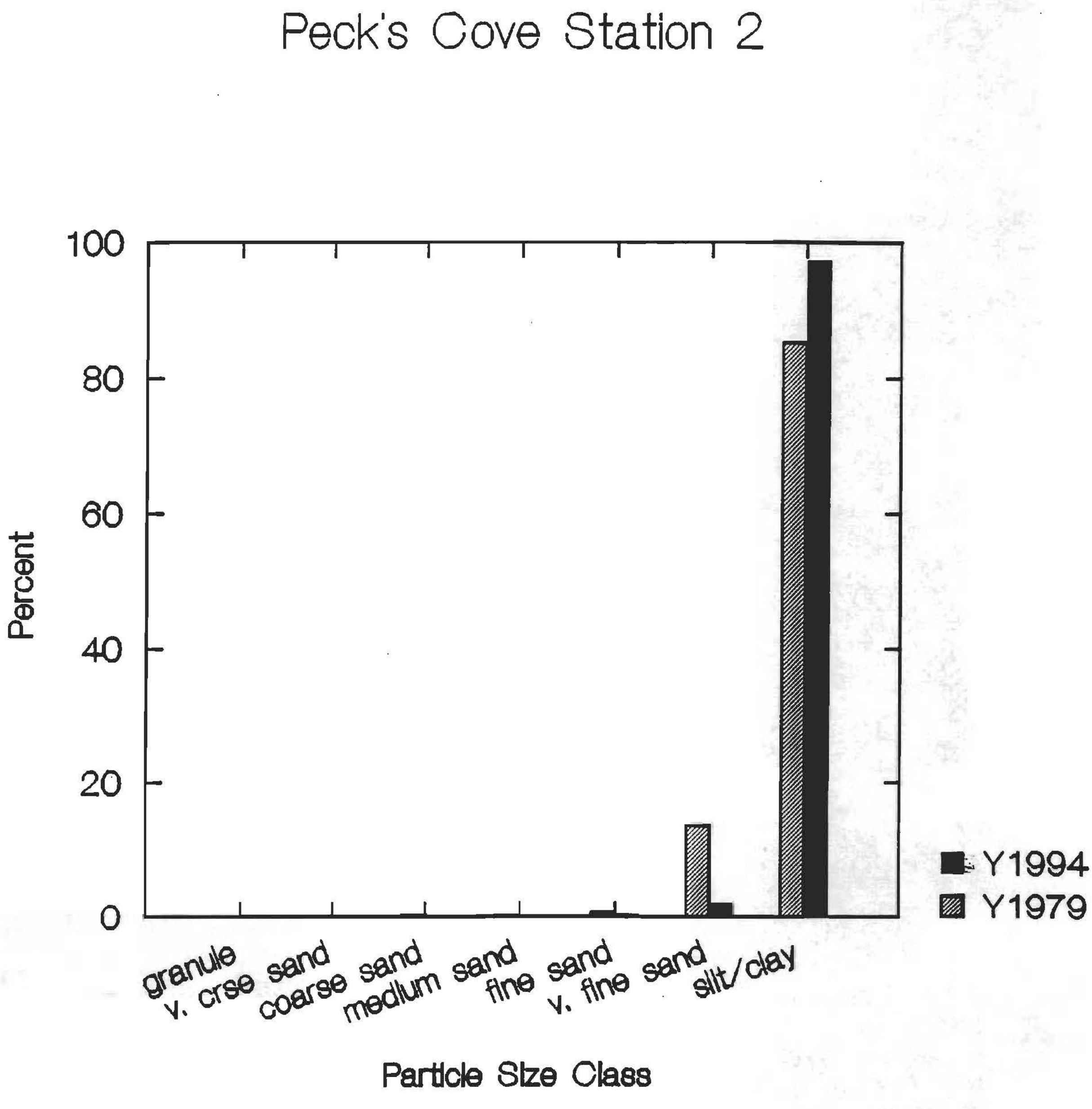
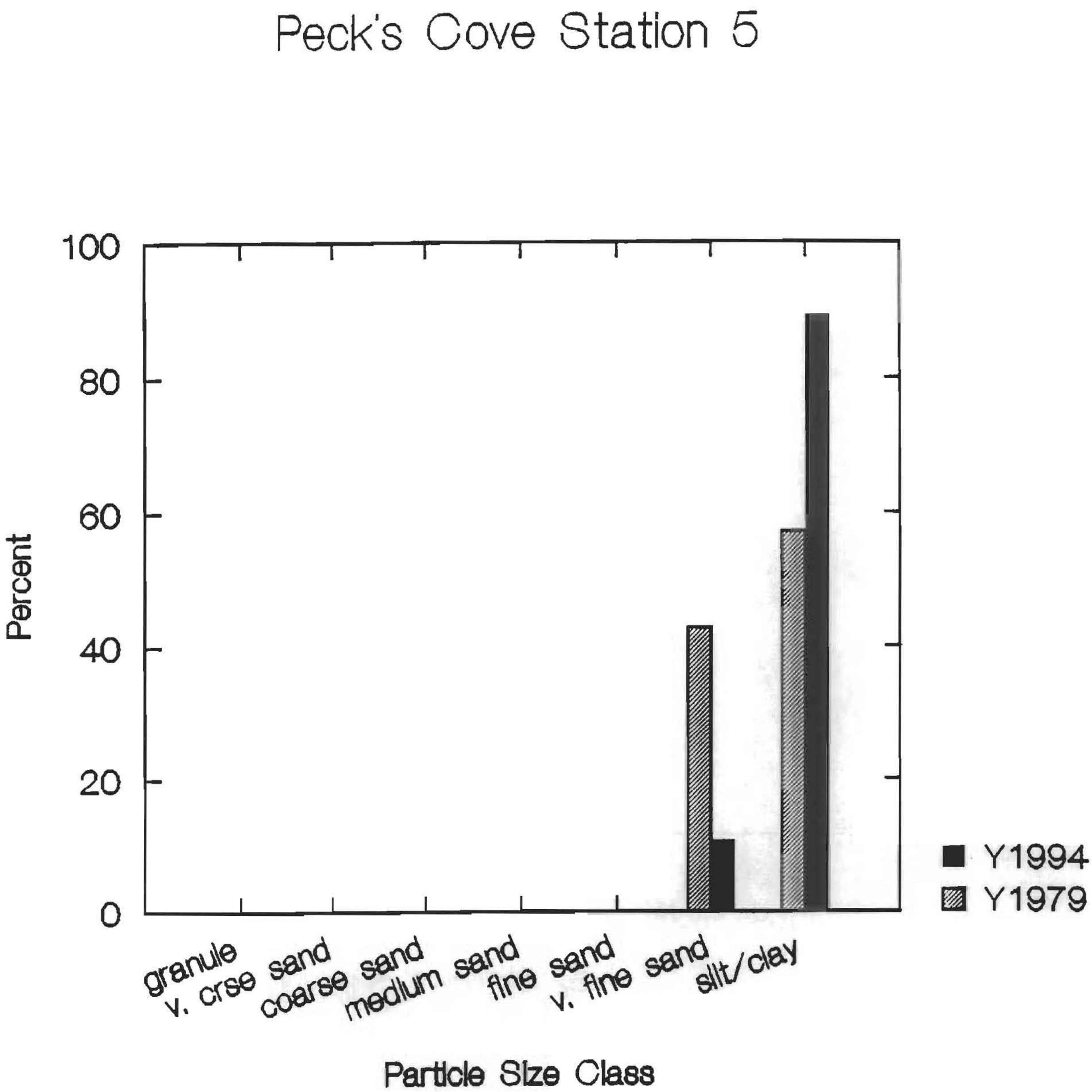

Peck's Cove Station 2
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.28



Peck's Cove Station 5
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.29

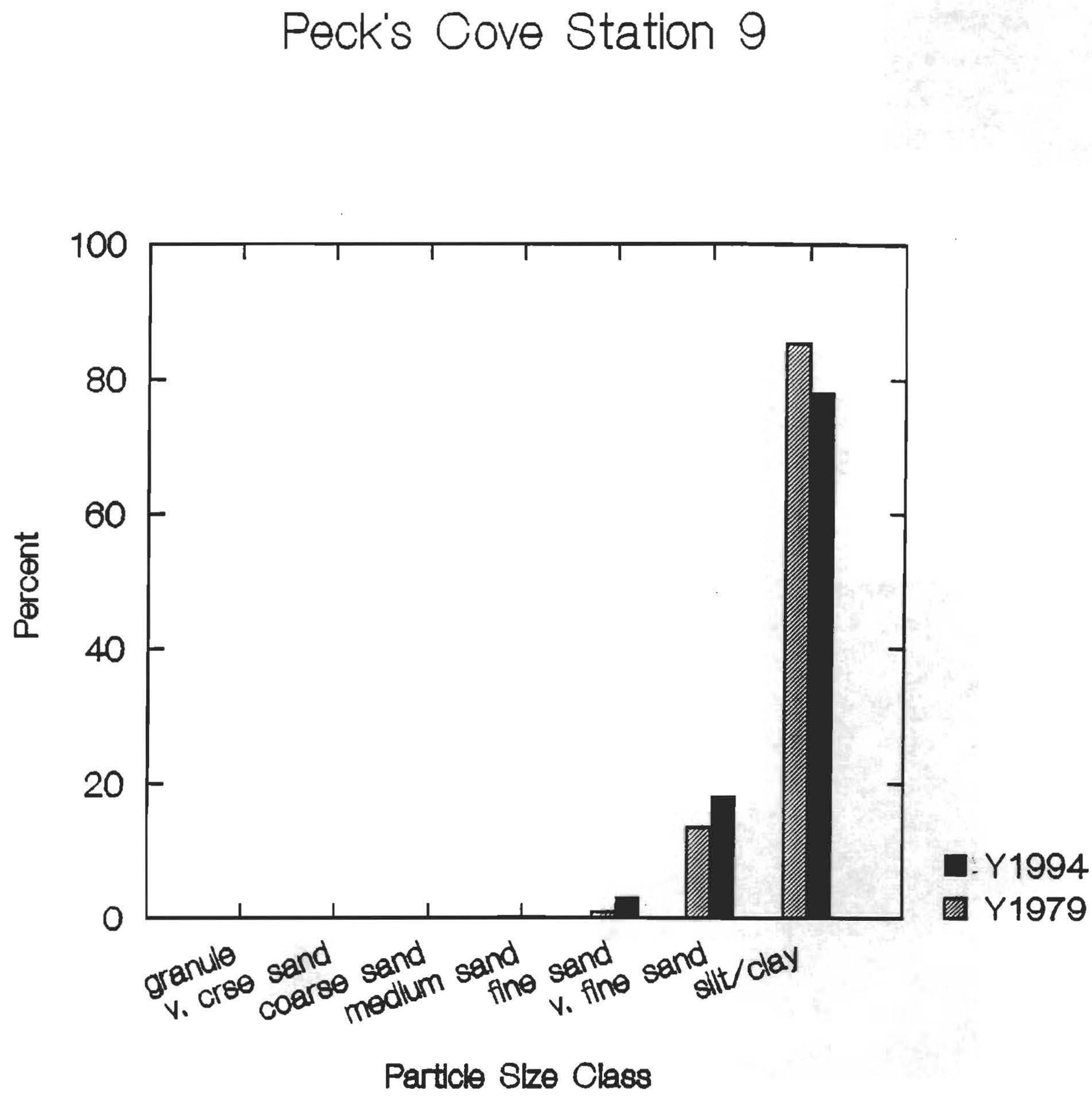

Peck's Cove Station 9
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.30

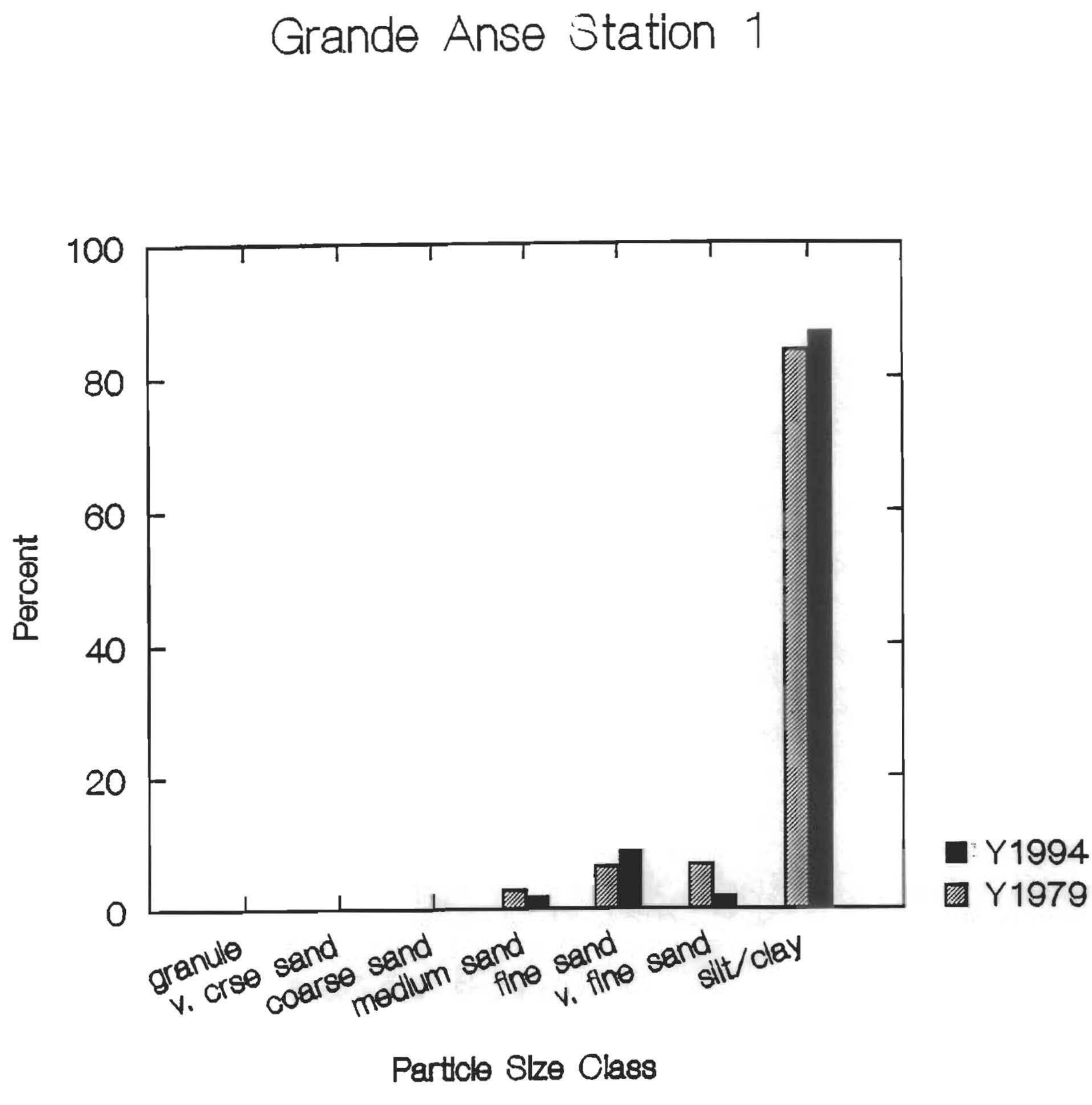
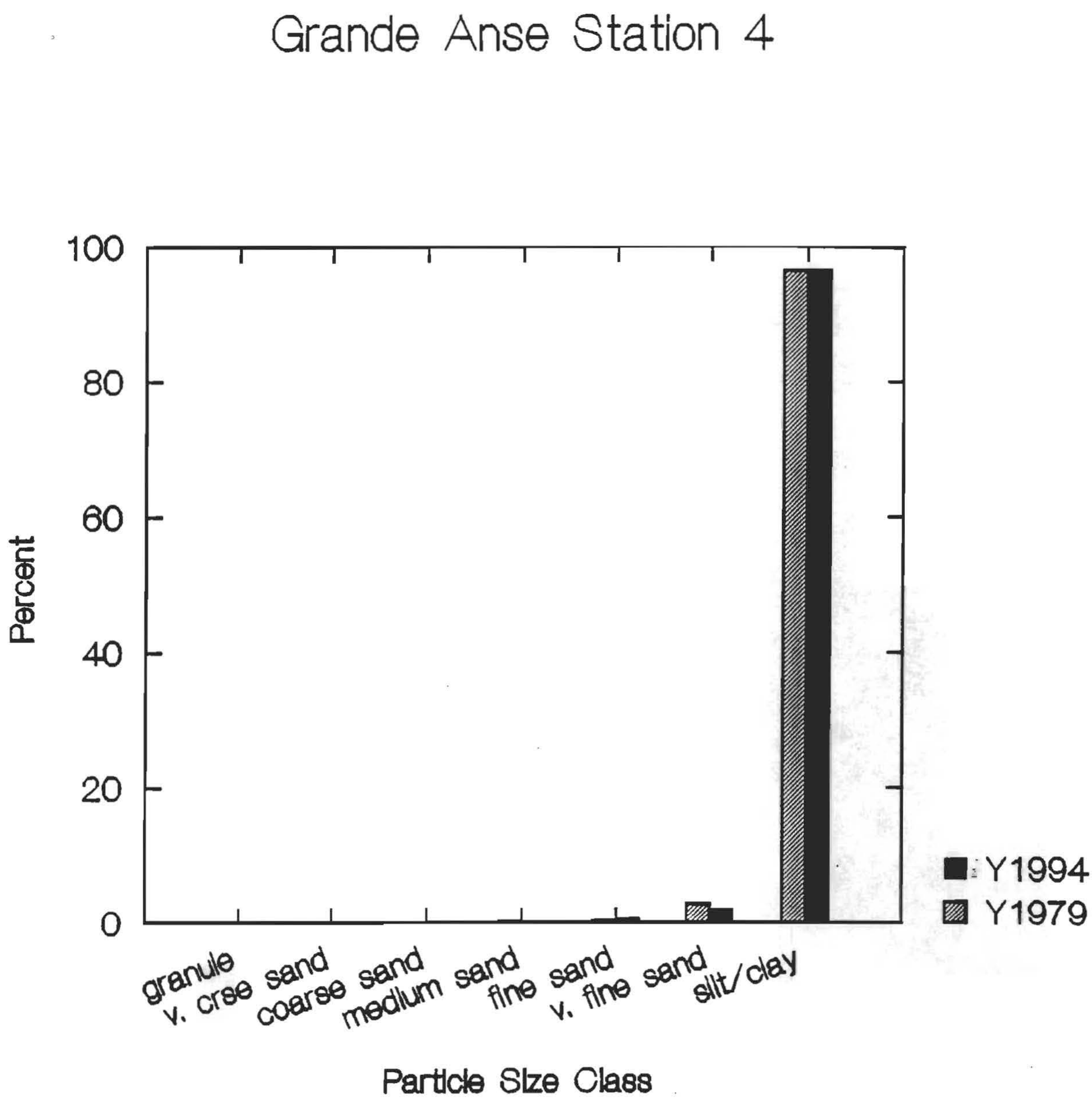

Grande Anse Station 1
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.31



Grande Anse Station 4
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.32

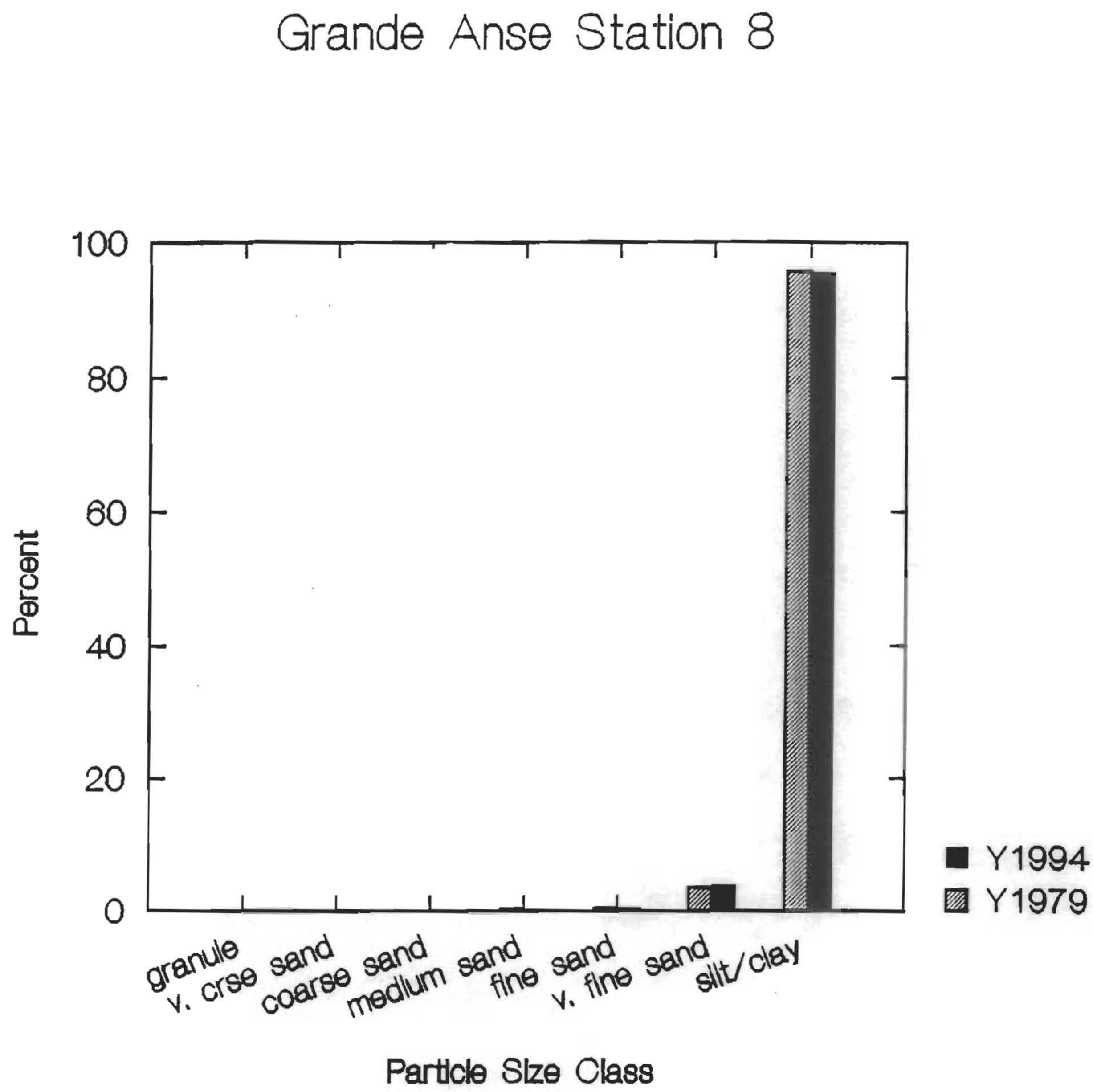
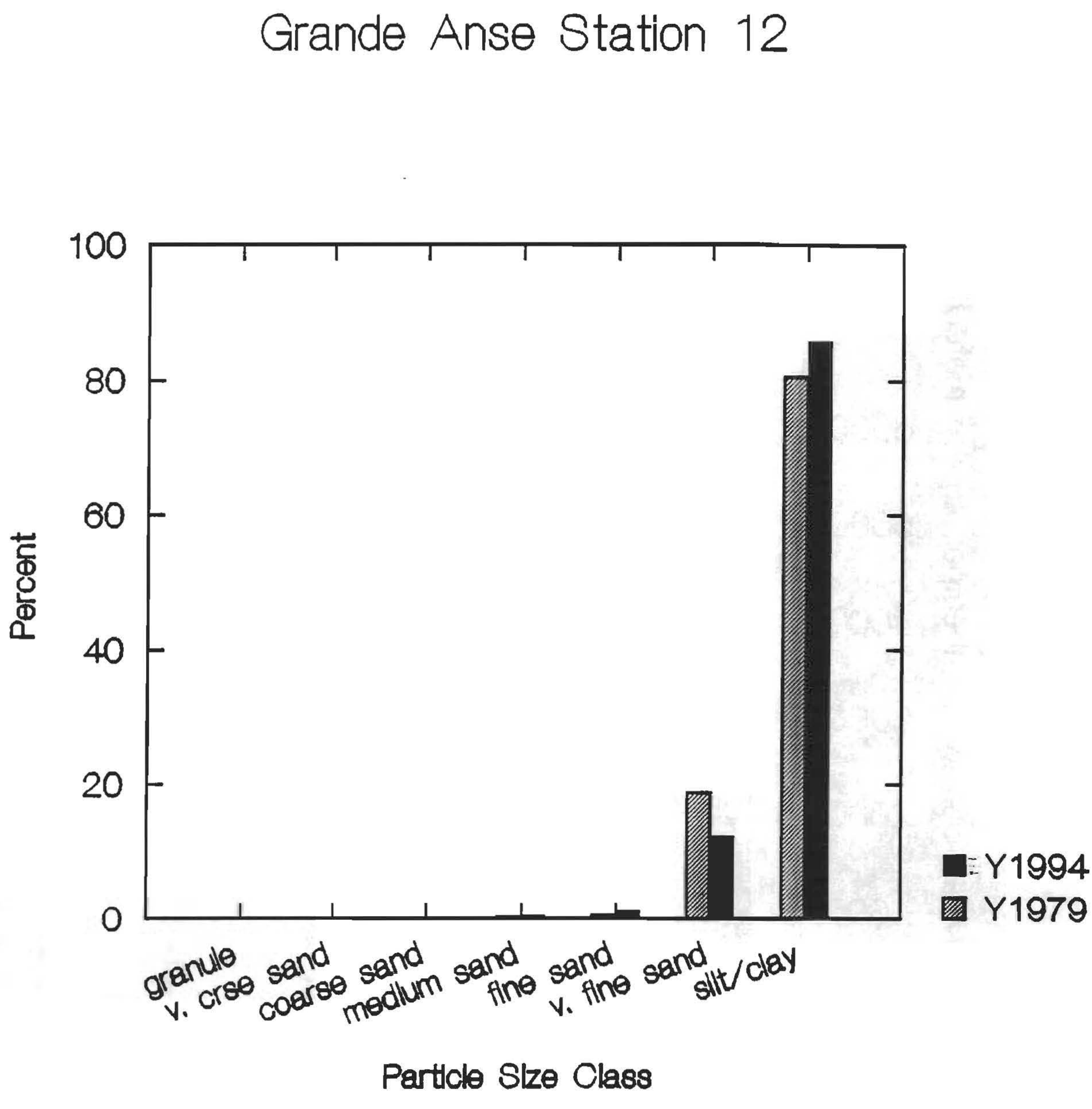
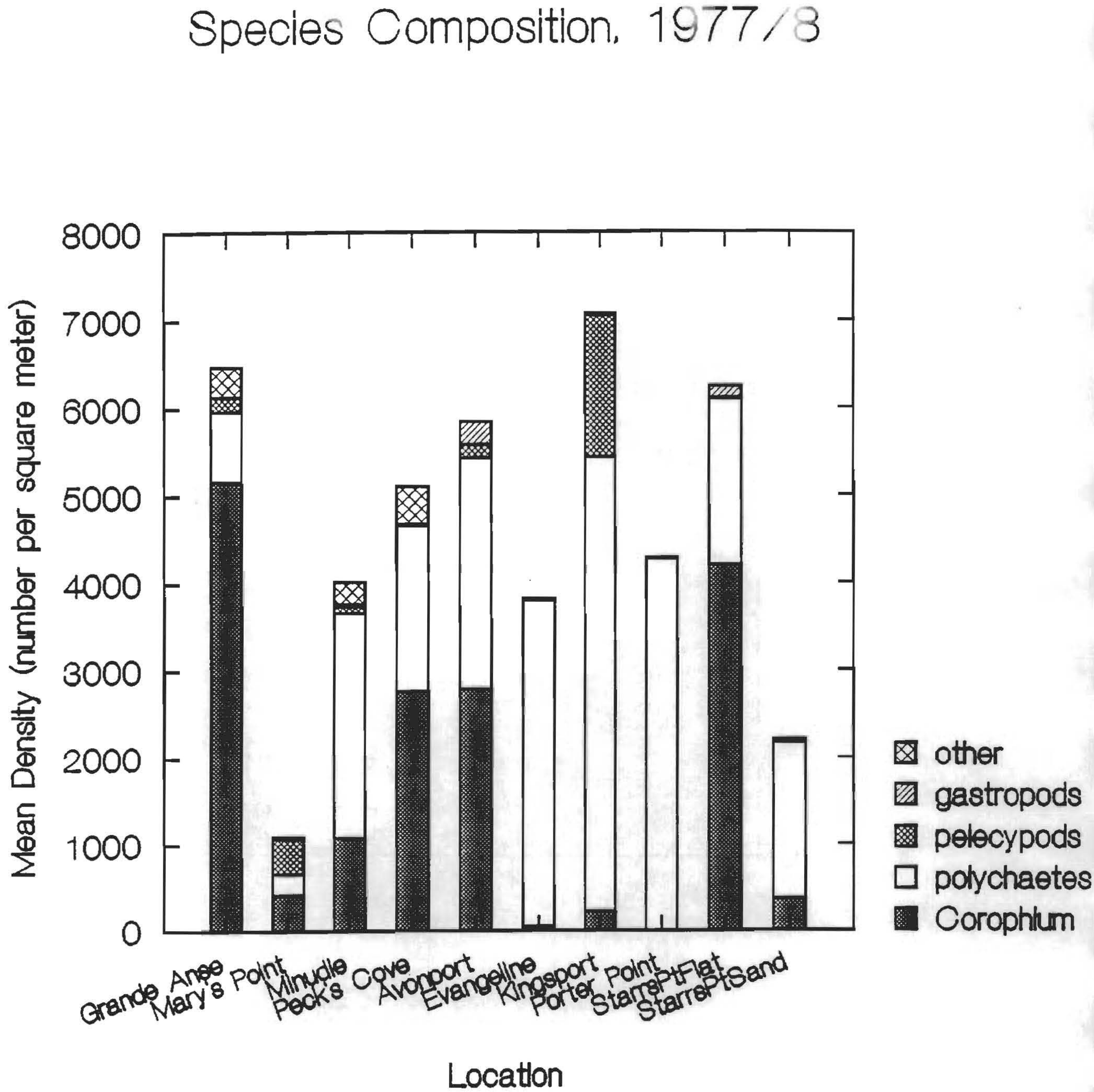

Grande Anse Station 8
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 5.33



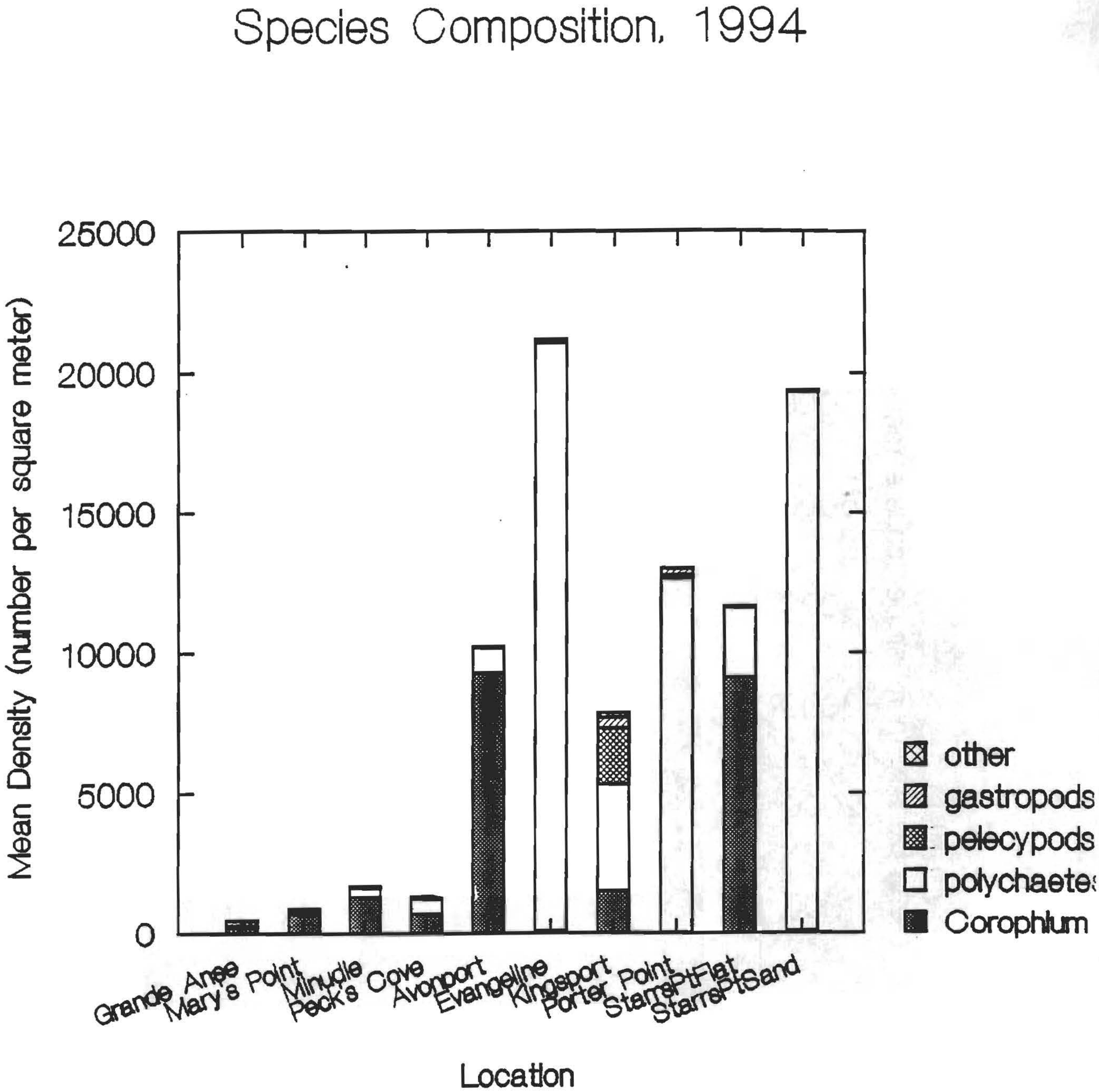
Grande Anse Station 12
100
80
60
40
20
0
Percent
granule
v. crse sand
coarse sand
medium sand
fine sand
v. fine sand
silt/clay
Particle Size Class
Y1994
Y1979

Figure 6.1



Species Composition, 1977/8
8000
7000
6000
5000
4000
3000
2000
1000
0
Mean Density (number per square meter)
Grande Anse
Mary's Point
Minudie
Peck's Cove
Avonport
Evangeline
Kingsport
Porter Point
StarrsPtFlat
StarrsPtSand
Location
other
gastropods
pelecypods
polychaetes
Corophium

Figure 6.2



Species Composition, 1994
25000
20000
15000
10000
5000
0
Mean Density (number per square meter)
Grande Anse
Mary's Point
Minudie
Peck's Cove
Avonport
Evangeline
Kingsport
Porter Point
StarrsPtFlat
StarrsPtSand
Location
other
gastropods
pelecypods
polychaetes
Corophium

Figure 7.1

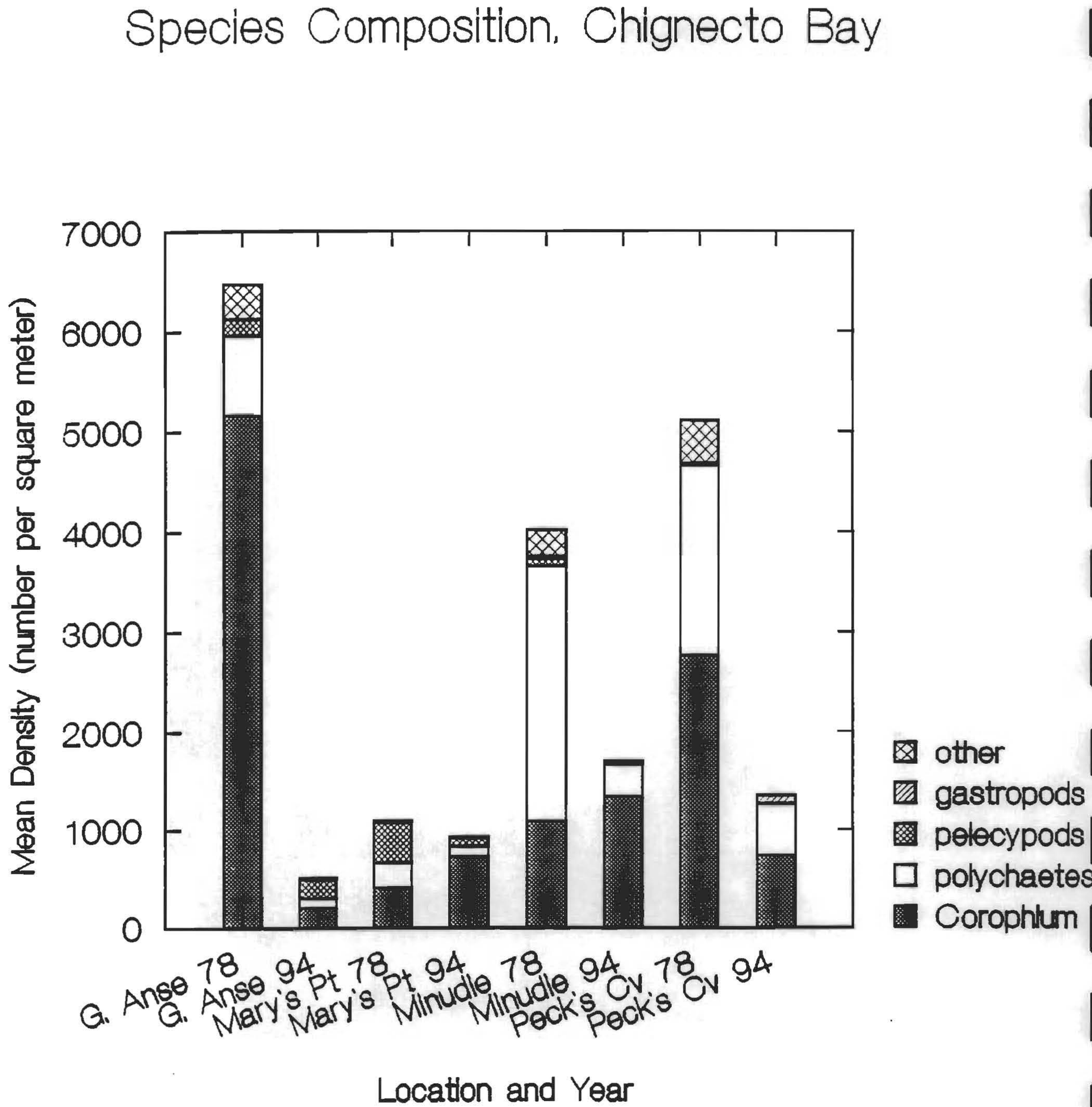
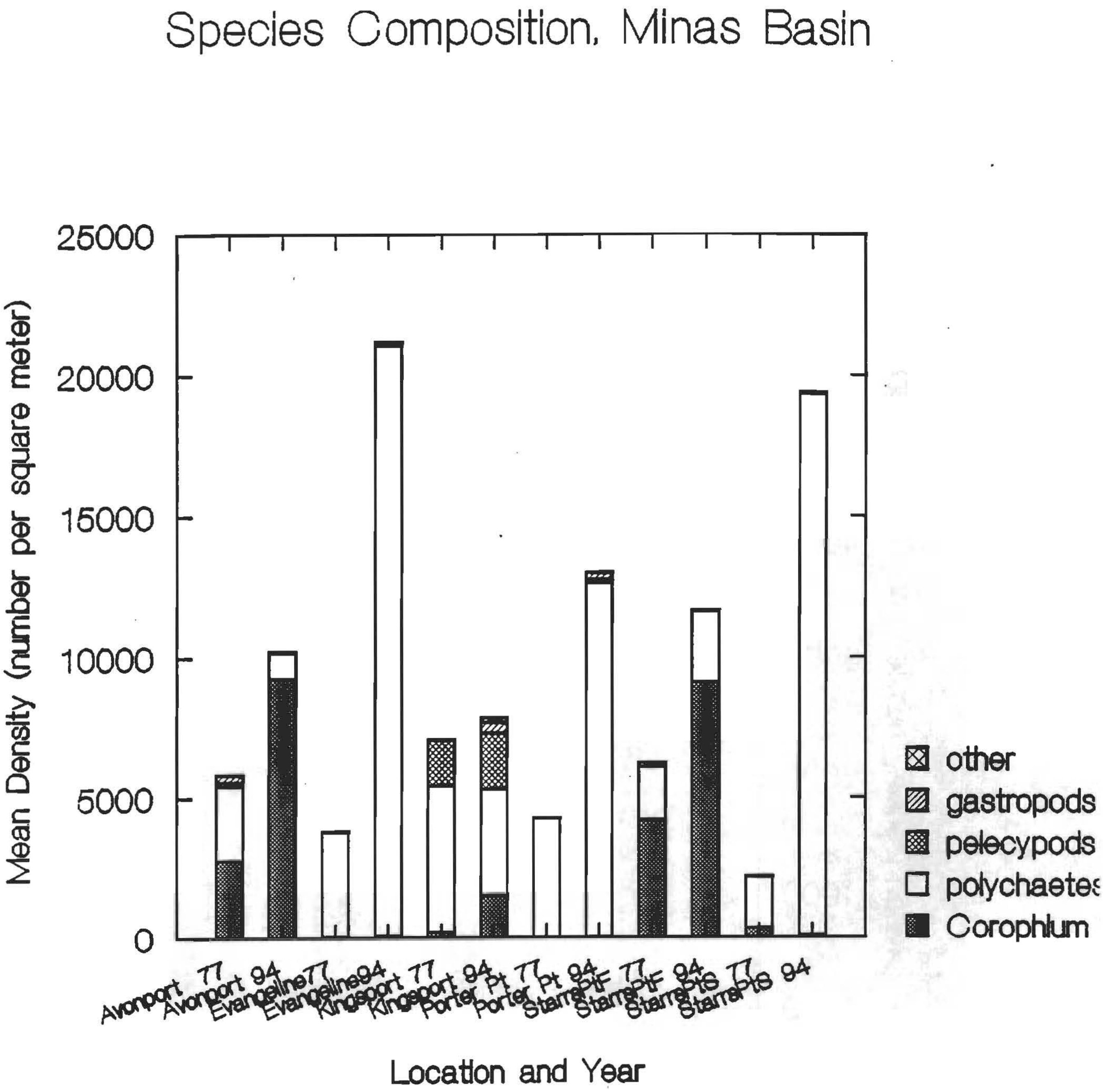

Species Composition, Chignecto Bay
Mean Density (number per square meter)
7000
6000
5000
4000
3000
2000
1000
0
G. Anse 78
G. Anse 94
Mary's Pt 78
Mary's Pt 94
Minudie 78
Minudie 94
Peck's Cv 78
Peck's Cv 94
Location and Year
other
gastropods
pelecypods
polychaetes
Corophium

Figure 7.2



Species Composition, Minas Basin
25000
20000
15000
10000
5000
0
Mean Density (number per square meter)
Avonport 77
Avonport 94
Evangeline77
Evangeline94
Kingsport 77
Kingsport 94
Porter Pt 77
Porter Pt 94
StarrsPtF 77
StarrsPtF 94
StarrsPtS 77
StarrsPtS 94
Location and Year
other
gastropods
pelecypods
polychaetes
Corophium

Figure 8.1

Corophium Abundance by Year, Chignecto Bay

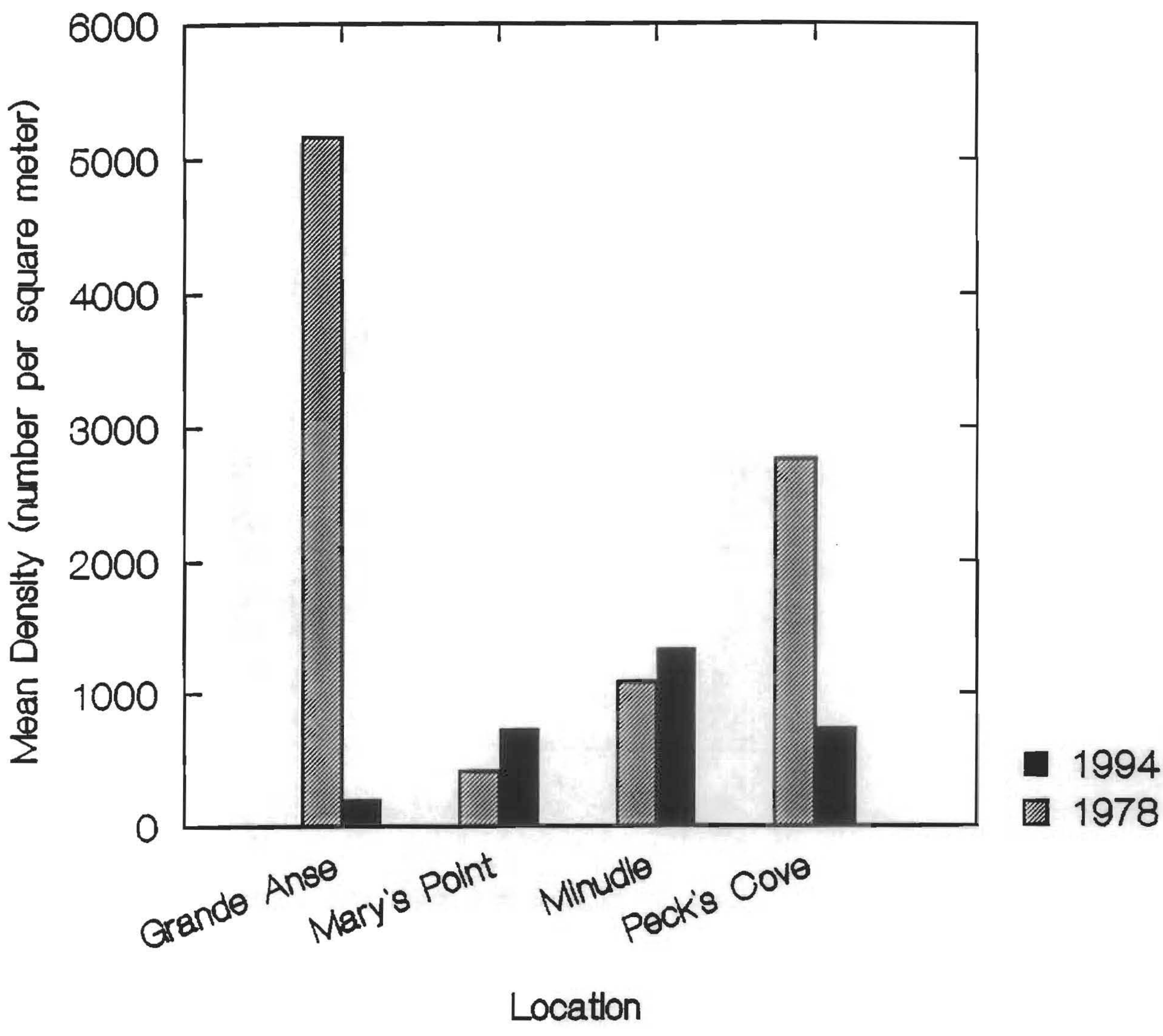


Figure 8.2

Corophium Abundance by Year, Minas Basin

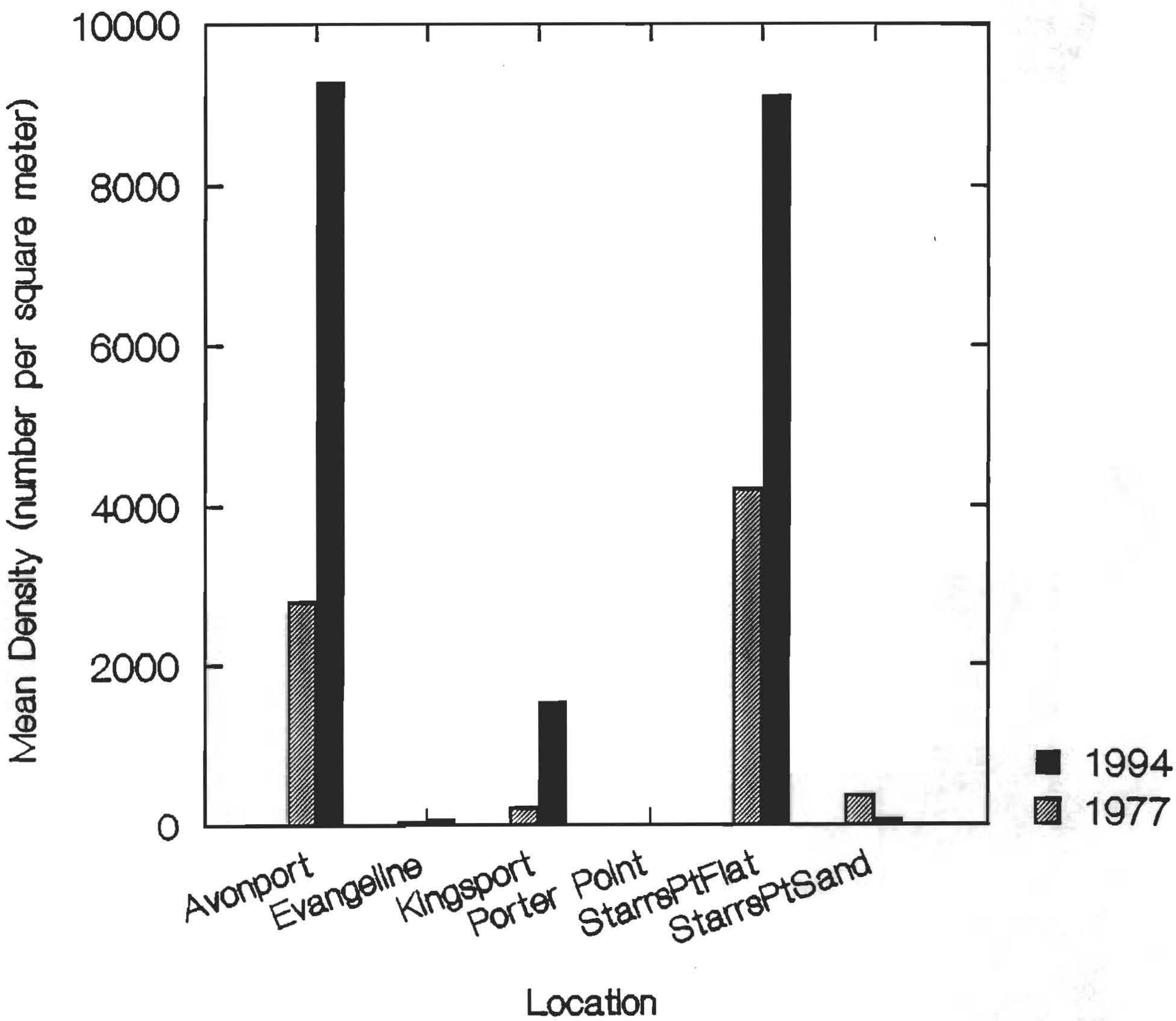


Figure 9.1

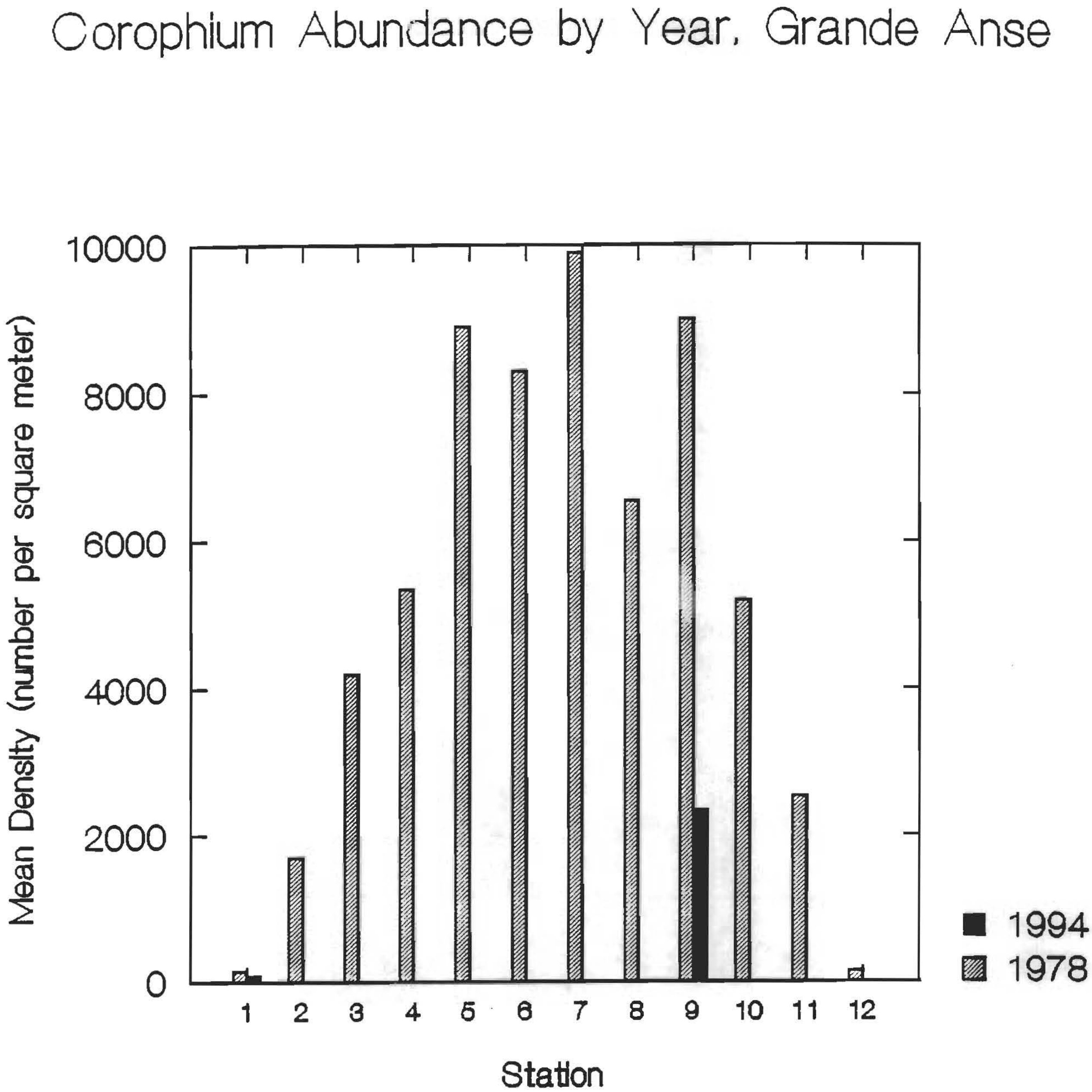
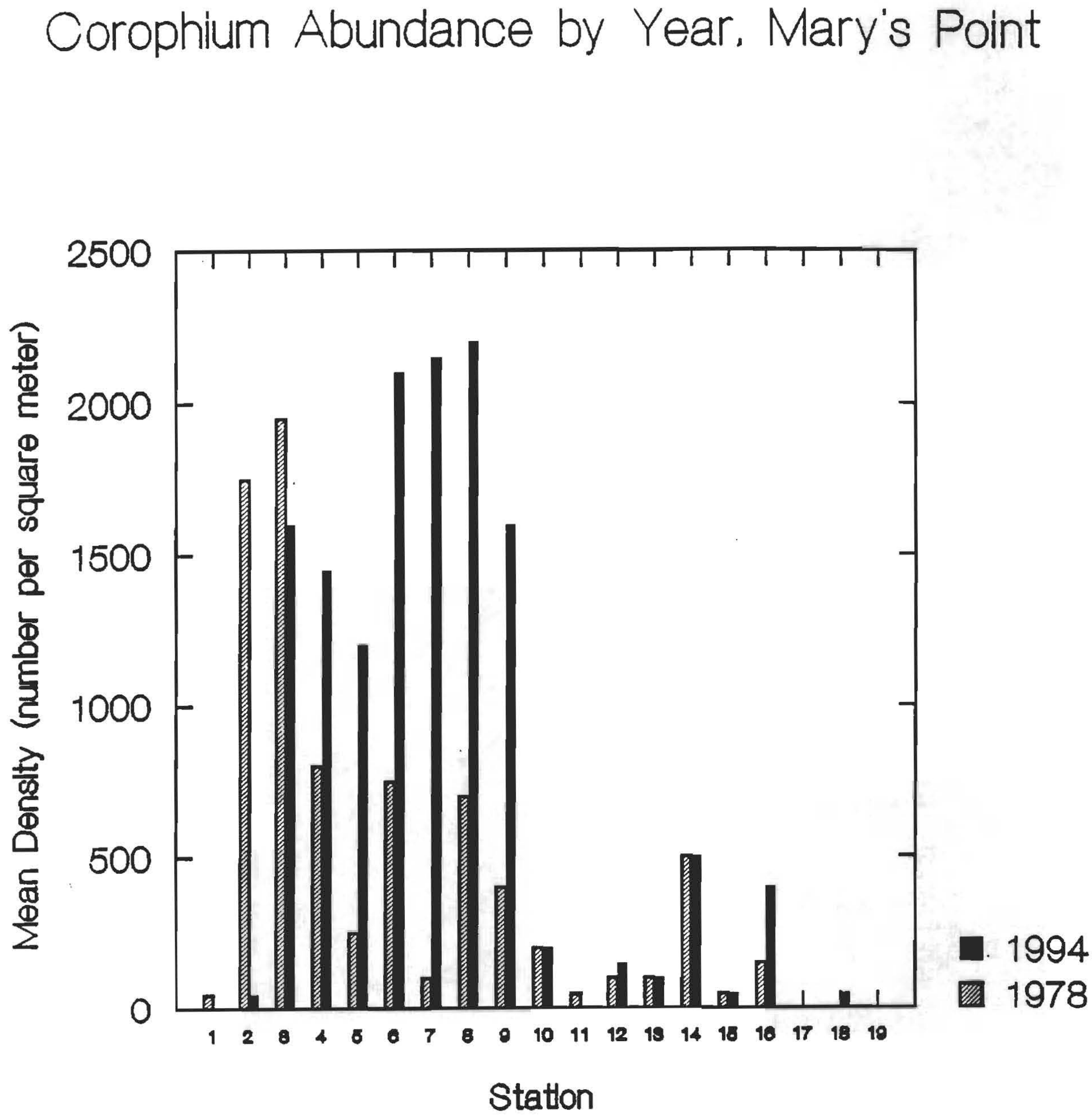

Corophium Abundance by Year, Grande Anse
Mean Density (number per square meter)
10000
8000
6000
4000
2000
0
1
2
3
4
5
6
7
8
9
10
11
12
Station
1994
1978

Figure 9.2



Corophium Abundance by Year, Mary's Point
2500
2000
1500
1000
500
0
Mean Density (number per square meter)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Station
1994
1978

Figure 9.3

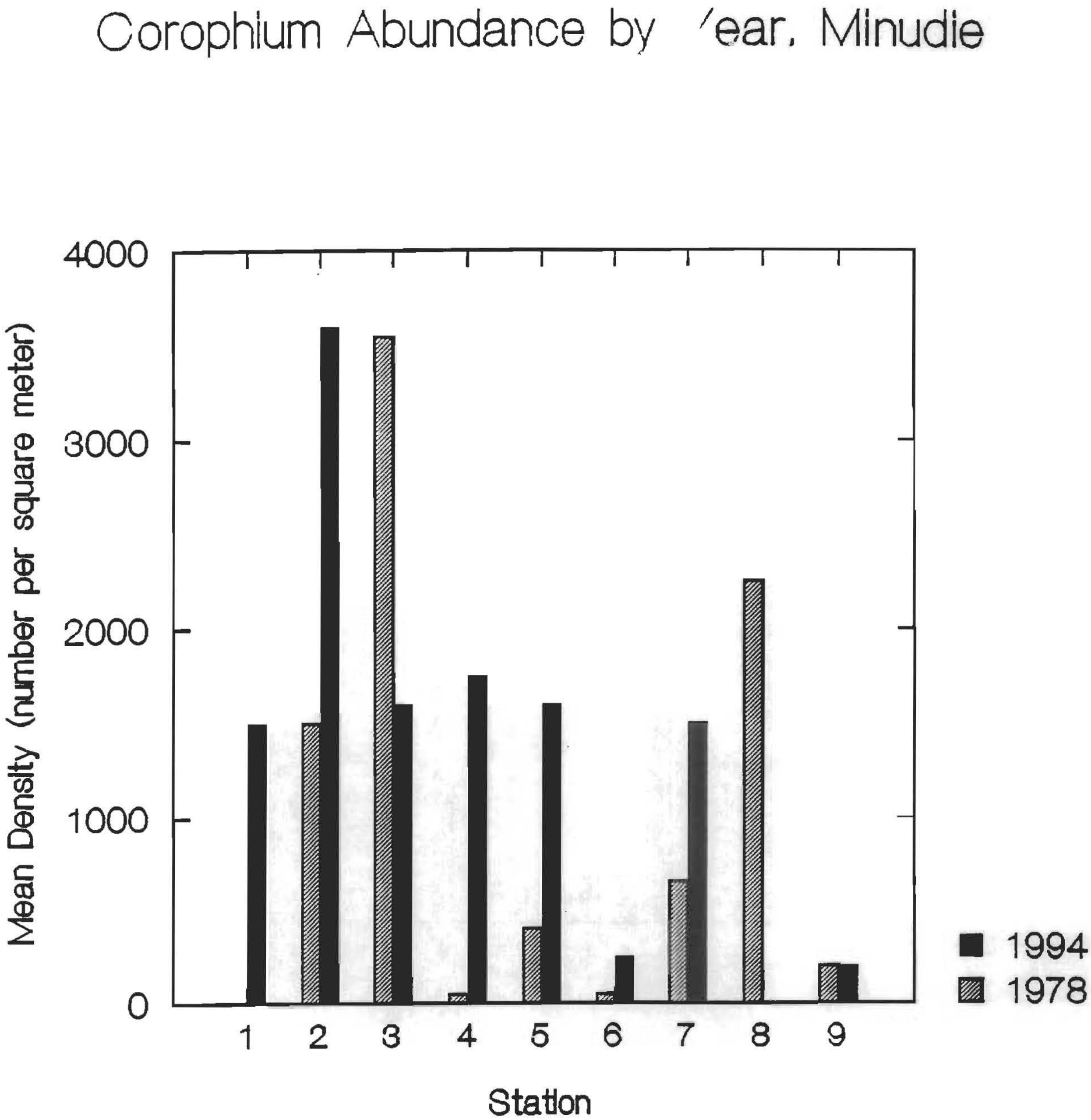

Corophium Abundance by 'ear, Minudie
Mean Density (number per square meter)
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
Station
1994
1978

Figure 9.4

Corophium Abundance by Year, Peck's Cove

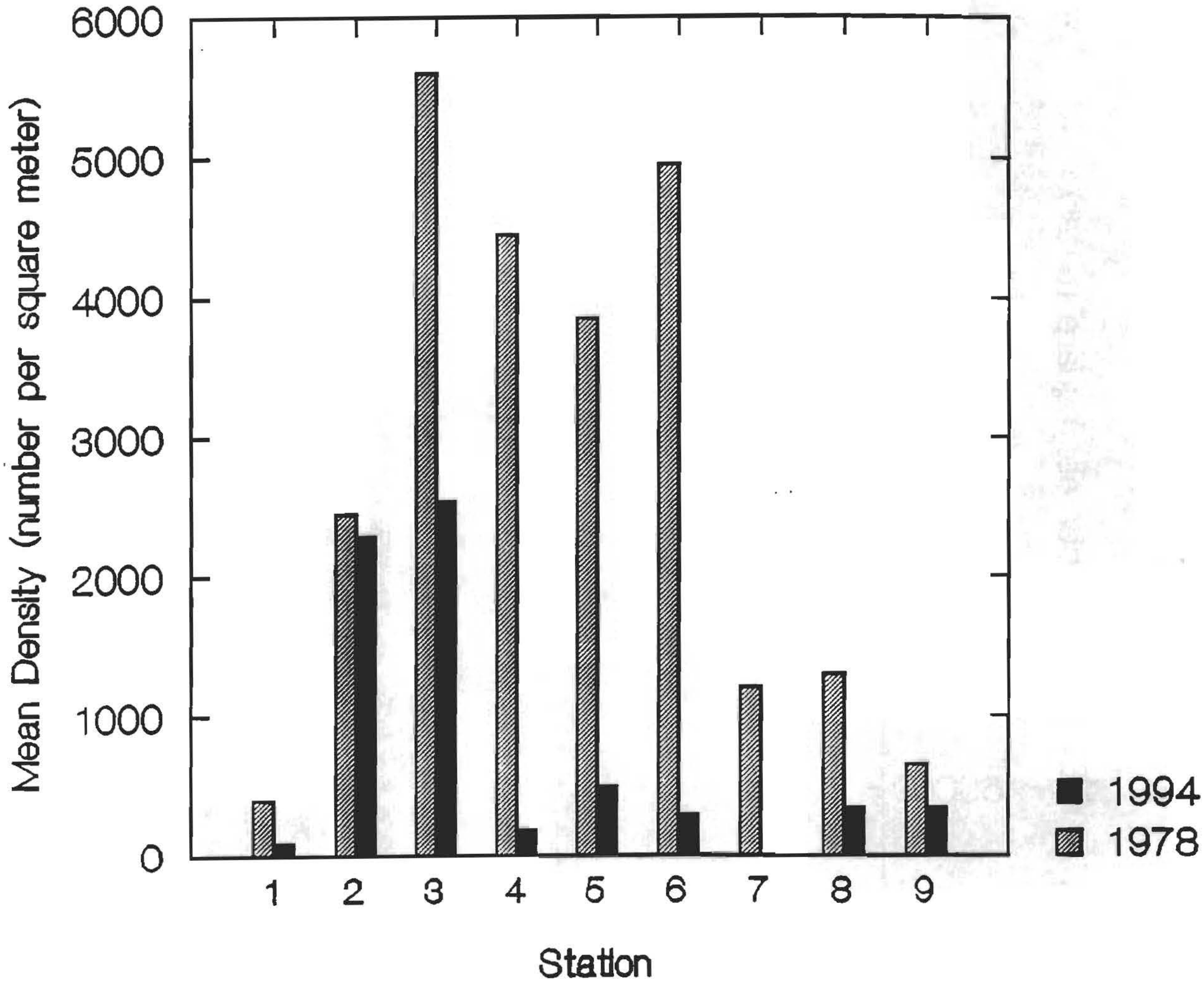


Figure 9.5

Corophium Abundance by Year, Avonport

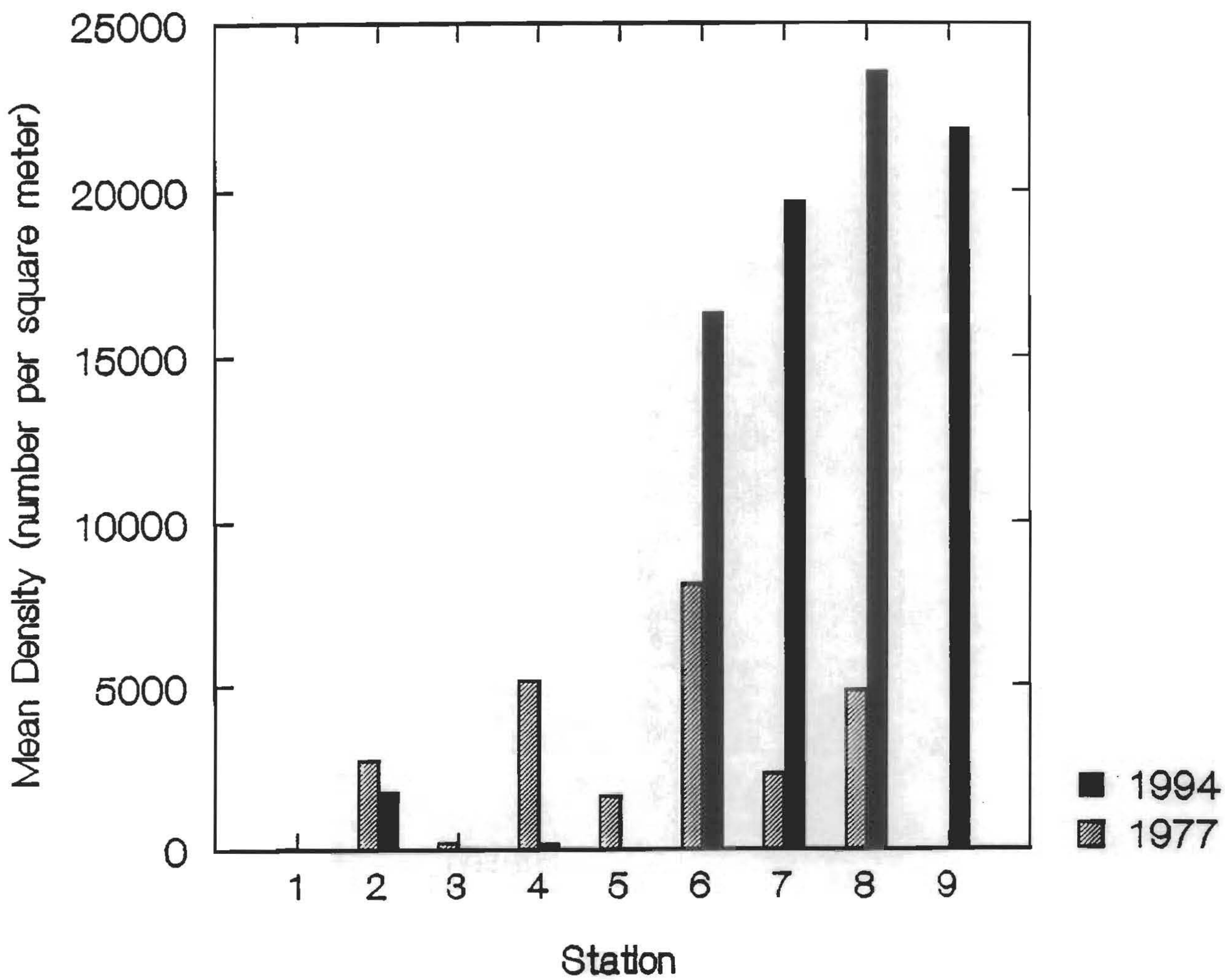


Figure 9.6

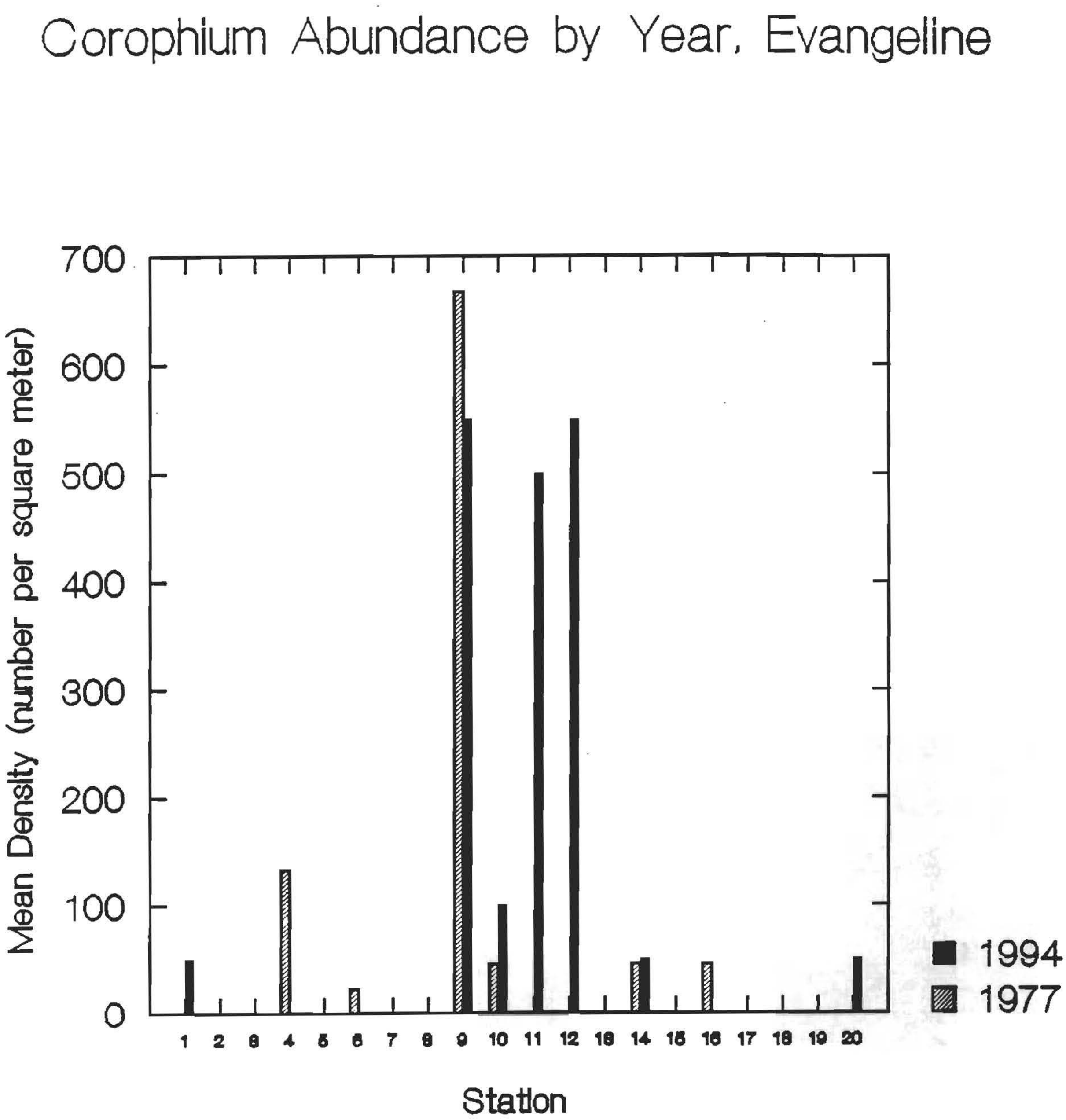

Corophium Abundance by Year, Evangeline
Mean Density (number per square meter)
0
100
200
300
400
500
600
700
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Station
1994
1977

Figure 9.7

Corophium Abundance by Year, Kingsport

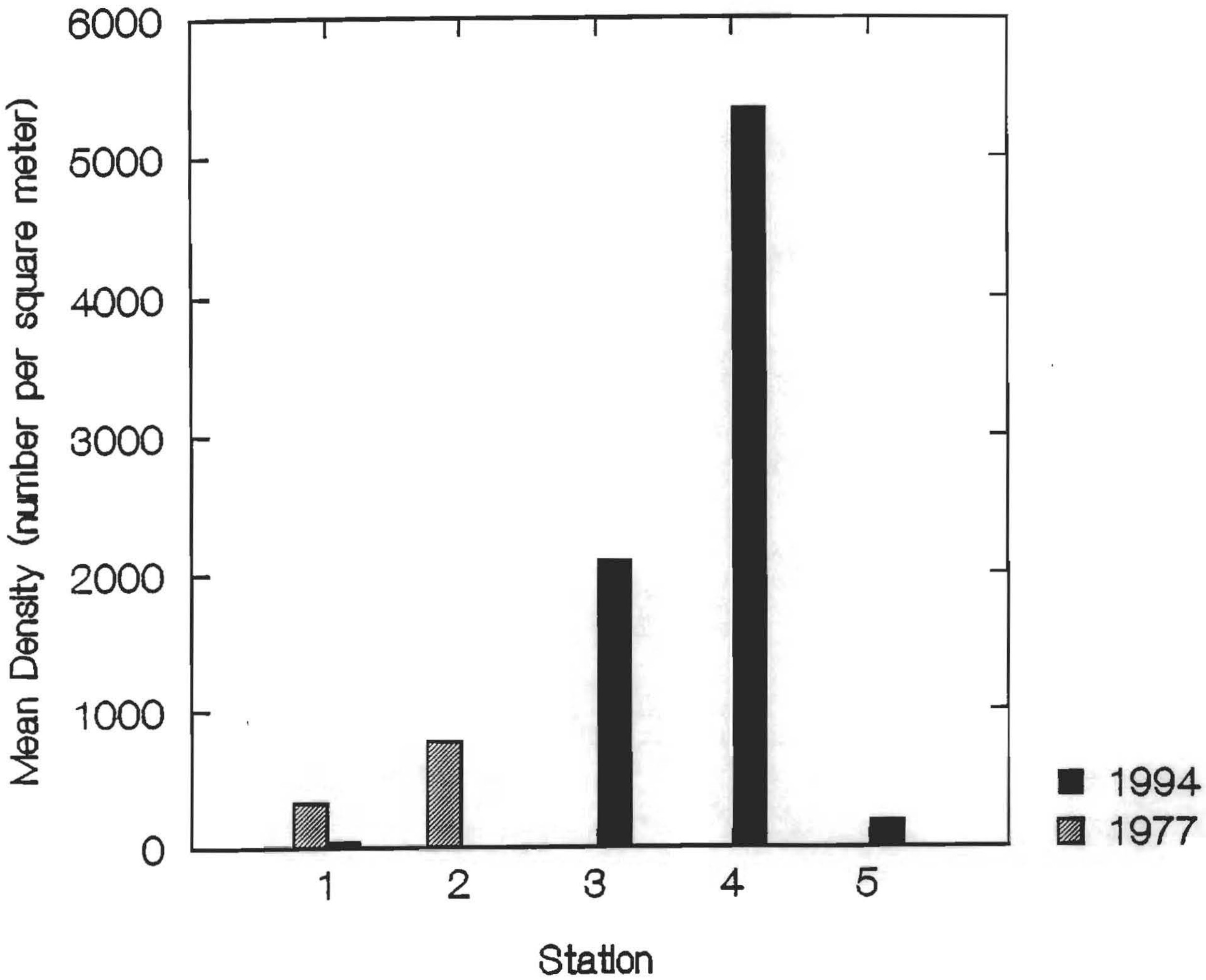


Figure 9.8

Corophium Abundance by Year, Porter's Point

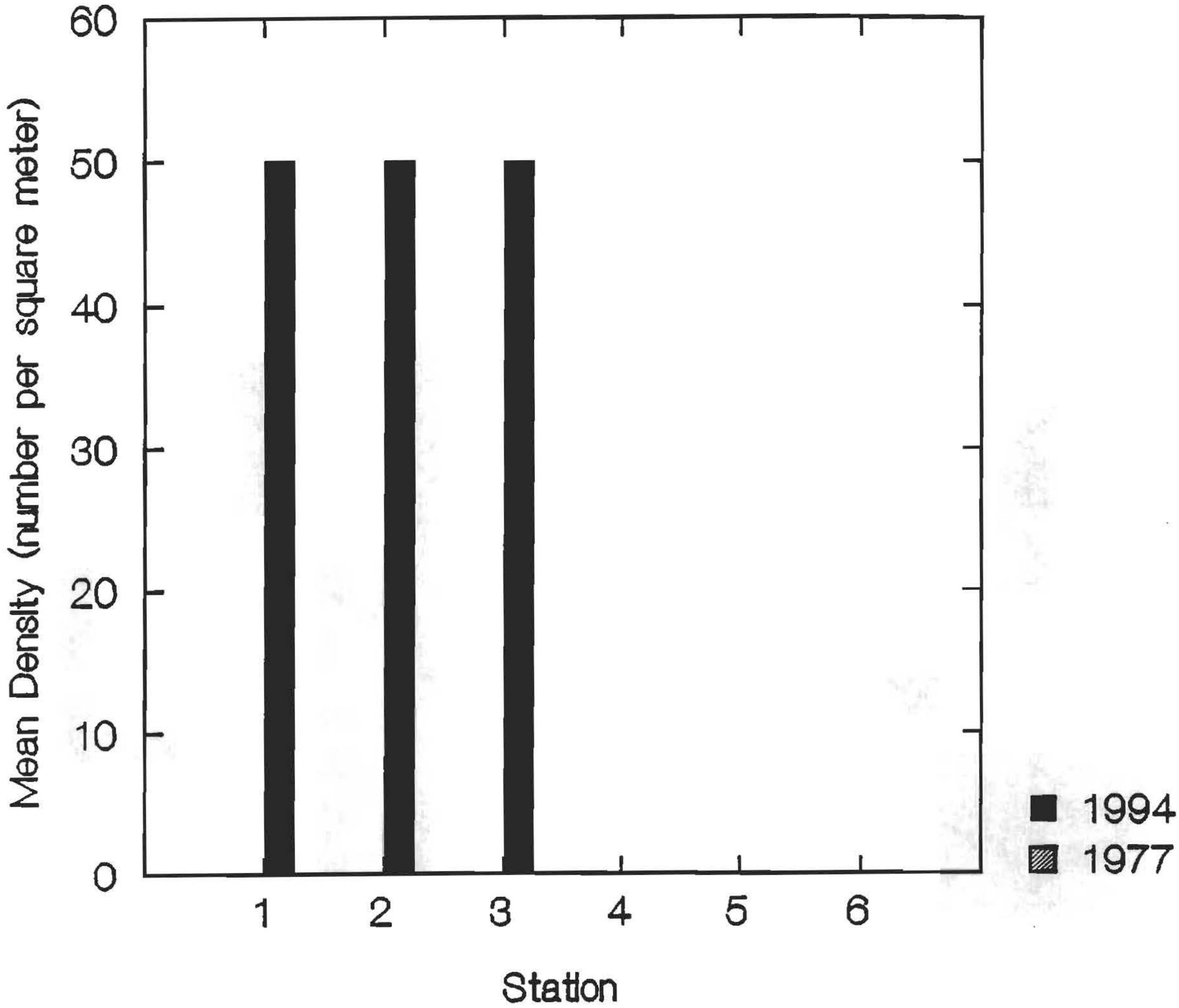


Figure 9.9

Corophium Abundance by Year, Starrs Point Flats

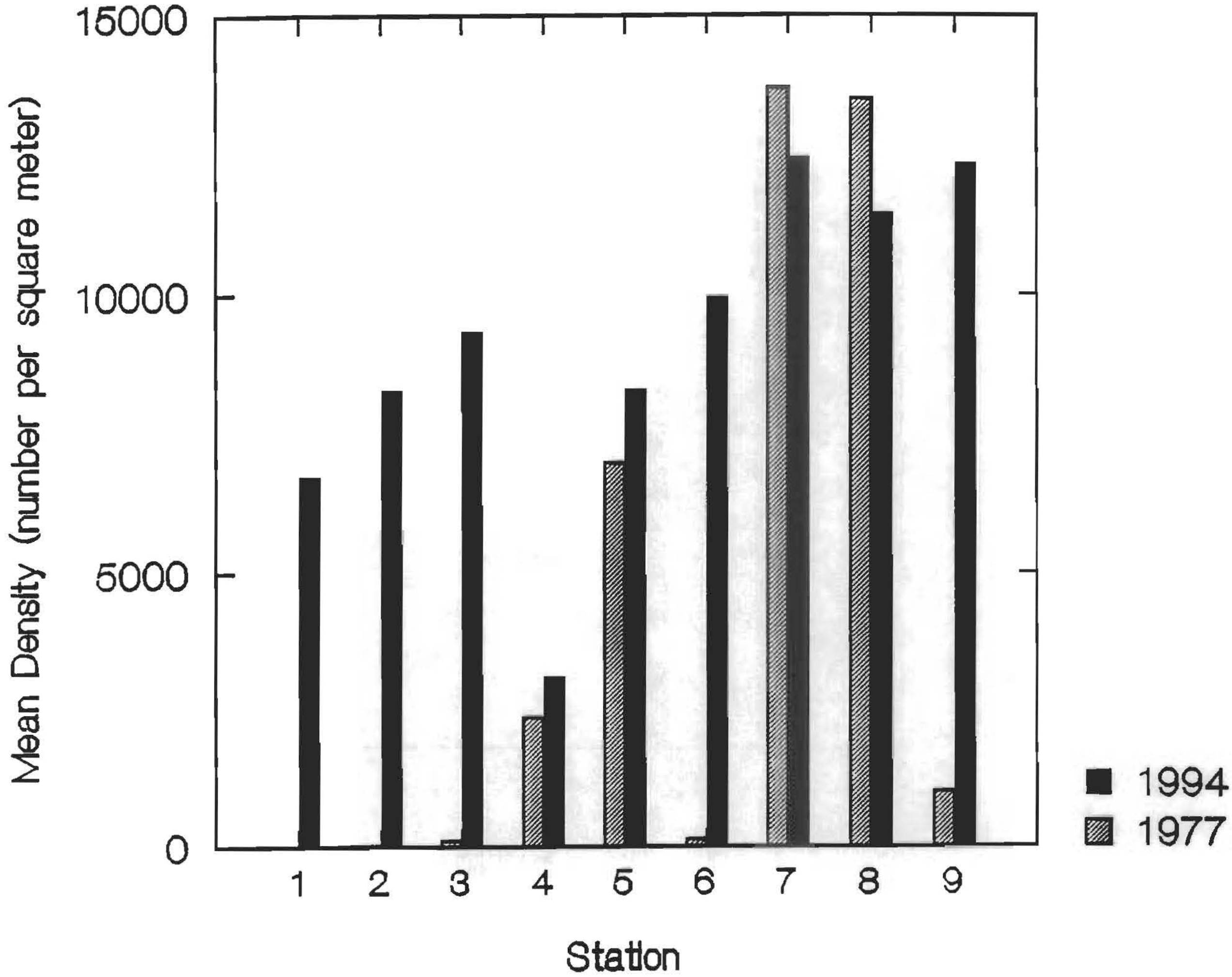


Figure 9.10

Corophium Abundance by Year, Starrs Point Sandbar

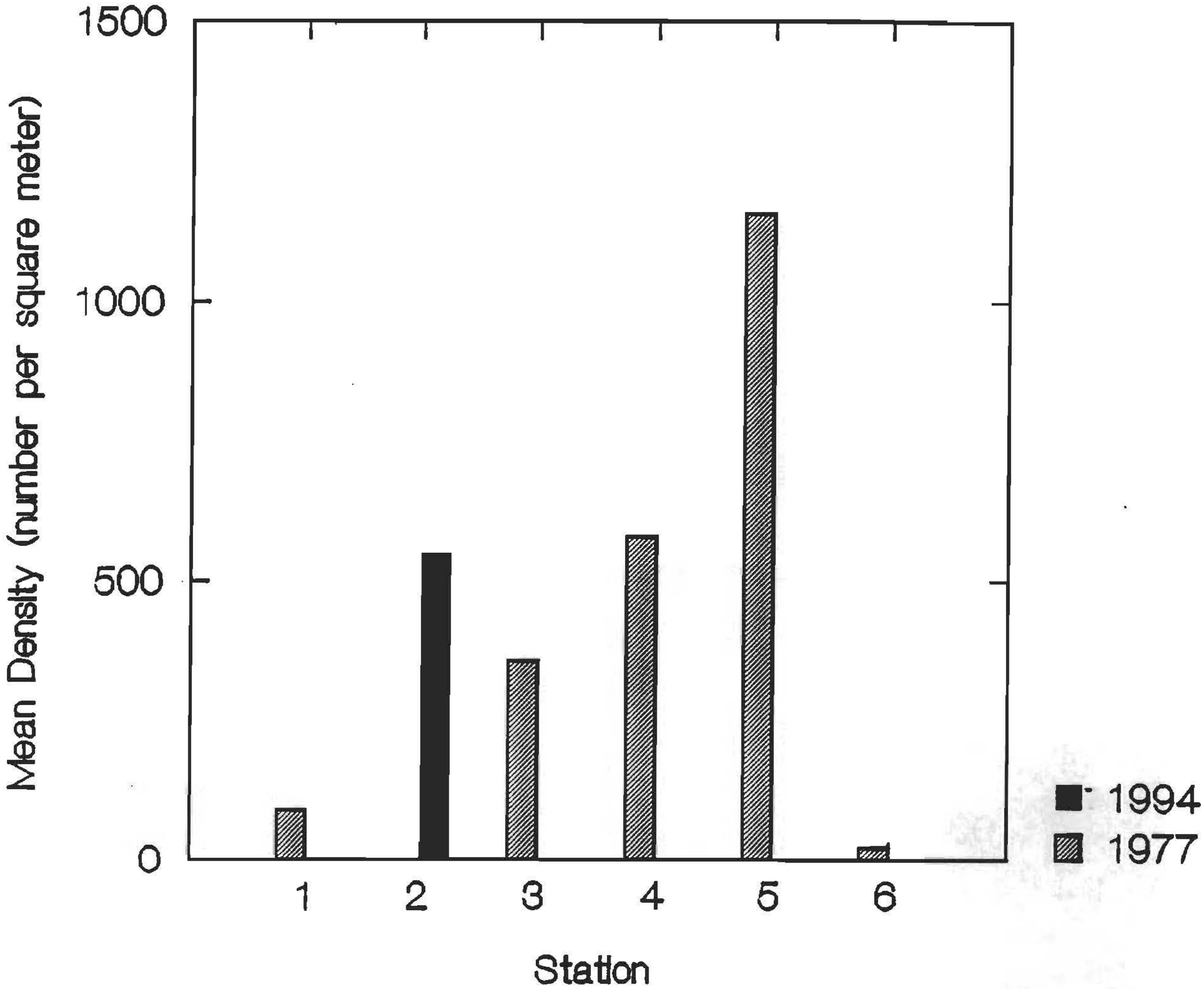
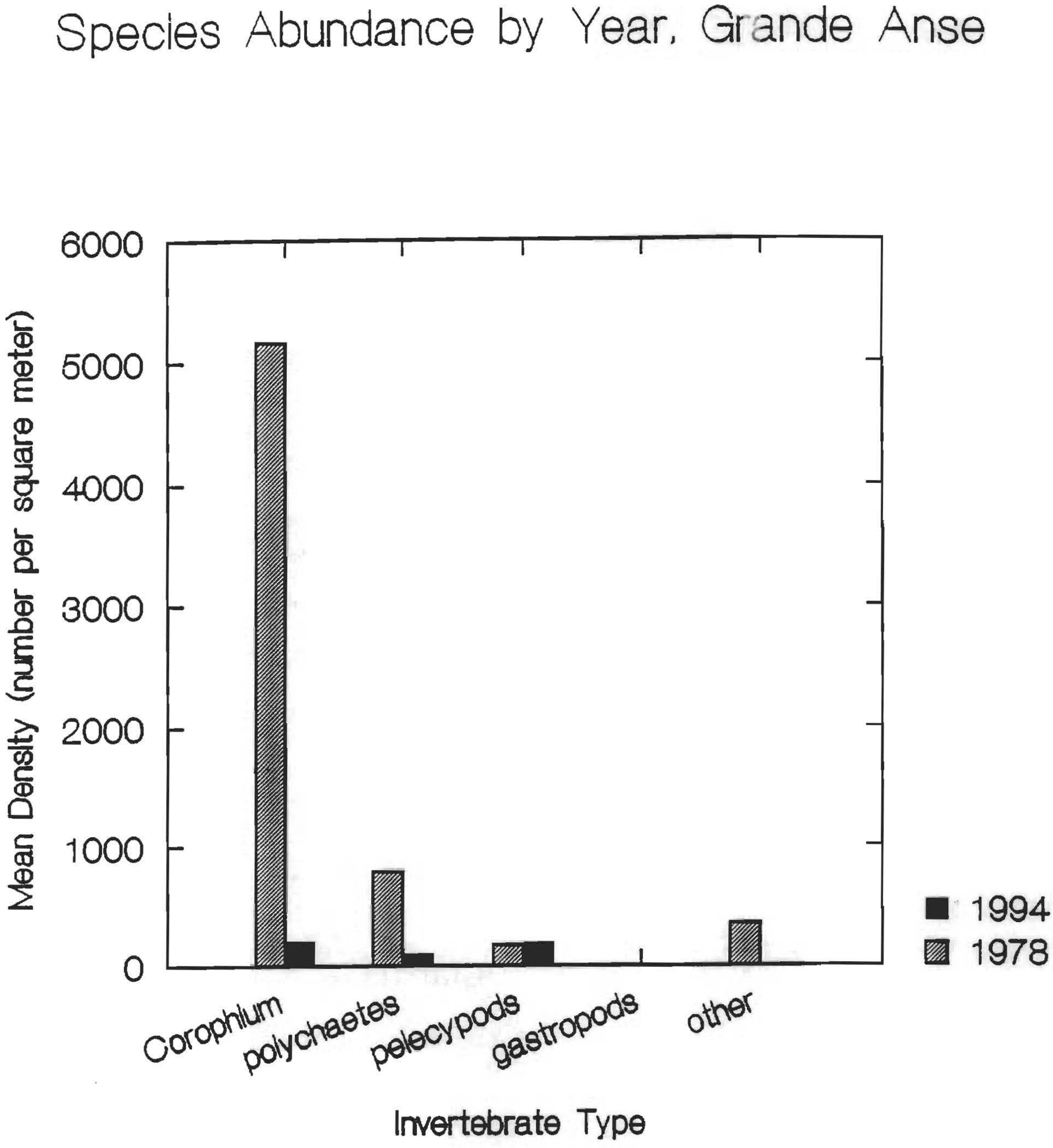


Figure 10.1



Species Abundance by Year, Grande Anse
Mean Density (number per square meter)
6000
5000
4000
3000
2000
1000
0
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1978

Figure 10.2

Species Abundance by Year, Mary's Point

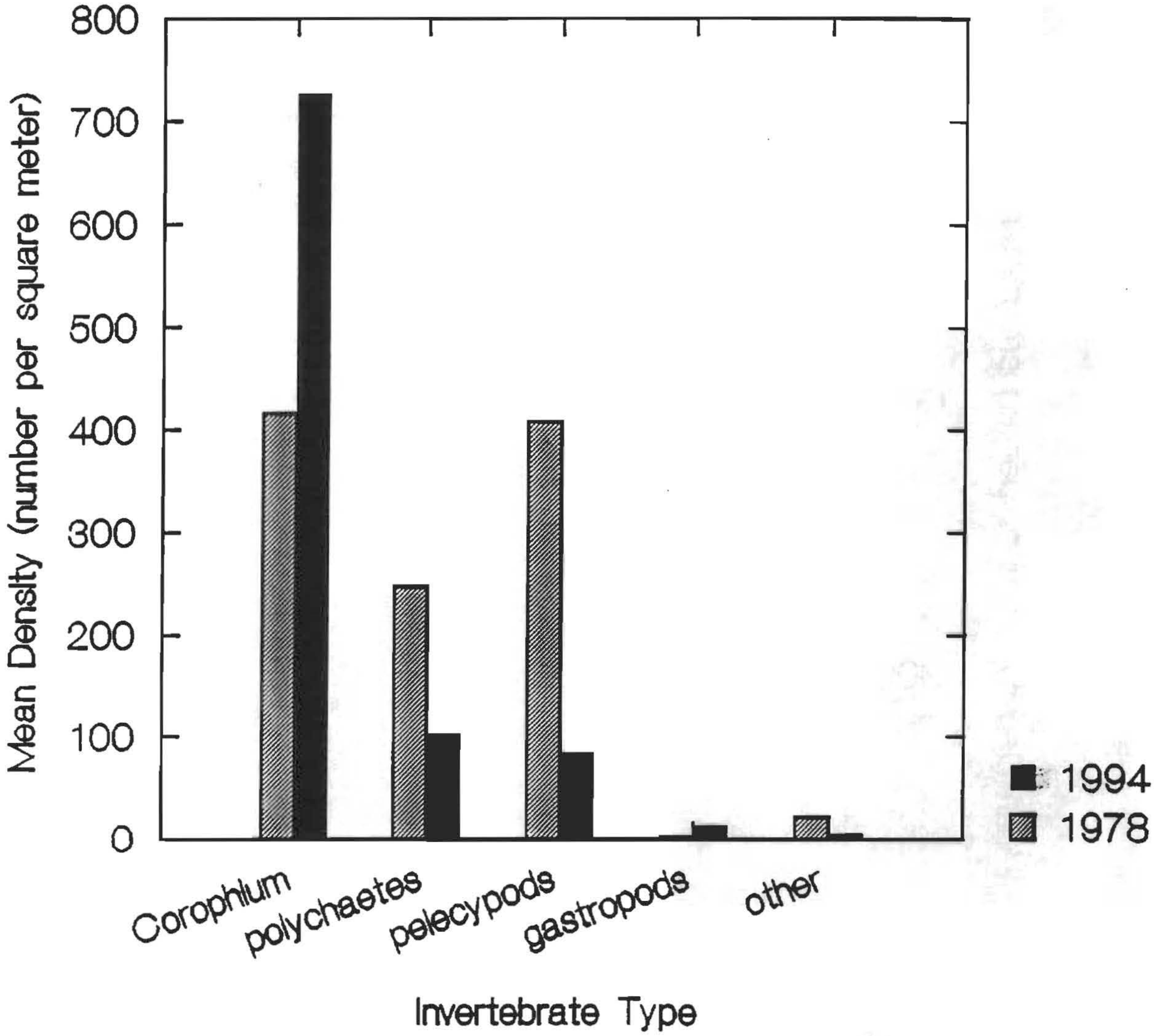


Figure 10.3

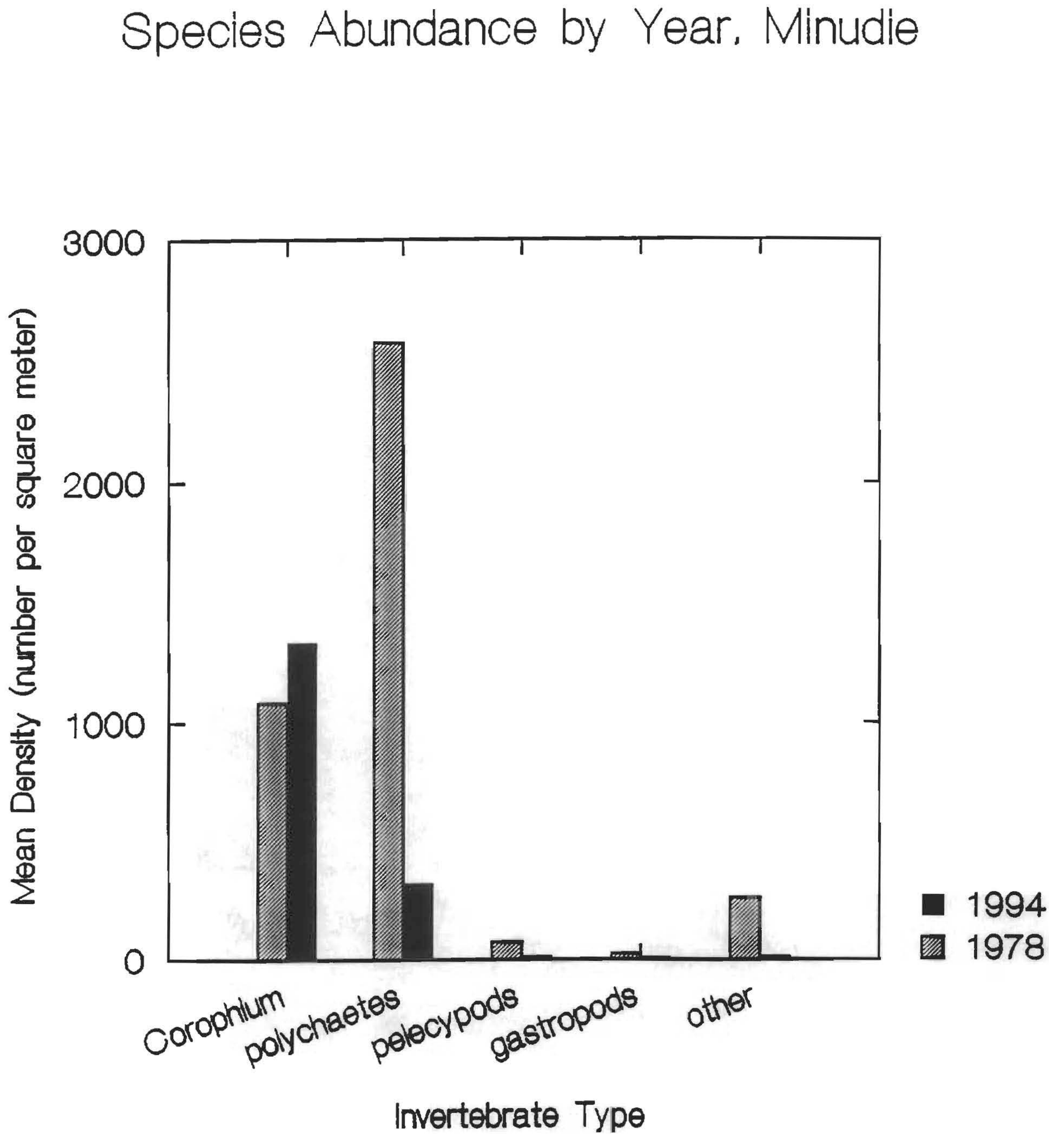

Species Abundance by Year, Minudie
3000
2000
1000
0
Mean Density (number per square meter)
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1978

Figure 10.4

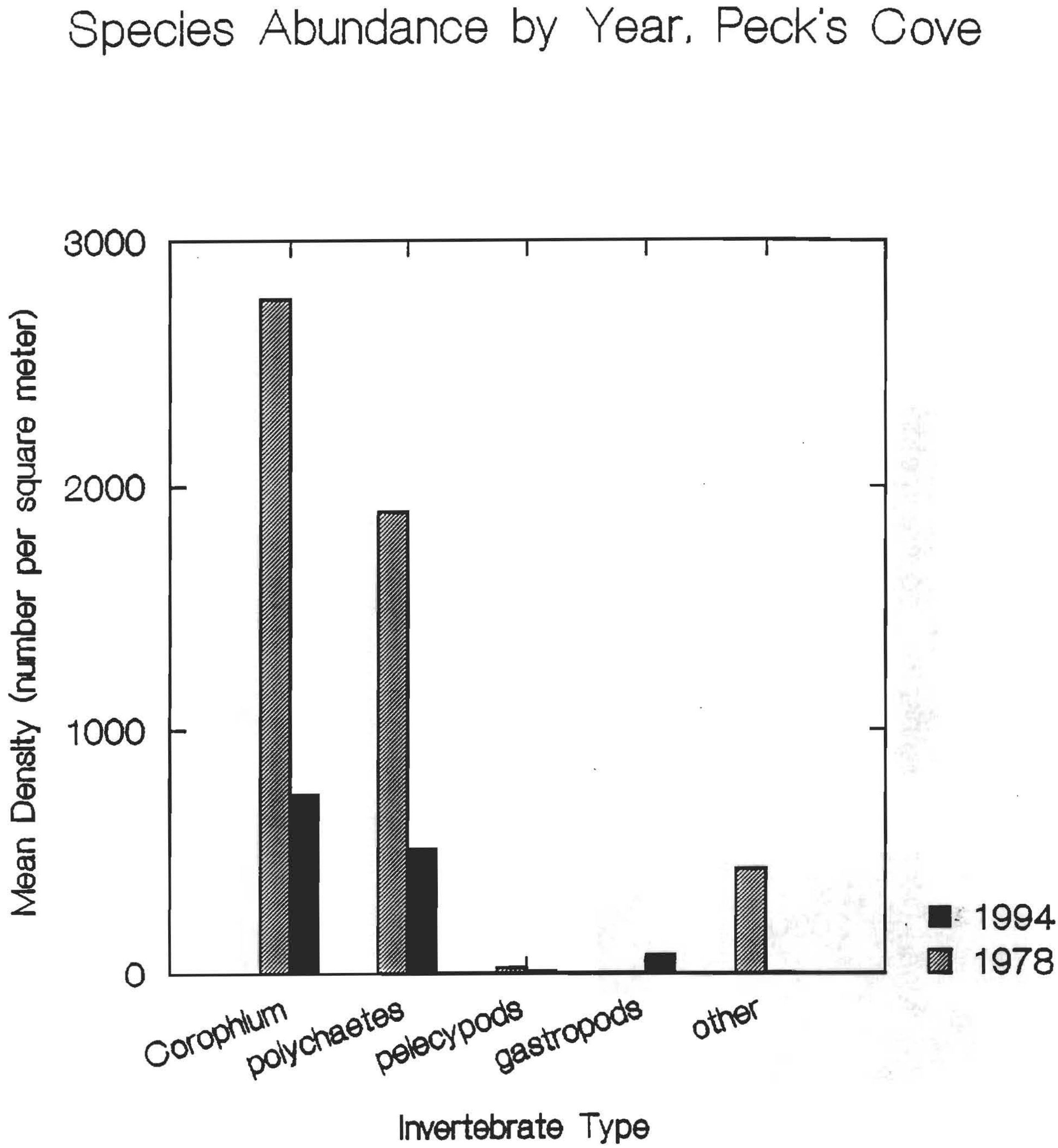

Species Abundance by Year, Peck's Cove
3000
2000
1000
0
Mean Density (number per square meter)
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1978

Figure 10.5

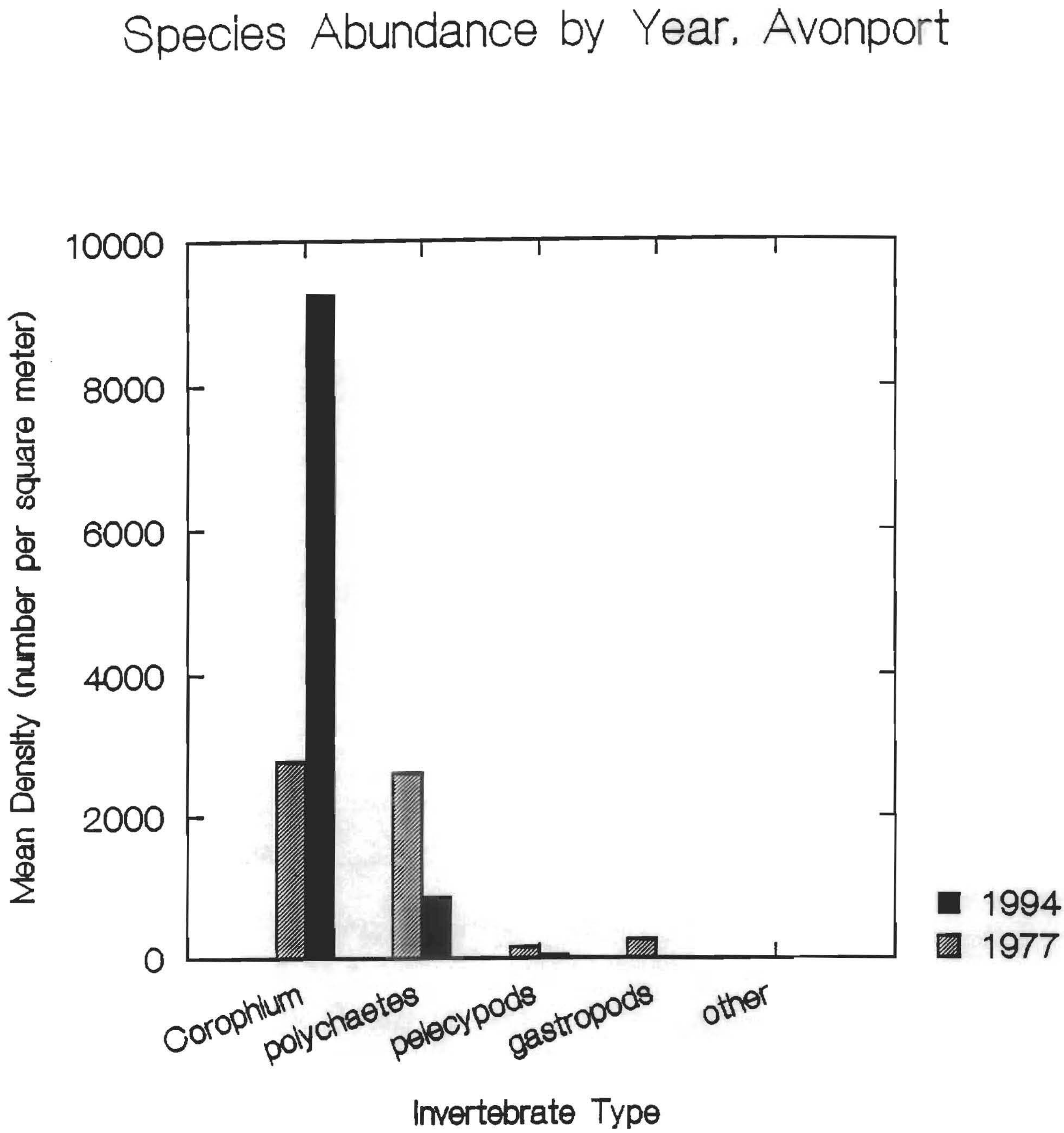
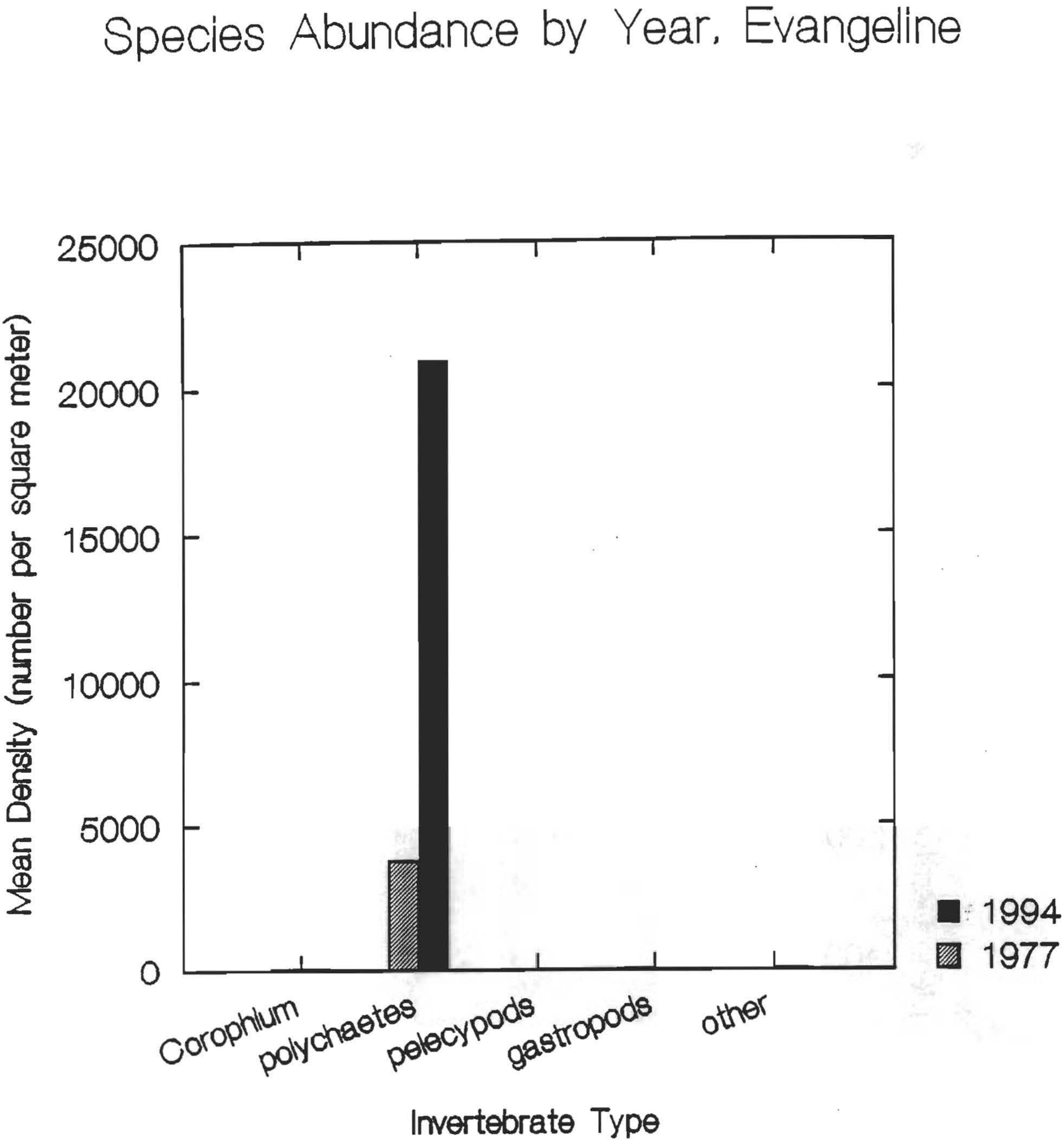

Species Abundance by Year, Avonport
Mean Density (number per square meter)
10000
8000
6000
4000
2000
0
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1977

Figure 10.6



Species Abundance by Year, Evangeline
25000
20000
15000
10000
5000
0
Mean Density (number per square meter)
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1977

Figure 10.7

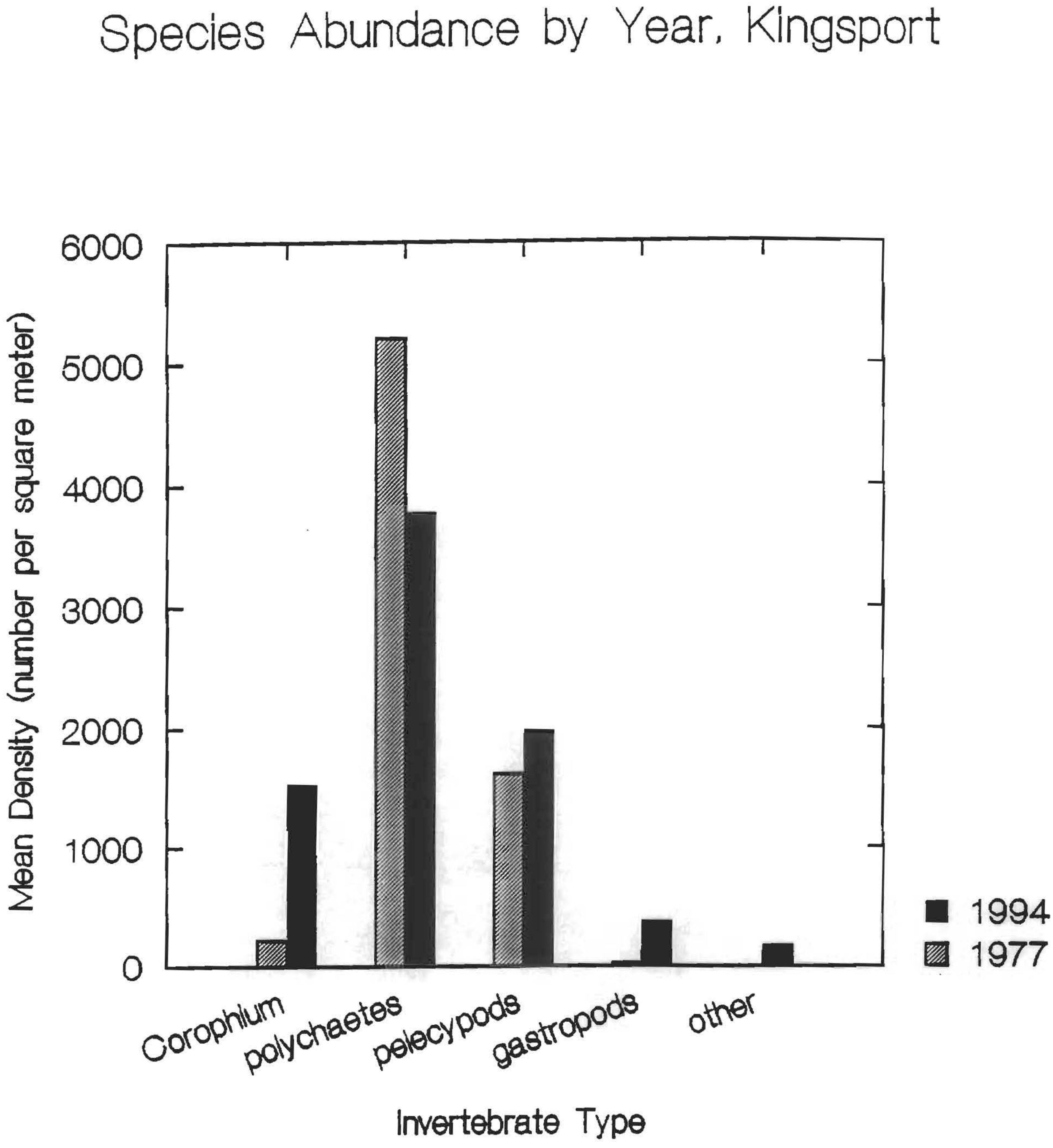

Species Abundance by Year, Kingsport
6000
5000
4000
3000
2000
1000
0
Mean Density (number per square meter)
Corophium
polychaetes
pelecypods
gastropods
other
Invertebrate Type
1994
1977

Figure 10.8

Species Abundance by Year, Porter's Point

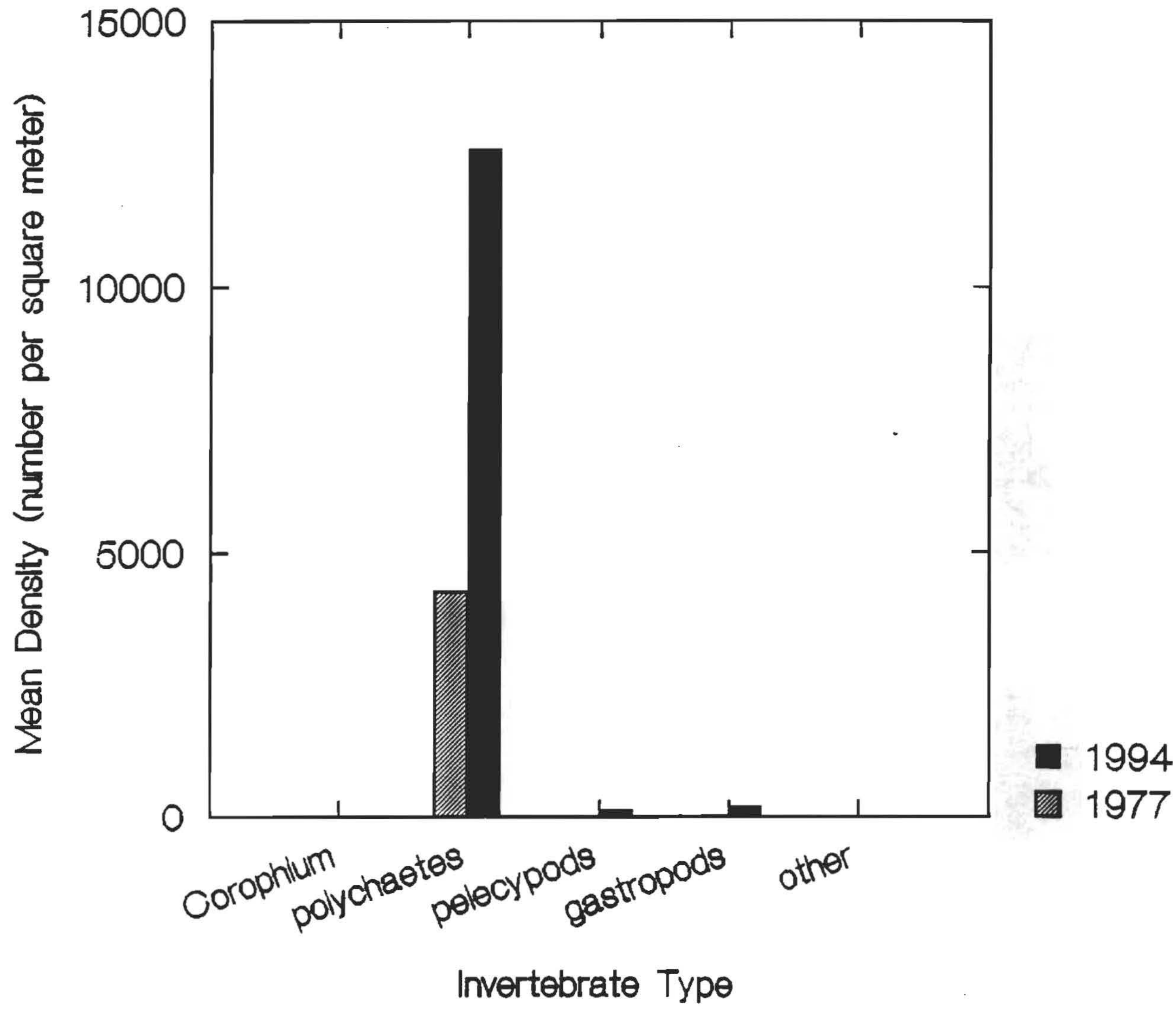


Figure 10.9

Species Abundance by Year, Starrs Point Flats

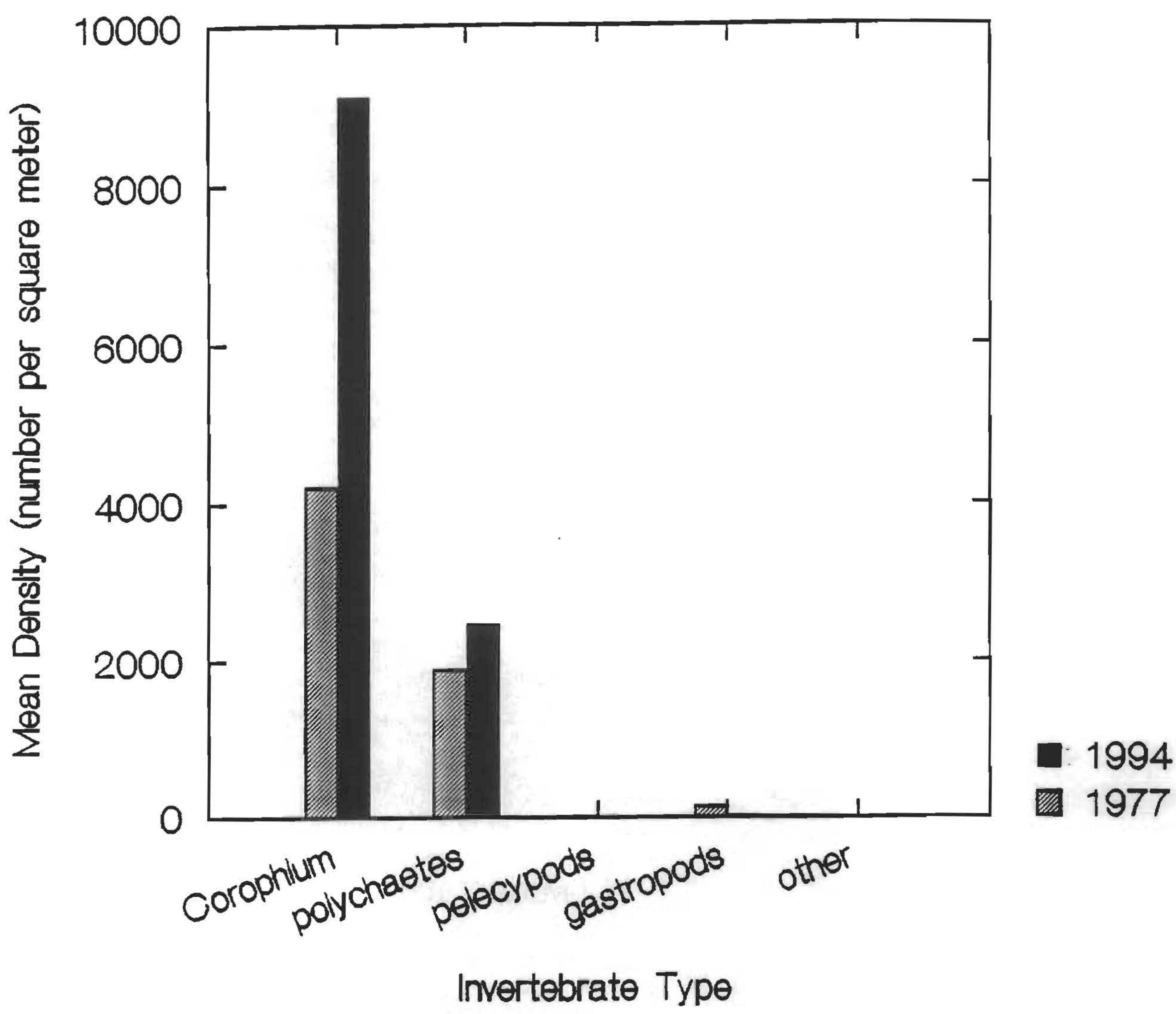
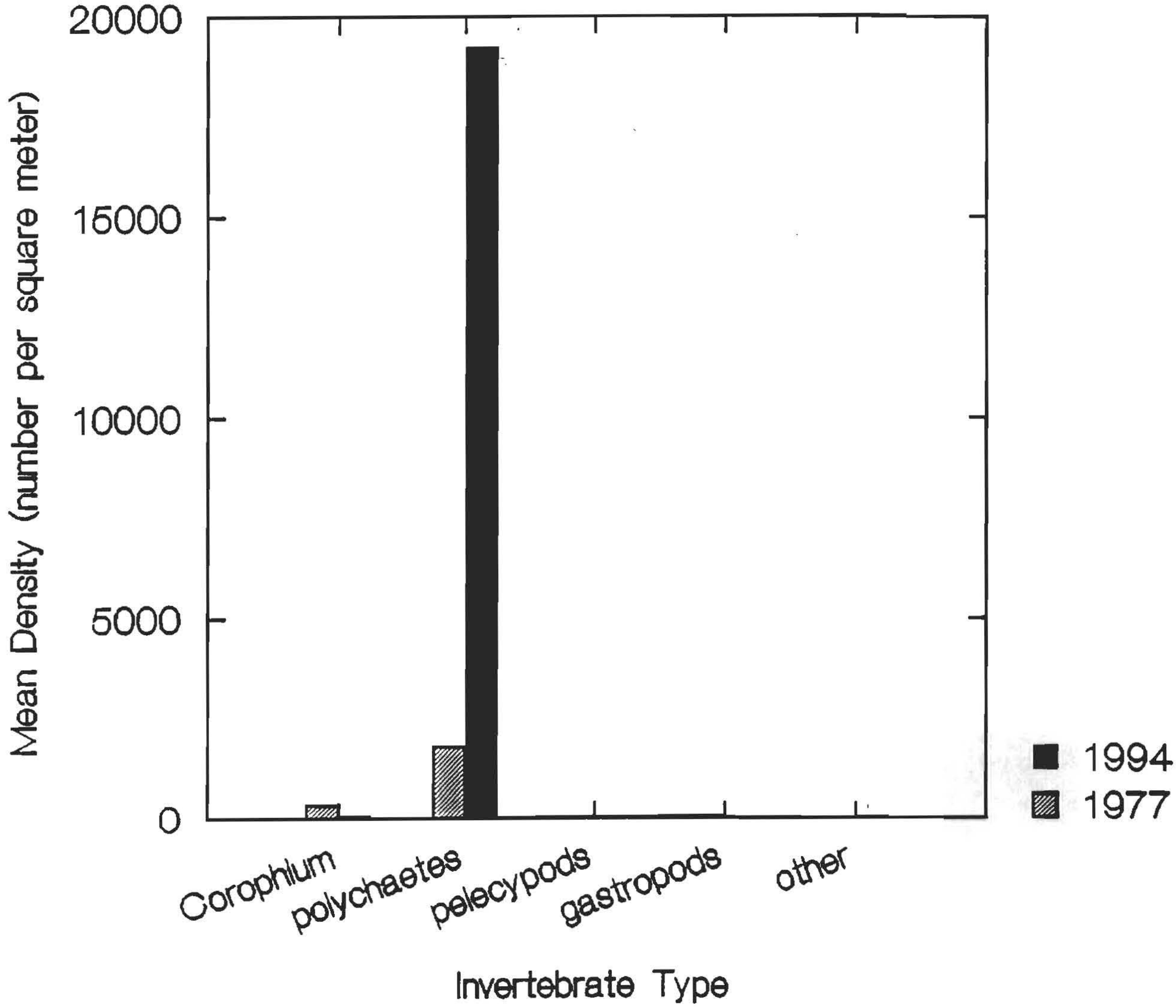


Figure 10.10

Species Abundance by Year, Starrs Point Sandbar



APPENDICES

Appendix 1

BAY OF FUNDY SEDIMENT ANALYSIS
1994

RAW DATA

PHILIPPA SHEPHERD

MARY'S POINT

Station 2:

sediment size class	1979	1994
Granule	0	0.09
Very coarse sand	1.24	0.17
Coarse sand	1.71	0.97
Medium sand	2.43	1.35
Fine sand	1.15	1.16
Very fine sand	3.79	4.88
Silt, clay (pan fraction)	3.65	0.04
Silt, clay (sieved out)	86.00	91.33
Silt, clay (total)	89.65	91.37

Water content	18.35	34.68

Station 7:

sediment size class	1979	1994
Granule	0	0.03
Very coarse sand	0	0.41
Coarse sand	0	3.59
Medium sand	0.12	13.62
Fine sand	0.29	8.88
Very fine sand	9.74	4.19
Silt, clay (pan fraction)	6.23	0.05
Silt, clay (sieved out)	83.63	69.24
Silt, clay (total)	89.86	69.29

Water content	19.48	27

MARY'S POINT (Con't)

Station 13:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.04
Medium sand	0.28	0.06
Fine sand	0.51	1.09
Very fine sand	19.96	10.08
Silt, clay (pan fraction)	12.88	0.15
Silt, clay (sieved out)	66.38	88.57
Silt, clay (total)	79.26	88.72

Water content	18.00	31.79

Station 19:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.05
Medium sand	0.88	0.22
Fine sand	7.59	7.01
Very fine sand	35.45	19.84
Silt, clay (pan fraction)	19.79	0.16
Silt, clay (sieved out)	36.29	72.72
Silt, clay (total)	56.08	72.88

Water content	17.48	29.60

PORTER'S POINT

Station 1:

sediment size class	1977	1994
Granule	0.28	0
Very coarse sand	0.21	0.02
Coarse sand	0.44	0.30
Medium sand	0.64	0.91
Fine sand	1.31	1.32
Very fine sand	5.62	6.32
Silt, clay (pan fraction)		0.09
Silt, clay (sieved out)		91.03
Silt, clay (total)	91.34	91.12

Water content		31.22

Station 3:

sediment size class	1977	1994
Granule	0.73	0
Very coarse sand	0.31	0.08
Coarse sand	0.60	0.13
Medium sand	0.73	0.28
Fine sand	1.39	3.92
Very fine sand	12.43	10.63
Silt, clay (pan fraction)		0.06
Silt, clay (sieved out)		84.90
Silt, clay (total)	83.86	84.96

Water content		30.39

PORTER'S POINT (Con't)

Station 5:

sediment size class	1977	1994
Granule	0.06	0.02
Very coarse sand	0.14	0.04
Coarse sand	0.37	0.11
Medium sand	0.61	0.27
Fine sand	1.45	1.48
Very fine sand	17.74	27.51
Silt, clay (pan fraction)		2.42
Silt, clay (sieved out)		68.15
Silt, clay (total)	80.06	70.57

Water content		30.87

KINGSPORT

Station 1:

sediment size class	1977	1994
Granule	0.96	0.04
Very coarse sand	2.66	1.21
Coarse sand	16.71	4.36
Medium sand	13.44	8.28
Fine sand	24.33	23.58
Very fine sand	11.89	24.83
Silt, clay (pan fraction)		0.38
Silt, clay (sieved out)		37.33
Silt, clay (total)	23.00	37.71

Water content		18.69

Station 3:

sediment size class	1977	1994
Granule	0.21	0.08
Very coarse sand	0.68	0.61
Coarse sand	3.84	2.69
Medium sand	9.51	4.13
Fine sand	25.22	19.34
Very fine sand	13.36	16.83
Silt, clay (pan fraction)		0.09
Silt, clay (sieved out)		56.23
Silt, clay (total)	47.08	56.32

Water content		25.17

KINGSPORT (Con't)

Station 5:

sediment size class	1977	1994
Granule	NOT COLLECTED	1.37
Very coarse sand	"	3.43
Coarse sand	"	14.75
Medium sand	"	26.35
Fine sand	"	29.78
Very fine sand	"	7.54
Silt, clay (pan fraction)	"	0.06
Silt, clay (sieved out)	"	16.72
Silt, clay (total)	"	16.78

Water content	"	20.91

AVONPORT BEACH

Station 1:

sediment size class	1977	1994
Granule	6.79	4.07
Very coarse sand	1.67	3.78
Coarse sand	3.92	6.68
Medium sand	6.48	11.01
Fine sand	16.40	12.33
Very fine sand	9.34	9.55
Silt, clay (pan fraction)		0.09
Silt, clay (sieved out)		52.48
Silt, clay (total)	55.17	52.57

Water content		16.60

Station 3:

sediment size class	1977	1994
Granule	3.32	0.10
Very coarse sand	1.19	1.00
Coarse sand	2.46	5.72
Medium sand	3.58	13.78
Fine sand	5.84	10.04
Very fine sand	14.12	5.05
Silt, clay (pan fraction)		0.04
Silt, clay (sieved out)		64.28
Silt, clay (total)	69.46	64.32

Water content		31.64

AVONPORT BEACH (Con't)

Station 5:

sediment size class	1977	1994
Granule	2.52	2.54
Very coarse sand	0.47	5.98
Coarse sand	0.75	14.11
Medium sand	1.19	20.19
Fine sand	3.10	9.94
Very fine sand	25.13	5.87
Silt, clay (pan fraction)		0.04
Silt, clay (sieved out)		41.34
Silt, clay (total)	66.69	41.38

Water content		23.28

Station 7:

sediment size class	1977	1994
Granule	0.83	0.90
Very coarse sand	0.47	3.07
Coarse sand	1.10	4.49
Medium sand	1.60	6.74
Fine sand	10.77	6.77
Very fine sand	40.82	21.55
Silt, clay (pan fraction)		0.41
Silt, clay (sieved out)		56.07
Silt, clay (total)	44.17	56.48

Water content		26.22

STARRS POINT FLAT

Station 2:

sediment size class	1977	1994
Granule	0.36	0
Very coarse sand	0.28	0.14
Coarse sand	0.71	0.29
Medium sand	0.83	0.34
Fine sand	1.55	2.60
Very fine sand	10.76	14.90
Silt, clay (pan fraction)		0.12
Silt, clay (sieved out)		81.61
Silt, clay (total)	85.43	81.73

Water content		31.01

Station 5:

sediment size class	1977	1994
Granule	0.04	0
Very coarse sand	0.02	0.01
Coarse sand	0.09	0.03
Medium sand	0.24	0.06
Fine sand	0.74	6.08
Very fine sand	28.54	27.44
Silt, clay (pan fraction)		1.23
Silt, clay (sieved out)		65.15
Silt, clay (total)	82.02	66.38

Water content		27.21

STARRS POINT FLAT (Con't)

Station 7:

sediment size class	1977	1994
Granule	0.14	0
Very coarse sand	0.03	0.02
Coarse sand	0.06	0.04
Medium sand	0.09	0.10
Fine sand	0.70	14.67
Very fine sand	35.16	26.08
Silt, clay (pan fraction)		1.44
Silt, clay (sieved out)		57.64
Silt, clay (total)	63.59	59.08

Water content		26.16

Station 9:

sediment size class	1977	1994
Granule	0.01	0
Very coarse sand	0.02	0
Coarse sand	0.55	0.07
Medium sand	0.13	0.23
Fine sand	2.70	10.03
Very fine sand	46.84	36.44
Silt, clay (pan fraction)		1.43
Silt, clay (sieved out)		51.81
Silt, clay (total)	50.20	53.24

Water content		25.98

STARRS POINT SANDBAR

Station 1:

sediment size class	1977	1994
Granule	0.03	0
Very coarse sand	0.05	0.01
Coarse sand	0.10	0.04
Medium sand	0.14	0.14
Fine sand	30.52	67.82
Very fine sand	53.04	16.19
Silt, clay (pan fraction)		0.27
Silt, clay (sieved out)		15.52
Silt, clay (total)	16.00	15.79

Water content		24.66

Station 3:

sediment size class	1977	1994
Granule	0.11	0
Very coarse sand	0.03	0.04
Coarse sand	0.60	0.15
Medium sand	0.19	0.55
Fine sand	19.20	70.09
Very fine sand	57.13	17.75
Silt, clay (pan fraction)		0.14
Silt, clay (sieved out)		11.27
Silt, clay (total)	23.28	11.41

Water content		23.61

STARRS POINT SANDBAR (Con't)

Station 5:

sediment size class	1977	1994
Granule	0	0.03
Very coarse sand	0	0.25
Coarse sand	0.02	1.10
Medium sand	0.23	5.70
Fine sand	24.61	72.90
Very fine sand	53.47	11.79
Silt, clay (pan fraction)		0.07
Silt, clay (sieved out)		8.16
Silt, clay (total)	21.50	8.23

Water content		18.94

*Average water content of the Starrs Point Sandbar on June 18, 1979 was 17.79% (from Boates 1980).

EVANGELINE BEACH

Station 5:

sediment size class	1977	1994
Granule	0.04	0.07
Very coarse sand	0.05	0.22
Coarse sand	0.35	0.99
Medium sand	0.60	1.85
Fine sand	1.75	4.75
Very fine sand	11.01	11.15
Silt, clay (pan fraction)		0.12
Silt, clay (sieved out)		80.85
Silt, clay (total)	86.02	80.97

Water content		33.93

Station 10:

sediment size class	1977	1994
Granule	0.24	0
Very coarse sand	0.23	0.04
Coarse sand	0.44	0.11
Medium sand	0.61	0.27
Fine sand	6.48	20.12
Very fine sand	33.26	15.15
Silt, clay (pan fraction)		0.22
Silt, clay (sieved out)		64.09
Silt, clay (total)	58.66	64.31

Water content		29.79

EVANGELINE BEACH (Con't)

Station 15:

sediment size class	1977	1994
Granule	0.03	0.06
Very coarse sand	0.04	0.18
Coarse sand	0.08	0.35
Medium sand	0.23	1.37
Fine sand	15.40	36.16
Very fine sand	40.31	25.07
Silt, clay (pan fraction)		0.41
Silt, clay (sieved out)		36.41
Silt, clay (total)	43.90	36.81

Water content		26.33

Station 20:

sediment size class	1977	1994
Granule	0.35	9.89
Very coarse sand	0.12	7.31
Coarse sand	0.12	12.02
Medium sand	0.49	16.46
Fine sand	29.97	29.99
Very fine sand	42.51	10.80
Silt, clay (pan fraction)		0.04
Silt, clay (sieved out)		13.50
Silt, clay (total)	26.08	13.54

Water content		18.03

MINUDIE

Station 2:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0.11
Coarse sand	0	0.70
Medium sand	0.63	3.66
Fine sand	0.75	6.38
Very fine sand	1.95	5.10
Silt, clay (pan fraction)	2.11	0.01
Silt, clay (sieved out)	94.56	84.05
Silt, clay (total)	96.67	84.06

Water content	20.39	40.10

Station 5:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.03
Medium sand	0.59	0.08
Fine sand	0.70	0.74
Very fine sand	5.48	5.21
Silt, clay (pan fraction)	10.25	0.01
Silt, clay (sieved out)	82.98	93.94
Silt, clay (total)	93.23	93.95

Water content	20.45	39.19

MINUDIE (Con't)

Station 9:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0.01
Coarse sand	0	0.01
Medium sand	0.22	0.07
Fine sand	0.67	1.98
Very fine sand	15.86	12.54
Silt, clay (pan fraction)	10.49	0.06
Silt, clay (sieved out)	72.76	85.33
Silt, clay (total)	83.25	85.39

Water content	18.02	34.47

PECK'S COVE

Station 2:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0.27	0.01
Medium sand	0.24	0.14
Fine sand	0.72	0.38
Very fine sand	13.63	2.13
Silt, clay (pan fraction)	24.01	0.01
Silt, clay (sieved out)	61.16	97.33
Silt, clay (total)	85.17	97.34

Water content	17.1	32.53

Station 5:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0
Medium sand	0	0.02
Fine sand	0	0.10
Very fine sand	42.80	10.73
Silt, clay (pan fraction)	53.81	0.03
Silt, clay (sieved out)	3.38	89.12
Silt, clay (total)	57.19	89.15

Water content	18.0	35.95

PECK'S COVE (Con't)

Station 9:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0.10	0.01
Medium sand	0.15	0.44
Fine sand	0.99	3.28
Very fine sand	13.53	18.18
Silt, clay (pan fraction)	13.52	0.14
Silt, clay (sieved out)	71.70	77.95
Silt, clay (total)	85.22	78.09

Water content	18.4	34.37

GRANDE ANSE

Station 1:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0.02
Coarse sand	0	0.17
Medium sand	2.84	2.03
Fine sand	6.44	8.88
Very fine sand	6.76	2.09
Silt, clay (pan fraction)	1.48	0.01
Silt, clay (sieved out)	82.48	86.80
Silt, clay (total)	83.96	86.81

Water content	21.9	35.34

Station 4:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.08
Medium sand	0.26	0.29
Fine sand	0.38	0.75
Very fine sand	2.95	2.29
Silt, clay (pan fraction)	3.32	0.01
Silt, clay (sieved out)	93.08	96.59
Silt, clay (total)	96.40	96.60

Water content	21.1	34.83

GRANDE ANSE (Con't)

Station 8:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.01
Medium sand	0.30	0.12
Fine sand	0.45	0.40
Very fine sand	3.54	3.97
Silt, clay (pan fraction)	2.90	0.01
Silt, clay (sieved out)	92.80	95.49
Silt, clay (total)	95.70	95.50

Water content	22.2	38.00

Station 12:

sediment size class	1979	1994
Granule	0	0
Very coarse sand	0	0
Coarse sand	0	0.09
Medium sand	0.27	0.45
Fine sand	0.47	1.29
Very fine sand	18.74	12.42
Silt, clay (pan fraction)	13.42	0.05
Silt, clay (sieved out)	67.11	85.69
Silt, clay (total)	80.53	85.74

Water content	16.8	35.69

Appendix 2

BAY OF FUNDY INVERTEBRATE ANALYSIS 1994

RAW DATA

VALERIE PARTRIDGE

Grande Anse

Invertebrate Density (#/sq. m)

1978	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	200	100	100	700	0	2300	0	0	200	100
2	0	3400	200	100	1500	100	0	0	0	0
3	4400	4000	800	600	0	0	0	0	1200	0
4	6400	4300	200	500	0	0	0	0	100	100
5	5100	12700	300	400	0	0	0	0	200	300
6	13400	3200	400	400	0	0	0	0	900	0
7	11600	8200	300	1600	0	100	0	0	1000	700
8	800	12300	100	1300	0	100	0	0	0	500
9	9800	8200	500	200	0	0	0	0	0	2000
10	3900	6500	3600	1400	0	0	0	0	0	400
11	800	4300	200	0	0	0	0	0	0	0
12	200	100	2800	2300	0	0	0	0	0	700
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	200	0	0	100	4300	0	0	0	0	100
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	100	0	0	0	0	0
5	0	0	100	0	0	0	0	0	0	0
6	0	0	0	100	0	0	200	0	0	0
7	0	0	100	300	0	0	0	0	0	0
8	0	0	100	200	0	0	0	0	0	0
9	0	4700	100	0	200	0	0	0	100	0
10	0	0	100	200	0	0	0	0	0	0
11	0	0	100	100	0	0	0	0	0	0
12	0	0	600	200	0	0	0	0	0	0

Minudie

Invertebrate Density (#/sq. m)

1978	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	.	.	.	.	.	.	.	.	.	.
2	1000	2000	1500	2500	0	0	0	0	0	0
3	4800	2300	1600	1900	500	0	0	0	0	300
4	100	0	3300	2500	100	0	0	0	200	600
5	800	0	2400	1500	0	200	0	100	0	100
6	0	100	1200	1300	300	0	0	0	900	700
7	1000	300	1600	1900	0	0	100	100	300	0
8	2800	1700	4600	4400	100	0	100	0	500	400
9	200	200	2200	6800	0	0	0	0	200	0
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	700	2300	0	0	0	0	0	100	0	0
2	3300	3900	100	200	0	0	0	0	0	0
3	700	2500	100	200	100	0	0	0	0	0
4	2800	700	.	200	0	100	0	0	0	0
5	2600	600	800	200	100	0	0	0	0	0
6	0	500	1100	700	0	0	0	0	100	0
7	3000	0	500	200	0	0	0	0	100	0
8	0	0	300	500	0	0	100	0	0	0
9	0	400	200	300	0	0	0	0	100	0

Mary's Point

Invertebrate Density (#/sq. m)

1978	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	100	0	400	6100	5500	0	0	0	0
2	1800	1700	1000	400	1600	1300	0	0	0	0
3	600	3300	500	300	0	100	0	0	0	0
4	600	1000	200	900	100	100	0	0	0	0
5	500	0	1200	400	0	100	0	0	0	0
6	200	1300	700	100	0	0	0	0	0	0
7	0	200	0	100	500	0	100	0	800	0
8	1200	200	0	200	0	100	0	0	0	0
9	0	800	200	100	0	0	0	0	0	0
10	300	100	300	900	0	0	0	0	0	0
11	100	0	200	400	0	0	0	0	0	0
12	0	200	0	200	0	0	0	0	0	0
13	0	200	0	200	0	0	0	0	0	0
14	200	800	0	0	0	0	0	0	0	0
15	0	100	0	0	0	0	0	0	0	0
16	0	300	0	200	0	0	0	0	0	0
17	0	0	100	0	0	0	0	0	0	0
18	0	0	100	100	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0

Mary's Point

Invertebrate Density (#/sq. m)

1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	.	0	.	400	.	0	.	0	.	100
2	100	0	100	200	1000	500	0	0	0	0
3	2400	800	200	400	1100	400	0	0	0	0
4	400	2500	0	0	0	100	0	0	0	0
5	1100	1300	0	100	100	0	0	0	0	0
6	2400	1800	0	0	0	0	0	0	0	0
7	2300	2000	0	100	0	0	100	0	0	0
8	1600	2800	300	0	0	0	0	0	0	0
9	2000	1200	100	0	0	0	0	0	0	0
10	0	400	200	200	0	0	0	0	0	0
11	0	0	0	100	0	0	0	0	0	0
12	0	300	100	0	0	0	0	0	0	0
13	0	200	0	100	0	0	0	0	0	0
14	0	1000	100	0	0	0	0	0	0	0
15	100	0	0	100	0	0	0	0	0	0
16	0	800	100	0	0	0	0	400	0	0
17	0	0	100	100	0	0	0	0	0	0
18	0	100	100	100	0	0	0	0	0	0
19	0	0	200	0	0	0	0	0	0	0

Peck's Cove

Invertebrate Density (#/sq. m)

1978	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	800	0	0	0	0	0	0	0	100
2	600	4300	3600	3800	100	100	0	0	100	600
3	7300	3900	2000	200	0	100	0	0	1000	0
4	3200	5700	6700	1700	0	0	0	0	1100	600
5	4500	3200	4100	1600	0	0	0	0	100	200
6	1800	8100	1700	2800	100	0	0	0	100	1200
7	1600	800	1200	1000	0	0	0	0	900	400
8	1000	1600	2800	200	0	0	0	0	900	300
9	200	1100	600	100	0	0	0	0	100	0
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	200	0	100	0	0	300	300	0	0
2	1500	3100	100	.	100	0	400	100	0	0
3	1100	4000	600	0	0	0	100	100	0	0
4	100	300	100	0	0	100	0	0	0	0
5	0	1000	600	300	0	0	0	0	0	0
6	400	200	900	100	0	0	0	100	0	0
7	0	0	800	1000	0	0	0	0	0	0
8	400	300	800	2400	0	0	0	0	0	0
9	0	700	1300	100	0	0	0	0	100	0

Avonport

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	89	0	712	668	1335	1068	0	0	.	.
2	3204	2270	1647	3204	0	356	0	0	.	.
3	178	223	5607	6453	0	45	1914	1914	.	.
4	10190	178	14863	1202	0	45	178	89	.	.
5	3115	134	1380	3382	0	0	45	356	.	.
6	7788	8500	2181	2670	0	45	0	0	.	.
7	712	3916	491	312	0	0	0	0	.	.
8	712	8989	401	712	0	0	0	134	.	.
9	0	0	356	1113	0	0	0	89	.	.

1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	100	0	0	0	100	200	0	0	0	0
2	.	1800	.	700	.	100	.	0	.	0
3	100	0	1000	1300	100	200	0	0	0	0
4	300	100	300	1300	0	200	0	0	0	0
5	0	0	700	800	0	100	0	0	0	0
6	1600	31100	3600	800	0	0	0	0	0	0
7	23700	15700	1000	300	0	0	100	0	0	0
8	27000	20100	800	1900	0	0	0	0	0	0
9	30900	12800	400	200	0	0	0	0	100	0

Evangeline

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	0	178	134	0	0	0	0	.	.
2	0	0	935	312	0	0	0	0	.	.
3	0	0	1513	45	0	0	445	224	.	.
4	267	0	2359	1380	0	0	178	0	.	.
5	0	0	10057	2092	0	0	0	0	.	.
6	45	0	4584	5830	0	0	0	0	.	.
7	0	0	6230	5785	0	0	0	45	.	.
8	0	0	1647	3471	0	0	0	0	.	.
9	1335	0	3560	1202	0	0	0	0	.	.
10	0	89	4317	3338	0	0	0	0	.	.
11	0	0	2181	7254	0	0	0	0	.	.
12	0	0	2804	1113	0	0	0	0	.	.
13	0	0	6275	1825	0	0	0	45	.	.
14	45	45	2403	4984	0	0	0	0	.	.
15	.	0	.	3249	.	0	.	0	.	.
16	45	45	12505	2893	0	45	0	89	.	.
17	0	.	5207	.	0	.	0	.	.	.
18	0	0	8322	356	0	0	89	0	.	.
19	0	0	14952	2403	0	0	45	0	.	.
20	0	0	.	1869	0	0	0	0	.	.

Evangeline

Invertebrate Density (#/sq. m)

1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	100	0	100	500	100	0	0	0	0
2	0	0	6800	3100	0	0	200	0	0	0
3	0	0	3000	4400	0	0	200	400	0	0
4	0	0	11500	8800	0	0	0	0	0	0
5	0	0	42500	11600	0	0	0	200	200	0
6	0	0	22500	5500	0	0	0	0	0	0
7	0	0	73500	3000	0	0	0	0	0	0
8	0	0	1900	7900	0	0	100	0	100	0
9	1100	0	37500	7500	0	0	0	0	100	0
10	100	100	43000	4000	0	0	0	0	100	0
11	600	400	45000	2500	0	0	0	0	0	0
12	1000	100	24000	2700	0	0	0	0	0	0
13	0	0	85400	2800	0	0	0	100	0	0
14	0	100	45200	2300	0	0	0	0	0	0
15	0	0	53300	11700	0	0	0	0	0	0
16	0	0	58500	1200	0	0	0	0	0	0
17	0	0	47500	3700	0	0	0	0	0	0
18	0	0	200	2300	0	0	0	0	0	0
19	0	0	43600	54500	0	200	100	100	0	100
20	0	100	45000	8700	0	0	100	300	2300	0

Kingsport

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	668	0	0	5340	3204	0	0	.	.
2	1335	223	11125	3427	134	267	0	45	.	.
3	0	0	2447	5251	45	45	45	89	.	.
4	0	0	8900	8322	712	979	0	0	.	.
5	0	0	3293	9301	5429	89	45	45	.	.
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	100	200	100	5200	2900	600	0	100	0
2	.	0	.	1800	.	1700	.	100	.	0
3	800	3400	800	4500	600	200	1200	100	400	200
4	2700	8000	2500	600	600	4700	200	0	200	0
5	400	0	25500	0	1100	1100	400	1100	500	400

Porter's Point

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	0	1558	3738	0	45	0	45	.	.
2	0	0	2937	7120	0	0	0	0	.	.
3	0	0	6186	2047	0	0	0	0	.	.
4	0	0	4406	1113	0	0	0	0	.	.
5	0	0	7610	4806	0	0	0	45	.	.
6	0	0	6453	3293	0	0	0	0	.	.
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	100	0	4300	900	300	200	0	200	0	0
2	100	0	3900	1900	700	100	300	800	0	0
3	0	100	300	3300	500	0	0	700	0	0
4	0	0	100	500	0	0	0	100	100	0
5	0	0	2500	1500	0	0	100	0	0	200
6	0	0	62700	69100	0	0	100	300	0	0

Starrs Point Flats

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	0	2270	935	0	45	890	401	.	.
2	45	0	490	1291	0	0	178	0	.	.
3	0	223	1023	1113	0	0	0	134	.	.
4	1869	2848	1558	3382	0	0	312	312	.	.
5	5385	8589	2537	1691	0	0	0	0	.	.
6	0	267	1691	2047	45	0	134	45	.	.
7	6675	20737	2804	4539	0	0	0	0	.	.
8	13350	13662	2848	1424	0	0	0	0	.	.
9	1691	312	1246	1068	89	0	0	0	.	.
1994	Corophium volutator		Polychaetes (estimated		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	7100	6400	4300	4000	0	0	200	200	0	0
2	4100	12500	1400	3500	0	0	0	0	0	0
3	8200	10500	3000	500	0	0	0	0	0	0
4	1000	5200	2900	1200	0	0	0	0	0	0
5	10900	5700	600	500	0	100	0	0	0	0
6	11900	8000	2400	2300	0	0	0	0	0	0
7	8800	16100	1900	1300	0	0	0	0	0	0
8	15500	7400	2600	3400	0	100	0	0	0	100
9	12300	12400	3900	5100	0	0	0	100	0	0

Starrs Point Sandbar

Invertebrate Density (#/sq. m)

1977	Corophium volutator		Polychaetes		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	134	45	6853	2626	0	0	45	89	.	.
2	0	0	2270	3427	0	0	45	0	.	.
3	223	490	1647	1558	0	0	0	0	.	.
4	579	.	890	.	0	0	134	0	.	.
5	445	1869	267	312	45	45	0	0	.	.
6	45	0	623	267	0	0	0	0	.	.
1994	Corophium volutator		Polychaetes (estimated)		Pelecypods		Gastropods		Other	
Station	A	B	A	B	A	B	A	B	A	B
1	0	0	20000	.	0	0	0	0	0	0
2	100	1000	60000	54000	0	0	100	100	0	400
3	0	0	42500	6200	0	0	100	0	0	100
4	0	0	25000	2700	0	0	0	0	0	0
5	0	0	0	200	100	0	0	0	0	0
6	0	0	100	0	0	0	0	0	0	0

Species List by Location (June-July, 1994)

	Grande Anse	Minudie	Mary's Point	Peck's Cove	Avonport	Evangeline	Kingsport	Porter's Point	Starrs Point Flats	Starrs Point Sandbar
Corophium volutator	√	√	√	√	√	√	√	√	√	√
Heteromastus filiformis or *Capitella capitata*	√	√	√		√	√		√	√	
Spiophanes spp.						√				√
Nereis spp.		√	√					√		
Nephtys spp.			√			√		√		
Glycera spp.			√	√	√	√		√		
Tharyx sp.						√				
Clymenella sp.						√				
Unidentified polychaete	√	√	√	√	√	√	√	√	√	√
Macoma balthica or *Mya arenaria*	√	√	√	√	√					
Unidentified pelecypod		√		√	√	√	√	√	√	√
Unidentified gastropod	√	√	√	√	√	√	√	√	√	√
Cerebratulus lacteus or other Nemertean	√				√	√	√	√		
Unidentified amphipod		√	√				√	√		
Unidentified crustacean	√	√		√	√		√	√	√	√
Unidentified barnacle						√				
Hermit crab										√