

THE EFFECTS OF SEDIMENT DISTURBANCE
ON THE MACROBENTHOS OF THE
ST. LUCIA NARROWS, NATAL

BY

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PREFACE

The work described in this thesis was carried out in the Department of Biology, University of Natal, Durban from January 1989 to February 1992, under the supervision of Doctor AT Forbes.

This study represents original work by the author unless specifically stated to the contrary in the text, and has not been submitted in any form to another University.

A handwritten signature in black ink, appearing to read 'Rodney Owen', with a small dot above the 'y'.

Rodney Kenneth Owen

February 1992

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ABSTRACT

Estuarine studies worldwide have shown that sediment disturbance effects on the macrobenthos are related to the nature and scale of the disturbance. Decreased species densities, diversity and richness have been found where the substratum and current patterns have been altered either by direct removal or by the creation of channels.

Sediment disturbance in the St. Lucia Narrows has occurred through dredging, beam trawling and episodic floods. The Narrows, a meandering tidal channel approximately 21 km long linking the St Lucia Lakes to the sea, were dredged between 1952 and 1971 to provide a greater flow of seawater to the lakes during periods of low lake levels. A canal was cut through land from the Mfolosi River to the Narrows in an attempt to ameliorate hypersaline conditions in the Lakes, but was never commissioned. Beam trawling has formed the basis of a prawn bait fishery since the 1930's. The bait boats trawl on the mudflats over the entire Narrows on a daily basis and often churn the substratum with their propellers.

The objectives of this study were to determine the effects of dredging, a once-off large scale disturbance, and beam trawling, a frequent small scale disturbance, on the macrobenthos of the Narrows. Studies in 1983 and 1984 showed

that the dredged channel was impoverished compared with the adjacent mudflat, and that the Link Canal was devoid of benthos. In 1988 species densities, especially of polychaetes, were found to be lower in areas open to beam trawling than in adjacent closed areas.

The dredged channel during the present study was again impoverished compared with the adjacent mudflats. The three most abundant species occurring on the mudflats, the crab *Tylogdiplax blephariskios*, the amphipod *Victoriopsis chilensis* and capitellid polychaetes, were recorded at densities an order of magnitude lower in the channel than on the mudflats. The substratum in the channel was generally sandier than the mudflats, and this condition appeared to be maintained by the scouring action of tidal currents. It was calculated that the creation of the dredged channel had reduced the standing benthic biomass in the Narrows by a minimum of approximately 20%. The Link Canal was colonised by the three major mudflat species, but at densities an order of magnitude lower than the mudflats.

Beam trawling of experimental sites at monthly and 6-monthly intervals on muddy and sandy substrata in the Narrows between July 1989 and July 1990 did not appear to have a negative effect on the benthos. The coverage of the bait boats was calculated to be comparable to the trawling effort

in this study, and suggested that the bait fishery is not having a detrimental effect on the benthos.

It was concluded that the macrobenthos in the Narrows represented a pioneering community characteristic of estuaries, either not affected by, or able to recover from small scale and episodic disturbances provided that there was no long term habitat modification.

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1.0 INTRODUCTION

1.1 Historical Aspects

The St. Lucia Narrows have a well documented history of substratum disturbance arising from dredging and beam trawling. The Narrows were extensively dredged between 1952 and 1971, while beam trawling has formed the basis of a bait fishery since the 1930's.

Dredging in the Narrows was undertaken largely as an attempt to ameliorate the effects of human interference. Drainage of the Mfolosi swamps and canalisation of the Mfolosi River from 1927 led to increased siltation of the lower Narrows between the mouth and Honeymoon Bend (Fig. 1.1). A separate mouth for the Mfolosi was cut to the south of the common Mfolosi/St. Lucia mouth in 1952 to alleviate the silting problem. Dredging activity commenced during the same year to clear the silted area between Honeymoon Bend and the mouth. The mouth was closed during most of the period from 1951 to 1955 (Hutchison, 1974). These increasing periods of mouth closure led to the mouth being artificially opened on three occasions between 1955 and 1961, remaining open each time for approximately a year, and maintained open from 1970 (Hutchison, 1974).

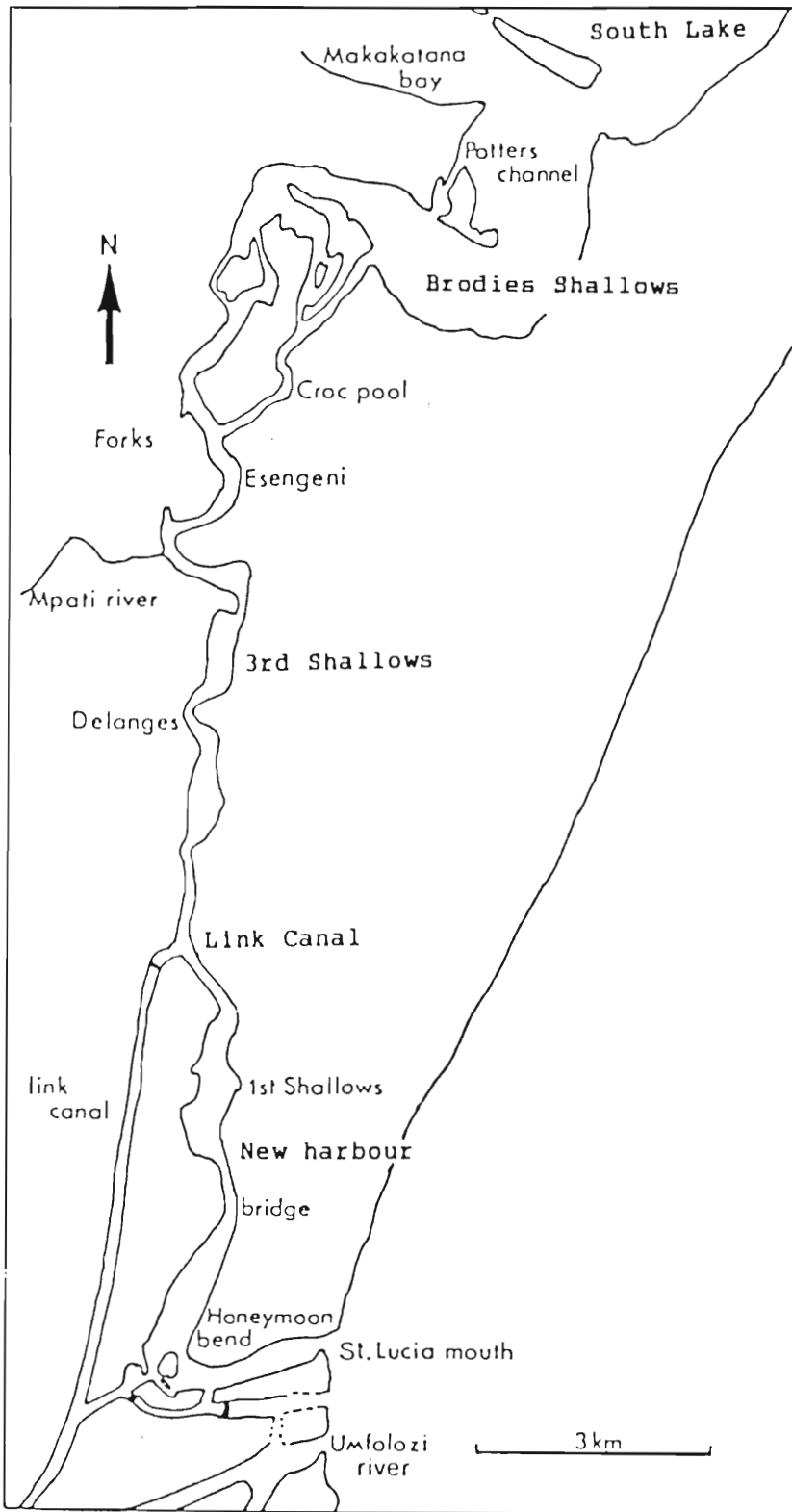


Fig. 1.1 The St. Lucia Narrows.

A channel approximately 90 m wide and 1.8 m deep was dredged from the mouth to Brodies Shallows (Fig. 1.1) between 1967 and 1969 to provide a greater flow of seawater into the lakes during periods of low lake levels (Hutchison, 1974). Potter's channel, 10-20 m wide and 1.2 m deep, was cut through land during the same period to provide a shorter link between Brodies Shallows and South Lake (Fig 1.1).

Low rainfall over the St. Lucia catchment between 1969 and 1971 combined with evaporation from the Lakes, the deeper channel in the Narrows and the direct link between Brodies Shallows and the lakes caused a prolonged inflow of sea water into the Lakes, with salinity levels exceeding three times that of sea water in the northern reaches of the system (Hutchison, 1974). In order to prevent similar hypersaline conditions from developing during subsequent dry periods, it was decided to increase the flow of fresh water into the St. Lucia system by cutting a canal linking the Mfolosi River and the Narrows (Hay, 1985).

Construction of the Link Canal (Fig 1.1), silting basin and an intake works on the Mfolosi River commenced in 1971 and, apart from the silting basin, was completed by 1983, but never commissioned. A reason for the failure of the scheme was that there was insufficient water in the Umfolosi to provide the required flow through the Link Canal during dry

periods. Doubt was expressed that any fresh water introduced to the Narrows would ameliorate hypersaline conditions in the northern reaches of the system (Hay, 1985). Extensive damage to embankments and canal walls at the intake works was caused by floods after Cyclone Domoina in 1984 and the Link Canal was subsequently blocked off into a series of impoundments by berms.

Beam trawling for prawns has formed the basis of a bait fishery since the 1930's (Forbes, 1982). The bait boats operate over the entire Narrows for an average of five hours per day. A maximum of three boats are used, depending on demand.

1.2 Factors Affecting Estuarine Benthic Communities

The most important environmental factors characterising estuaries are fluctuations and gradients in salinity, the nature of the substratum, the input of detritus and shelter from wave action (Barnes, 1974). Chemical mixing of fresh and sea water, fluctuations in temperature and the oxygen demand placed on interstitial water by microbial decomposition are also considered important physical variables in estuaries (Barnes, 1974).

It is accepted that within a tolerable salinity and temperature range, the nature of the substratum is the most

important factor determining the distribution of benthic organisms (Day, 1981). Richer estuarine benthic faunas are found in mixtures of sand and silt compared with sandier or more silty substrata (Reid and Wood, 1976).

The two most important properties of substrata for benthic organisms are grain size and organic content (Gray, 1981). The grain size distribution of substrata in estuaries varies with current velocities and the nature and proportion of sediments derived from the sea and river catchment. The granular composition and stability of the substratum is in turn important to burrowing organisms. Detrital organic matter in substrata is derived through sedimentation from the overlying water column and generally increases with decreasing particle size (Gray, 1981).

1.3 Stability and Diversity of Benthic Communities

The stability of a community is generally defined as its ability to return to an equilibrium state after being disturbed and is interpreted on the basis of patterns in numerical abundance and biomass evident over time (Gray, 1981). Communities are either persistent in that they maintain constant species compositions and densities over time or display cyclic changes over varying periods. If the cycles are predictable, the community is considered stable (Gray, 1981).

Community ecology recognises two basic theoretical levels of stability - global and neighbourhood, or local stability, in which communities are likened to a "ball in a basin of attraction" (Gray, 1981). A globally stable community returns to the same species composition within a recognised 'universe', irrespective of the size of the disturbance. Local stability refers to communities returning to the same species composition within a broader globally stable universe after smaller disturbances. Benthic communities may shift from one locally stable state to another as a result of salinity changes, increased predation, competition or other disturbance. A globally stable community may have many locally stable states, or multiple equilibria, but a sufficiently large perturbation may cause a community to shift to another global stable state, in which case the community does not return to its original species composition. Random disturbances however, can theoretically maintain a system in a state of constant flux so that the system is not constant at a particular point, but can be stable around that point (Lewontin, 1969).

In contrast to global and local stability which do not distinguish degrees of stability, the concept of relative stability considers the magnitude of the disturbance, the distance moved by the community from its equilibrium and the

time required for the community to return to that equilibrium (Lewontin, 1969). Relative stability includes the concepts of resistance and resilience of communities. Resistance refers to the ability of a community to withstand perturbation, while a resilient community returns rapidly and directly to its original species composition after being disturbed. Theoretical community ecology hypothesises some balance between these two extremes.

Many authors (Day and Grindley, 1981; Sousa and Connell, 1985) argue that such equilibria are rarely achieved in the real world because natural systems such as estuaries are subject to fluctuating conditions which result in fewer stabilising feedback mechanisms between organisms and their environment being established. A review of studies of communities in soft marine sediments by Sousa and Connell (1985) led them to conclude that either multiple stable states do not exist in nature, or that the studies had not addressed the question in sufficient depth.

Up to 1970 the view was commonly held that community stability was achieved through increasing complexity, or species diversity (Begon, Harper and Townsend, 1986). Their arguments were based on assumptions that stability was related to the number of energy flow pathways through a community, with more species providing more species

interactions based on feeding activity. More complex communities, with more alternative feeding pathways available, were thought to be more stable.

This thinking was largely inverted by May (1974), who showed that increased diversity in a variety of model systems led to more fragile community structures. He argued that a stable environment would permit the evolution of a complex, but dynamically fragile community, while an unstable environment would result in a simpler, persistent and dynamically robust community. This accords with the low biological diversity found in estuaries, which are characterised by a fluctuating physical environment (Day and Grindley, 1981).

1.4 Benthic Research at St. Lucia

Quantitative research on the benthic communities of the St. Lucia system has focused on the Lakes following stable and hypersaline periods. A northward reduction in species diversity was recorded in the Lakes in 1972 with salinities ranging from 45-58 ppt. in South Lake, through 55-60 ppt. in North Lake to 70-80 ppt. in False Bay (Boltt, 1975). Colonisation of the impoverished northern reaches of the system from South Lake was evident by 1973 after salinities dropped to levels below that of seawater.

The benthos of South Lake was surveyed between 1981 and 1982 during a stable period of salinities at approximately 35 ppt. (Blaber, Kure, Jackson and Cyrus, 1983). The mean biomass was found to be approximately four times higher than that reported by Bolt (1975) between 1972 and 1973. This increase was accounted for by the increase of gravimetrically dominant bivalve species in the later survey. A difference between the average biomasses on sandy and muddy substrata in South Lake was noted during the 1982-1983 survey. The mean benthic biomass on sandy substrata was approximately four times greater than on muddy substrata.

Samples collected by Bolt (1974) from the upper Narrows in 1972 and 1973 showed very different species compositions in the Lakes and Narrows benthic communities. These differences were emphasised by the contrast in biomass. The biomasses at the stations sampled in the Narrows were approximately 100 times greater than the average for similar substrata in the Lakes during the same period.

The first extensive survey of the Narrows macrobenthos was undertaken by Hay (1985) during 1983 and 1984. The dredged channels was found to carry significantly fewer species and a lower biomass than adjacent undredged mudflats, although no attempt was made to account for this difference. Two

broad benthic groups based on substratum preference were identified. The first group comprised bivalve molluscs and the numerically and gravimetrically important crab *Tylodiplax blephariskios*. This group was characteristic of mudflats, being rare in the dredged channel and absent from sandy substrata. The second component comprised amphipods and polychaetes which were found in all habitats.

Increased species abundance and biomass were recorded by Hay (1985) in all habitats in the Narrows north of the road bridge (Fig 1.1) after floods caused by Cyclone Domoina in February 1984. This colonisation, by benthic species typical of the Lakes, apparently resulted through non-selective settling. A survey in December 1984 showed that the Lakes species had disappeared and that the dredged channels were again impoverished.

Two areas at Esengeni and Brodies Shallows (Fig 1.1), were closed to beam trawling as part of caged prawn growth experiments during 1987 and 1988. Grab samples taken in the closed areas, and from adjacent areas open to trawling in November and December 1987, and February 1988 suggested that species abundance and diversity, especially of polychaetes, were lower in the open areas than in the closed areas (Owen, 1988).

1.5 Motivation and Objectives

St. Lucia is the largest estuarine system in South Africa comprising some 80% of the total estuarine area of Natal (Begg, 1978). The combination of its size, sub-tropical location and generally soft-bottomed, turbid nature provide a unique estuarine habitat in South Africa. Relatively little benthic research has been undertaken at St. Lucia compared with the temperate estuaries of the eastern and southern Cape. Benthic research at St. Lucia has focused on the Lakes and has been salinity orientated whereas hypersaline conditions do not occur in the Narrows, an area where human disturbances become more significant.

Dredging and trawling activity commenced before any benthic investigations took place in the Narrows, hence no quantitative data existed prior to these disturbances. Although the Lakes have not been dredged or trawled, the differences in benthic community composition preclude them from being used to provide baseline data for the Narrows.

Concern was expressed for the possible impact of trawling on the benthos through habitat modification or destruction (Forbes, 1982), but no study was implemented. It was considered important, because of the paucity of data relating to dredging and trawling activity in the Narrows,

to establish some baseline data relating to the effects of sediment disturbance on the benthos.

The intention of this study was to investigate the response of the macrobenthos in the Narrows to substratum disturbance through dredging, a large scale, once-off disturbance and beam trawling, a small scale, frequent disturbance. Community and species responses were investigated and interpreted on the basis of environmental fluctuations, the relative scale and frequency of the disturbance and changes in sediment characteristics brought about by the disturbance. These results were considered in terms of community theory relating to disturbance and stability. Detailed objectives of each component of this study are included in the relevant sections.

2.0 STUDY AREA

2.1 Geographic Location and Description

St. Lucia is an estuary linked lake system located on the east coast of southern Africa between 27°50'S to 28°25'S and 32°21'E to 32°34'E (Fig. 2.1). The system covers an area approximately 300 to 350 km² depending on lake level (Begg, 1978). Four rivers drain into the Lakes and one into the Narrows (Fig. 2.1), with a total catchment of 9000 km². These rivers provide an estimated mean annual total freshwater inflow of 295×10^6 m³, based on an average of 890 mm rainfall p.a. (Begg, 1978).

The system comprises a series of three shallow lakes connected to the sea by a meandering channel 21 km long, 100 to 400 m wide and between one and three metres deep, although it reaches a depth of four metres between the road bridge and the new harbour (Fig. 2.2). This channel is known as the Narrows and consists of a series of narrows and shallow mudflats with the dredged channel running along its length. Dredger spoil dumped on the shoreline of the Narrows has altered the topography of the shoreline (Hay, 1985), but there has been extensive recolonisation by *Hibiscus tiliaceus*, the mangroves *Avicennia marina* and *Bruguiera gymnorrhiza*, and the reed *Phragmites australis*. This study

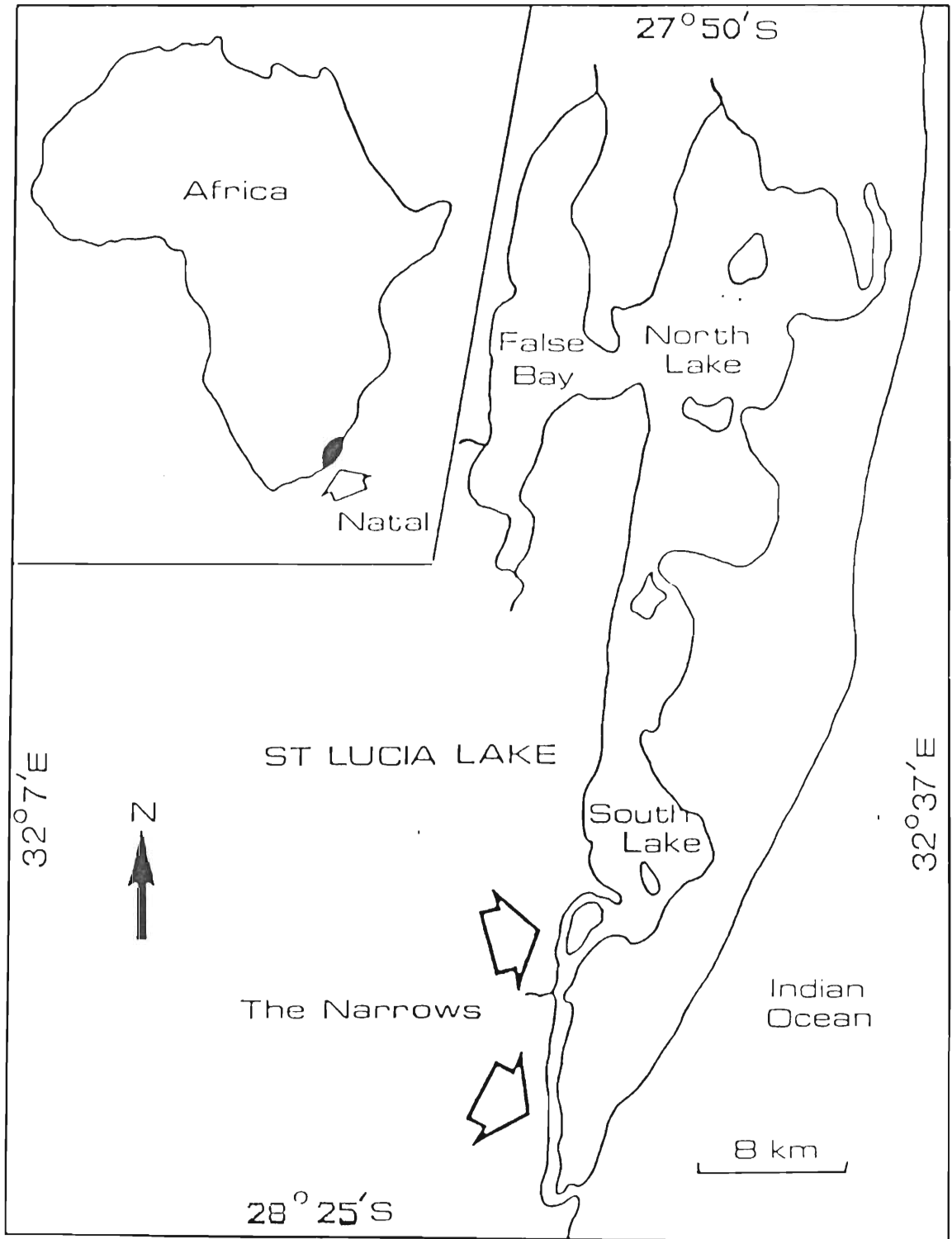


Fig. 2.1 Location of the St. Lucia Lakes and Narrows.

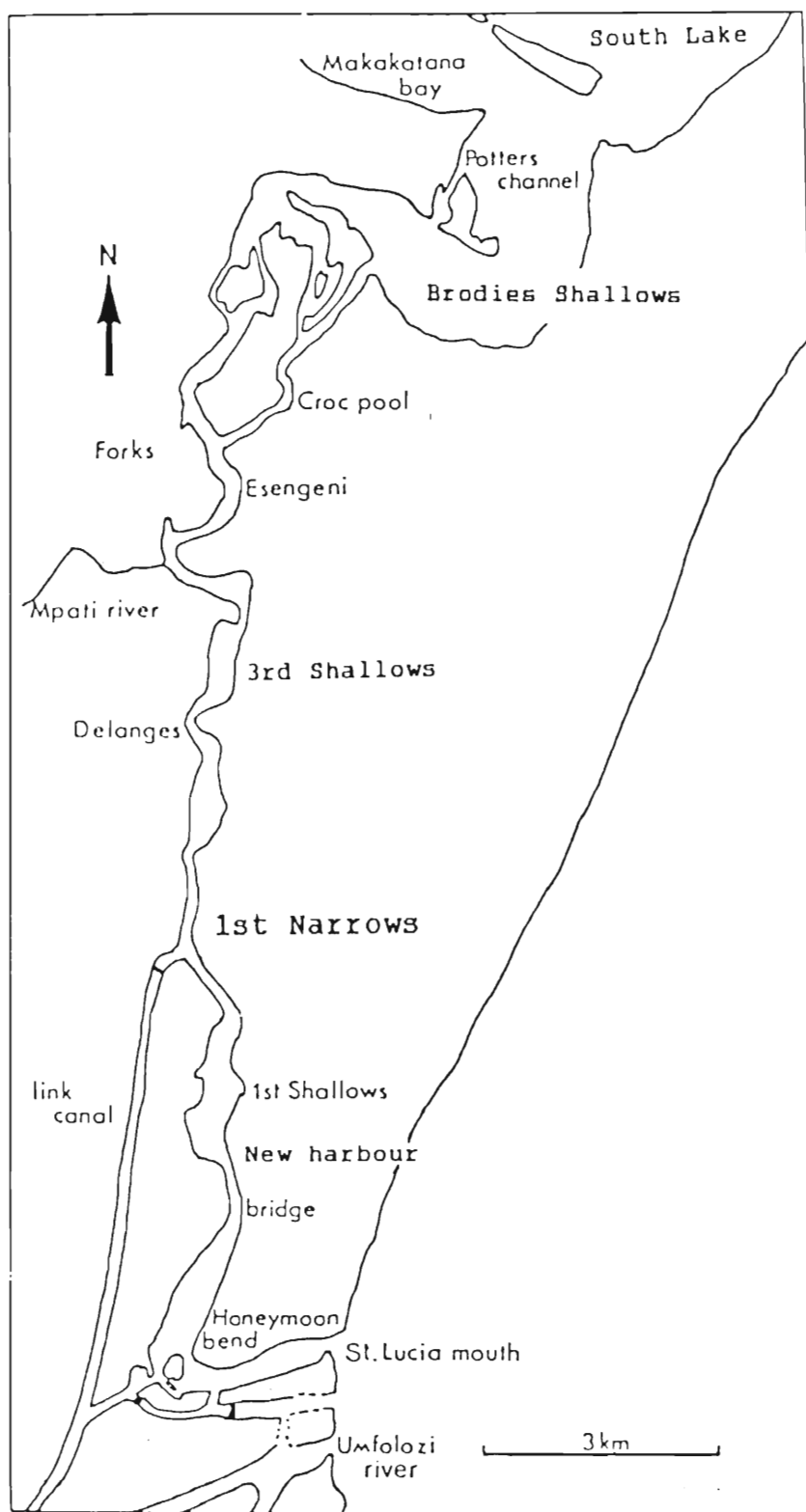


Fig. 2.2 Study areas in the St. Lucia Narrows.

was confined to the area between the Link Canal and Brodies Shallows (Fig. 2.2).

2.2 Physical Conditions in the Narrows

Physical factors pertinent to this study were salinity, temperature, the nature of the substratum and current velocities. Although each of these parameters was investigated during the course of the study, a brief review of conditions prior to this study is given here.

2.2.1 Salinity

Salinities in the Narrows are determined by the salinity and level of the Lakes, local rainfall, flooding and tidal influence. The maintenance of an open mouth prevents hypersaline conditions from developing in the Narrows. Tidal action occurs at least as far as the water level recorder at Esengeni (Fig. 2.2), but is influenced by lake level (Hay, 1985). Salinities up to 45 ppt. have occurred in the northern Narrows (unpublished Natal Parks Board data) during periods of hypersalinity in the Lakes. Fresh conditions in the Narrows follow high lake levels and a nett outflow of water from the system.

2.2.2 Temperature

Few temperature data are available for the Narrows. Data obtained during 1983 and 1984 indicated that temperatures varied between 25 and 31°C in summer and between 17 and 19.5°C in winter, with daily tidal variations of one to two degrees (Hay, 1985).

2.2.3 Substrata

Surveys by Hay (1985) and Van Heerden (unpublished, in Hay, 1985) identified two broad sediment types in the Narrows north of Honeymoon Bend. Mudflats and dredged channels between Honeymoon Bend and Croc Pool (Fig. 2.2) were found to have mean particle sizes of 17-32 microns and total combustible organic contents of 4-9.4%. The mean particle sizes of muddy sandflats and muddy sand channels between Croc Pool and Brodies Shallows ranged from 65 to 200 microns, with a total combustible organic content of 1.2-5.2%. No significant difference in organic content was found between channels and shallows in adjacent areas.

2.2.4 Current Velocities

Current velocities were recorded over spring tides in the 1st Narrows (Fig. 2.2) during April 1983 and June 1984 by

Hay (1985). The relationship between ebb and flood tide currents depended on lake level. A nett inflow was recorded in April 1983 with velocities up to 0.8 ms^{-1} and 0.6 ms^{-1} on the flood and ebb tides respectively. This situation was reversed in June 1984 with a nett outflow from the Lakes. Velocities up to 0.5 ms^{-1} on the flood tide and 0.6 ms^{-1} on the ebb tide were recorded. Current velocities have rarely exceeded 1.0 ms^{-1} in the Narrows, although velocities between 1.5 and 2.0 ms^{-1} were estimated for the outflow from the Lakes following Cyclone Domoina in 1984 (Hay, 1985).

3.0 MATERIALS AND METHODS

This study comprised three major sections, including dredging and beam trawling aspects, and a pilot study involving both dredging and beam trawling. Although details pertaining to each aspect will be covered in separate sections, sampling and analytical techniques were standardised throughout and are given here.

Fieldwork was carried out from a 4.5 m ski-boat powered by two 30 hp. outboard motors capable of operating in 0.5 m of water.

3.1 Grab Sampling

All benthic and sediment samples were taken using a Zabolocki-type Ekman grab covering an area of 0.0236 m² and sampling to a depth of 12-15 cm.

3.1.1 Benthic Samples

Each sample was emptied into a bucket, additional water added and the contents swirled and agitated with a stick. The contents of the bucket were poured through a 0.5 mm sieve. As much mud as possible was washed out of the sieve before the contents were transferred to a honey jar

containing a 10% formaldehyde solution and the dye Phloxine B, which stained the animals pink and facilitated sorting.

3.1.2 Sediment Samples

Each sample was emptied into a bucket and stirred with a stick without adding extra water. A honey jar was three quarter filled with sediment and 10% formaldehyde added.

3.2 Sample Analysis

3.2.1 Benthic Samples

Samples were sorted under a dissecting microscope and the animals from each sample separated into different taxa and counted. Each taxon was identified as far as possible using keys and descriptions by Day (1951), Day (1969), Griffiths (1976), Kensley (1978) and a reference collection housed in the Natal Parks Board laboratory at St. Lucia. The density of each species was expressed as the number of individuals per square metre. Once identified, an average individual mass for each species and size class was obtained by oven drying at 60°C for 48 hours and weighing to four decimal places on a Sartorius balance.

3.2.2 Sediment Samples

Samples were shaken vigorously and a 30 ml sub sample taken for organic content analysis. The relative percentages of mud sand and gravel, based on the Atterberg size limits given below (P Ramsay, Dept. of Geology, University of Natal; pers. comm.) were used to compare samples for trends toward increasing sandiness or muddiness.

Samples were wet sieved through a 2 mm and 63 micron sieve into a five litre bucket marked at three litres capacity. The gravel and sand fractions, retained by the 2 mm and 63 micron sieves respectively, were transferred to weighed 250 ml beakers and dried at 70°C in an air oven to constant mass. The mud fraction in the bucket was made up to three liters with water and stirred vigorously. A 25 ml aliquot was pipetted into a weighed evaporating dish and dried to constant mass at 70°C. The masses of each fraction were determined and the relative percentage of each fraction in the sample calculated.

Approximately five grams of each sample for organic analysis was dried at 70°C to constant mass in an air oven and ground with a pestle and mortar. Approximately one gram of the dried and ground sample was weighed to four decimal places in a crucible and placed in a muffle furnace at 550°C for

one hour. The crucible was cooled to room temperature in a desiccator and reweighed. The organic content of the sample was calculated as a percentage from the difference in mass.

3.3 Salinity

Salinities were measured using an American Optical Corporation (AO) calibrated optical refractometer, accurate to 0.5 ppt. Only surface salinities were measured.

3.4 Temperature

Temperatures were measured using a standard mercury thermometer accurate to 0.1°C. Only surface temperatures were measured.

3.5 Current Velocities

Current velocities were measured over 12 hour tidal cycles on spring and neap tides using a General Oceanics model 2035 MK III portable flowmeter. Surface and bottom velocities were recorded.

4.0 PILOT STUDY

4.1 Introduction

The paucity of benthic data relating to dredging and beam trawling in the Narrows necessitated a pilot study to establish whether the trends noted by Hay (1985) and Owen (1988) were still evident and warranted further study.

The dredged channel, impoverished before floods caused by Cyclone Domoina in February 1984, was found to carry a higher species diversity and biomass in March before reverting to the pre-cyclonic condition by December 1984 (Hay, 1985). The Link Canal was found to be colonised after the floods whereas no benthic species had been recorded in the Canal before the flood. The Link Canal was not resampled after March 1984 to establish whether colonisation was temporary.

Owen (1988) found that species richness and abundance, especially of polychaetes, were higher in areas closed to beam trawling at Esengeni and Brodies Shallows in 1987 and 1988. The frequency and intensity of trawling in open areas were not known however, so it could not be determined whether the lower species richness and abundance recorded in these areas were related to trawling activity.

The objectives of this pilot study were to:

1. Determine whether the dredged channel sampled by Hay (1985) was still impoverished compared with adjacent subtidal mudflats.
2. Determine whether the Link Canal was again impoverished.
3. Determine the short term effects of beam trawling on the macrobenthos in a controlled study.
4. Identify abundant and important indicator species.
5. Investigate commonly used statistical techniques in analysing benthic data and to determine their suitability for this study.

4.2 Materials and Methods

4.2.1 Dredged Areas

Sampling

Ten grab samples were taken from the Link Canal, the dredged channel opposite the Link Canal and the adjacent mudflat (Fig. 4.1) in March 1989.

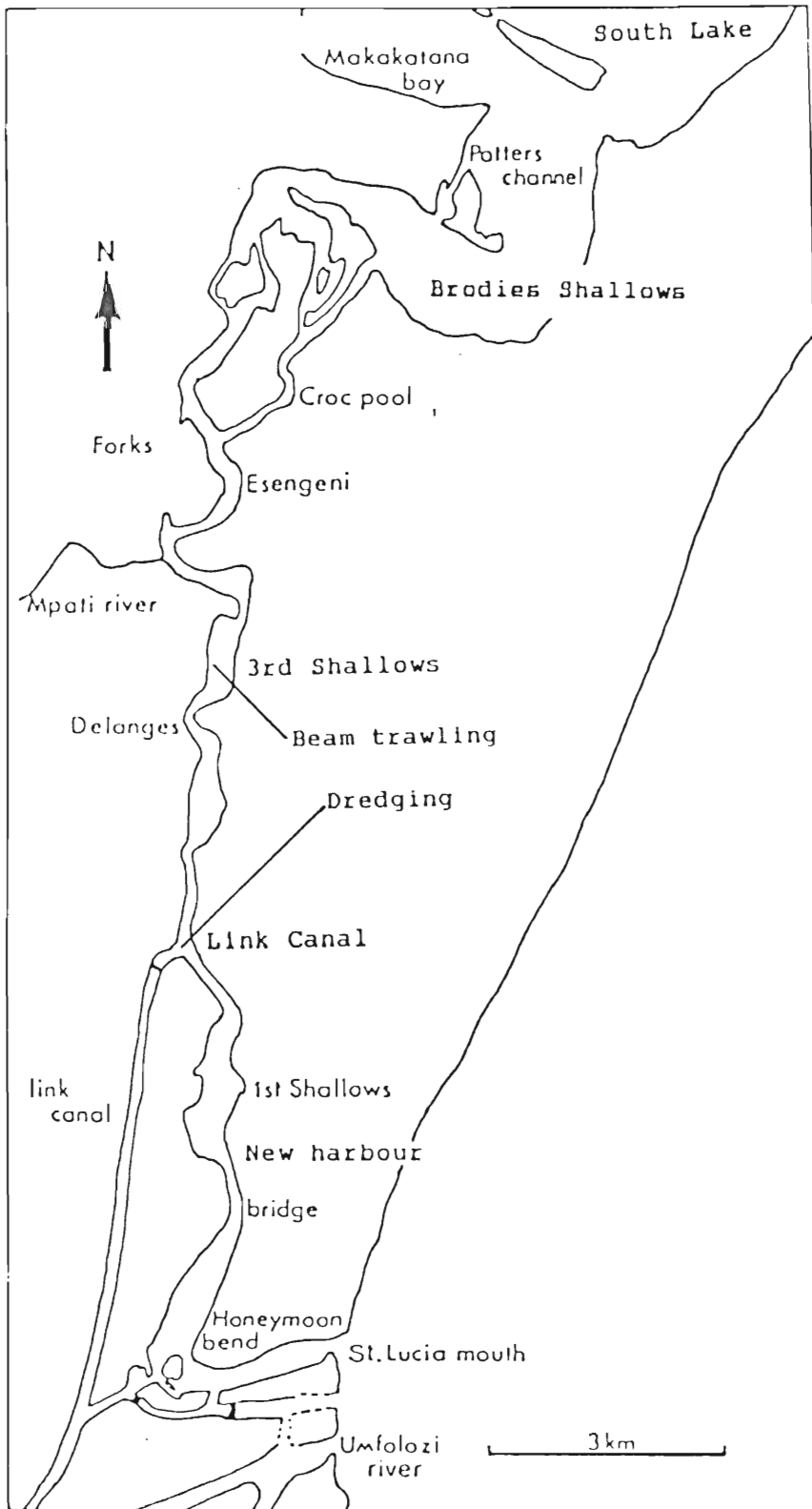


Fig. 4.1 Location of the dredged areas and the trawled and control quadrats used for the pilot study.

Analysis

The average density (no.m^{-2}) and sample standard deviation were calculated for each species for the mudflat, dredged channel and Link Canal and compared. The average dry biomass for each species and the total average dry biomass (mg.m^{-2}) was calculated for each area. The coefficient of variation was calculated for each species to compare the variability of species densities among the sampling sites.

The density of each species in each sample from the mudflat, dredged channel and Link Canal was calculated and subjected to GENSTAT-5 correspondence analysis. Sample scores of the first two ranked axes were plotted to elucidate the variability in the data and related to the location sampled. Species scores obtained from the ordination were plotted to determine the variability of species densities and inter-species relationships in the ordination. Species scores were interpreted in conjunction with the coefficient of variation of each species in each location.

The density data used for the correspondence analysis was subjected to NT-SYS Bray-Curtis similarity analysis. The resultant dissimilarity matrix was analysed using arithmetically averaged, unweighted pair-group cluster

analysis and expressed as a dendrogram. These results were compared with the results of the correspondence analysis.

4.2.2 Beam trawling

Sampling

Two adjacent quadrats were staked out on the 3rd Shallows approximately 1 km north of DeLange's Bend in February 1989 (Fig. 4.1). The north quadrat (area 3825 m²) was not trawled and was used as a control. The south quadrat (area 3888 m²) was trawled for a total of 65 minutes over two days with a 3.5 x 1 m beam trawl with a 25 mm stretch mesh net and 12 mm mesh bag attached. The shallow depth often resulted in the substratum being churned by the outboard propellers. This was not undesirable however, as the bait boats were often seen to deliberately churn the substratum in this manner. Ten grab samples were taken from each quadrat prior to trawling and thereafter 3, 13, 23, 31 and 42 days after trawling. Water temperature and surface salinity were measured on each occasion.

Analysis

The average density, sample standard deviation, coefficient of variation and average biomass of each species in the

control and trawled quadrats were calculated for the entire study period.

The density of each species in each sample in the control and trawled quadrats was calculated. These data were subjected to GENSTAT-5 correspondence analysis. The sample and species scores of the first two ranked axes were plotted. The variability of the sample scores was interpreted on the basis of the time after trawling, salinity and temperature. The species scores were interpreted in conjunction with the coefficients of variation of each species from the trawled and control quadrats over the study period.

Counts of each of the numerically and gravimetrically important species from the control and trawled quadrats over the study period were subjected to the STATGRAPHICS Mann-Whitney non-parametric comparison of two samples. Counts were used in preference to densities as non-transformed data generally show a better Poisson distribution as the medians and ranges of the data are not changed (Greenacre, 1984). The Mann-Whitney test, based on ranks, estimates whether two populations have the same variance (Zar, 1984). The populations of each species in the control and trawled quadrats were considered different if the probability of equalling or exceeding the large test statistic was below 0.05.

Trends occurring in the numerically and gravimetrically important species over the study period were investigated using STATGRAPHICS simple linear and exponential regression analyses on the counts of individuals of each species selected from each sample. Exponential regression includes a log transformation of the data so the value of 10 was added to each count to overcome the zero counts in the data set. The probabilities and the R^2 values of the regressions were compared to determine whether linear or exponential regression gave the best fitted curve for the data. A lower probability indicates that the regression is less likely to be due to chance than a higher probability while a higher R^2 value indicates a better fitted curve. The slopes of the regressions were used to detect any overall difference in trends in species numbers in the trawled and control quadrats over the study period. The range of each slope was calculated by adding and subtracting twice the standard error of the slope, and if the ranges of the slopes for each species from the two quadrats did not overlap at the 95% significance level, the species in the two quadrats were considered to be increasing or decreasing in numbers independently of each other over time.

Frequency distributions were calculated using the method described by Gray (1981), in which the cumulative percentage

of species in geometric size classes was plotted for each quadrat. The numbers of species, expressed as the density (no.m^{-2}) occurring in each size class, were placed in eleven geometric size classes based on a x2 arithmetic scale as follows: 1 (1), 2 (2-3), 3 (3-7), 4 (8-15), 5 (16-31), 6 (32-63), 7 (64-127), 8 (128-255), 9 (256-511), 10 (512-1023) and 11 (1024-2047). The cumulative percentage of species was plotted against the size classes and a best fit line was drawn using STATGRAPHICS simple linear regression analysis. The calculated slopes of the lines were compared to detect changes in species density and frequency of occurrence.

4.3 Results

Thirteen benthic taxa were recorded from the Link Canal, dredged channel, mudflat and the trawled and control quadrats (Table 4.1).

Table 4.1 Taxa recorded from the Link Canal, dredged channel, mudflat and trawled and control quadrats between February and April 1989.

Annelida	Polychaeta	<i>Scololepis squamata</i> <i>Dendronereis arborifera</i> <i>Glycera convoluta</i> Capitellidae
Mollusca	Bivalvia	
Crustacea	Isopoda	<i>Cyathura aestuaria</i> <i>Victoriopsis chilkensis</i> <i>Grandidierella bonnierii</i> <i>Bolttsia minuta</i> <i>Apseudes digitalis</i> <i>Mesopodopsis africana</i> <i>Macrobrachium sp.</i> <i>Tylodiplax blephariskios</i>
	Amphipoda	
	Tanaidacea	
	Mysidacea	
	Caridea	
	Brachyura	

4.3.1 Dredged Areas

Nine benthic species were recorded from the mudflat, dredged channel and Link Canal. All nine species recorded occurred on the mudflat, four in the dredged channel and five in the Link Canal (Fig. 4.2). The crab *Tylodiplax blephariskios*, numerically the most important, was present at four times the density on the mudflat than in the channel, and twice the density on the mudflat than in the Link Canal. The mysid *Mesopodopsis africana* occurred at a density 70 times greater on the mudflat than the dredged channel and at three times the density of the Link Canal. The amphipod *Victoriopsis chilensis* was present on the mudflat at 50 times the density of the dredged channel and at 11 times the density of the Link Canal. Capitellid polychaetes and the polychaete *Scololepis squamata* were present on the mudflat but only capitellids were recorded from the Link Canal, while no polychaetes at all were recorded in the dredged channel.

The total average biomass of all benthic species recorded on the mudflat was 4661.80 mgm^{-2} compared with 1118.76 mgm^{-2} from the dredged channel and 2173.16 mgm^{-2} in the Link Canal. *T.blephariskios* dominated the biomass at all three locations, contributing 95, 96 and 97 percent to the biomass of the mudflat, dredged channel and Link Canal respectively (Fig. 4.3).

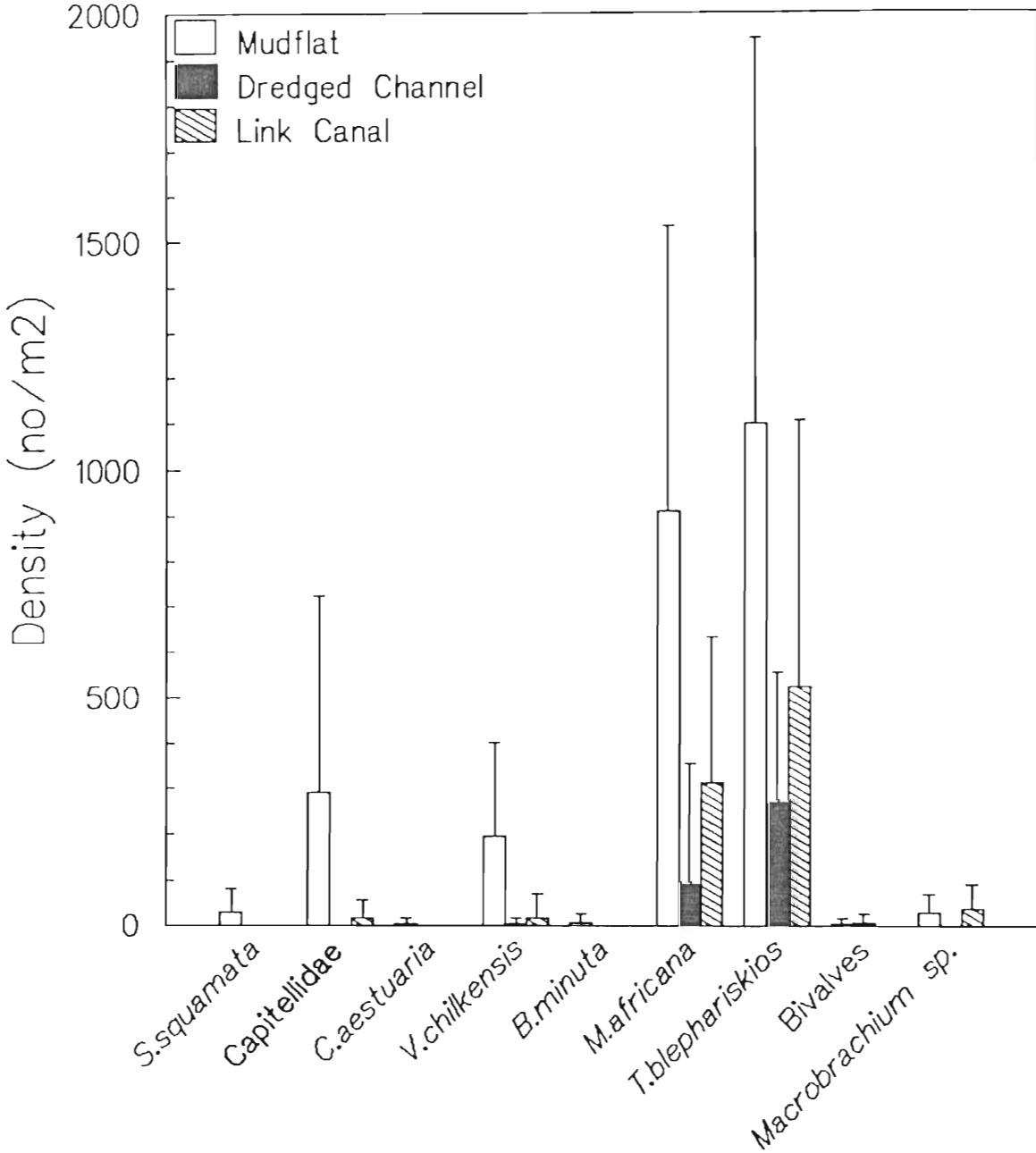


Fig. 4.2 Average densities and sample standard deviations of species recorded in the Link Canal, dredged channel and adjacent mudflat during March 1989. (n=10)

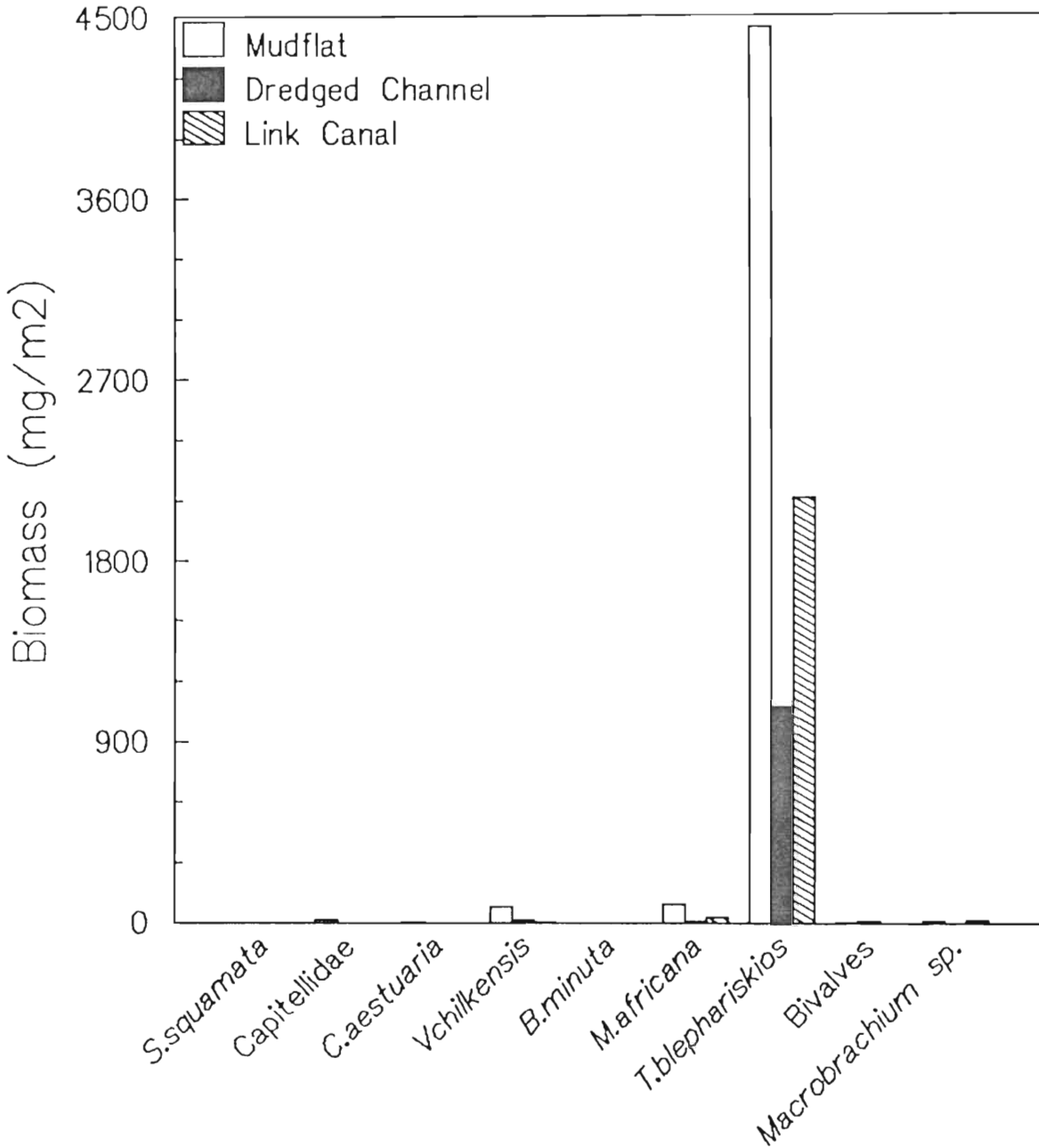


Fig. 4.3 Average dry biomass of species recorded from the Link Canal, dredged channel and adjacent mudflat during March 1989. (n=10)

The first two axes of the sample ordination, accounting for 54.88% of the variability in the data, show some separation of the samples according to their location (Fig.4.4). The tighter grouping of the mudflat samples, dominated by *T.blephariskios*, *M.africana* and *V.chilkensis* compared with the dredged channel and Link Canal samples indicates that the dredged channel and Link Canal were more variable in terms of species densities and composition than the mudflat. The outlying samples from the dredged channel (16 & 19) and the Link Canal (21 & 24) are separated in the ordination due to the presence of bivalves and *Macrobrachium* sp. respectively. The outlying mudflat samples (2 & 6) are separated from the central grouping due to higher densities of capitellid polychaetes, which were not recorded in the dredged channel.

The species scores of the first two axes of the ordination (Fig 4.5) show the relationship among the species in the ordination. The length of the line representing each species is proportional to the variability of that species in the samples. Lines at 180° to each other indicate an inverse relationship between species, while those at 90° to each other varied independantly of each other. The amphipods *V.chilkensis* and *Bolttsia minuta*, the isopod *Cyathura aestuaria*, *T.blephariskios* and *S.squamata* varied the least in the ordination, with bivalves showing the greatest

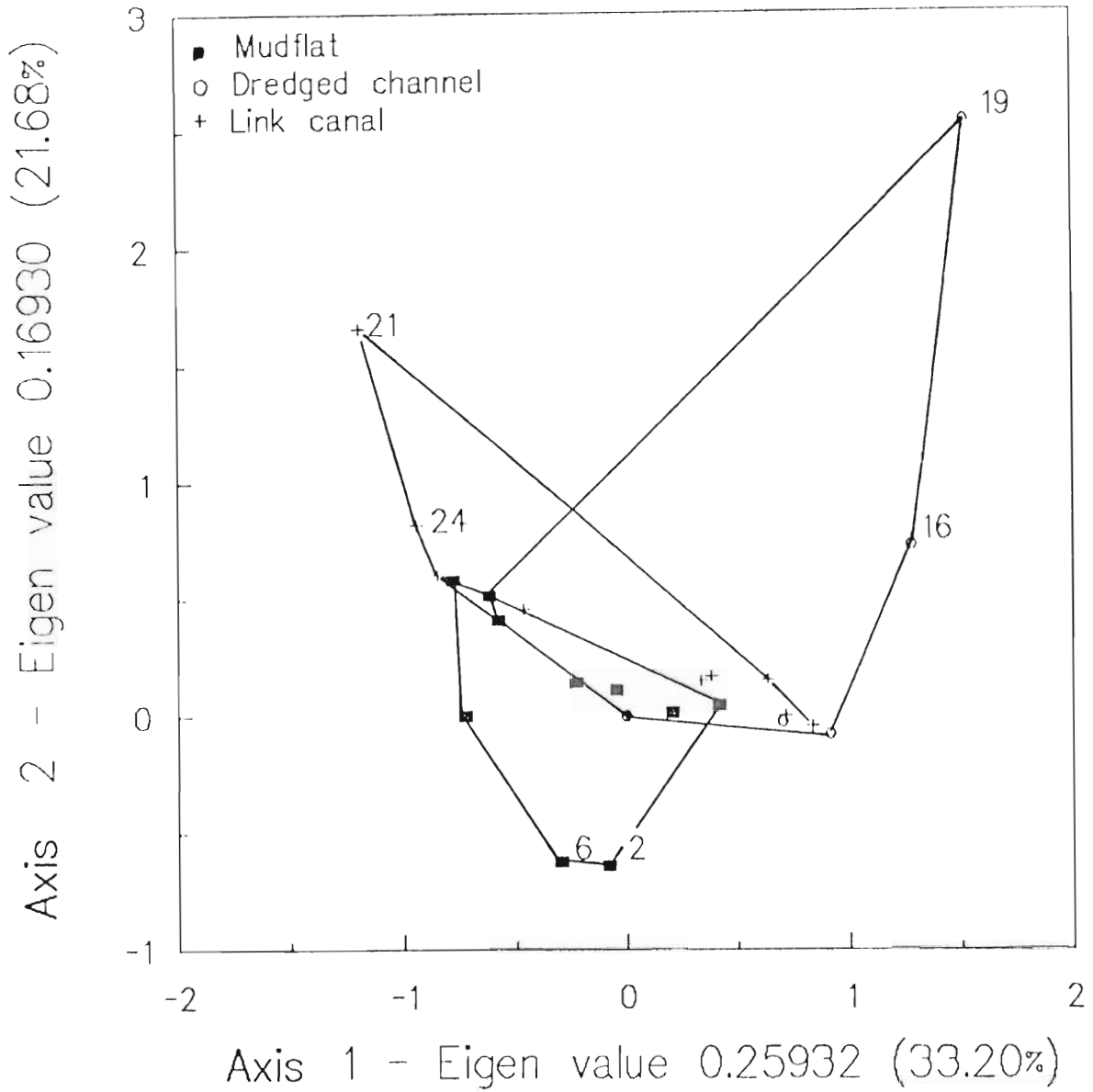


Fig. 4.4 Sample scores of the first two axes of the correspondence analysis of species densities from the mudflat, dredged channel and Link Canal in March 1989. Sample numbers of the outlying points are given.

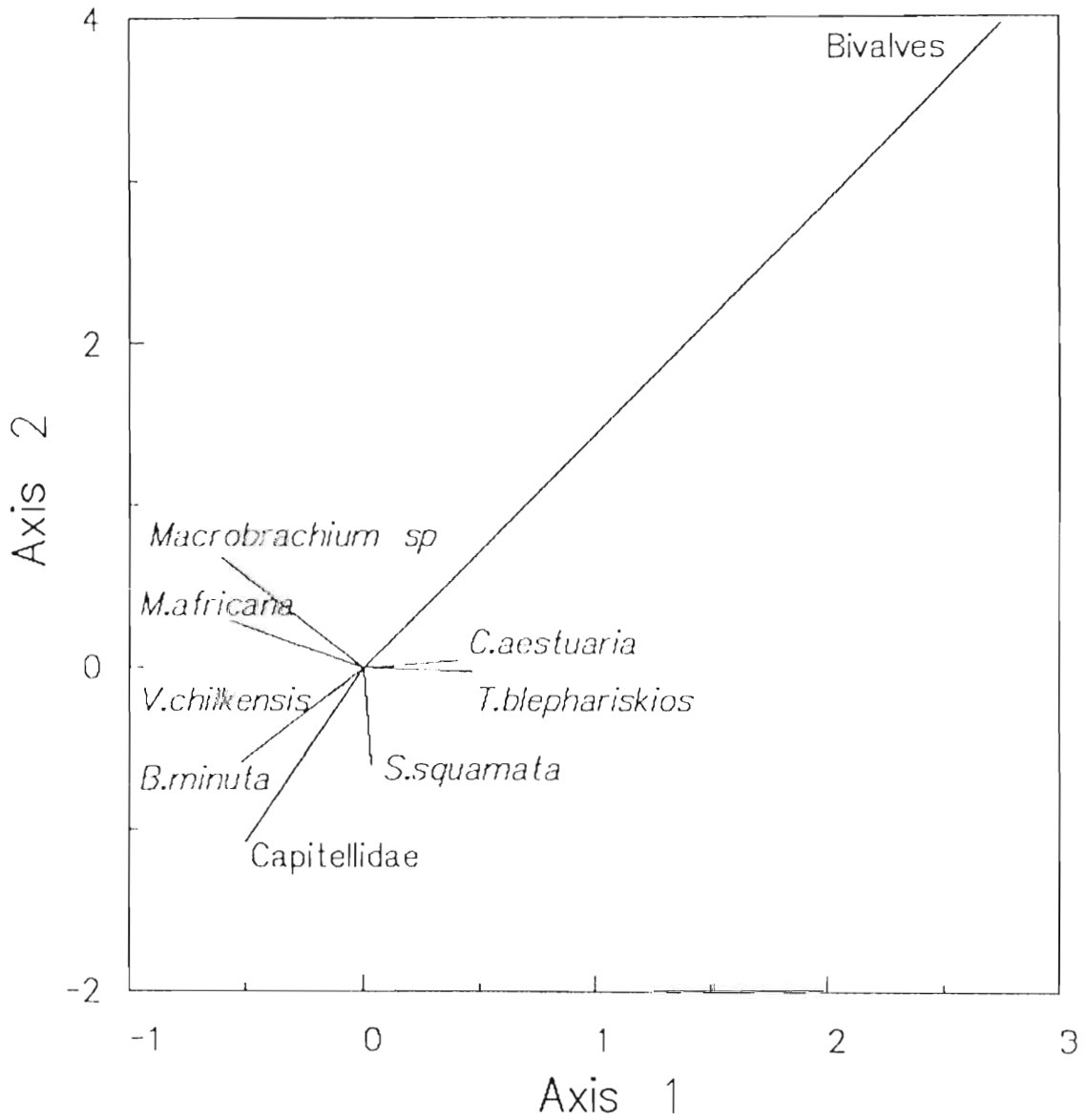


Fig. 4.5 Species scores of the first two axes of the correspondence analysis of species densities from the mudflat, dredged channel and Link Canal in March 1989.

variability. The ordination indicates that *V.chilkensis* and *B.minuta*, and *T.blephariskios* and *C.aestuaria* varied similarly, although their densities were markedly different.

Of the species identified by the correspondence analysis as being the least variable, only *T.blephariskios*, *V.chilkensis*, *M.africana* and Capitellid polychaetes were numerically and gravimetrically important. The coefficient of variation of *T.blephariskios* was the lowest and most similar at the three sites (Fig. 4.6). The coefficients of variation of *V.chilkensis*, *M.africana* and Capitellids were all lower on the mudflat than in the dredged channel and Link Canal if they occurred there (Fig. 4.6).

The dendrogram, derived from the results of the Bray-Curtis dissimilarity indices (Fig. 4.7), generally separates the mudflat samples (1-10) from the dredged channel samples (11-20) as dissimilar habitats with the Link Canal (samples 21-30) showing elements of both the mudflat and dredged channel. The branches at cophenetic value 1 and 0.85 contain channel and Link Canal samples (17, 20 & 23) with no animals in them and the sample (21) from the Link Canal containing only *Macrobrachium* sp. The branch at value 0.62 contains mainly channel and Link Canal samples dominated by *T.blephariskios* and *M.africana*. The clustering from value 0.47 contains mainly mudflat and Link Canal samples dominated by *M.africana* and

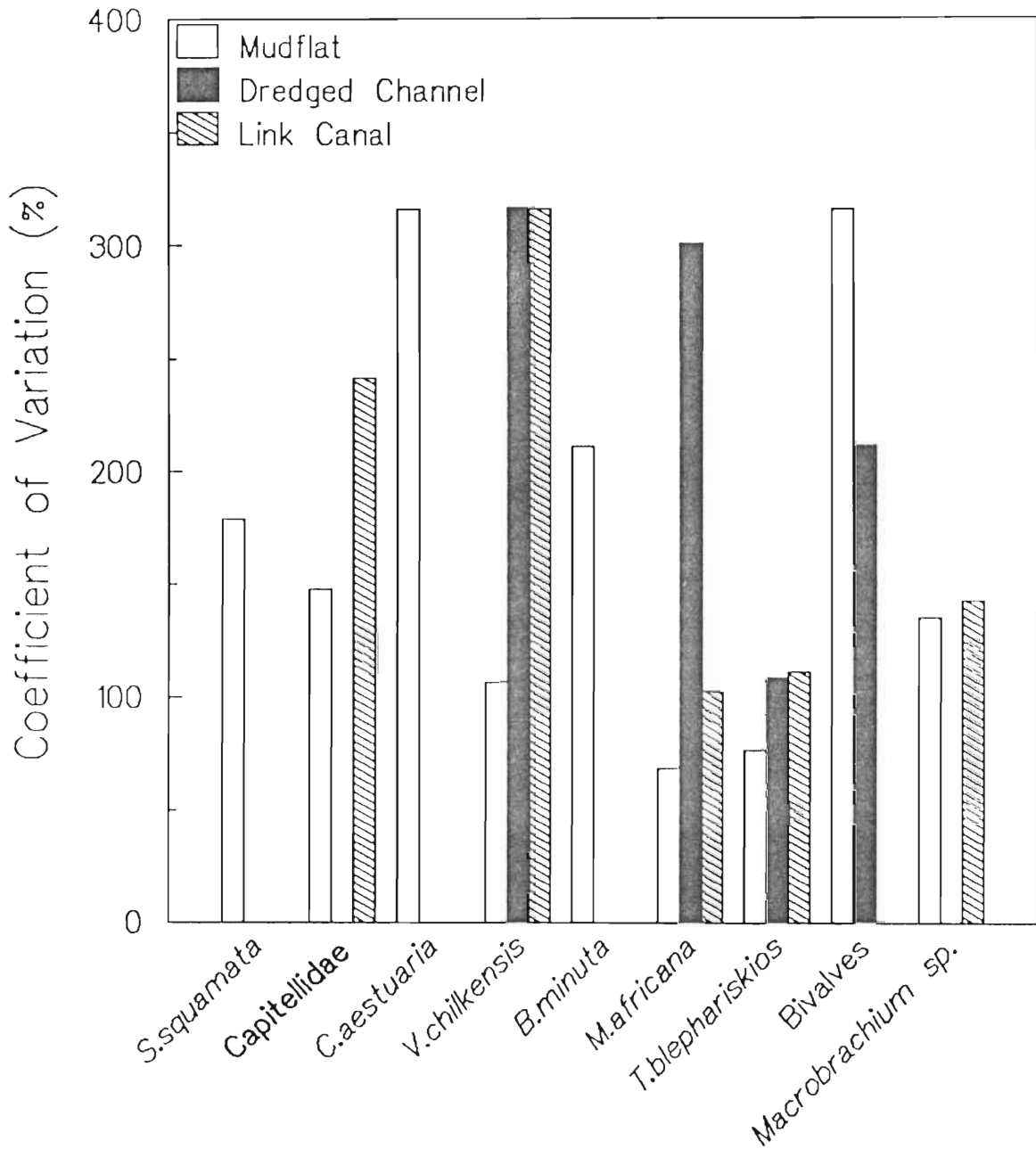


Fig. 4.6 Coefficients of variation of the species recorded from the mudflat, dredged channel and Link Canal in March 1989.

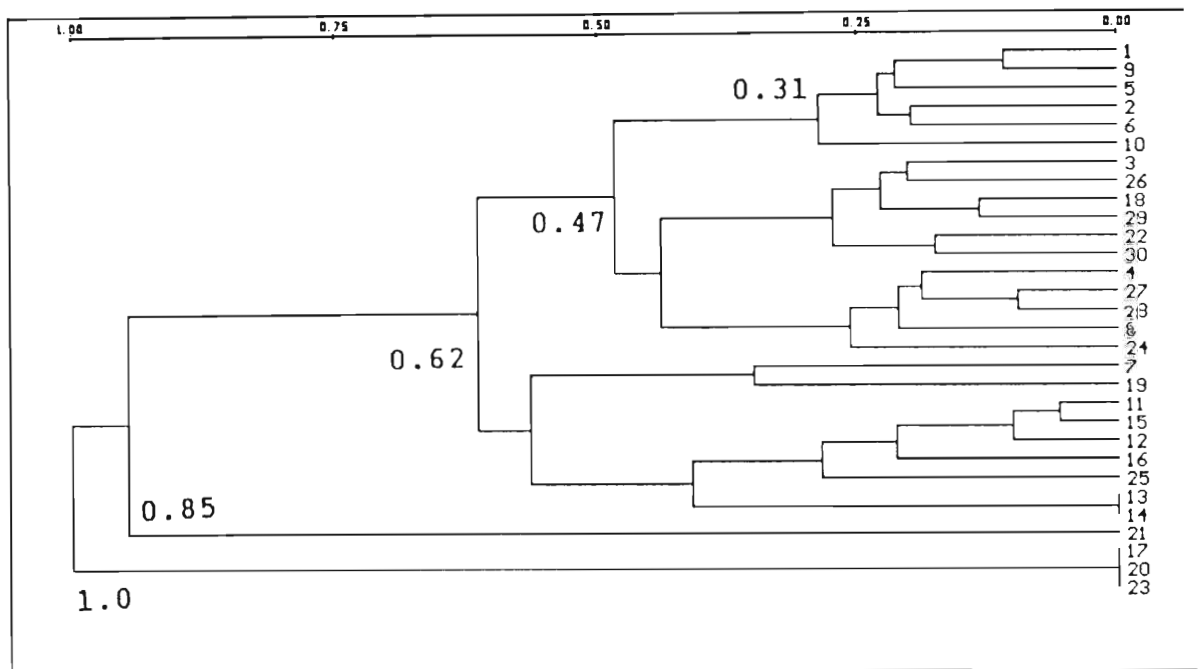


Fig. 4.7 Cluster analysis of the Bray-Curtis dissimilarity indices of samples taken from the mudflat (1-10), dredged channel (11-20) and Link Canal (21-30) in March 1989.

V.chilkensis while the cluster at value 0.31 contains mudflat samples dominated by *T.blephariskios* and *V.chilkensis*.

4.3.2 Beam Trawling

A total of 11 benthic species were recorded in the trawled and control quadrats over the study period (Fig 4.8). The most abundant species in both the control and trawled quadrats over the study period were *T.blephariskios*, *V.chilkensis* and capitellid polychaetes. The remaining species were recorded at densities one to two orders of magnitude lower. The average densities of *T.blephariskios*, *V.chilkensis* and Capitellids over the study period were lower in the trawled quadrat than in the control. The densities of the other polychaete species were higher in the trawled quadrat than in the control. The biomass of the control and trawled quadrats was dominated by *T.blephariskios* and *V.chilkensis* and the polychaete *D.arborifera* (Fig. 4.9).

Ordination of species densities from the trawled and control quadrat showed a greater variability over the study period in the trawled quadrat compared with the relatively tight cluster of the control samples (Fig. 4.10). The outlying points represent samples taken 13, 23 & 31 days after

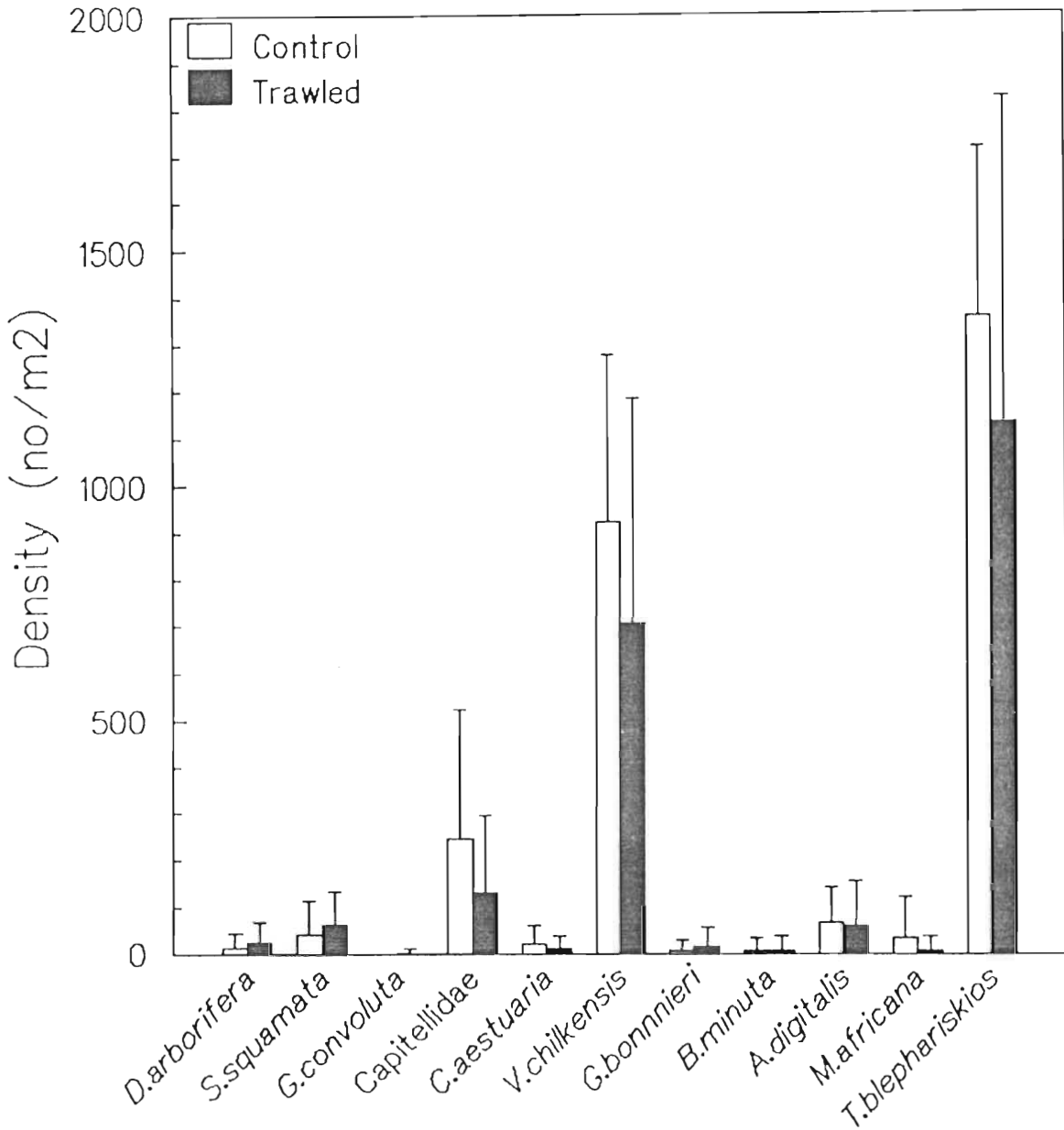


Fig. 4.8 Average densities and sample standard deviations of species recorded in the control and trawled quadrats from February to March 1989. (n=60)

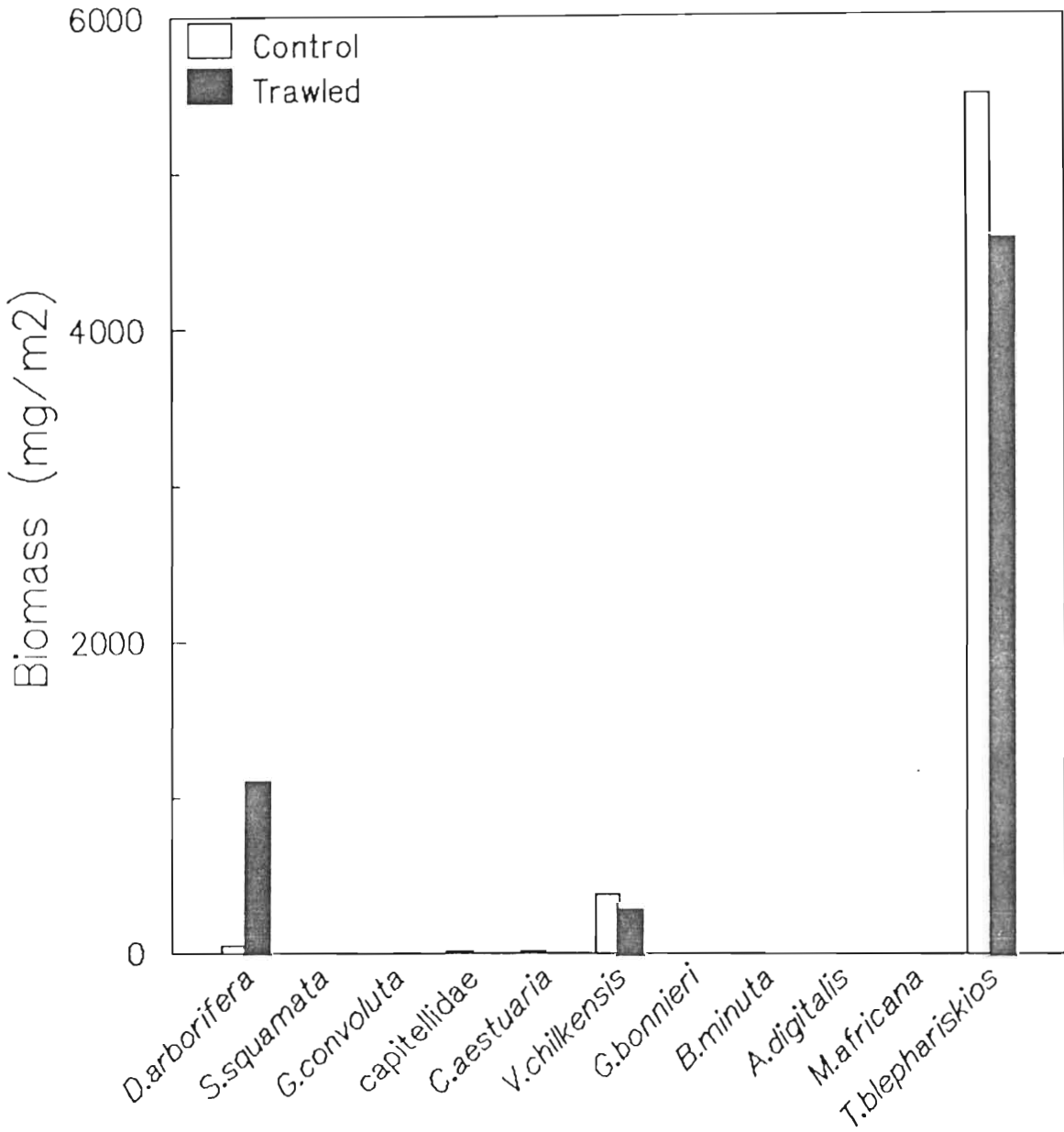


Fig. 4.9 Average biomass of species recorded in the control and trawled quadrats from February to March 1989. (n=60)

trawling, indicating that trawling did have an effect on the benthos. The spread of points in the ordination was not related to salinity or temperature, which varied between 8 ppt. and 17 ppt., and 20°C and 29°C respectively over the study period.

The species scores (Fig. 4.11) indicate that the most stable species in the ordination were *T.blephariskios* and *V.chilkensis*, which varied similarly, and *A.digitalis*. The gravimetrically important *D.arborifera* and *G.convoluta* showed the highest variabilities in the ordination due to their irregular occurrence in high numbers in the trawled quadrat.

The coefficients of variation of *T.blephariskios* and *V.chilkensis* in the control and trawled quadrats are markedly lower than those of the other species. The coefficients of variation were lower in the control than in the trawled quadrat (Fig 4.12).

It was concluded from the Mann-Whitney comparisons between the numbers of capitellids, *V.chilkensis* and *T.blephariskios* in the control and trawled quadrats that the medians of the numbers of *V.chilkensis* and capitellids were significantly lower at the 95% confidence level in the trawled quadrat than in the control over the study period (Table 4.2).

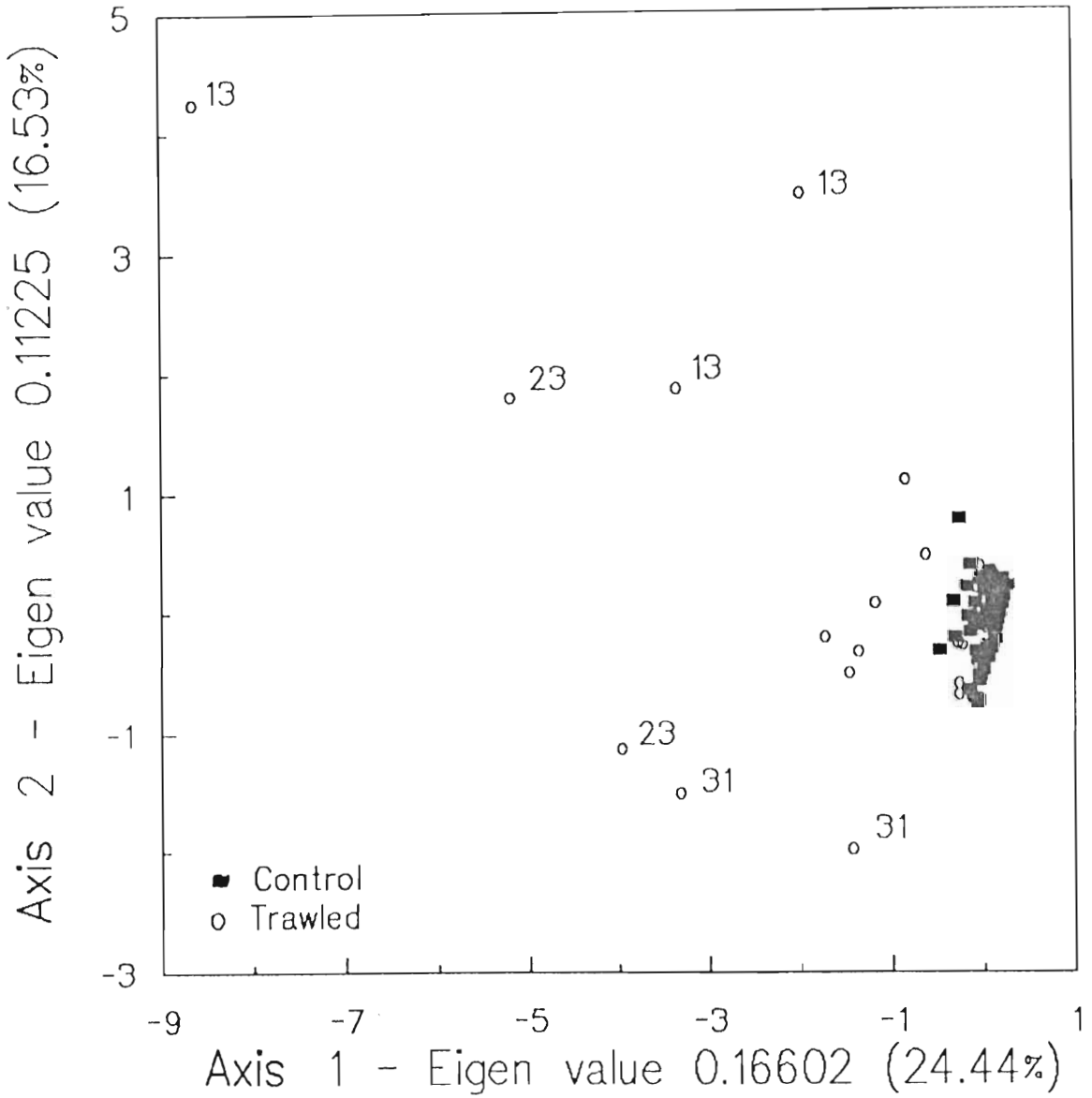


Fig. 4.10 Sample scores of the first two axes of the correspondence analysis of the species densities from the control and trawled quadrats from February to March 1989. Numbers indicate days after trawling.

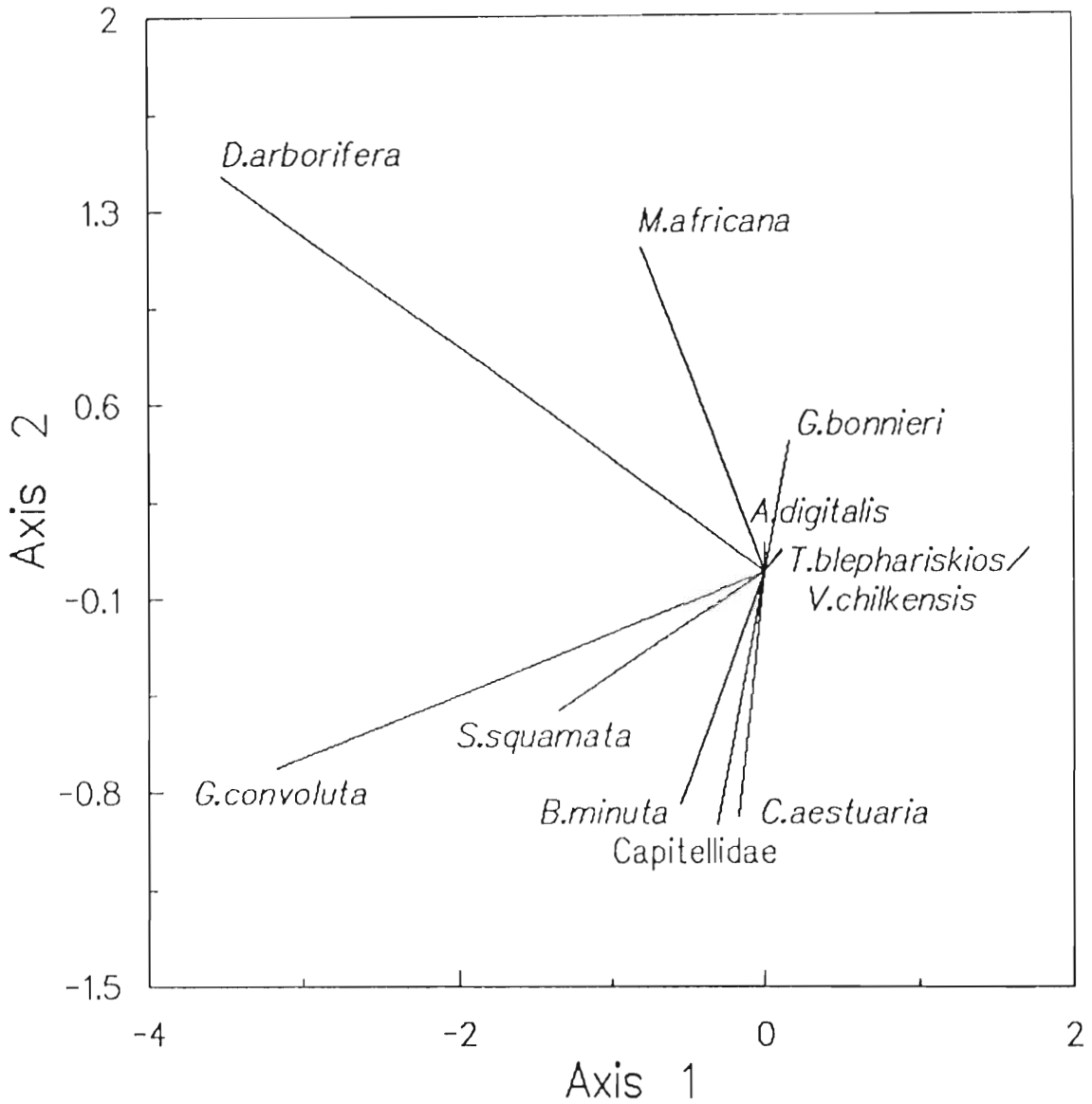


Fig. 4.11 Species scores of the first two axes of the correspondence analysis of the species densities from the control and trawled quadrats from February to March 1989.

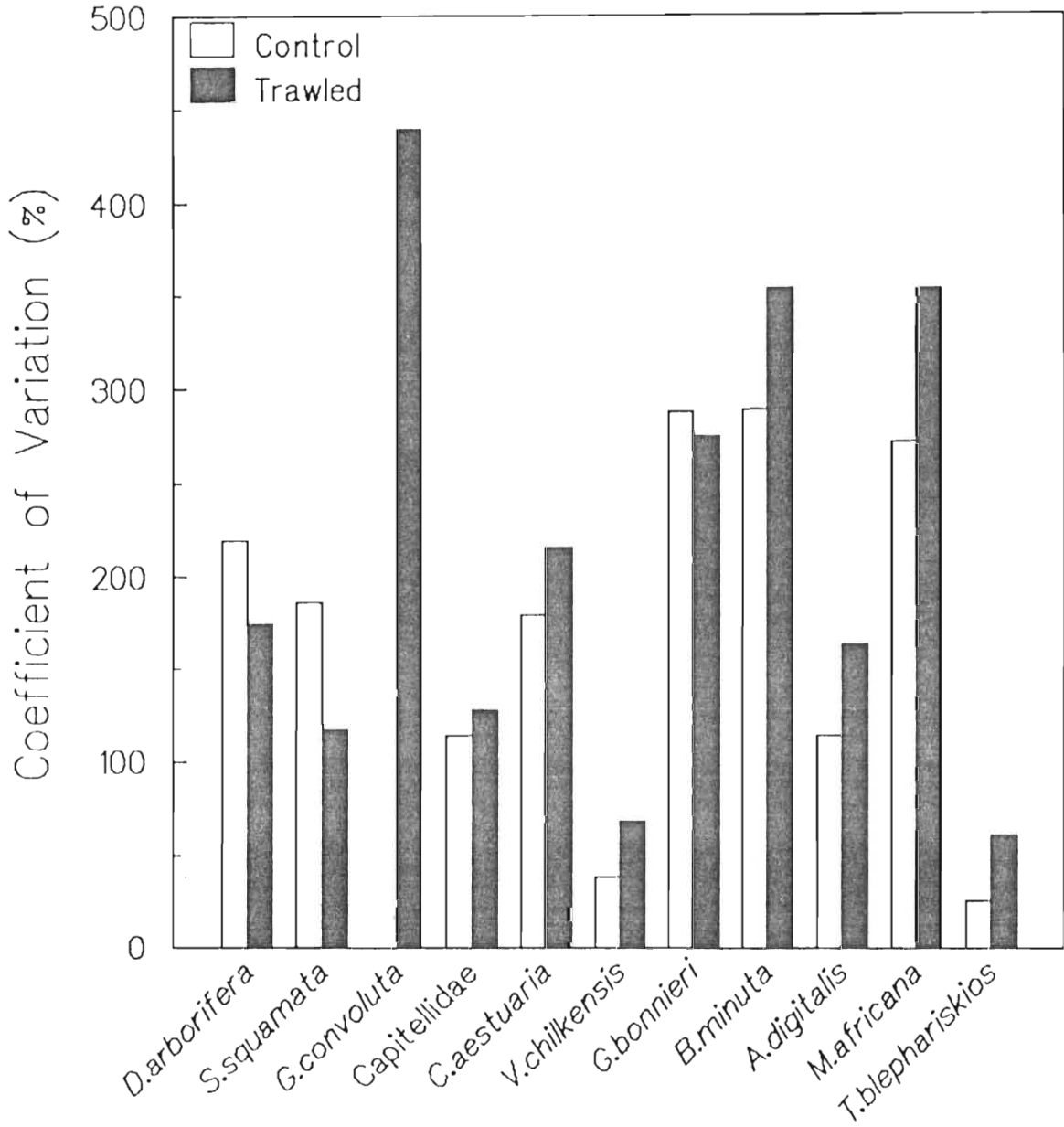


Fig. 4.12 Coefficients of variation of the species recorded in the control and trawled quadrats between February and March 1989.

Table 4.2 Mann-Whitney average ranks, large sample test statistic (Z) and two tailed probability of equalling or exceeding Z for the three most abundant species in the control and trawled quadrats. (60 values in each group)

	Capitellids	<i>V.chilkensis</i>	<i>T.blephariskios</i>
Average rank of 1st group.	68.92	70.10	65.08
Average rank of 2nd group.	52.08	50.90	55.92
Z	-2.69	-3.02	-1.44
Probability of equalling or exceeding Z.	0.007	0.003	0.149

The higher probability of the numbers of *T.blephariskios* being similar in the two quadrats indicates that there was no significant difference between the two populations and that they were unaffected by trawling.

The linear and exponential regressions of the counts of capitellids, *V.chilkensis* and *T.blephariskios* in the control and trawled quadrats over the study period are given in Figs 4.13 to 4.15. No general trend between the numbers of each species in the control and trawled quadrats and the type of regression was evident. The exponential regression gave the best fit for the counts of capitellids and *V.chilkensis* (Figs 4.13 & 4.14) in the control quadrats while the counts of these two species in the trawled quadrat showed a better

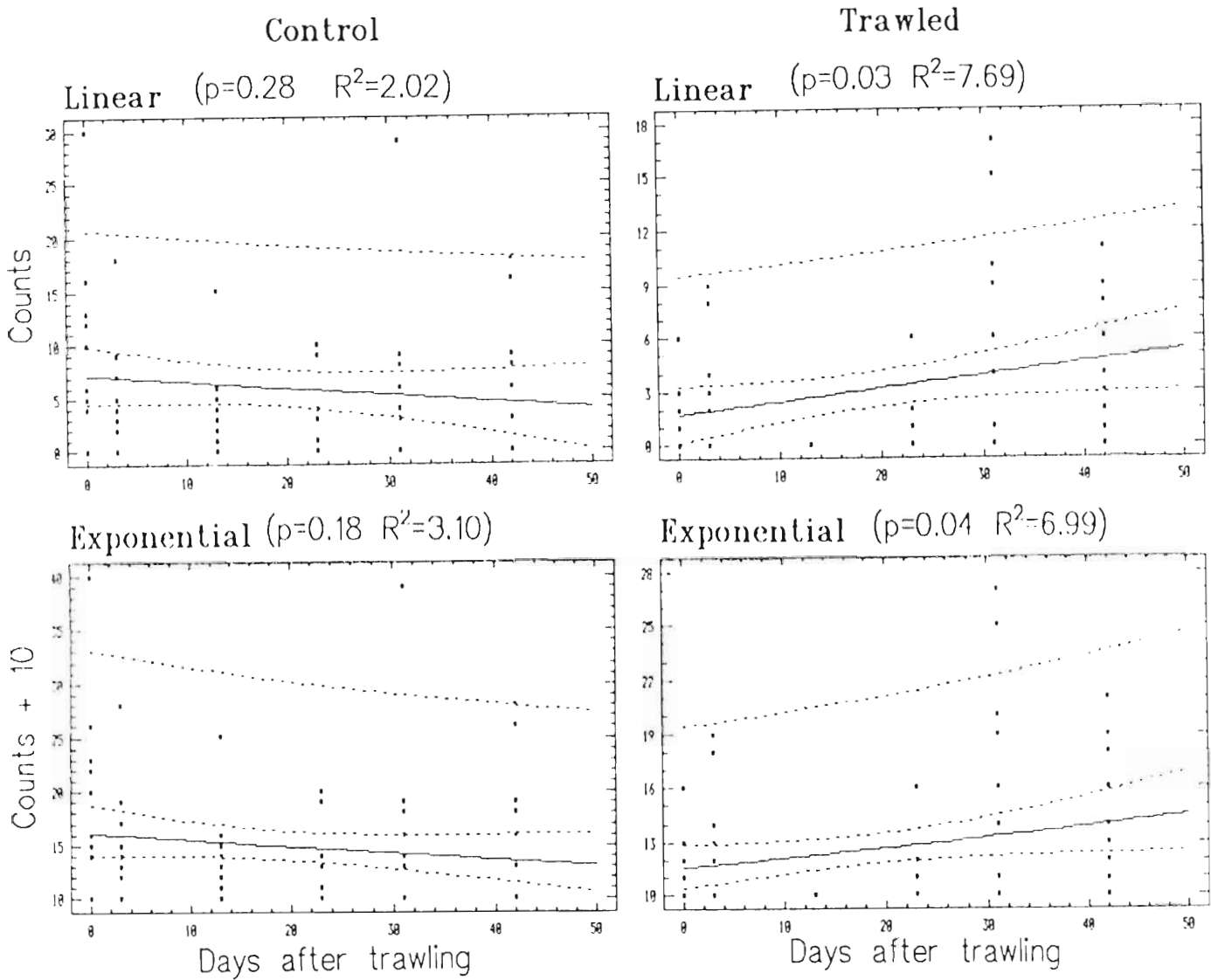


Fig. 4.13 Regression analysis of counts of Capitellidae in the control and trawled quadrats from February to March 1989. [95% confidence limits are shown for the regression (inner) and the counts (outer)]

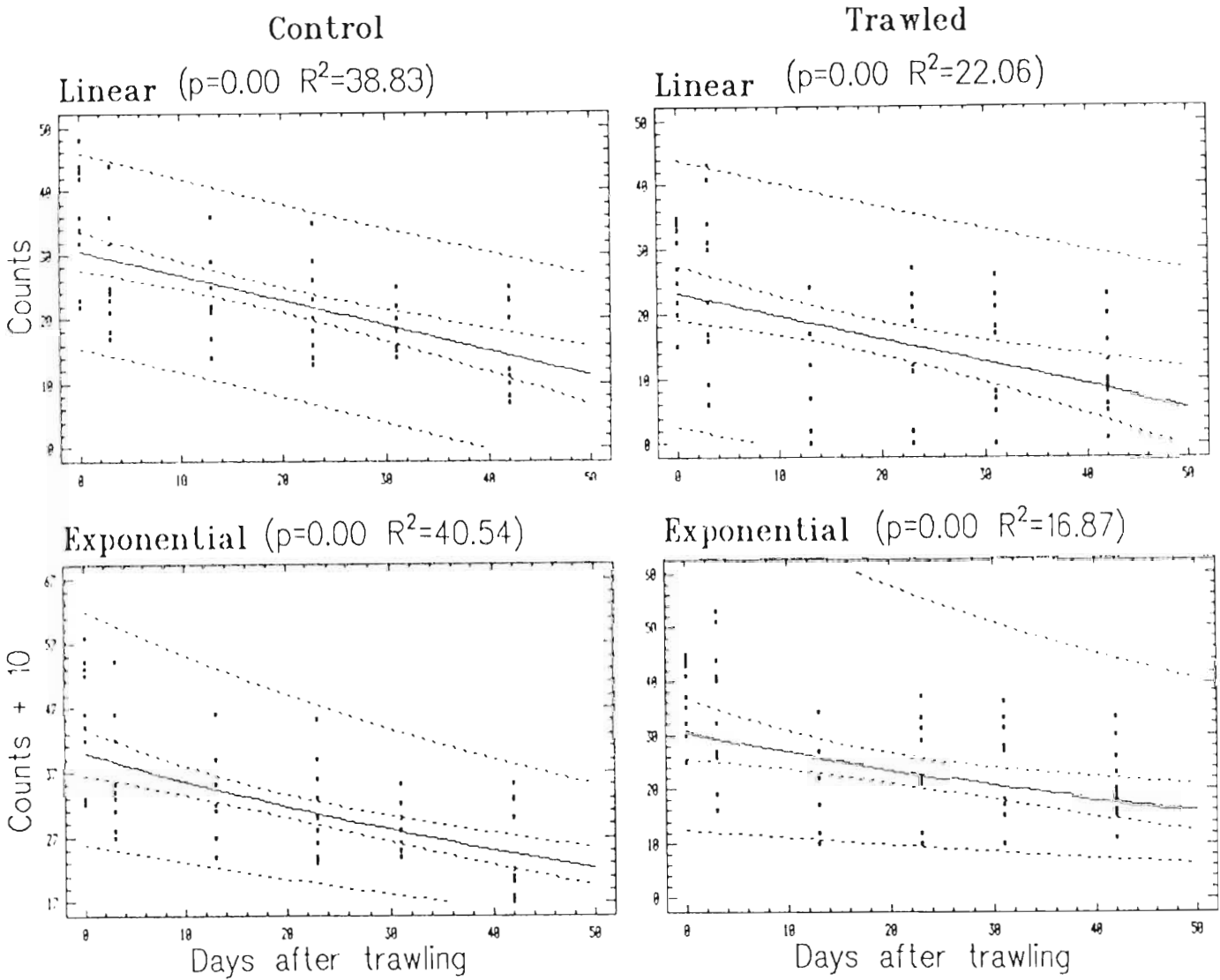


Fig. 4.14 Regression analysis of counts of *V. chilensis* in the control and trawled quadrats from February to March 1989. [95% confidence limits are shown for the regression (inner) and the counts (outer)]

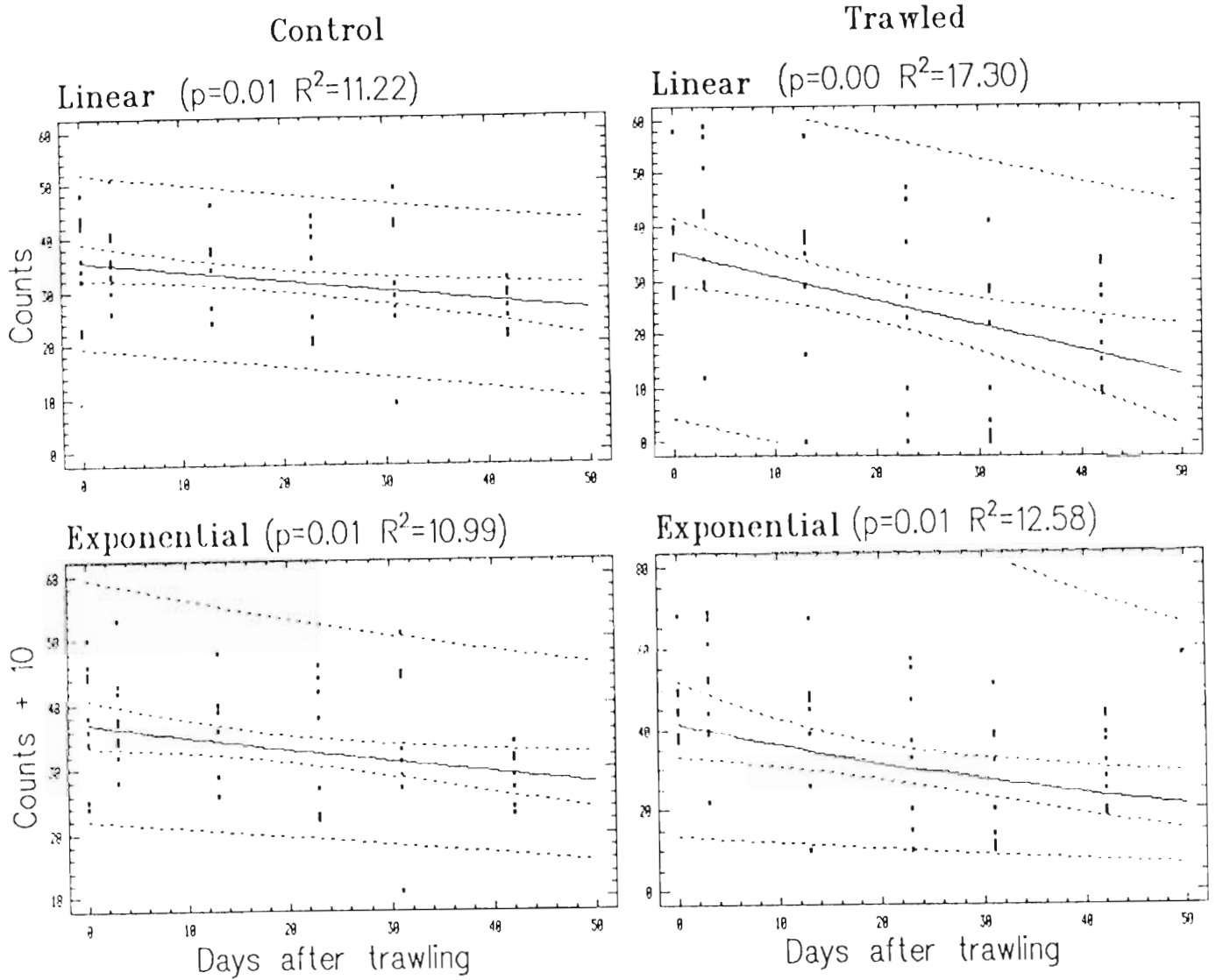


Fig. 4.15 Regression analysis of counts of *T. blephariskios* in the control and trawled quadrats from February to March 1989. [95% confidence limits are shown for the regression (inner) and the counts (outer)]

linear fit. It would appear that the numbers of capitellids in the control quadrat decreased exponentially with time while their numbers increased linearly in the trawled quadrat (Fig 4.13). The better exponential fit of the decreasing numbers of *V.chilkensis* in the control quadrat study period indicates that the numbers of *V.chilkensis* dropped and recovered with time in the control quadrat compared with the trawled quadrat (Fig 4.14). The counts of *T.blephariskios* in both the control and trawled quadrats showed a better linear fit and showed a steady decrease over time in both quadrats (Fig 4.15).

The ranges of the slopes of both the linear and exponential regressions of the counts of capitellids, *V.chilkensis* and *T.blephariskios* in the control and trawled quadrats overlap (Fig. 4.16), indicating that there was no significant difference between the numbers of the three species in the two quadrats.

No significant differences were evident between the slopes of the frequency distribution plots for trawled and control quadrats (Fig. 4.17). The increase in slope evident from the trawled quadrats over the study period suggests that the number of species in higher density classes increased, which may reflect the increased polychaete densities, but this is contradictory to the lower densities of the numerically dominant species recorded in the trawled quadrat.

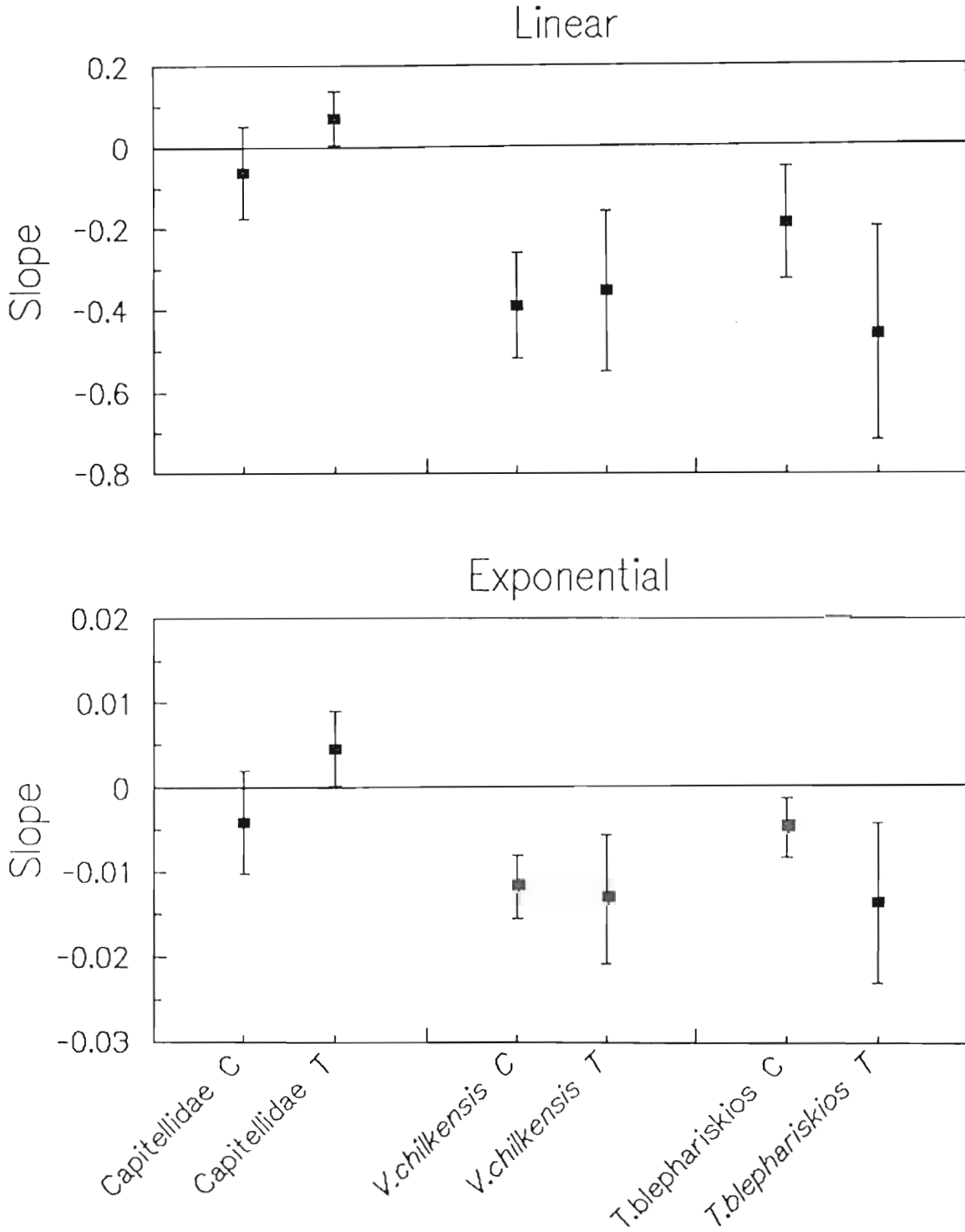


Fig. 4.16 Regression slope ranges for Capitellidae, *V.chilkensis* and *T.blephariskios* in the control and trawled quadrats from February to March 1989.

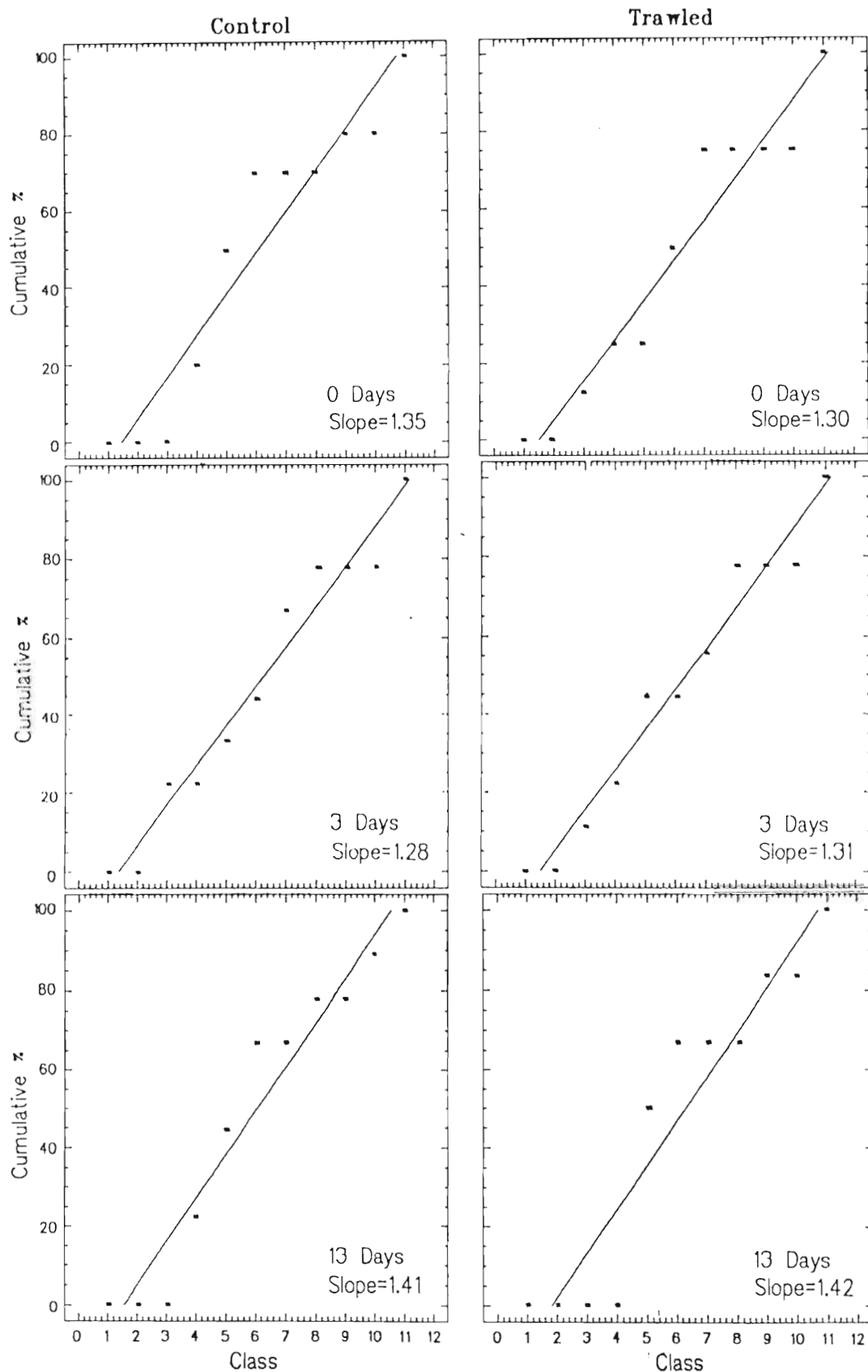


Fig. 4.17 Frequency distributions of species from the trawled and control quadrats from February to March 1989.

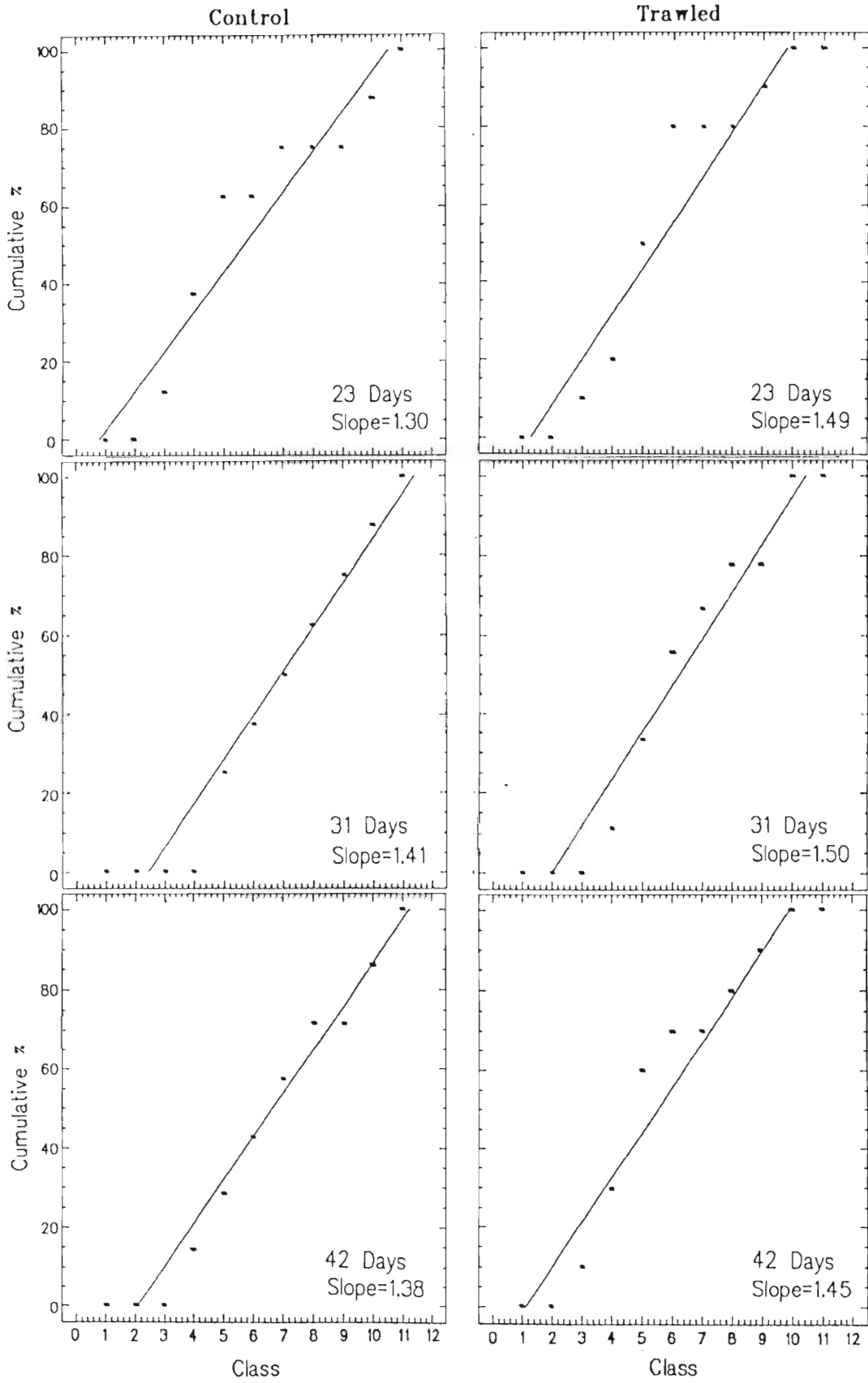


Fig. 4.17 (Continued)

4.4 Discussion

4.4.1 Dredged Areas

The dredged channel was still impoverished compared with the adjacent mudflat, but with a different species composition from that recorded by Hay (1985) in the July 1983 pre-flood survey. A fourteen-fold increase in total biomass over the 1983 survey was found in the dredged channel, while a biomass approximately half that of the 1983 survey was found on the mudflat. These differences in biomass were due to the increased density of *T.blephariskios* in the dredged channel and its decreased density on the mudflat during this study compared with the 1983 study. The polychaetes *Marphysa macintoshi* and *D.arborifera*, present on the mudflat and dredged channel in 1983, were not recorded in these habitats during the pilot study. These polychaetes appear to have been replaced by *Scololepis squamata* and capitellids on the mudflat, although the oligochaetes recorded by Hay (1985) from the mudflat and dredged channel may have been misidentified capitellids. The amphipod *Grandidierella lignorum*, recorded from the mudflat and dredged channel in 1983, was not recorded in this study, and appeared to have been replaced by *V.chilkensis*. This comparison was based on data collected during different seasons however, and may reflect seasonal variation in the benthos.

The Link Canal appears to have remained colonised after the 1984 floods with a total biomass approximately double that of the adjacent dredged channel. The presence of capitellid polychaetes in the Link Canal is noteworthy because no polychaetes were recorded in the dredged channel.

It would appear that dredging creates an unfavourable habitat for benthic organisms in the long term. This would occur either directly through substratum removal, or indirectly through the creation of channels. Channels would focus currents and increase scouring, thereby influencing sediment deposition and composition.

4.4.2 Beam Trawling

No conclusive evidence was found to suggest that beam trawling negatively affected the benthos. Although the numbers of capitellids and *V.chilkensis* were significantly lower in the trawled quadrat than in the control, there were no significant trends in the numbers of these species over the study period to suggest that the lower numbers in the trawled quadrat were due to trawling. It is notable that the numbers of capitellids increased in the trawled quadrat during the study period, even though their average density was lower in the trawled quadrat than in the control. The

lower average density of *T.blephariskios* in the trawled quadrat compared with the control was not found to be significant.

The lower densities of *T.blephariskios* and *V.chilkensis*, and the higher density of capitellids in the closed area compared with the area open to trawling at Esengeni during February of the 1987-1988 study (Owen, 1988) are contradictory to the present study. *D.arborifera* and *S.squamata* were absent from samples taken in open areas at Esengeni and Brodies Shallows, but present in the adjacent closed areas during the 1987-1988 study, which is also contradictory to the present study. Only two grab samples were taken at each area during 1987-1988 study however, and the low number of replicates may not have been sufficient to obtain a representative sample to allow a comparison between the open and closed areas to be made.

The higher coefficients of variation of *T.blephariskios*, *V.chilkensis* and capitellids in the trawled quadrat compared with the control suggests that these species were less evenly distributed in the trawled quadrat. An uneven species distribution could reflect an uneven or patchy substratum. Although no quantification of the sediment characteristics of the trawled and control quadrats was undertaken, it was observed from the samples that *T.blephariskios* and

V.chilkensis were absent from very sandy samples, which tended to contain higher numbers of *D.arborifera* and *S.squamata*. The higher variability of the numerically dominant species in the trawled quadrat than in the control suggests that trawling reduced the evenness of their distribution without significantly affecting their numbers. The degree of inherent substratum patchiness in the trawled and control quadrats was however, not known.

4.4.3 Abundant and Important Indicator Species

The general presence and numerical dominance of *T.blephariskios*, *V.chilkensis* and capitellid polychaetes in dredged areas and the trawled and control quadrats indicated that these species would be the most important to monitor. Furthermore, their distribution appeared to be uniform in that they were generally present in the same relative proportions on muddy substrata in the Narrows. Their coefficients of variation, although higher in the trawled quadrat than in the control, were markedly lower than the other species. *T.blephariskios* dominated the benthic biomass where it occurred, and consequently any decrease in its density significantly reduced the benthic biomass.

The importance of the capitellid *Capitella capitata* as an opportunistic indicator species in disturbed and polluted

sediments has been emphasised by Gray (1981). He suggested that as a classically r-selected species, its ability to reproduce rapidly (three weeks from egg to maturity) by both benthic and planktonic larvae adapted them to rapidly repopulate disturbed substrata. This accords with the presence of capitellids in the Link Canal and their high densities in the trawled quadrat.

Although *M.africana* was abundant in the Link Canal and adjacent mudflat, it occurred in low densities in the trawled and control quadrats. This indicated that its distribution in the Narrows was patchy and not necessarily determined by the nature of the substratum. Their patchy distribution may be explained by their planktonic behaviour. Mysids have been recorded at high densities in zooplankton samples from night trawls in the Narrows (Forbes, 1989), which suggest that they undergo vertical migrations on a diurnal basis, and are therefore not strictly benthic.

4.4.4 Statistical Techniques

The most useful techniques used to analyse the data in this study were those that gave an overall indication of species density, richness and variability at the different sampling sites, and those that indicated species trends over time.

The average density of each species was the most practical and useful method of showing and comparing the overall number of each species at the different sample sites, and together with the sample standard deviations, indicated the species variability among the replicates taken at each sample site. Coefficients of variation for each species were used to compare the variability of each species among the different sample sites because they are independent of the magnitude of the data (Zar, 1984), and thereby provide a more tenable means of comparing species variability.

Correspondence analysis is commonly used to detect variability in a data set. This variability can then be interpreted in conjunction with observed parameters. Correspondence analysis in this study showed that the dredged channel and Link Canal were more variable than the undredged mudflat in terms of species density and richness, and that the trawled quadrat was more variable than the control. The species scores derived from the ordination were useful in determining the variability of each species together with their coefficients of variation.

The cluster analysis of the Bray-Curtis dissimilarity indices gave comparable results to the correspondence analysis. However, the correspondence analysis of the mudflat, dredged channel and Link Canal provided more detail

in terms of sample and species variability, as well as being easier to interpret.

The Mann-Whitney non-parametric comparison was used to determine whether there was a significant difference between the numbers of the numerically important species in the trawled and control quadrats, but did not take trends over time into account. Regression analysis was then used to show trends in species numbers over time. The increasing numbers of capitellids over time in the trawled quadrat was not detected by comparing their densities in the trawled and control quadrats, or by the Mann-Whitney test, both of which indicated lower numbers of capitellids in the trawled quadrat than in the control. However, this trend was shown by the regression analysis.

Gray (1981) maintained, from numerous examples, that benthic communities could be accurately described by a log-normal distribution, the only requirements being that the communities are heterogeneous and that a 'large enough' sample is taken. The scatter of points in the frequency distribution plots from the trawled and control quadrat (Fig.4.5) showed that many of the size classes did not contain any species. This implies that either the sample was too small or that the benthos in this instance was not normally distributed. If the benthos was not normally

distributed, the question arises as to whether disturbance through trawling or some other factor is preventing the benthic community from assuming Gray's (1981) "normal distribution".

Diversity and evenness indices were not considered for this study. An investigation by Hay (1985) of the Shannon-Weiner and Heip indices yielded inconsistent results when applied to existing benthic data from the Narrows and Lakes. He argued that these indices failed to detect obvious changes in community structure. A decrease in species density from 10 000 to 9 990 would be treated in the same way as a decrease from 10 to 0, which is misleading in a biological context.

4.4.5 Conclusion

It would appear that the response of the benthos to sediment disturbance is related to the nature and scale of the disturbance. Whereas beam trawling did not appear to have a negative effect on the benthos, dredged channels were impoverished compared with the adjacent mudflats. This suggests that benthic organisms are either not affected by, or rapidly recover from small scale disturbances, but not large scale disturbances in which their habitat is altered in the long term.

5.0 DREDGED AREAS

5.1 Introduction

The effects of dredging consolidated estuarine substrata have been well documented in an extensive literature. Removal with, and burial by dredge spoils, habitat destruction through physical and chemical change of sediments and alteration of circulation patterns have all been identified as major factors affecting the distribution and abundance of benthic organisms (Morton, 1977).

Studies have shown that dredged areas are generally impoverished compared with undredged areas. Decreased species densities and richness have been recorded where the nature of the substratum has been changed or current patterns have been altered through dredging. Lower species densities were noted in dredged areas compared with undredged areas of West Bay, Texas (Gilmore and Trent, 1974). The removal of mud and silt through dredging in Goose Creek, New York, exposed sandy substrata and was found to decrease benthic species diversity and biomass (Kaplan, Welker, Kraus and McCourt, 1975). Differences in species composition and richness were reported by Jones and Candy (1981) between dredged and undredged areas in Botany Bay, Australia, where species composition was found to be

associated with sediment type. Species richness, highest in sandy areas, was found to decrease where the nature of the substratum had been changed from sandy to muddy through dredging.

Changes in bottom topography through dredging can change current patterns and velocities in estuaries, and have an indirect effect on benthic organisms through altered sediment erosion, transport and deposition (Morton, 1977). The creation of channels would tend to focus and increase current velocities, while deepening natural or existing channels would tend to decrease current velocities. Kaplan et al. (1975) found that decreased current velocities caused by deepening existing channels increased silt deposition in sandy areas of Goose Creek.

Recovery of benthic communities after dredging has been reported to occur over periods of weeks to months, and although species densities often remained lower in the long term, they generally recovered to the same order of magnitude as pre-dredging densities (Morton, 1977). Rates of recovery in dredged areas depended on natural recruitment, the number of individuals and species not removed by the dredge and the degree of slumping of channel walls (Van Dolah, Calder and Knott, 1984; Jones, 1986). The extent to which these factors contributed to the recovery of the

benthos depended on the nature and extent of dredging operations, the nature of the substratum and the erosional and depositional influence of currents on larval and sediment transport.

While the effects of dredging on benthic communities have been extensively researched overseas, there is very little information from southern African estuaries. Local information is limited to pre- and post harbour development benthic surveys of Richards Bay in Natal (Begg, 1978), the ALUSAF Canal at Richards Bay (Hay, 1985), and environmental impact studies carried out in conjunction with marina developments in the southern Cape (Baird, Marais and Wooldridge, 1981).

A benthic survey of the Richards Bay harbour immediately after its opening in 1976 showed decreased species richness and densities compared with the pre-harbour condition (Begg, 1978). Whereas the crab *Tylodiplax blephariskios* had been recorded as numerous and widespread over the entire bay before harbour development, only a single specimen was recorded in the post-development survey. *T.blephariskios* was the only benthic species recorded in the ALUSAF Canal, at an order of magnitude lower than the mudflat at the entrance of the Canal in January 1984 (Hay, 1985), indicating the impoverished nature of the Canal. The polychaetes *Marphysa*

macintoshi and *Dendronereis arborifera* were recorded on the mudflat but not in the canal. The ALUSAF Canal was formerly a river entering the bay and was dredged during the development of the harbour.

Surveys of benthic communities in marina canals on the lower reaches of the Kromme estuary indicated that species richness and densities in the canals were not significantly different from the main estuary, with the exception of benthic species exploited for bait such as *Callianassa kraussi*, *Arenicola loveni* and *Solen capensis*, which were recorded in higher densities in the canals (Baird et al., 1981). These canals were dredged in saltmarsh areas of the estuary and as such are comparable to the Link Canal at St. Lucia, which was also cut through saltmarsh vegetation. It would seem that the apparent colonisation of the Link Canal noted in the pilot study accords with the situation in the Kromme, in that artificially created canals eventually become extensions of the estuary.

The impoverished nature of the dredged channel sampled during the pilot study and previously by Hay (1985), indicated that the dredged areas of the Narrows were still impoverished compared with mudflats in terms of benthic richness, density and biomass 20 years after dredging. Although there is no record of the benthos in naturally

occurring channels before dredging, this impoverishment appears to be permanent.

The objectives of this investigation into the dredged areas of the Narrows were to:

1. determine to what extent benthic communities in the dredged channel in other areas of the Narrows were impoverished compared with adjacent mudflats.
2. compare the differences in substratum composition and organic content in the dredged channel and adjacent mudflats, and to relate any differences to benthic community structure in dredged channels and mudflats.
3. compare current velocities in the dredged channel and adjacent mudflats over different tidal cycles, and during dry and wet seasons, and to relate these to the nature of the substratum.
4. determine whether the Link Canal was still colonised, and to determine its sediment characteristics.

5.2 Materials and Methods

5.2.1 Study Area

Study sites were selected at the 1st Narrows, DeLanges (Third Shallows) and Brodies Shallows, each comprising the

dredged channel and adjacent mudflat 8, 12 and 20 km respectively from the mouth to allow for possible variations in substratum type, salinity and tidal action in the Narrows. These stations corresponded to transects surveyed by the Provincial Water Engineer before and after dredging (Fig. 5.1).

5.2.2 Grab Sampling

Five benthic samples and one sediment sample were taken from the dredged channel and from the adjacent mudflat at each station in September 1989 and in March 1990. Surface salinity and temperature were recorded at each station. Five benthic samples and one sediment sample were taken from the Link Canal in April 1990.

5.2.3 Current Velocities

Current velocities were recorded at hourly intervals over a 12 hour period at each station over spring and neap tides in September 1989 and March 1990. The deepest part of the channel across each transect was located using a shot line. Surface and bottom velocities were recorded in the channels and bottom velocities were recorded on the mudflats. Surface velocities were measured 0.25 m below the surface and bottom velocities were measured 0.25 m off the bottom. Water depth

and surface salinity were recorded at hourly intervals at each station.

5.2.4 Data Analysis

Benthic Samples

Average densities, sample standard deviations and coefficients of variation were calculated for each species in the dredged channel and on the mudflat at each station. The total dry biomass was calculated for each station. Species densities from all the stations were subjected to correspondence analysis. The sample and species scores were plotted and interpreted in terms of location, time of sampling, salinity, sediment characteristics and temperature.

Sediment analysis

The percent composition of mud and sand, and organic matter was determined for each sediment sample and compared by means of stacked histograms.

Current Velocities

Current velocities were plotted for each station. Ebb currents were assigned a negative value. Velocities were

plotted commencing with the start of the flood tide at Hour 1, irrespective of the time of day.

5.3 Results

5.3.1 Species Richness, Density and Biomass

Fourteen taxa were recorded from the dredged channel and adjacent mudflats (Figs. 5.2 - 5.4). Of these the isopod *Synidotea variegata*, the amphipod *Melita zeylanica*, the crab *Hymenosoma orbiculare* and the bivalve *Solen cylindraceus* were not recorded in the pilot study. While all stations were dominated by *T.blephariskios*, *V.chilkensis* and capitellids, the densities of *T.blephariskios* were an order of magnitude lower at the Brodies stations than at the 1st Narrows and DeLanges stations. *S.cylindraceus* and *S.variegata* were the only species not found on the mudflats, with one and two individuals respectively recorded in the dredged channel at Brodies Shallows in September 1989 (Fig. 5.4).

Decreasing trends in species richness and densities were evident with time, and between dredged channels and mudflats at each location. Species richness and densities declined on both mudflats and in dredged channels in March compared with September (Figs. 5.2 - 5.4). The densities of

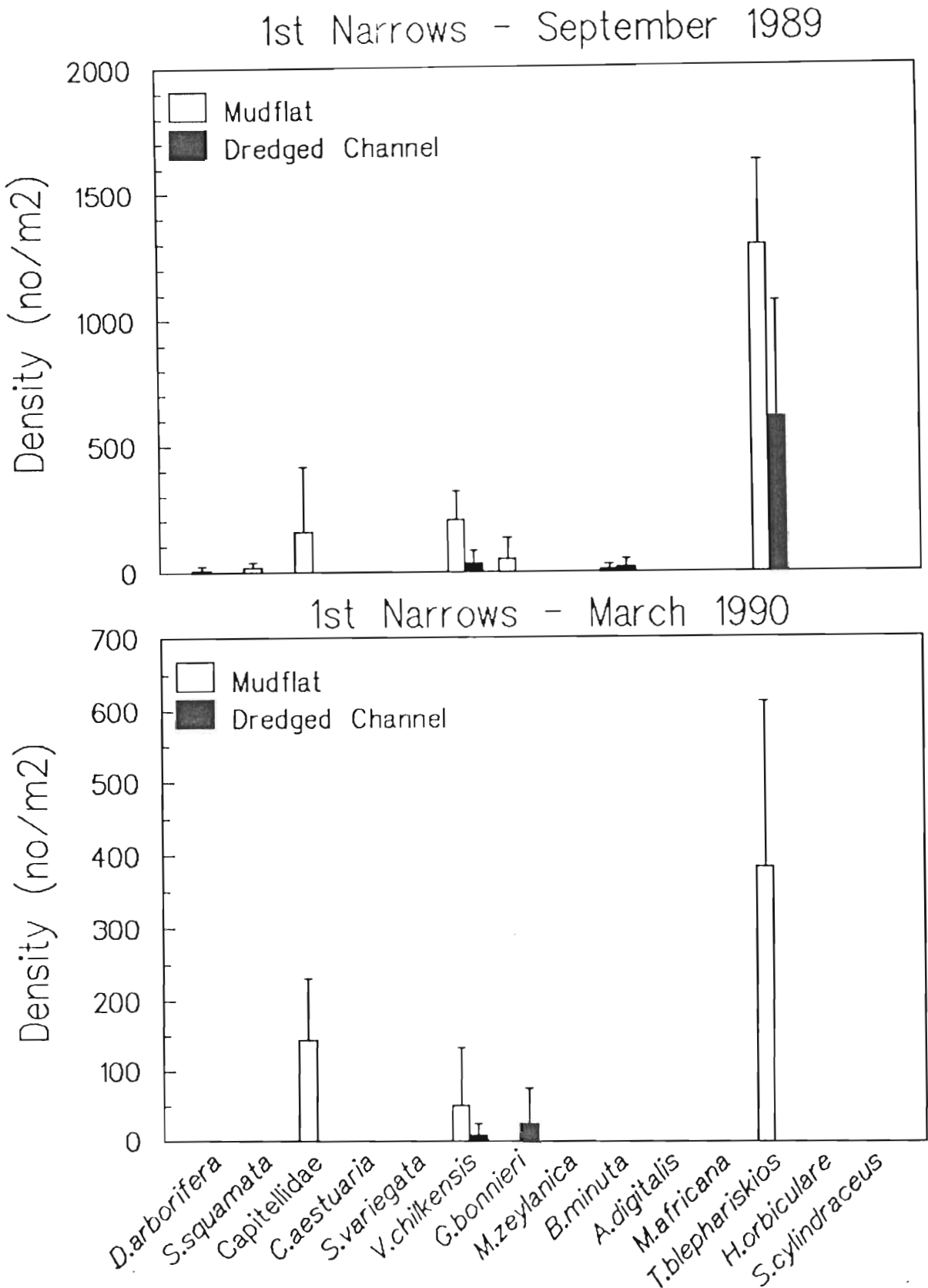


Fig. 5.2 Average densities and sample standard deviations of species recorded in the dredged channel and on the adjacent mudflat at the 1st Narrows in September 1989 and March 1990. (n=5)

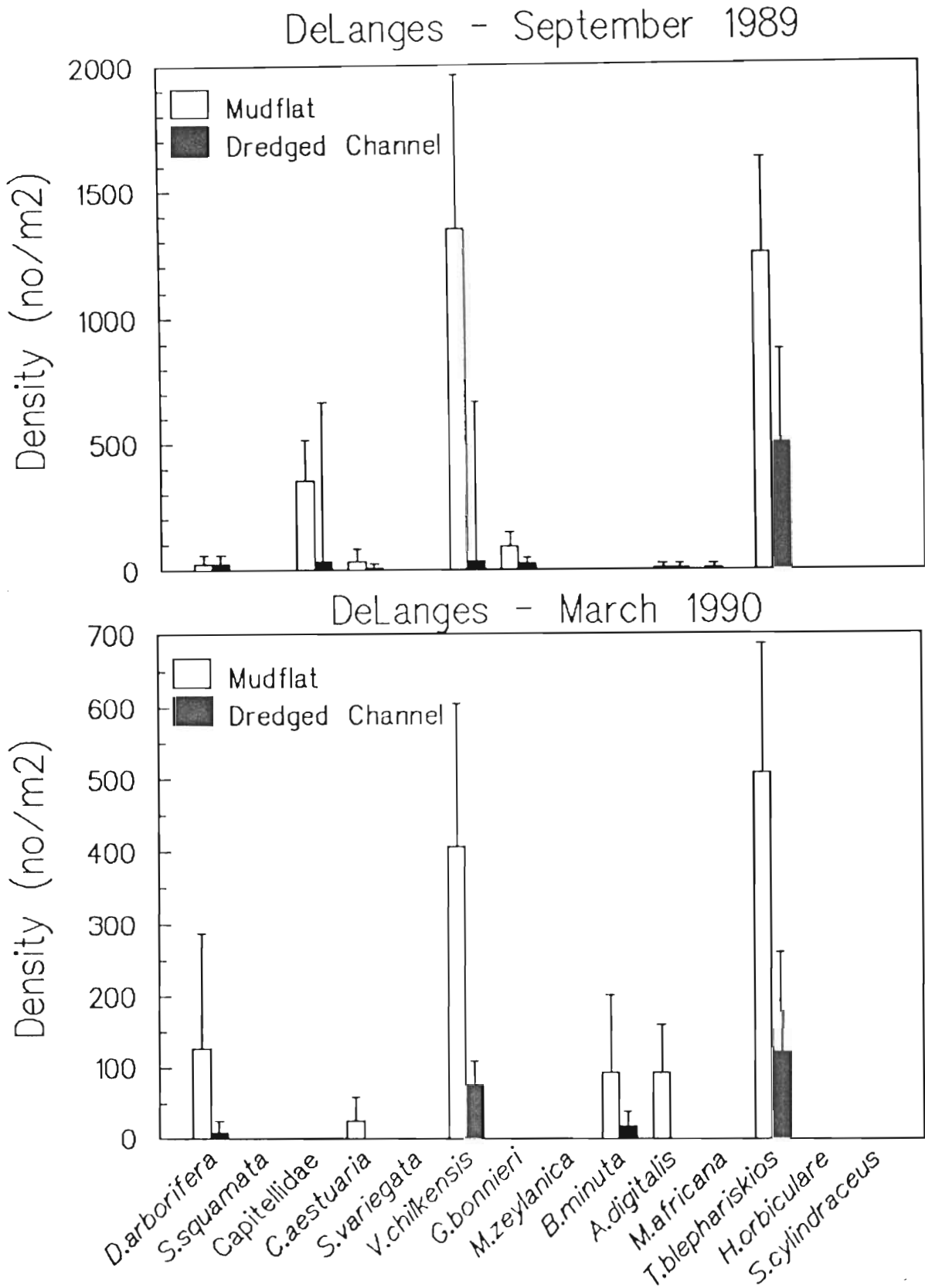
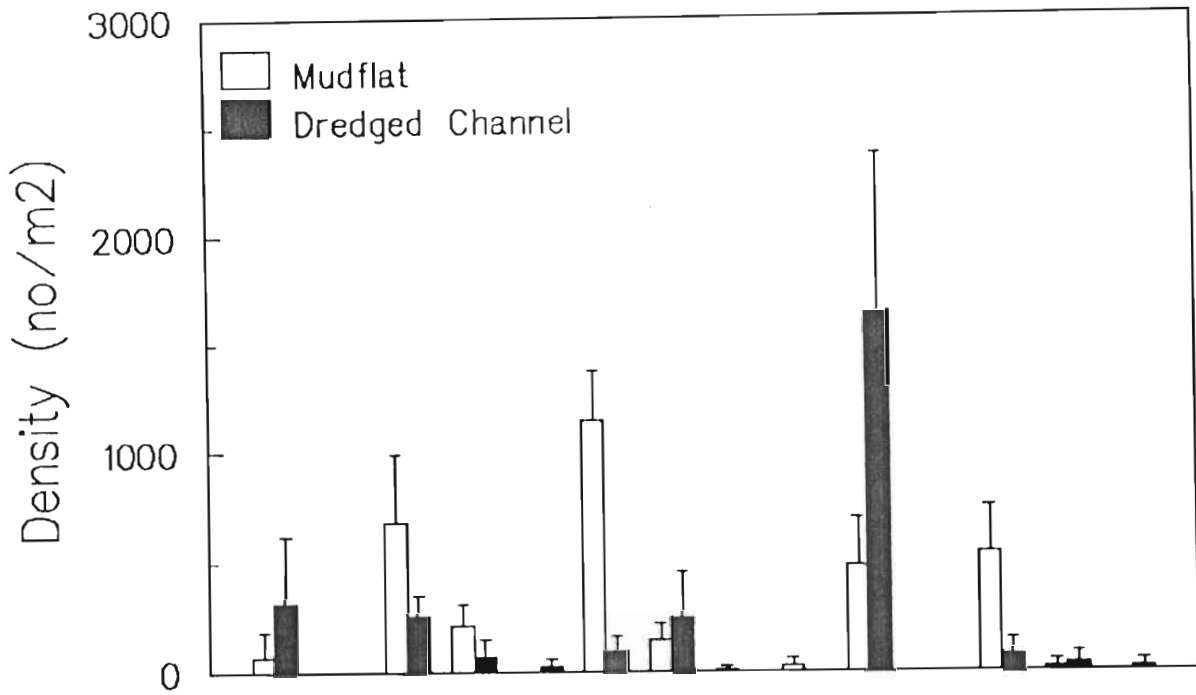


Fig. 5.3 Average densities and sample standard deviations of species recorded in the dredged channel and on the adjacent mudflat at DeLanges in September 1989 and March 1990. (n=5)

Brodies - September 1989



Brodies - March 1990

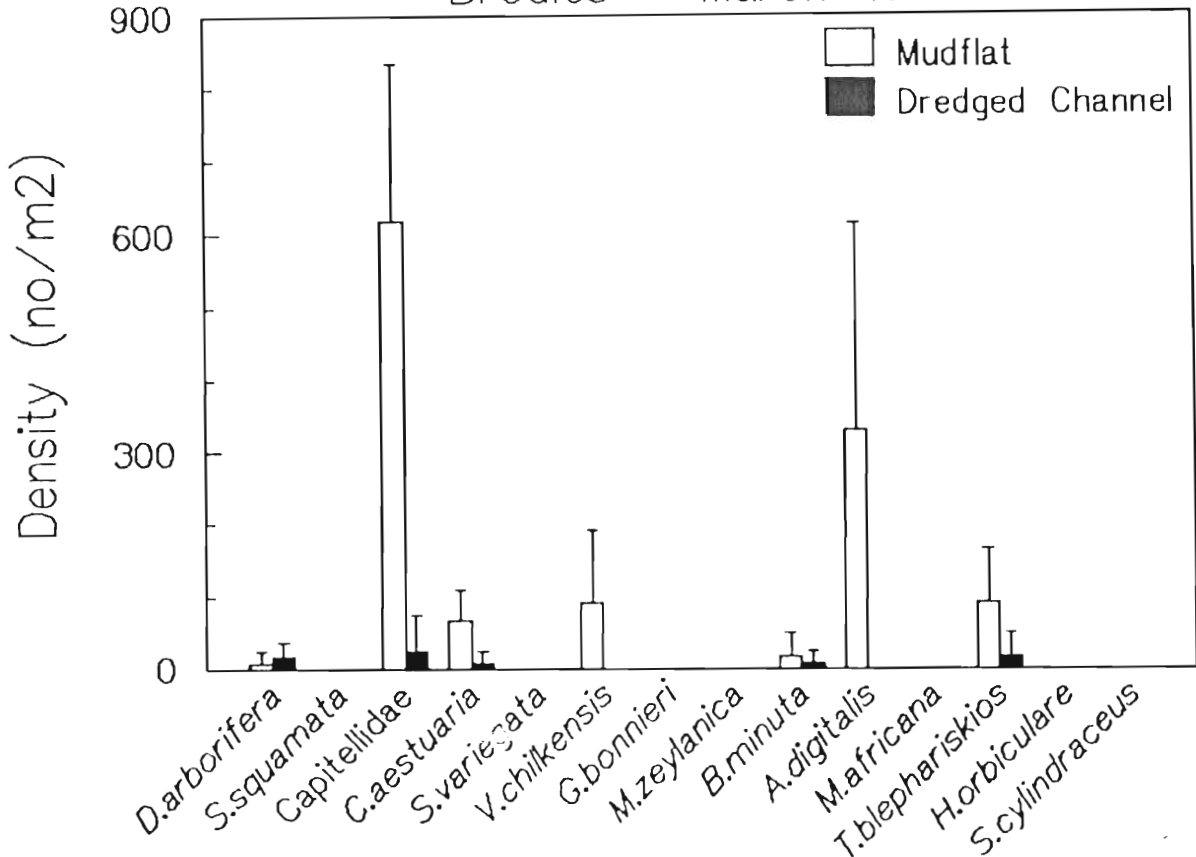


Fig. 5.4 Average densities and sample standard deviations of species recorded in the dredged channel and on the adjacent mudflat at Brodies Shallows in September 1989 and March 1990. (n=5)

T.blephariskios and *V.chilkensis* declined by a minimum of 75% from September to March. Forty percent fewer species were recorded at the 1st Narrows and Brodies, and 25% fewer at DeLanges in March compared with September. In spite of the lower number of species on the mudflats in March, the impoverished nature of the dredged channels compared with the mudflats was still evident.

The densities of *T.blephariskios*, *V.chilkensis* and capitellid polychaetes were generally an order of magnitude lower in the dredged channel than on the adjacent mudflats. The densities of *T.blephariskios* in the dredged channel in September were approximately 50% that of the mudflats at the 1st Narrows and DeLanges, and 85% lower in the channel compared with the mudflat at Brodies. *T.blephariskios* was not recorded in the dredged channel at the 1st Narrows in March, and at densities approximately 25% lower in the channels than the mudflats at DeLanges and Brodies. *V.chilkensis* was present in the dredged channel at densities of 17% or less than the mudflats, and was not found in the channel at Brodies in March. Capitellids occurred in the dredged channel at DeLanges and Brodies in September at densities 10% and 33% that of the mudflats, and at 5% the density of the mudflat at Brodies in March. Capitellids were not found in the channel at the 1st Narrows at all, nor in the channel and mudflat at DeLanges in March. Although

A.digitalis numerically dominated the benthos in the dredged channel at Brodies in September, it was not found in the channel in March, but was recorded on the mudflat in March at 75% of its September density.

The biomasses in the dredged channel were generally lower than the mudflats as would be expected from the lower densities of the numerically important species in the channel. The channel biomasses at the 1st Narrows and DeLanges were respectively approximately 50% and 66% lower than the adjacent mudflats in September, and a minimum of 80% lower than the mudflat biomasses in March (Fig. 5.5). The biomass in the dredged channel at Brodies was higher than the mudflat in September due to the presence of *S.cylindraceus*. This situation was reversed in March when *S.cylindraceus* was not recorded and the biomass in the channel was approximately 17% that of the mudflat.

5.3.2 Ordination of Species Densities

Ordination of the species densities from the 1st Narrows, DeLanges and Brodies Shallows in September 1989 and March 1990 showed an overall separation with regard to location (Fig. 5.6) and indicated a change in species densities and composition from the 1st Narrows to Brodies Shallows. The Brodies samples, apart from one channel sample identical to

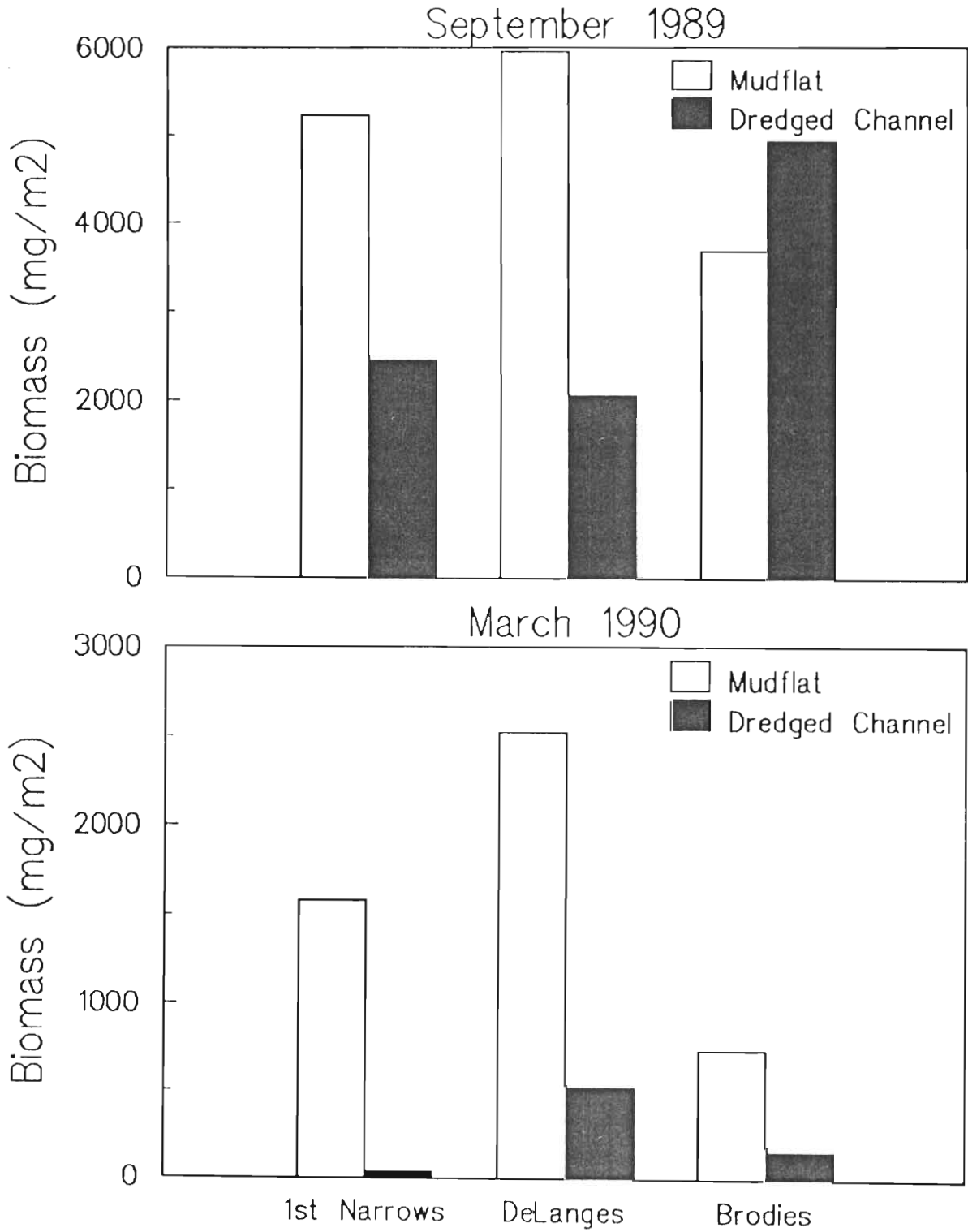


Fig. 5.5 Total biomasses of dredged channels and adjacent mudflats at the 1st Narrows, DeLanges and Brodies Shallows in September 1989 and March 1990.

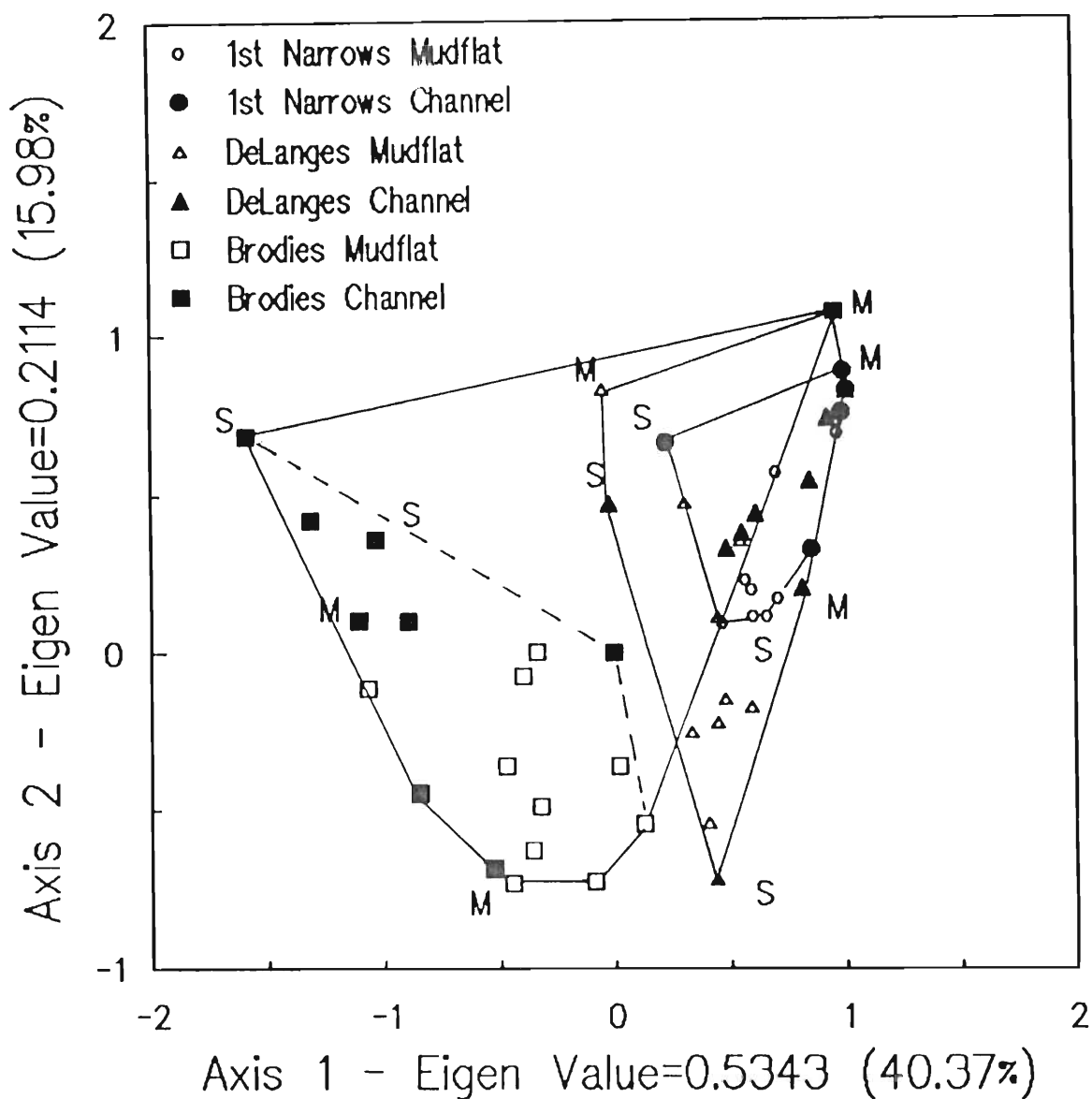


Fig. 5.6 Sample scores of the first two axes of the correspondence analysis of species densities from the mudflats and dredged channel at the 1st Narrows, DeLanges and Brodies Shallows in September 1989 (S) and March 1990 (M). Polygons outline the points from each location. The dotted line indicates the outline of the Brodies sample points excluding the one common point with DeLanges.

a DeLanges channel sample containing only *B.minuta* and *T.blephariskios*, were separated from the other locations in the ordination and showed the greatest variation in species density and composition. The 1st Narrows and DeLanges samples overlapped in the ordination with the DeLanges samples showing a greater variability than the 1st Narrows samples.

General trends within each location were evident with regard to time and the site (Fig. 5.6). September 1989 samples were generally separated from the March 1990 samples on Axis 1 indicating different species densities and composition at each location at the two sampling times. A general separation of mudflat and channel samples at each location is evident on Axis 2 of the ordination, indicating that the mudflats and dredged channels differed in species densities and composition in September and March.

The sample scores of the ordination revealed three broad groups of species varying independently of each other (Fig. 5.7). Of the numerically important species, *T.blephariskios* and *V.chilkensis* showed similar, but independent, degrees of variability in their densities. The coefficients of variation of *T.blephariskios* and *V.chilkensis* (Figs. 5.8 - 5.10) were higher in the dredged channel than on the mudflats at all three locations in September, and higher on

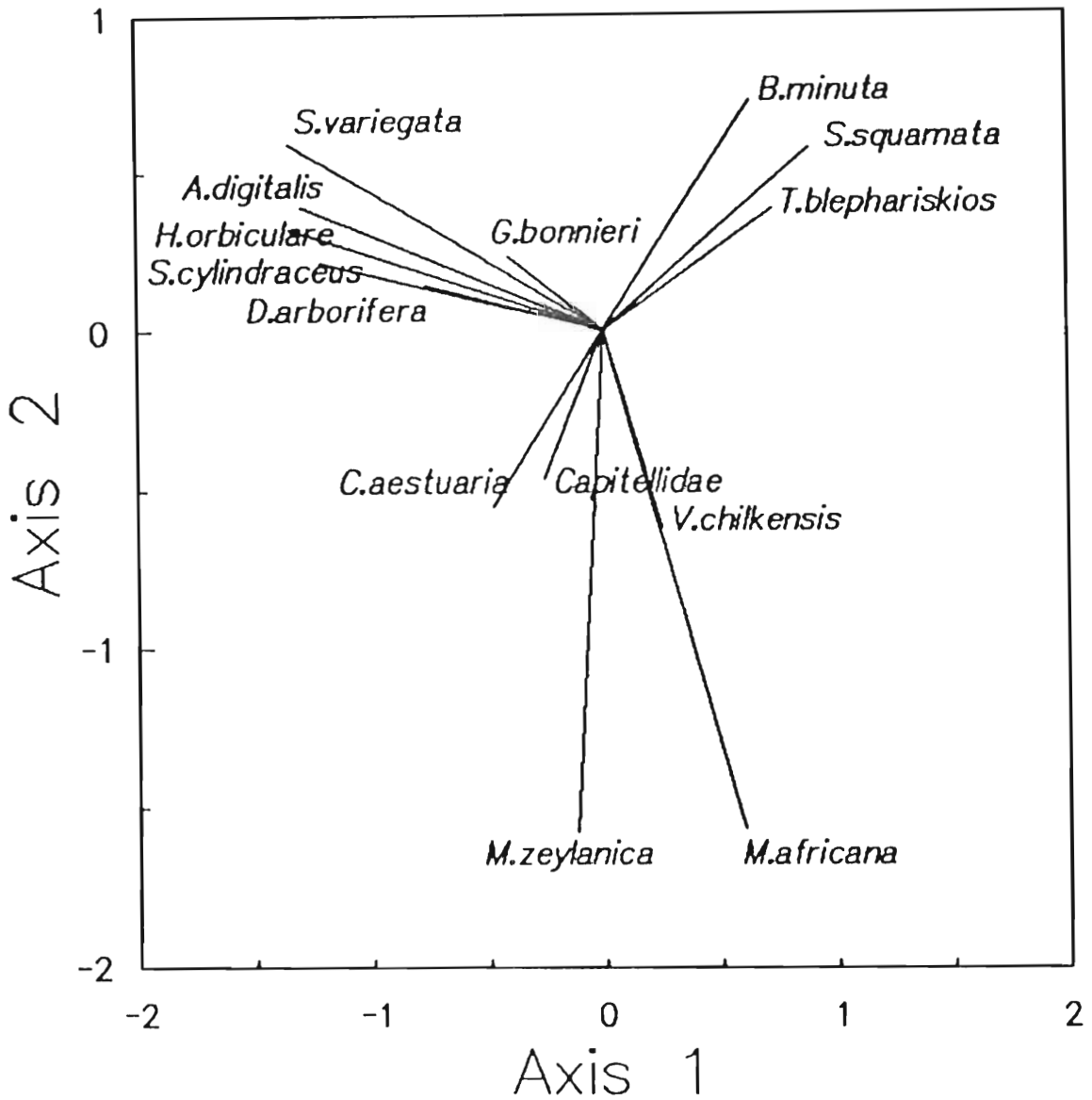


Fig. 5.7 Species scores of the first two axes of the correspondence analysis of species densities from the mudflats and dredged channel at the 1st Narrows, DeLanges and Brodies Shallows in September 1989 and March 1990.

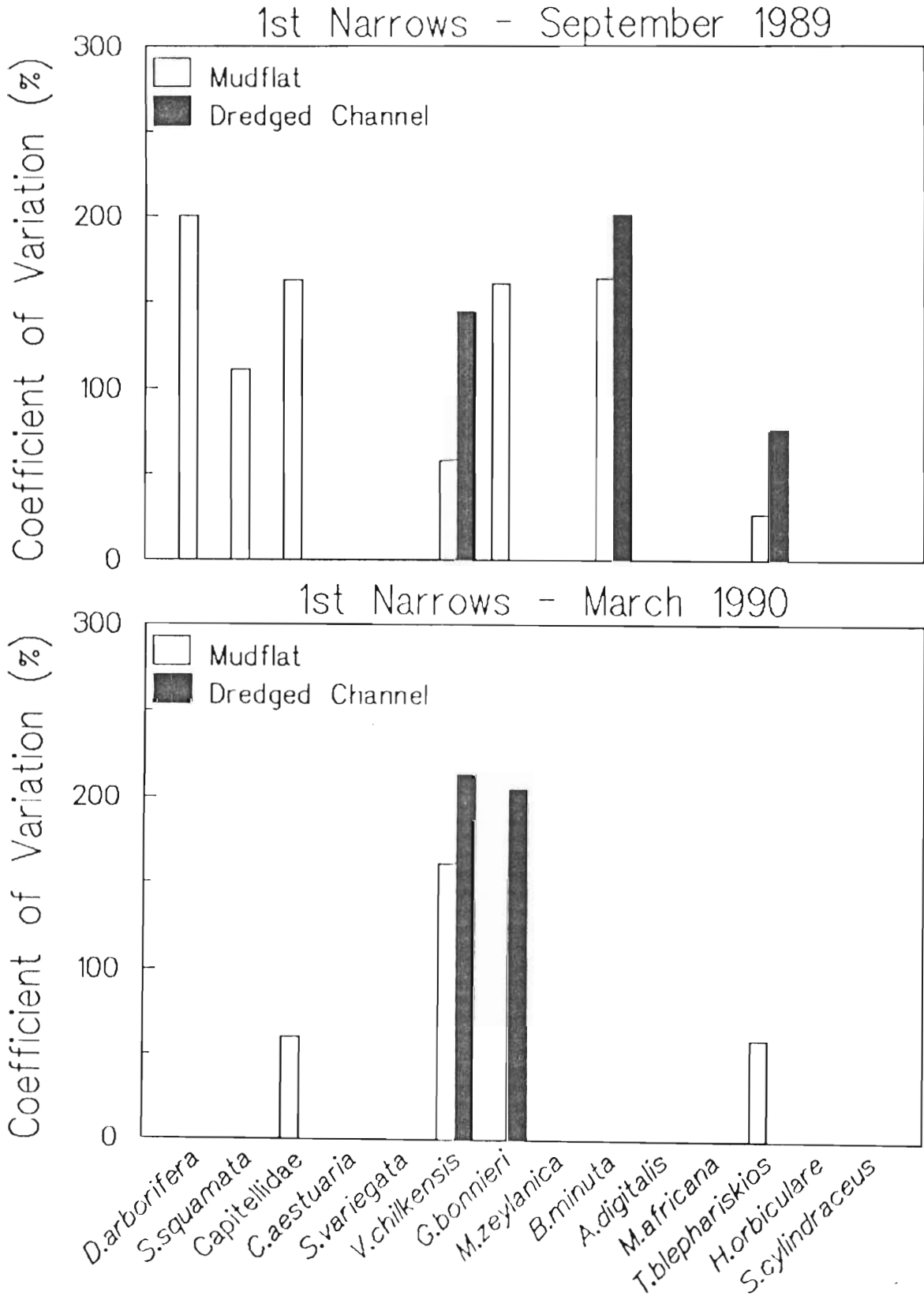


Fig. 5.8 Coefficients of variation of the species recorded from the mudflat and dredged channel at the 1st Narrows in September 1989 and March 1990.

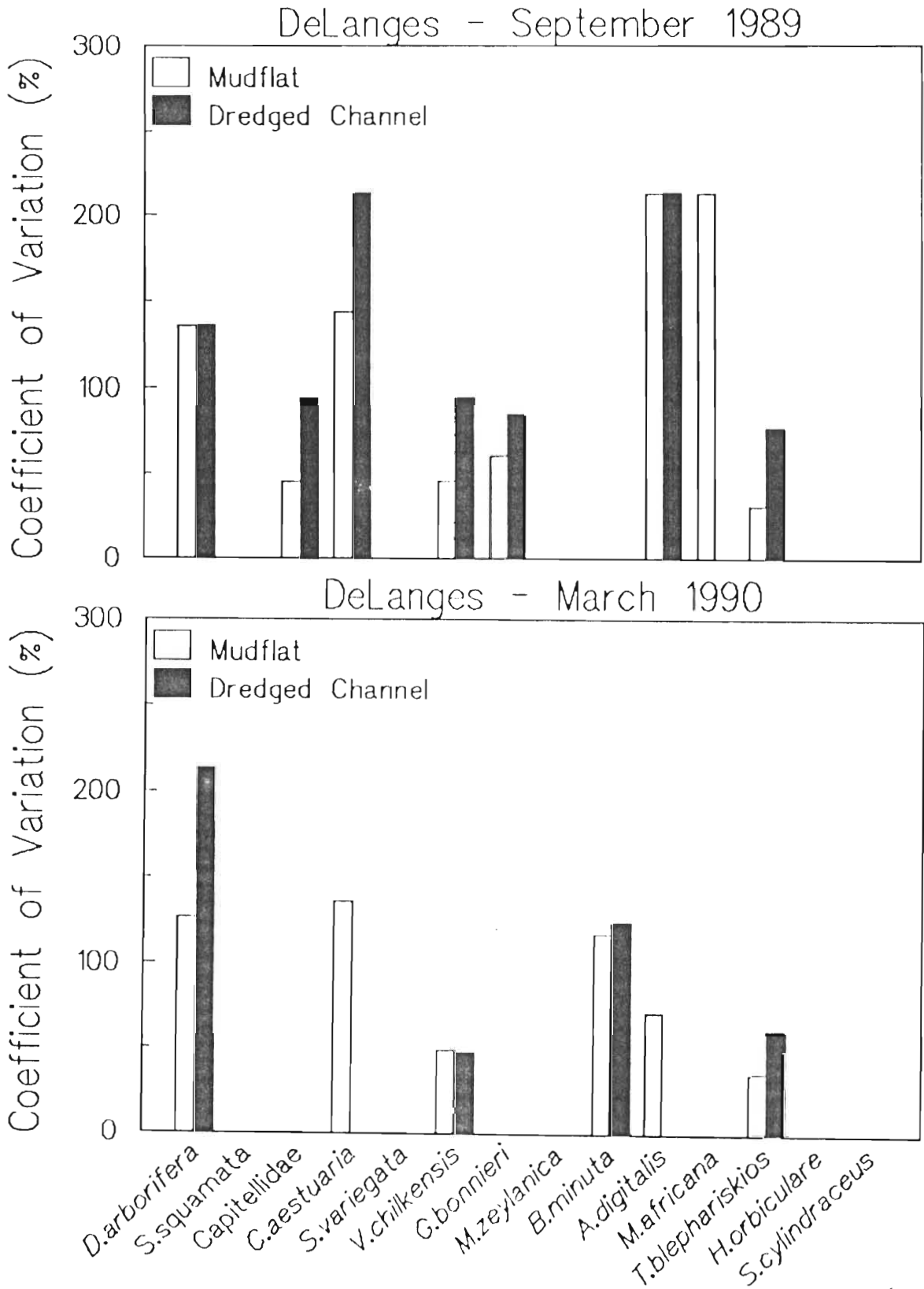


Fig. 5.9 Coefficients of variation of the species recorded from the mudflat and dredged channel at DeLanges in September 1989 and March 1990.

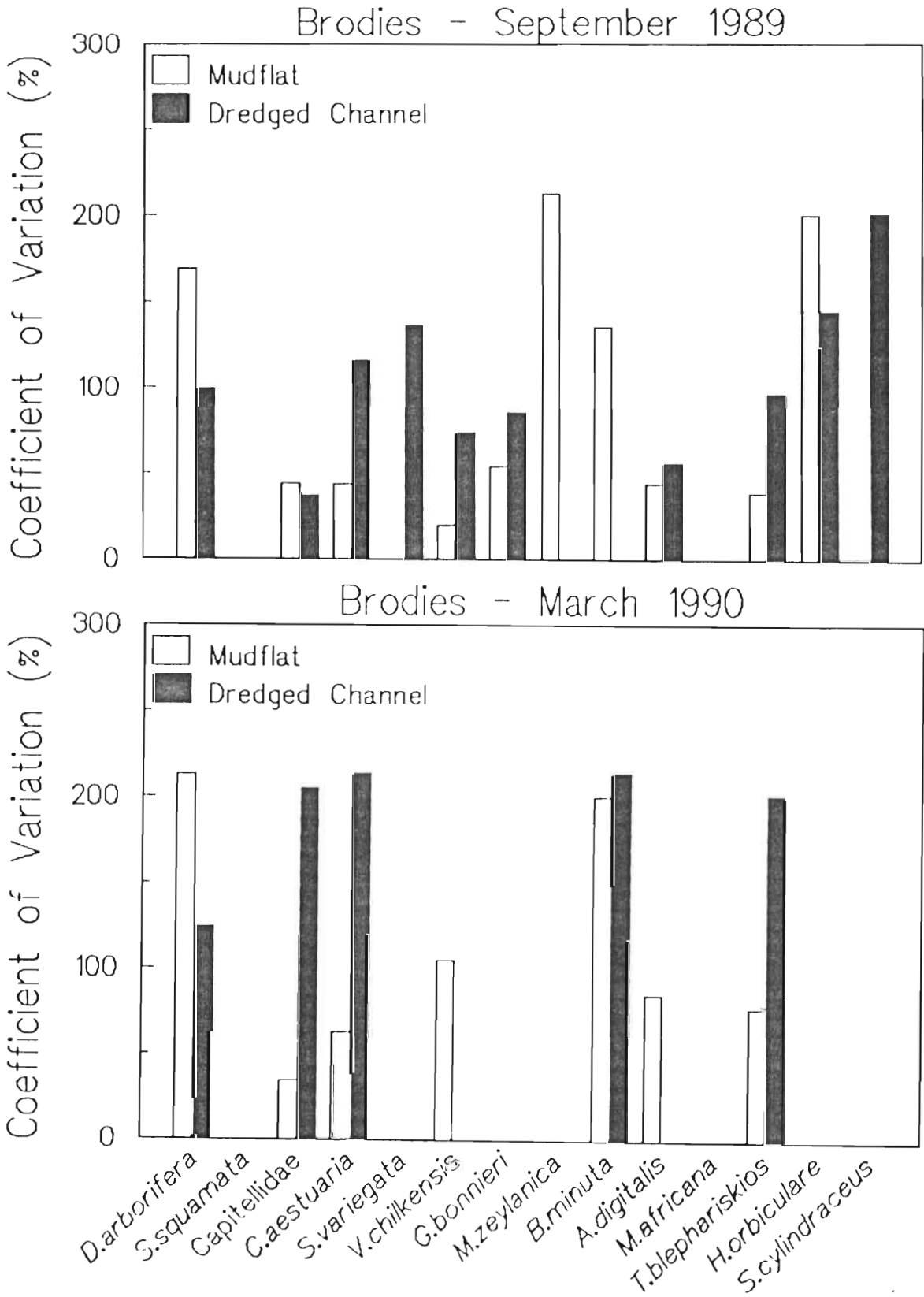


Fig. 5.10 Coefficients of variation of the species recorded from the mudflat and dredged channel at Brodies Shallows in September 1989 and March 1990.

the mudflats in September than the mudflats in March at the 1st Narrows and Brodies. Capitellids showed a similar variability in density to *T.blephariskios* and *V.chilkensis* in the ordination (Fig. 5.7) but were not recorded in the channel at the 1st Narrows and at DeLanges in March (Figs. 5.8 & 5.9). Their coefficient of variation was lower in March on the mudflat at the 1st Narrows in March compared with September (Fig. 5.7), which is opposed to the higher variability of *T.blephariskios* and *V.chilkensis* in March.

5.3.3 Salinity and Temperature

A decrease in salinities toward the Lakes was measured in September and is indicative of a normal salinity gradient (Table 5.1).

Table 5.1: Surface salinity (ppt.) and temperature (°C) data recorded at the 1st Narrows, DeLanges and Brodies Shallows stations in September 1989 and March 1990.

		SEPTEMBER	MARCH
1st Narrows	Salinity	28	0.5
	Temperature	19	28.5
DeLanges	Salinity	22	0.5
	Temperature	19	28.5
Brodies	Salinity	15	0.5
	Temperature	22	28.5

The drop in salinities at all stations in March followed increased Lake levels and a net outflow of fresh water after

heavy rains in November 1989. The approximately 10° temperature difference between September and March indicated two distinct seasons. While Brodies was notably warmer than the lower Narrows in September, the temperature was the same at the three stations in March.

5.3.4 Sediment Analysis

The generally muddy nature of the Narrows is evident from the relative mud and sand contents of substrata in the study area (Fig. 5.11). In September 1989, the dredged channel at the 1st Narrows showed a slightly higher sand content than the mudflat, while the dredged channel at Brodies was notably more sandy than the adjacent mudflat. The dredged channel at DeLanges however, was muddier than the adjacent mudflat. Although this overall pattern was similar in March 1990, the proportions of sand in the channel and mudflats at each station increased. This was particularly noticeable in the dredged channel at the 1st Narrows and Brodies, which became notably sandier than the adjacent mudflats.

The organic contents of the substrata were generally proportional to the mud contents (Fig. 5.11). Decreased organic contents in the dredged channels at the 1st Narrows and Brodies in March corresponded to the increased sand contents in these areas.

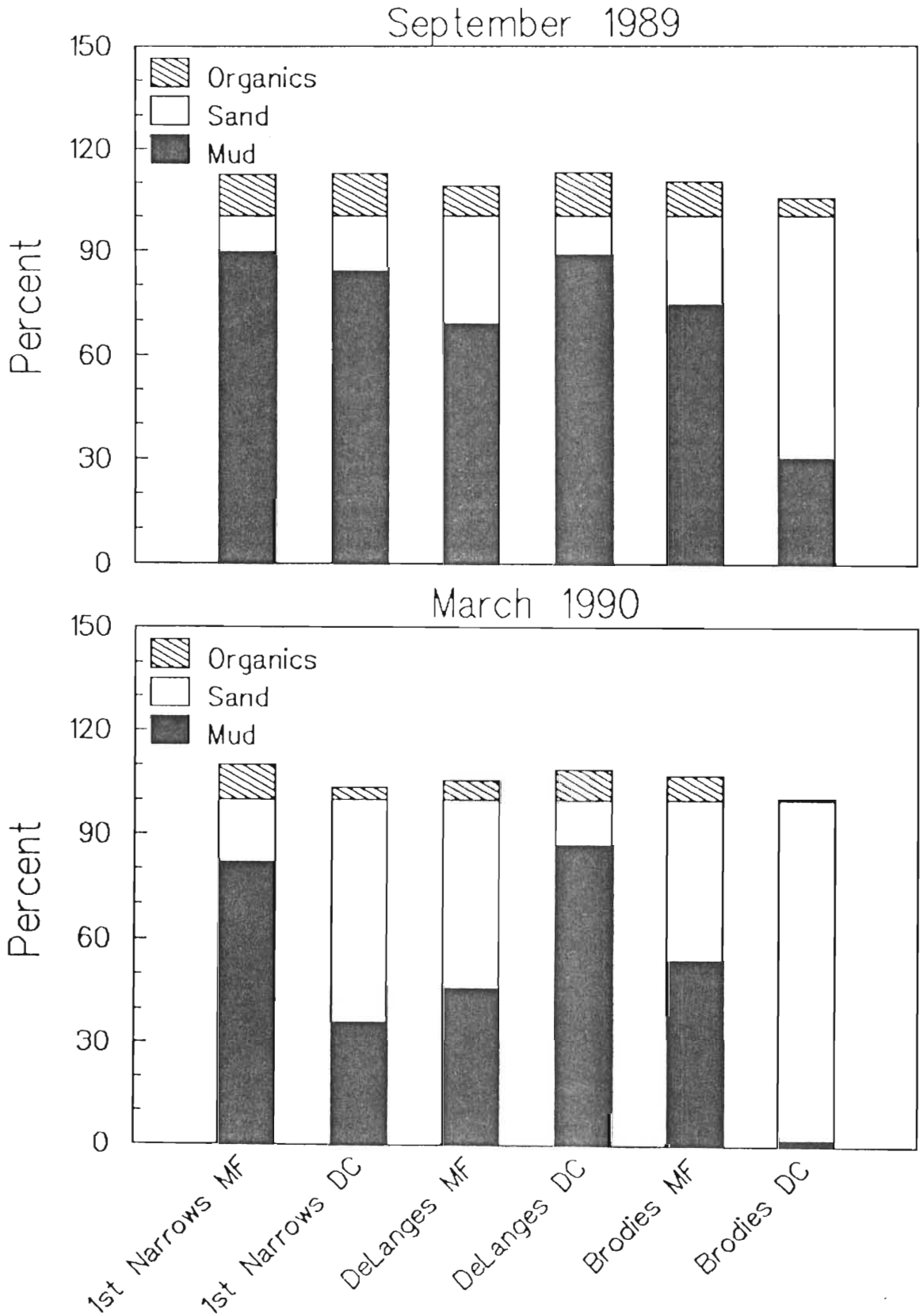


Fig. 5.11 Percentage mud, sand and organic content of substrata from dredged channels (DC) and adjacent mudflats (MF) at the 1st Narrows, DeLanges and Brodies Shallows in September 1989 and March 1990.

5.3.5 Current Velocities

Current velocities measured in September 1989 and March 1990 are given in Figs. 5.12 and 5.13. Lake levels were low in September but increased after heavy rains in November 1989, when the water level at Brodies Shallows rose by approximately 0.75 m.

Current velocities in the Narrows varied with lake level, position in the estuary and the state of the tides. Surface currents were generally faster than bottom currents in the dredged channel and bottom currents on the mudflats were generally slower than bottom currents in the channel.

Neap and spring ebb and flood tides were of approximately equal duration at the 1st Narrows and DeLanges in September compared with the predominantly ebb dominated currents at these stations in March. Differences between current velocities were evident in September and March. The fastest currents were recorded on the surface of the channel at the 1st Narrows during spring flood tides, measuring 0.75 ms^{-1} and 0.70 ms^{-1} in September and March respectively. Although the magnitude of these currents was similar, the duration of the flood tide in March was two hours less than in September.

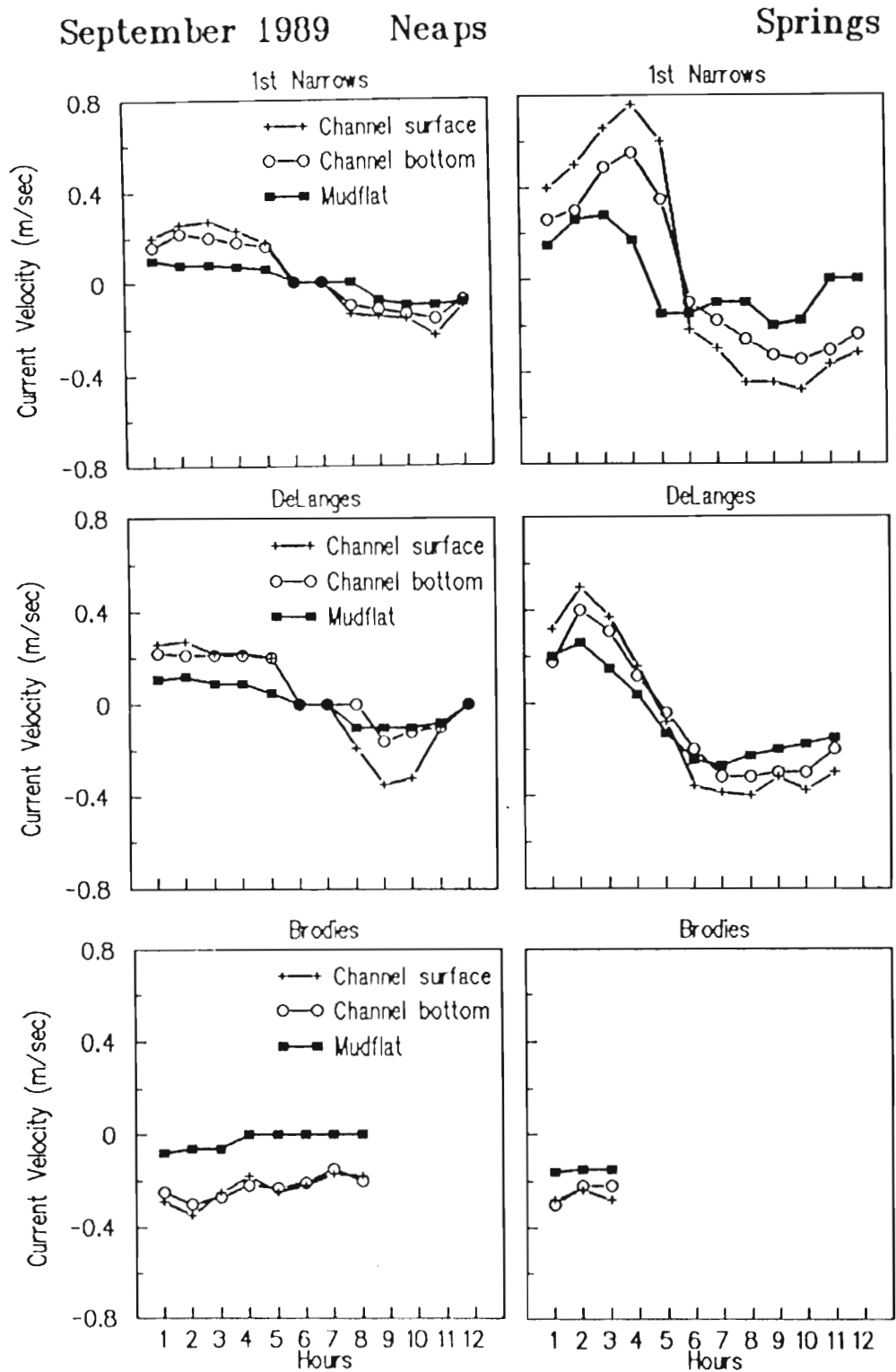


Fig. 5.12 Current velocities recorded in the dredged channel and over the adjacent mudflat at the 1st Narrows, DeLanges and Brodies Shallows at neap and spring tides in September 1989 (-ve values indicate ebb flow).

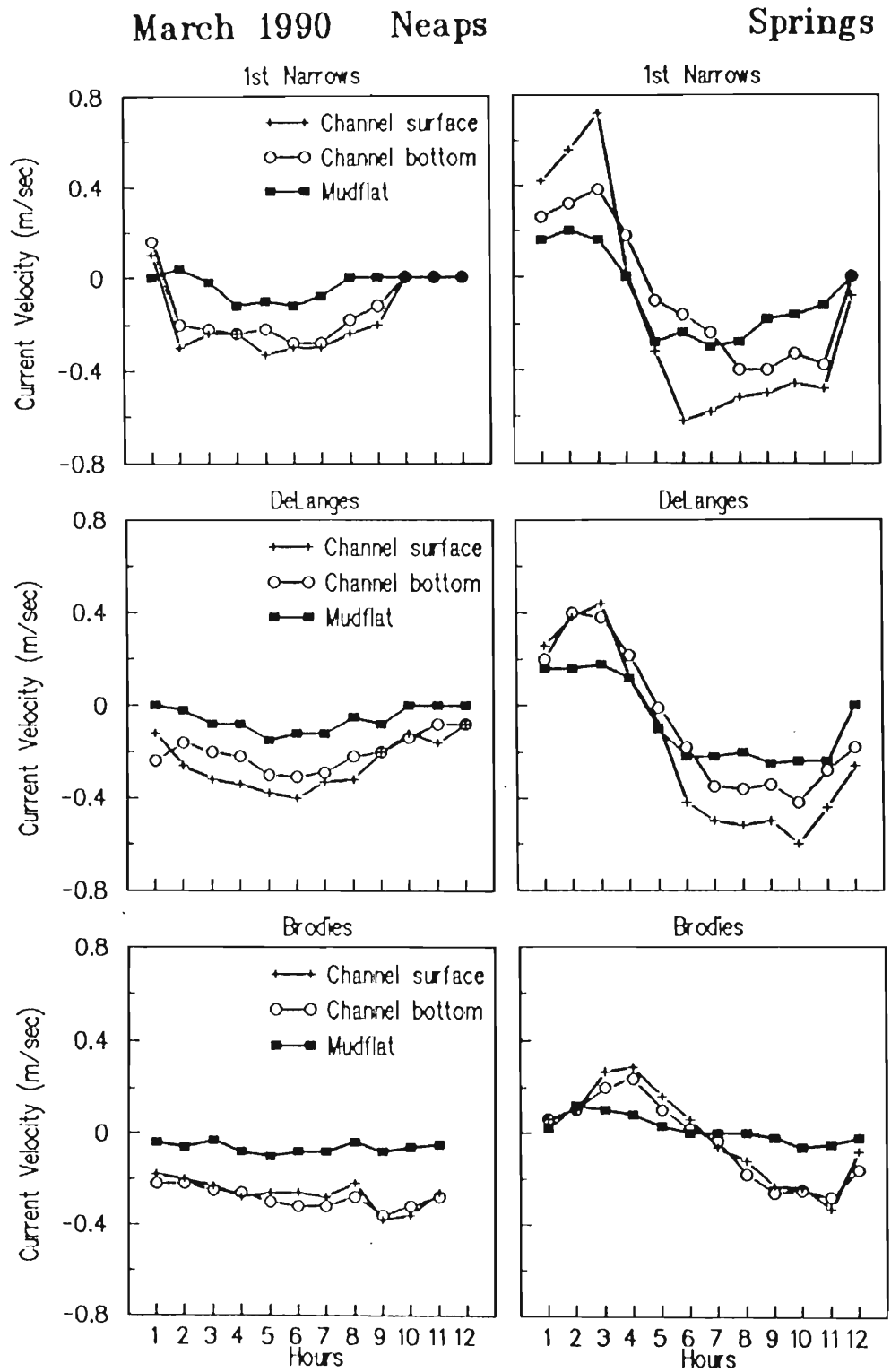


Fig. 5.13 Current velocities recorded in the dredged channel and over adjacent mudflats at the 1st Narrows, DeLanges and Brodies Shallows at neap and spring tides in March 1990 (-ve values indicate ebb flow).

Current velocities generally decreased with increasing distance from the mouth. Distinct ebb and flood currents were recorded at the 1st Narrows and DeLanges over the study period, except for the predominantly ebb currents at neap tide at DeLanges in March. Currents at Brodies Shallows were ebb dominated and did not appear to be directly influenced by tidal action. Flood current velocities were higher at the 1st Narrows than at DeLanges, with the difference being more marked over spring tides, when differences of approximately 0.3 ms^{-1} were recorded. Ebb currents were generally faster at DeLanges over neaps and faster at the 1st Narrows over springs, although these differences did not exceed 0.1 ms^{-1} .

The greatest differences between neap and spring tidal velocities were recorded during flood tides at the 1st Narrows, with differences of 0.5 ms^{-1} in channel surface velocities in September and March. The difference between neap and spring current velocities was less marked at DeLanges, with differences of approximately 0.2 ms^{-1} between flood and ebb tides. The predominantly ebb currents at Brodies were approximately equal in speed over neap and spring tides in September and March. The only flood current measured at Brodies occurred on the spring flood tide in March during strong south-westerly winds. North-easterly winds were recorded at Brodies during the other measuring periods.

Currents over the mudflats at the three stations were notably slower than bottom currents in the dredged channels. Current velocities over the mudflats at the 1st Narrows and DeLanges were approximately half the velocities of bottom currents in the dredged channels. Velocities over mudflats at these stations were approximately 0.1 ms^{-1} over neap tides, and between 0.2 ms^{-1} and 0.3 ms^{-1} over spring tides. Currents over the mudflat at Brodies were a half to two thirds slower than bottom currents in the channel and did not exceed 0.15 ms^{-1} .

5.3.6 The Link Canal

Five taxa were recorded in the Link Canal in April 1990 (Fig. 5.14), of which *T.blephariskios*, *M.africana* and capitellids were numerically dominant. Only adult *T.blephariskios* were found. The high sample standard deviations and coefficients of variation relative to their densities indicated that the distribution of these species was uneven. The biomass was dominated by *T.blephariskios* which made up approximately 95% of the total biomass of 2216 mgm^{-2} .

The mud content of the substratum in the Link Canal was 97%, and the organic content of the substratum was 9.4%.

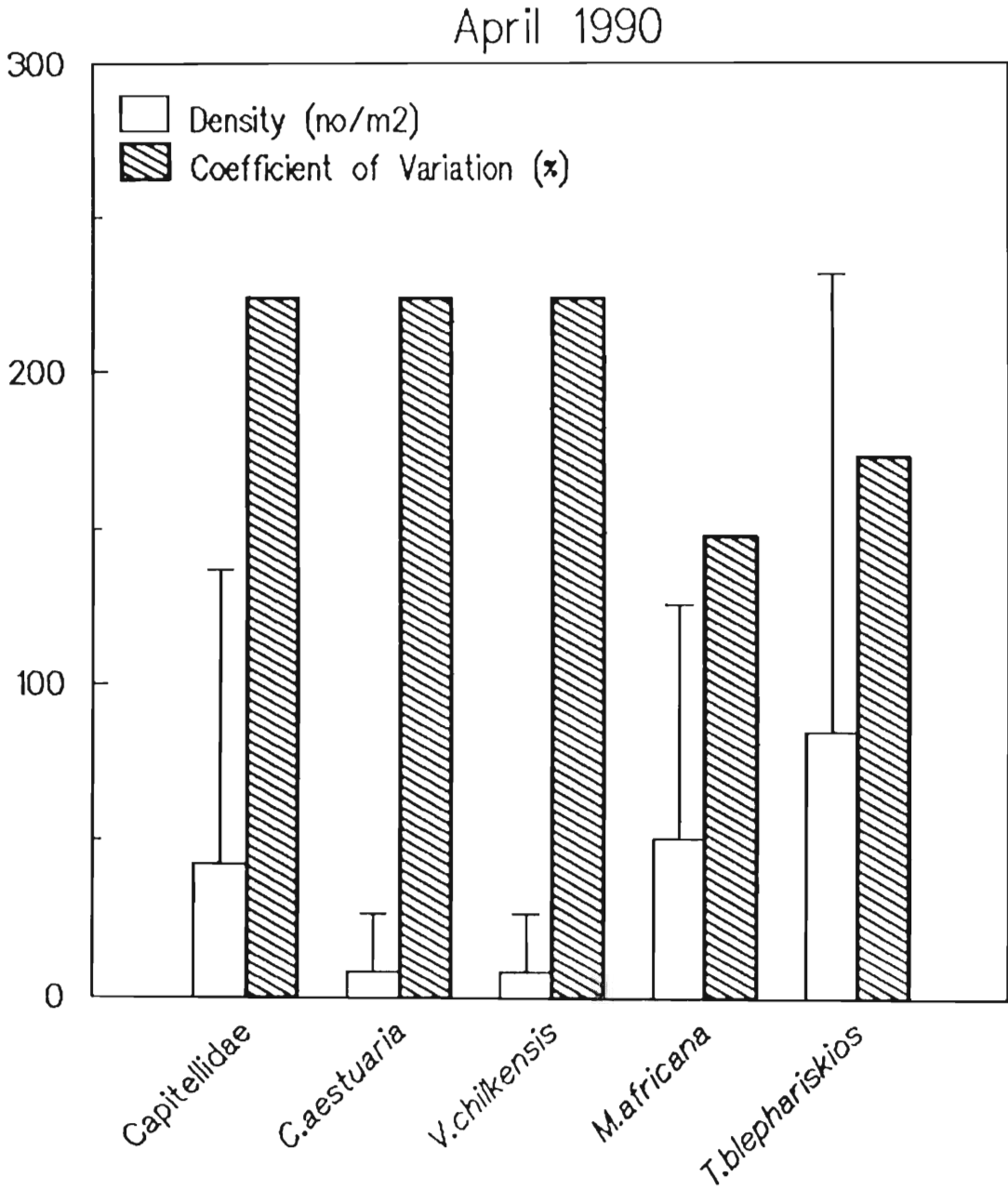


Fig. 5.14 Average densities, sample standard deviations and coefficients of variation of species recorded in the Link Canal in April 1990. (n=5)

5.4 Discussion

5.4.1 The Benthos in Dredged and Undredged Areas of the Narrows

The impoverished nature of the dredged channel compared with the mudflats at the 1st Narrows and DeLanges supported the indications of the pilot study that benthic communities in dredged channel in the Narrows have only partially recovered after 20 years. While the numerically dominant species on the mudflats were also dominant in the dredged channel, they occurred at densities approximately an order of magnitude lower than on the mudflats.

The apparent lack of recovery of the benthos in dredged areas of the Narrows contrasted with the period and extent of recovery of benthic organisms in dredged areas described in the literature. Reported periods of complete benthic recovery ranged from two weeks after maintenance dredging in Coos Bay, Oregon (McCauley, Parr and Hancock, 1977), to two years after large scale dredging operations in Botany Bay, Australia (Jones and Candy, 1981). Kaplan et al. (1974) however, reported that the benthic diversity, density and biomass in dredged channels of Goose Creek, New York, had not recovered to pre-dredging levels 11 months after dredging, although recolonisation by the errantid polychaete

Nereis succinea, the crab *Neopanope texana sayi* and small lamellibranch molluscs was evident within weeks. No difference between species diversity, density and biomass was evident in dredged and control areas six months after oyster shell dredging in Tampa Bay, Florida (Conner and Simon, 1979). Errant nereid and nephytid polychaetes were observed in the water column and, together with the brachyuran *Pinnixia sp.*, were present on the bottom of dredged areas 30 minutes after dredging. The decreased benthic diversity and abundance after dredging in the Dahwo River in South Carolina appeared to be short term (Van Dolah et al., 1984). The recovery of the dominant benthic species, including the polychaetes *Sabellaria vulgaris* and *Paraprionospio pinnata*, the decapod *Ogyrides limicola* and the bivalve *Mulinia lateralis*, was evident with similar or greater densities recorded in dredged areas three months after dredging. Full recovery to pre-dredging densities of the polychaete *Terebellides stroemi* and the amphipod *Grandidierella gilesi*, the two most common species in dredged areas of the Hawkesbury estuary, New South Wales, occurred within four weeks after dredging (Jones, 1986). They were found to recover at different rates however, with the polychaete recovering after two weeks and the amphipod after four weeks.

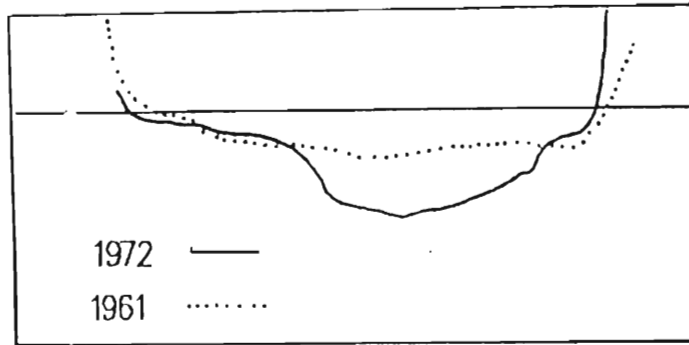
The incomplete recovery of the benthos in the Narrows is unusual compared with the complete recoveries within much

shorter periods described in the literature. The rate of benthic recovery in dredged areas depends on a number of factors, including the scale of dredging operations, the degree of slumping of channel walls and natural recruitment (Van Dolah *et al.*, 1984; Jones, 1986). The rapid recolonisation of the benthos, comprising mainly polychaetes, bivalves and amphipods, after small scale (by area) maintenance dredging in Coos Bay was ascribed to the proximity of dredged areas to undredged areas (McCauley *et al.*, 1977).

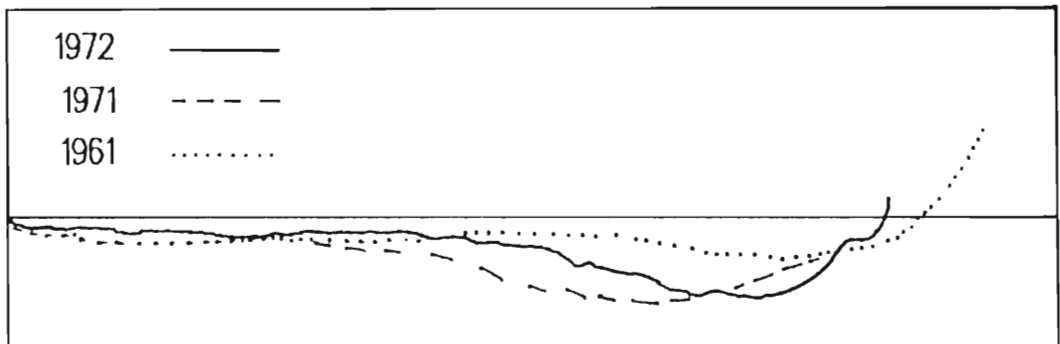
It is likely that colonisation of the new channels in the Narrows would have been mainly by transfer of benthic organisms from the adjacent mudflats through slumping of channel walls, and migration of epibenthic species. The degree of slumping that occurred is evident from transects surveyed in the Narrows at intervals before and after dredging (Fig. 5.15). Approximately half the channel at DeLanges had filled in from the mudflat over a period of 14 months, which would facilitate recolonisation of the channel within a relatively short period either by bringing in animals or restoring the habitat.

It would appear from this study that, following initial removal by the dredger, the benthos is primarily affected by the action of currents. Although the marked reduction in

1st Narrows (Section 9a)



DeLanges (Section 13)



Brodies (Section 19)

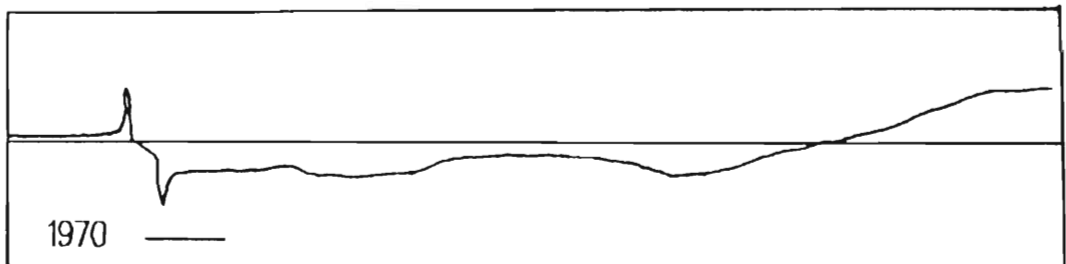


Fig. 5.15 Surveyed bottom profiles of the stations at the 1st Narrows, DeLanges and Brodies before, and at intervals after dredging. After Hutchison (1974).

species richness and densities between September and March occurred during a period of net freshwater outflow from the Lakes, the dredged channels were impoverished to a greater degree than the adjacent mudflats in March compared with September. This indicated that, while the reduction in salinity had an over-riding negative effect on the benthos, the channels were scoured to a greater extent than the mudflats. Increased current velocities may affect the benthos by direct removal and preventing the settling of larvae, or indirectly through modification of the substratum.

The creation of the dredged channel has reduced the standing benthic biomass in the Narrows. The dredged channel covers approximately 1.8 km², which comprises 45% of the total Narrows area of approximately 4 km². The average biomasses of the locations sampled (Fig. 5.5) show that the mudflats carried a biomass of 11 tons and 3.5 tons in September and March respectively. Similarly, dredged channels were calculated to carry 5.4 tons and 0.36 tons respectively in September and March. The total biomasses in the Narrows in September and March were thus 16.4 tons and 3.86 tons respectively. If it is assumed that the entire Narrows comprise undredged mudflats, the biomasses in September and March would be 20 tons and 6.4 tons respectively. These estimated biomasses indicate reductions due to the presence

of the dredged channel of 18% and 40% of the Narrows' potential carrying capacity in September and March respectively. It would appear that, on a percentage basis, dredging has generally reduced the standing benthic biomass in the Narrows by a minimum of approximately 20%.

5.4.2 Current and Sediment Characteristics in Dredged and Undredged Areas of the Narrows

The generally sandier nature of dredged channels compared with mudflats, and the increased sandiness of the substratum at all stations in the Narrows during the period of freshwater outflow from the Lakes, suggested that currents in the Narrows are an important factor in determining the nature of the substratum.

The approximate critical current velocities for movement of sediment particles are shown in Hjulstrom's diagram (Fig. 5.16). This indicates that the maximum current velocities of $0.25-0.75 \text{ ms}^{-1}$ recorded in the channels were capable of transporting the full range of particle sizes that constituted the substrata in these channels. Current velocities on the mudflats did not exceed 0.15 ms^{-1} and, according to Hjulstrom's diagram, were not capable of transporting mud or sand particles. The current velocities recorded in the channels however, would be capable of

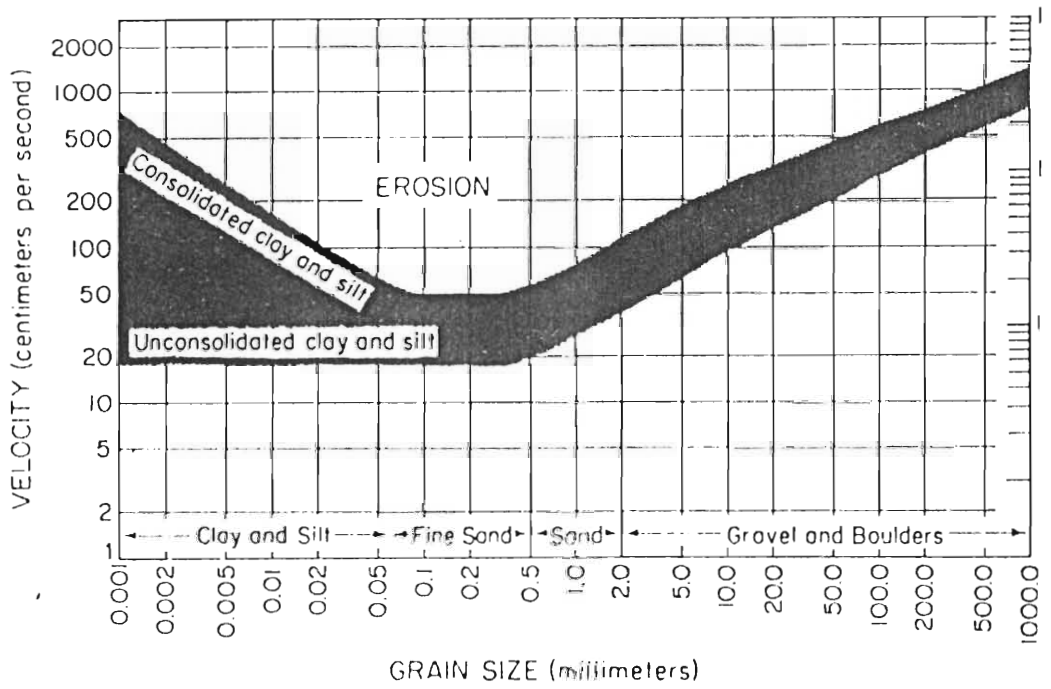


Fig. 5.16 Hjulstrom's Diagram, giving the critical velocity for movement of quartz grains on a plane bed at a water depth of one metre. The shaded area indicates the scatter of experimental data. There are very few reliable data in the clay and silt region. After Blatt, Middleton and Murray (1972).

eroding the substratum and appear to maintain the configuration and relative sandiness of the channels.

The muddier nature of the dredged channel at DeLanges compared with the channel at the 1st Narrows and Brodies correlated with the slower tidal current velocities recorded at DeLanges and exhibited the typical gradation of sediments associated with currents in estuaries, with the middle reaches having the finest sediments (Reid and Wood, 1976). The dredged channel at DeLanges was notably wider than at the 1st Narrows in 1972 (Fig. 5.15), and together with the reduced tidal action recorded at DeLanges, would explain its muddier nature. The sandier nature of the mudflat compared with the channel at DeLanges at both sampling times is atypical however, and probably reflects the patchy nature of the substratum on mudflats in the Narrows.

Changes in the substratum from muddy to sandy in dredged areas of Goose Creek, New York occurred following increased current velocities of up to 0.2 ms^{-1} (Kaplan et al., 1975). Kaplan et al. (1975) predicted that these currents would prevent the redeposition of clay and silt particles to form the original sediment composition. The organic content of substrata in channels exposed to stronger currents through dredging (Morton, 1977) was found to be low. Deepening and widening existing channels in Goose Creek was found to cause

a 50% reduction in current velocity and a change in the nature of the substratum from sandy to muddy. The increased deposition of fine particulate matter in dredged channels in Botany Bay was primarily due to decreased current velocities (Jones, 1981).

Natural channels in the Narrows were evident from the surveyed transects prior to dredging at the 1st Narrows and DeLanges (Fig. 5.15). These channels were approximately half the width and 80% shallower than the dredged channel. Water flow in the Narrows would have been spread over a much wider area prior to dredging, with lower current velocities resulting in increased sediment deposition. It would appear that the dredged channel has focused currents in the Narrows and that the scouring action of these currents prevents the re-establishment of the original substratum.

The nature of the substratum in an estuary is dependent on the interaction of sediment erosion, transport and deposition (McCauley et al., 1977). These processes are affected by the nature of the currents within the estuary, and determine the distribution and organic content of sediments. Erosional, transitional and depositional periods, and their effects on the substratum have been quantified in a deep-sea environment off Nova Scotia (Aller, 1989). "Benthic storms" (Aller, 1989) were recorded at intervals of

approximately three weeks and lasted approximately two days, during which bottom currents up to 0.25 ms^{-1} were measured at depths between 4815 m and 4830 m. These velocities are similar to those recorded on mudflats in the Narrows during this study, and the frequency of the 'storms' could be likened to spring tidal cycles. Deposition of sediments and settling of particulate organic matter from the surface in the deep study were found to occur when current velocities were less than 0.1 ms^{-1} . Transitional periods occurred when current velocities ranged from 0.1 ms^{-1} to 0.2 ms^{-1} , and were characterised by an influx of fresh organic matter, decreased fine particulate matter in the surface sediments and increased sand to silt ratios. Erosional periods were characterised by current velocities up to 0.25 ms^{-1} with erosion of organic matter from the surface layer and a further increase in sand to silt ratios. The tidal current velocities of up to 0.15 ms^{-1} recorded on mudflats in the Narrows correspond to the depositional and transitional currents described by Aller (1989), and would ensure a constant flux of fine sedimentary and organic matter.

The erosion of the substratum in the Narrows during the period of freshwater outflow from the Lakes could be expected to occur on an annual basis, corresponding to high Lake levels in summer. On the basis of this assumption, mudflats would be exposed to erosional currents once a year,

whereas the substratum in the dredged channel is exposed to erosional tidal bottom currents on a semi-diurnal basis. The lower frequency of occurrence of erosional currents on mudflats compared with the channel would permit the stabilisation of mudflats, whereas the frequent cycle of erosional currents in the channel would result in its continuous erosion and instability.

5.4.3 Relationships between the Benthos, Sediments and Currents in Dredged and Undredged Areas of the Narrows

The relation of current patterns to the distribution of benthic organisms, and their influence on the organic content and particle size distribution of the substratum have been well documented (Morton, 1977). The long term effects of dredging on benthos, apart from initial removal with dredge spoil, appear to be through modification of the substratum and the creation of an unfavourable habitat.

The general impoverishment of the dredged channel compared with mudflats in the Narrows appeared to be related to the increased sandiness of the substratum and increased current velocities in the channels. The impoverished nature of the dredged channel at DeLanges, in spite of being muddier than the adjacent mudflat, suggested that current velocities could have an independent influence on the benthos. While

increased current velocities would facilitate larval transport in the Narrows, the scouring action would tend to remove juveniles and prevent the settling of larvae.

While the species succession in the re-colonisation of the dredged channel in the Narrows is not known, it would appear that the long term re-colonisation of the channels in terms of species richness is complete. This is supported by the occurrence of the major species on the mudflats in the dredged channel. Although numerous studies in the literature have reported decreased species diversities and densities following changes in the nature of the substratum due to dredging, they focus on the recovery of the benthos immediately after dredging rather than the long term effects. These studies do however, emphasise the importance of substratum type in determining benthic distribution. A decrease in species diversity and density was noted in Goose Creek where the substratum was changed from sandy to muddy, and from muddy to sandy after dredging (Kaplan et al., 1975). Mobile polychaetes and crabs dominated the benthos in these altered substrata. Similarly, a marked decrease in species diversity was noted in areas of Botany Bay where the substratum had been changed from sandy to muddy through dredging (Jones and Candy, 1981), with polychaetes being abundant after dredging.

Many authors have found that the distribution of benthic organisms is determined primarily by the organic content of the substratum (Morton, 1977), and thus indirectly by the clay and silt (mud) content, and current action. The organic content of the substratum is generally proportional to the clay and silt content and will vary with the nature of the substratum. The generally decreased species densities at Brodies Shallows compared with the 1st Narrows and DeLanges appeared to be related to the sandier nature and lower organic content of the substratum at Brodies. Species densities were lower in the dredged channel at the 1st Narrows and DeLanges than on the mudflats even though the organic contents of the channels in September were similar and higher respectively than the adjacent mudflats. It would thus appear that the impoverishment of the channels is maintained through the direct action of currents.

The presence of benthos in the Link Canal in this study compared with the zero record in July 1983 (Hay, 1985) showed that the Link Canal had been colonised. The lower species densities in the Link Canal compared with the adjacent mudflat appeared to relate to the excessively muddy nature of the substratum. Although the densities of *T.blephariskios*, *V.chilkensis* and capitellids were an order of magnitude lower in the Link Canal than the mudflat, their presence suggested that they are pioneer benthic species

capable of inhabiting disturbed or 'new' habitats. The colonisation of the Link Canal is comparable to the colonisation of the artificial marina canals in the Kromme estuary (Baird et al., 1981) in that benthic species in estuaries are capable of colonising disturbed substrata and that artificial canals eventually become extensions of the estuary.

6.0 BEAM TRAWLING

6.1 Introduction

Few studies worldwide have examined the effects of beam trawling on benthic communities. Research into beam trawling operations has tended to focus on improving catches and protecting the fishery rather than addressing the effects of trawling on the benthos and the habitat (Somers, 1990). The scant literature which does address this problem has originated from the Australian prawn trawling industry (Hutchings, 1990) and bottom trawling in the North Sea (Bergman, Fonds, Hup, Lewis, van der Puyl, Stam and den Uyl, 1990).

A recent review of the effects of beam trawling on the epibenthos of the Australian trawling grounds cited removal in nets or damage by tickler chains as factors affecting sponges and corals (Hutchings, 1990). Although this review was mainly concerned with the effects of beam trawling on the epibenthos, isolated studies have investigated the fate of the by-catch, and the relationship between the benthos and the substratum in trawled areas. Crustaceans formed the major portion of the by-catch on trawlers in Moreton Bay, Australia, but the majority were reported to be returned alive to the sea. (Wassenberg and Hill, 1990). Prawn

trawling was found to decrease sediment stability on the central Great Barrier Reef and was cited as a contributory factor in maintaining infaunal species at a pioneering state of succession characteristic of disturbed substrata (Alongi, 1989). The infauna in these areas comprised burrowing amphipods and tube building polychaetes.

An investigation into the effects of beam trawling on the benthos of the southern North Sea showed that the densities of echinoderms and tube dwelling polychaetes were reduced by approximately 50% two weeks after trawling (Bergman et al., 1990). The densities of crustaceans, particularly cumaceans and amphipods, were reduced by approximately 10-25%. An increase in the density of the polychaete *Magelona papillicornis* was noted and was thought to be related to the movement of the polychaete closer to the surface of the substratum after trawling.

These Australian and North Sea investigations were recent and were prompted by concern for the possible impacts of increased trawling activities on the marine benthic environment. More attention in Australia has been focused on prawn breeding and nursery areas, and the conservation of species other than those which are commercially important (Somers, 1990). However, no literature was found on the effects of trawling on benthos in estuaries.

Beam trawling has formed the basis of a prawn bait fishery in the St. Lucia Narrows since the 1930's (Forbes, 1982), with annual prawn catches averaging 16.6 tonnes (Fielding, 1989). A 4.9 x 1 m beam trawl with a 25 mm stretch mesh net attached is trawled behind a boat powered by a 25 hp outboard motor. A maximum of three boats is used, depending on demand, and these operate on the mudflats in the Narrows. The propellers churn the substratum in shallow water and the wash drives the disturbed organisms into the net.

Although no conclusive evidence was found in the pilot study to indicate that beam trawling had an effect on the benthos, the effects of frequent trawling had not been investigated, or whether any effects would be apparent on different substrata in other areas of the Narrows. The distribution of the benthic species recorded in the pilot study suggested that the substratum was patchy and that this patchiness influenced the distribution of the benthos. Beam trawling could be altering the nature of the substratum and consequently having an indirect effect on the distribution of the benthos. It was thus considered necessary to investigate the possible effects of beam trawling on the substratum, as well as the effects of trawling on the benthos.

The objectives of this study on beam trawling and the macrobenthos were to:

1. determine the effects of different trawling frequencies on the benthos.
2. determine and compare the rates of benthic recovery after beam trawling under different trawling frequencies.
3. determine and compare the effects of beam trawling on the macrobenthos on different substrata in the Narrows.
4. determine and compare the effects of beam trawling on the substratum, and to relate any changes to benthic community structure in trawled and untrawled areas.
5. determine the extent of substratum variation in the study area, and the influence of this variation on the distribution of the benthos.

6.2 Materials and Methods

6.2.1 Study Area

Study sites were selected at DeLanges (Third Shallows) and Brodies Shallows to include variations in community structure and substratum type in the Narrows (Fig. 6.1). It was decided to duplicate the investigation at each location to establish whether the potential effects of trawling were reproducible at each location.

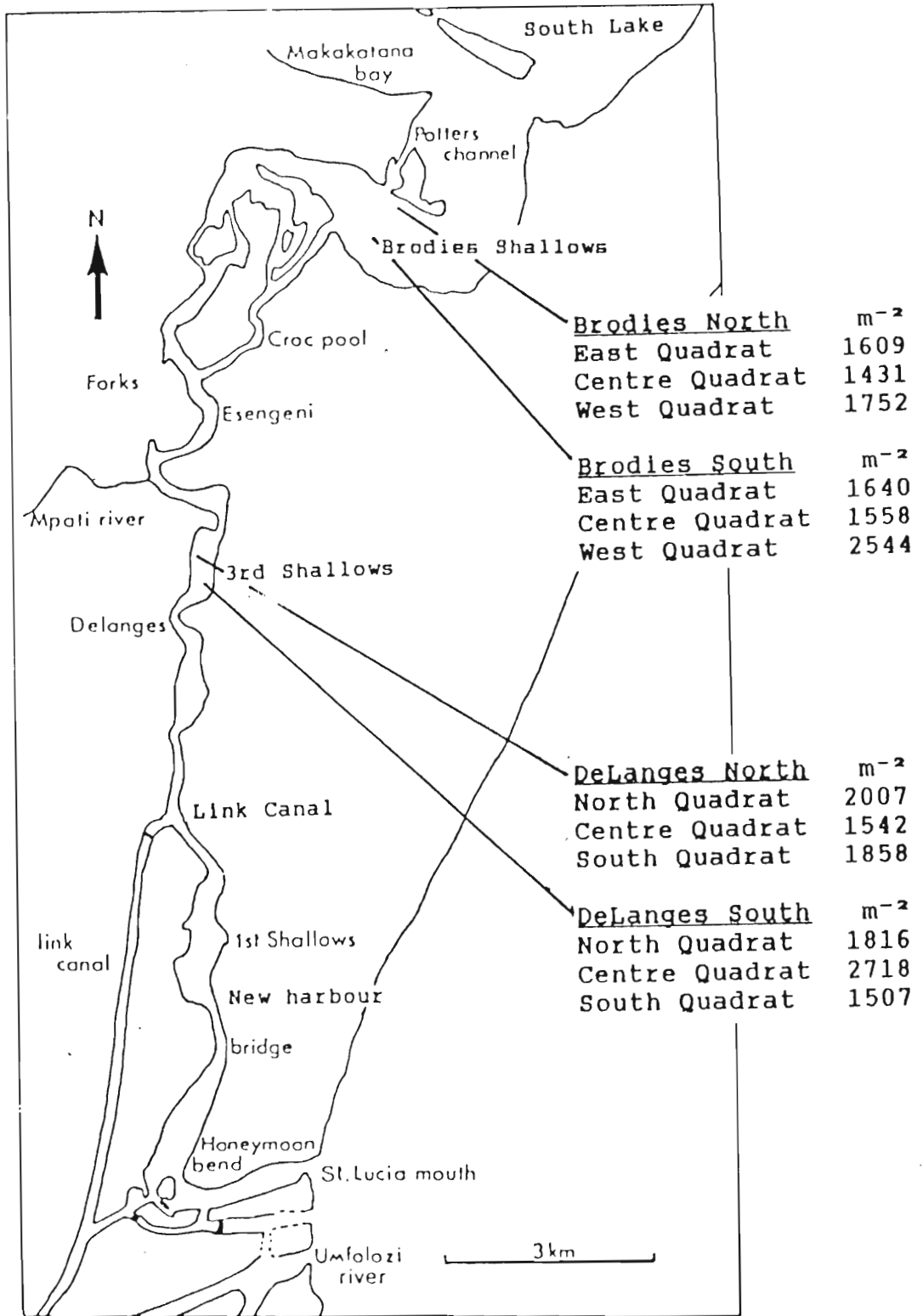


Fig. 6.1 Locations and areas (m²) of the trawled and control quadrats at Delanges and Brodies Shallows.

The areas were staked out in April 1989 and left 'fallow' until July to ensure that they were as undisturbed as possible before the initial grab sampling. The mudflat areas were selected on the basis of being subtidal and being accessible by boat.

The area used for the pilot study at DeLanges (DeLanges North) was retained for this study and a second area (DeLanges South) was staked out approximately 200m to the south of the original area (Fig. 6.1). Two areas (Brodies North and Brodies South) were staked out on the eastern section of Brodies Shallows (Fig. 6.1). Each area was subdivided into three quadrats, comprising control, monthly trawled and six-monthly trawled quadrats. The bait boat operators were asked not to trawl in the experimental areas.

6.2.2 Beam Trawling

The DeLanges North and South areas were each sub-divided into North, Centre and South quadrats, and the areas at Brodies Shallows sub-divided into East, Centre and West quadrats (Fig. 6.1). The north quadrats in the DeLanges North and South areas, and the east quadrats at Brodies were trawled once a month from July 1989 to June 1990. The centre quadrats in each area were used as a control and were not trawled. The south quadrats at DeLanges and the west

quadrats at Brodies were trawled in July 1989 and January 1990.

The quadrats, apart from the controls, were trawled for 30 minutes on each occasion using a 1 m wide beam trawl with a tickler chain attached. A 30 minute trawling period was decided on to allow all the quadrats to be trawled on the same day during high water. The 1 m wide trawl without a net attached was used after shallow conditions during the initial trawling caused difficulty in maneuvering the boat within the quadrats while trawling the larger net used in the pilot study. The net rapidly filled with mud making progress impossible. The justification for changing to the smaller beam trawl without the net was that the object of trawling was to disturb the substratum and that the benthic organisms pertinent to this study were small enough to pass through the net. Where trawling and sampling dates coincided, the quadrats were sampled first.

6.2.3 Grab Sampling

Five grab and one sediment sample were taken from each quadrat before trawling and then 5, 15, 30, 60, 90, 180, 270 and 360 days after the initial trawling in July 1989, ending in July 1990. The benthic samples were taken at each corner and in the approximate centre of each quadrat, while the

sediment samples were taken from the approximate centres of the quadrats on each occasion.

A series of three sediment samples, one at each end and one in the centre, was taken across each quadrat in July 1990 to determine the degree of substratum patchiness in each quadrat.

The surface salinity and temperature were recorded at each set of quadrats on each sampling occasion.

6.2.4 Data Analysis

Benthic Samples

The densities, sample standard deviations and coefficients of variation of the abundant species in the pilot study, *T.blephariskios*, *V.chilkensis* and capitellid polychaetes, were calculated for each quadrat over the study period.

The average densities of all species recorded in each quadrat at each sampling date were subjected to GENSTAT-5 correspondence analysis. Sample scores of the first two axes were plotted for the DeLanges North, DeLanges South, Brodies North and Brodies South trawled and control quadrats. The ordination was interpreted on the basis of time and

frequency of trawling. Species scores of the first two axes of the ordination were plotted to determine the variability of species densities in the trawled and control quadrats, and were interpreted in conjunction with the coefficients of variation of the abundant species.

The counts of *T.blephariskios*, *V.chilkensis* and capitellids over the study period in the control quadrats were separately compared with the adjacent monthly and 6-monthly trawled quadrats using the STATGRAPHICS Mann-Whitney non-parametric comparison of two samples. The numbers of each species in the control and trawled quadrats were considered to be significantly different if the probability of equalling or exceeding the large test statistic was less than 0.05. Simple linear and exponential regression analyses were carried out on the counts of the species in the quadrats determined to be significantly different by the Mann-Whitney test. If the ranges of the slopes of the best fit lines for a species in both quadrats did not overlap, the numbers of that species were taken to be increasing or decreasing independently in the two quadrats over the study period.

Sediment Samples

The percent composition of mud and sand, and organic matter was determined for each sediment sample and compared using stacked histograms.

6.3 Results

6.3.1 Species Densities in Trawled and Control Quadrats

T.blephariskios, *V.chilkensis* and capitellid polychaetes, as in the pilot study, were consistently the most abundant species in this study. However, higher densities of the tanaid *A.digitalis* were recorded in all quadrats at the last sampling date (360 days) than previously. Their densities generally increased by an order of magnitude to approximately 1000 per m² in the DeLanges quadrats, and to approximately 20 000 per m² in the Brodies quadrats.

No clear trends were evident in the densities of *T.blephariskios*, *V.chilkensis* and capitellids in the monthly or six-monthly trawled quadrats compared with the control quadrats over the study period (Figs. 6.2 - 6.7). Differences between the densities of these species in the monthly and six-monthly trawled quadrats, and the adjacent control quadrats were not consistent.

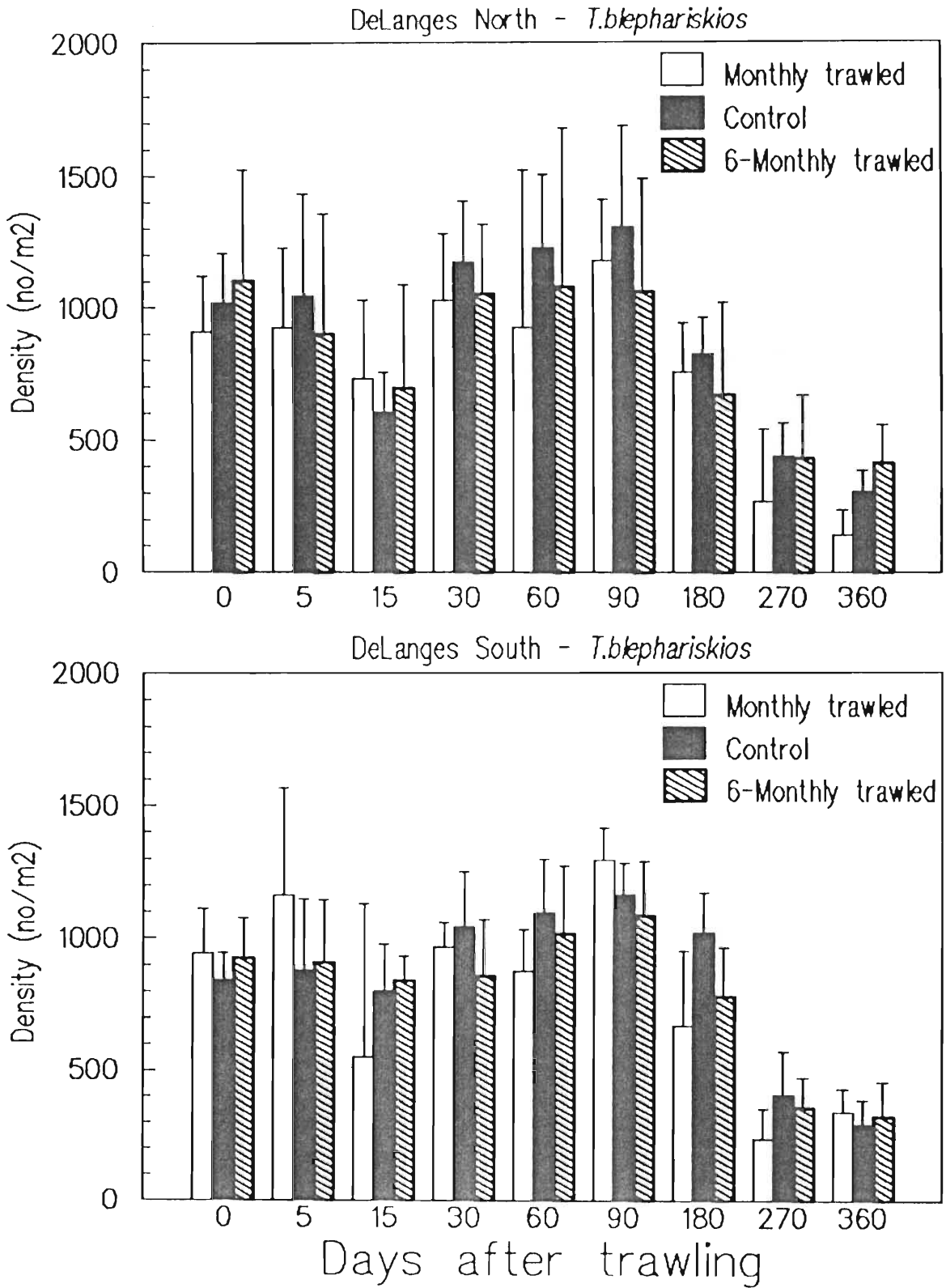


Fig. 6.2 Average densities and sample standard deviations of *T.blephariskios* recorded in the DeLanges North and DeLanges South quadrats from July 1989 to July 1990. (n=5)

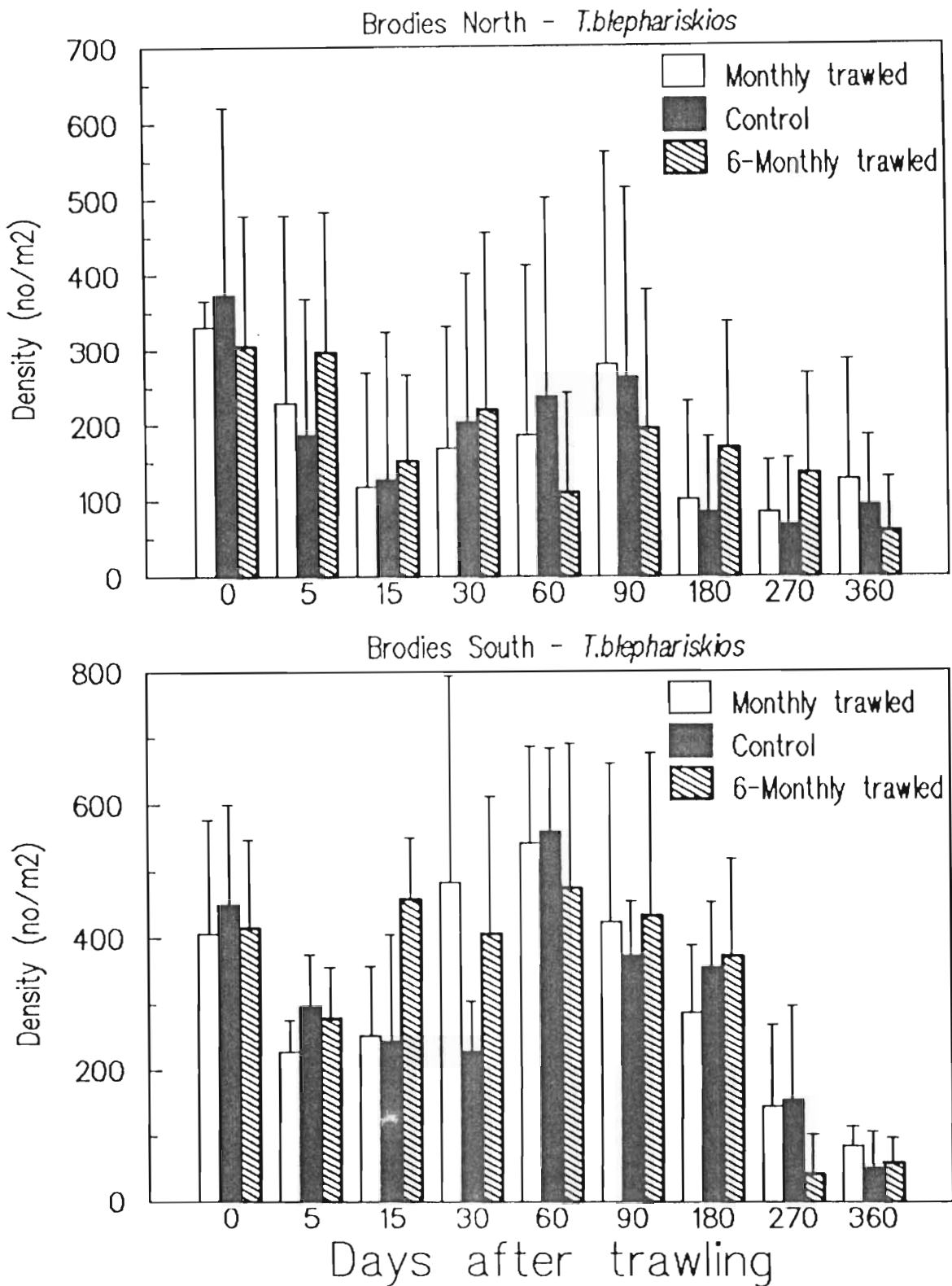


Fig. 6.3 Average densities and sample standard deviations of *T.blephariskios* recorded in the Brodie's North and Brodie's South quadrats from July 1989 to July 1990. (n=5)

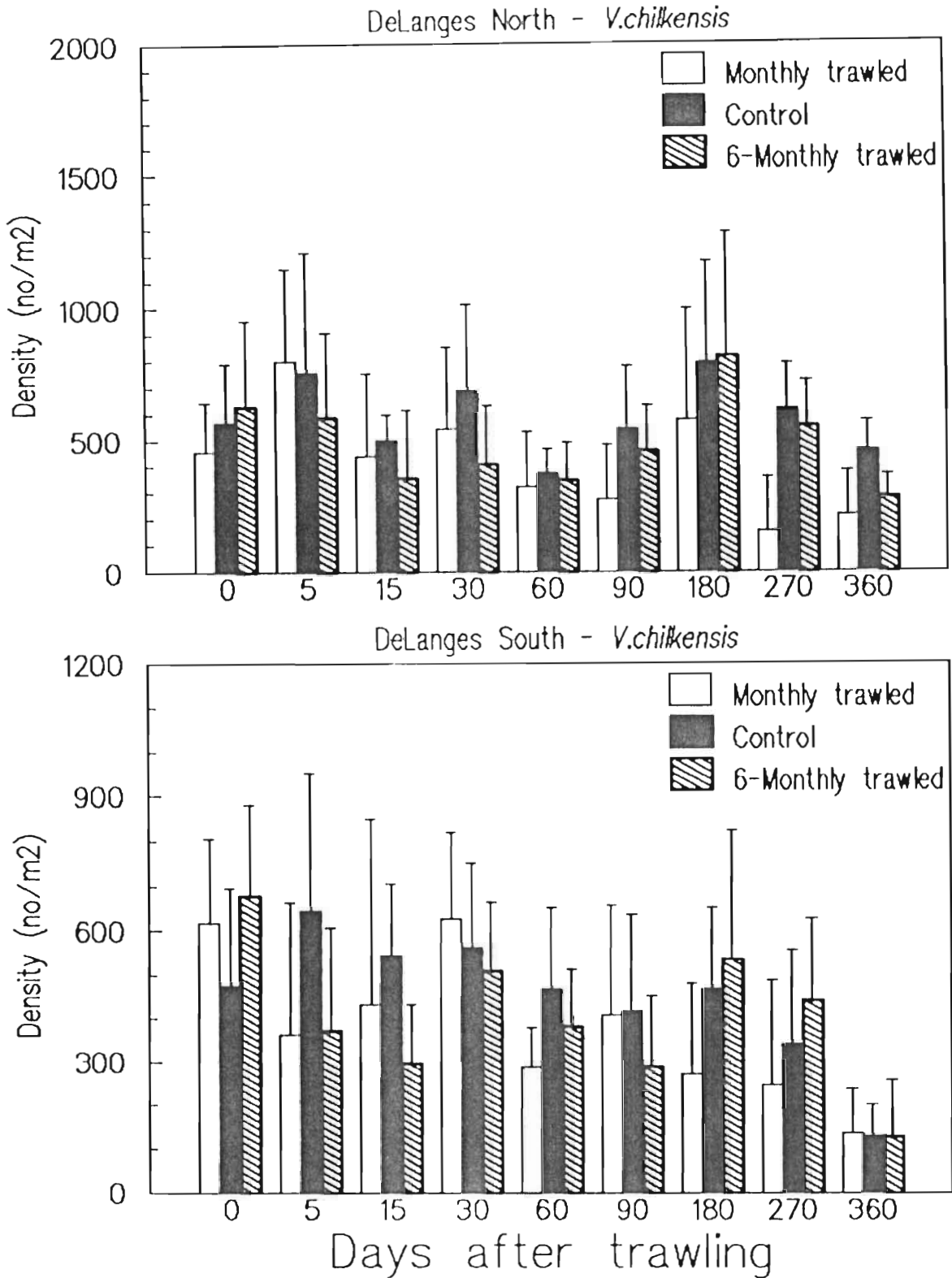


Fig. 6.4 Average densities and sample standard deviations of *V. chilensis* recorded in the DeLanges North and DeLanges South quadrats from July 1989 to July 1990. (n=5)

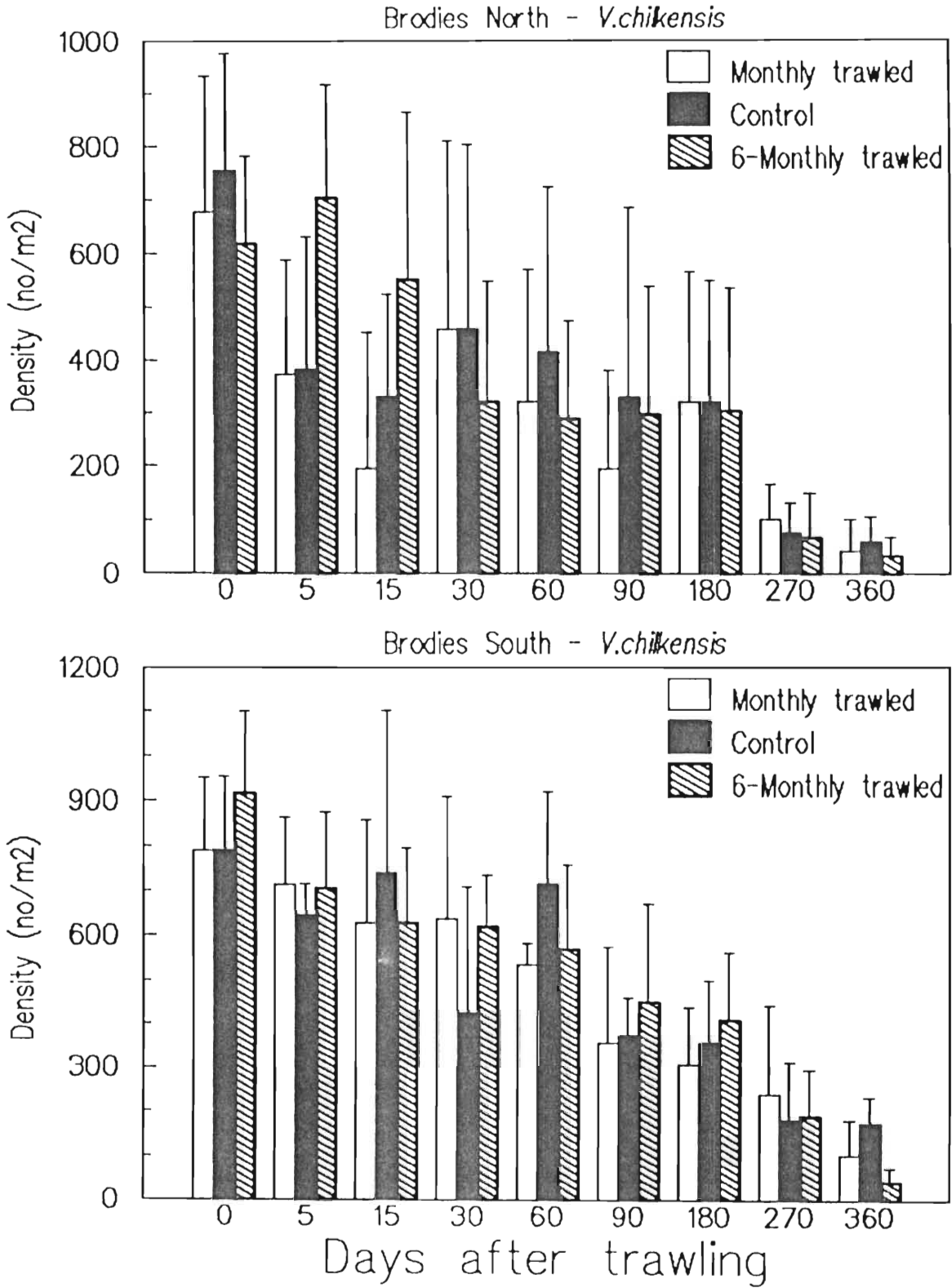


Fig. 6.5 Average densities and sample standard deviations of *V.chilkensis* recorded in the Brodies North and Brodies South quadrats from July 1989 to July 1990. (n=5)

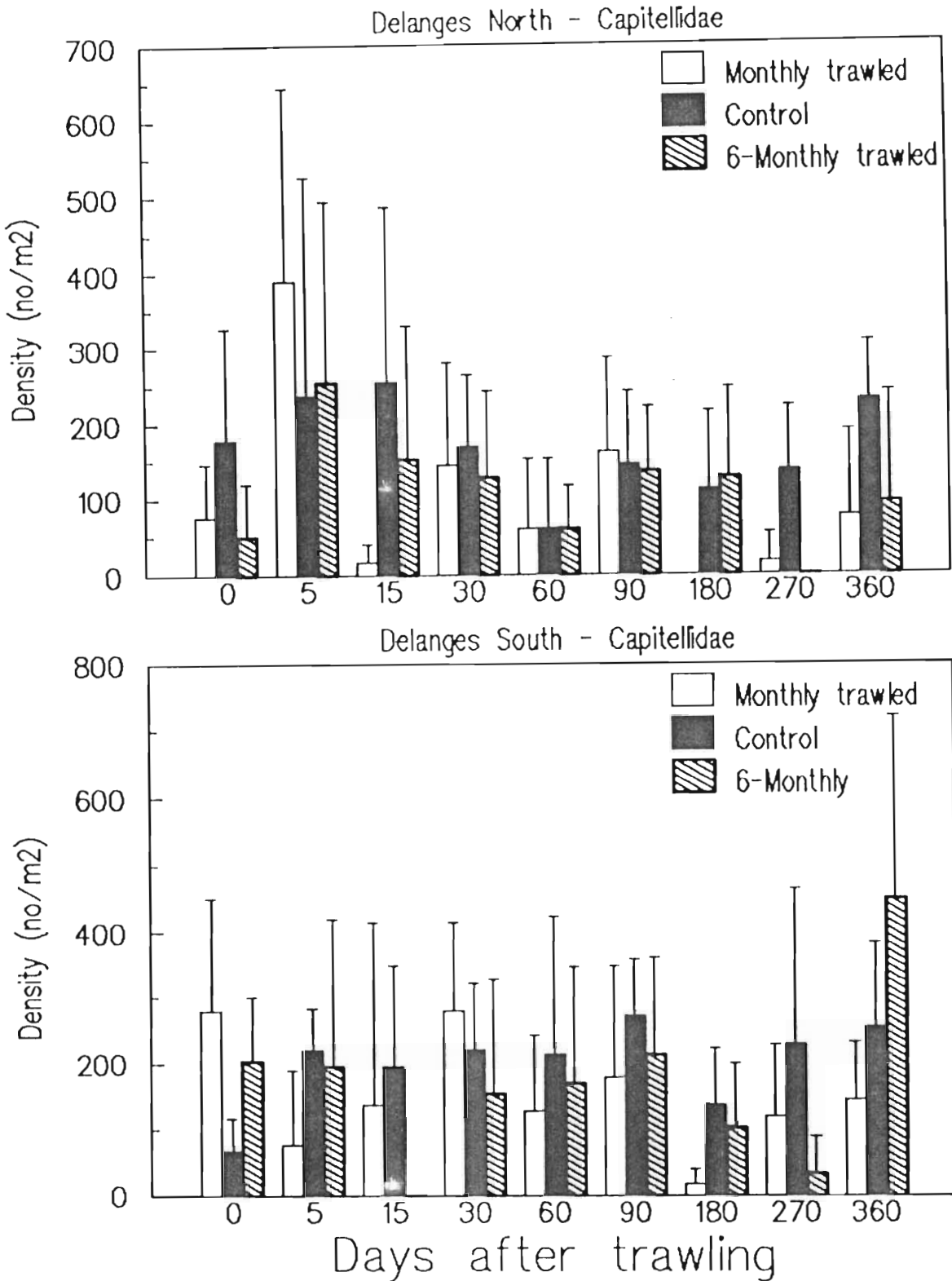


Fig. 6.6 Average densities and sample standard deviations of Capitellidae recorded in the DeLanges North and DeLanges South quadrats from July 1989 to July 1990. (n=5)

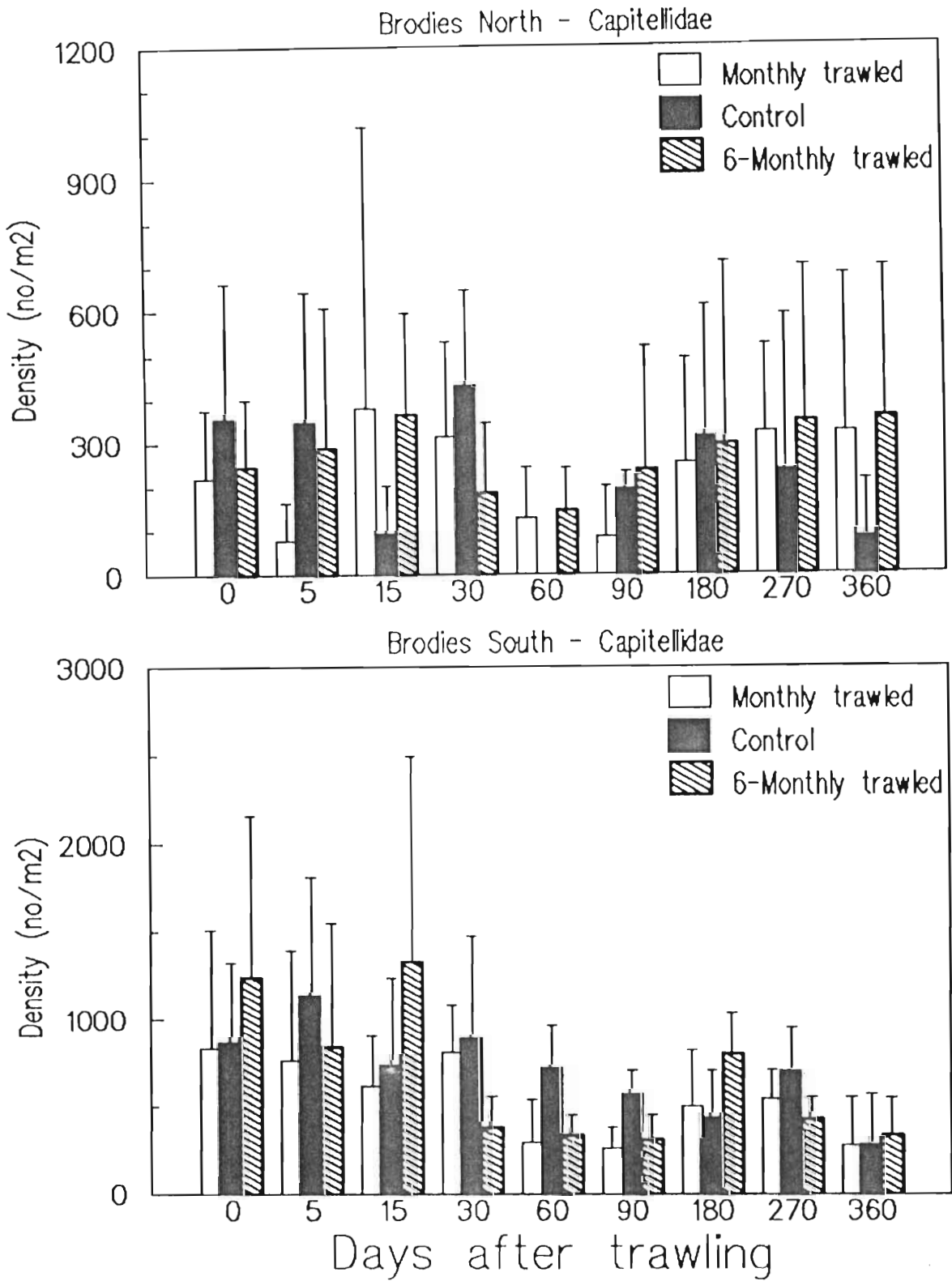


Fig. 6.7 Average densities and sample standard deviations of Capitellidae recorded in the Brodiess North and Brodiess South quadrats from July 1989 to July 1990. (n=5)

The densities of *T.blephariskios* and *V.chilkensis* in all quadrats decreased markedly between October 1989 and July 1990, i.e. between 90 and 180 days after trawling (Figs. 6.2 - 6.5). This trend was not evident in the capitellid densities (Figs. 6.6 & 6.7), which fluctuated erratically in each quadrat over the study period.

6.3.2 Ordination of Species Densities

No separation of trawled and control quadrats at DeLanges or Brodies was evident from the ordination, which suggested that trawling did not have an effect on the benthos (Figs. 6.8 - 6.11). The high Eigen value of the first axis of the ordination indicated a significant separation of species densities with time in all quadrats due to the high densities of *A.digitalis*, and generally decreased densities of *V.chilkensis* in the Brodies North and Brodies South quadrats towards the end of the study period. The separation of points on the second axis was caused by the decreased densities of *T.blephariskios* in all quadrats at the end of the study period, and the decrease of capitellids in the Brodies quadrats.

The inverse relationship between *A.digitalis* and the other abundant species in the ordination is evident from

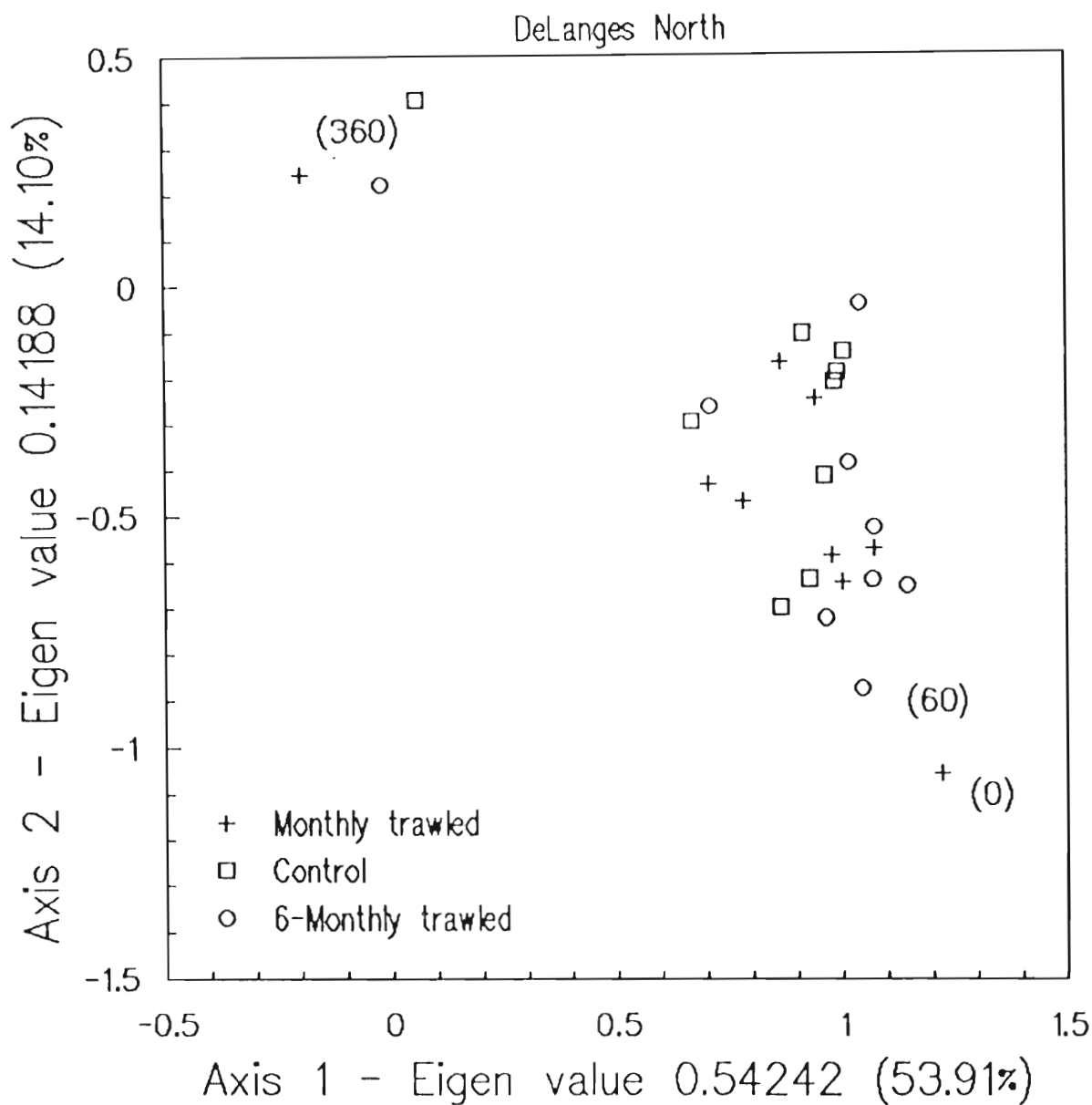


Fig. 6.8 Sample scores of the first two axes of the correspondence analysis of the species densities in the DeLanges North quadrats between July 1989 and July 1990. Labelled points indicate days after trawling.

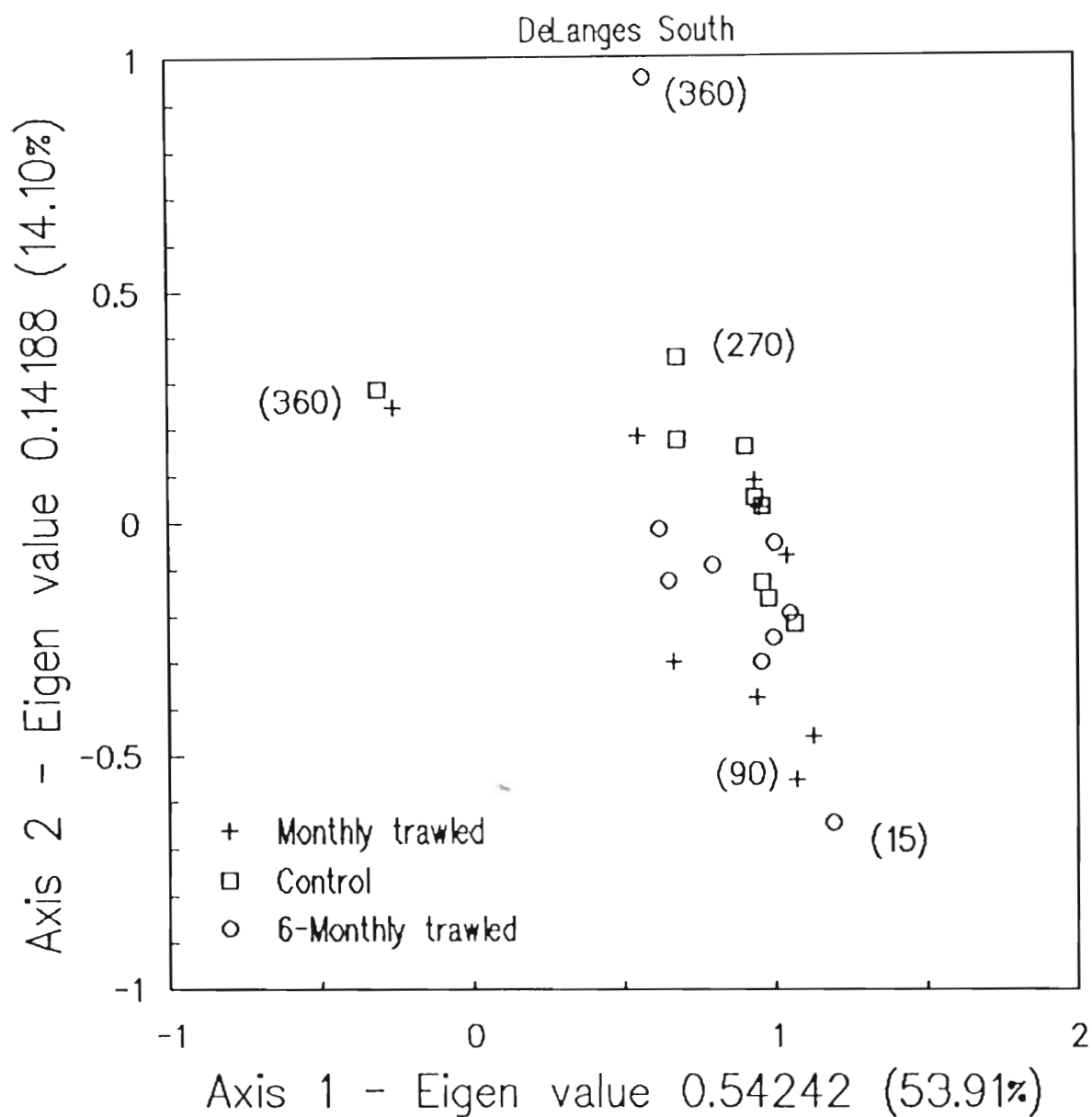


Fig. 6.9 Sample scores of the first two axes of the correspondence analysis of the species densities in the DeLanges South quadrats between July 1989 and July 1990. Labelled points indicate days after trawling.

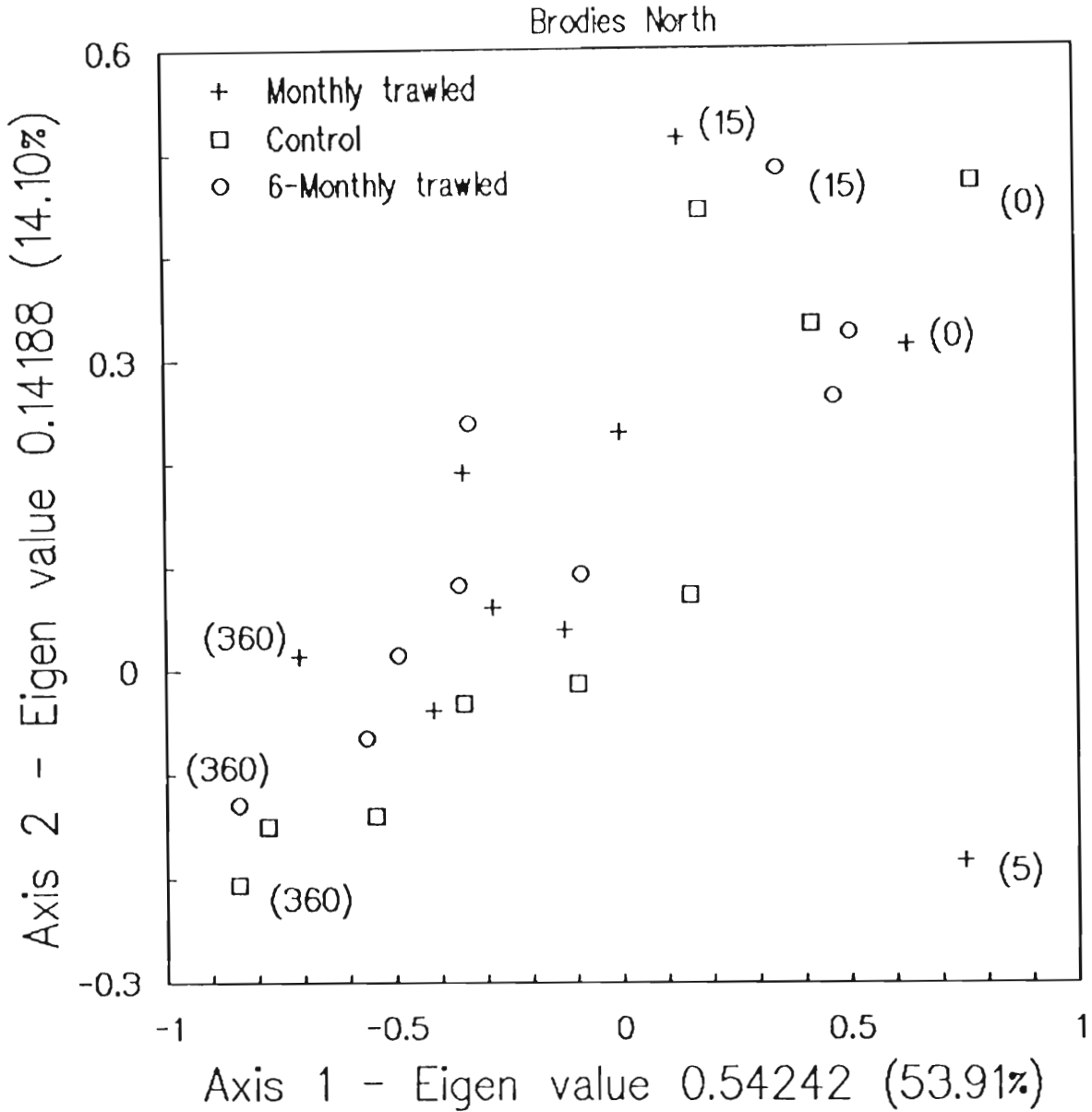


Fig. 6.10 Sample scores of the first two axes of the correspondence analysis of the species densities in the Brodie's North quadrats between July 1989 and July 1990. Labelled points indicate days after trawling.

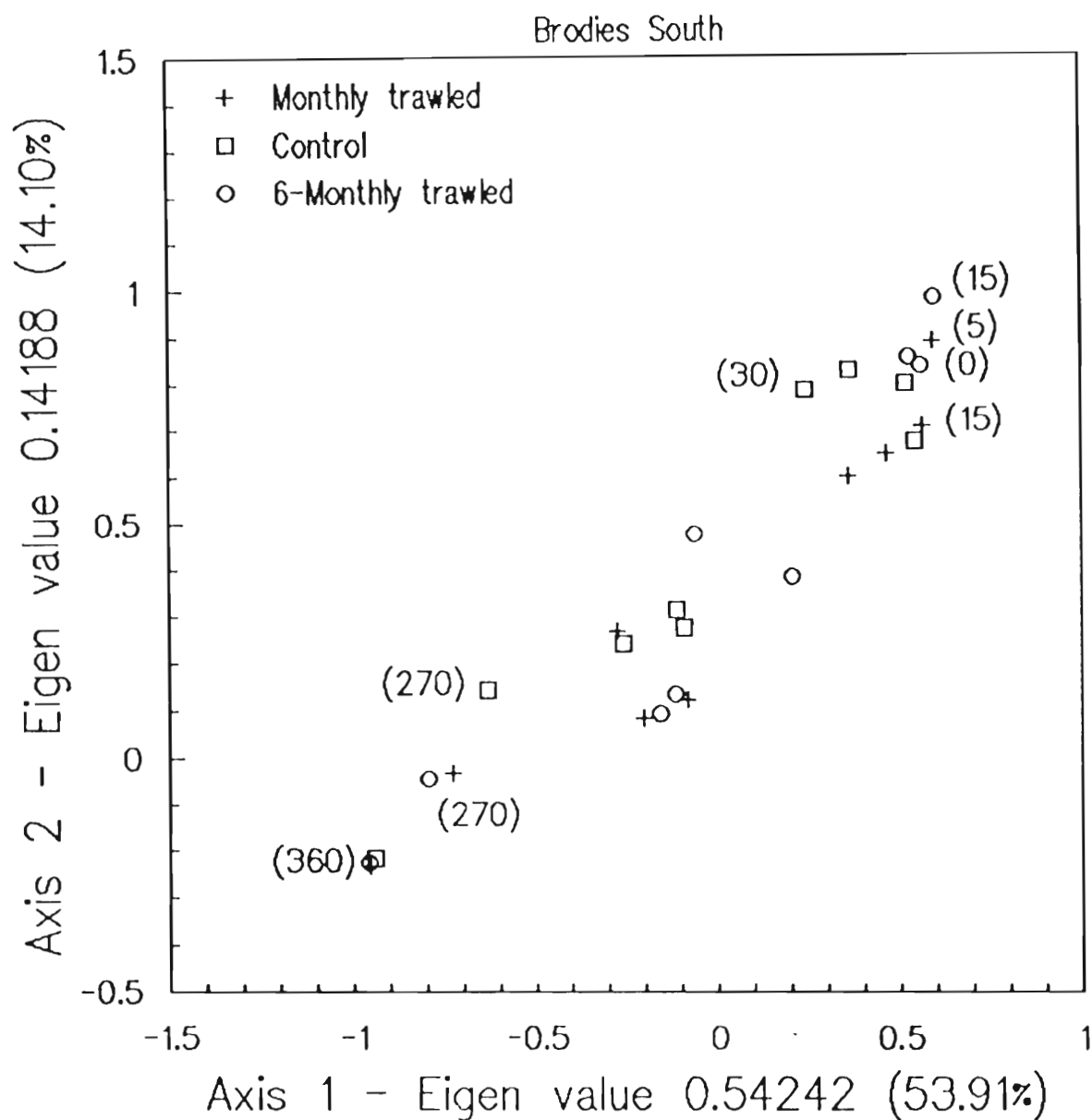


Fig. 6.11 Sample scores of the first two axes of the correspondence analysis of the species densities in the Brodies South quadrats between July 1989 and July 1990. Labelled points indicate days after trawling.

the plot of species scores (Fig. 6.12). The inverse relationship between *A.digitalis* and *V.chilkensis* on the first axis of separation in the sample ordination is confirmed by the opposition of their species scores. The relationship between *T.blephariskios* and capitellid densities to *A.digitalis* densities was not as marked as the relationship between *A.digitalis* and *V.chilkensis* however, and accounted for the variability on the second axis of separation in the sample ordination.

The coefficients of variation of the densities of *T.blephariskios*, *V.chilkensis* and capitellids are given in Figs. 6.13 to 6.18. No trends were evident to suggest that the variability in the density of these species increased or decreased with time in the trawled quadrats compared with the controls.

6.3.3 Comparison of Trawled and Control Quadrats

The Mann-Whitney comparisons of the numbers of *T.blephariskios*, *V.chilkensis* and capitellids in trawled and control quadrats at DeLanges and Brodies Shallows over the study period are given in Table 6.1.

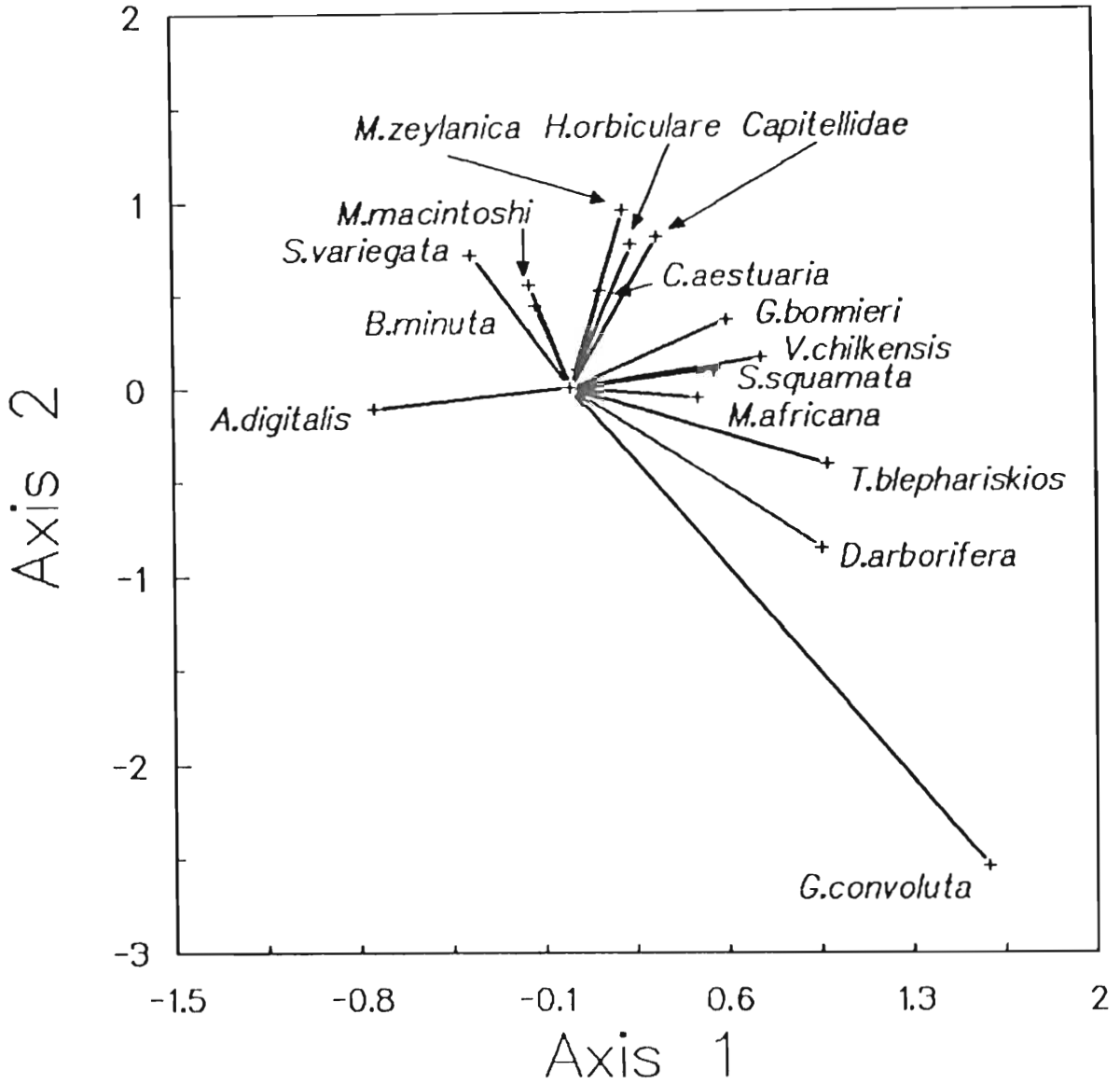


Fig. 6.12 Species scores of the first two axes of the correspondence analysis of species densities in the DeLanges and Brodies trawled and control quadrats between July 1989 and July 1990.

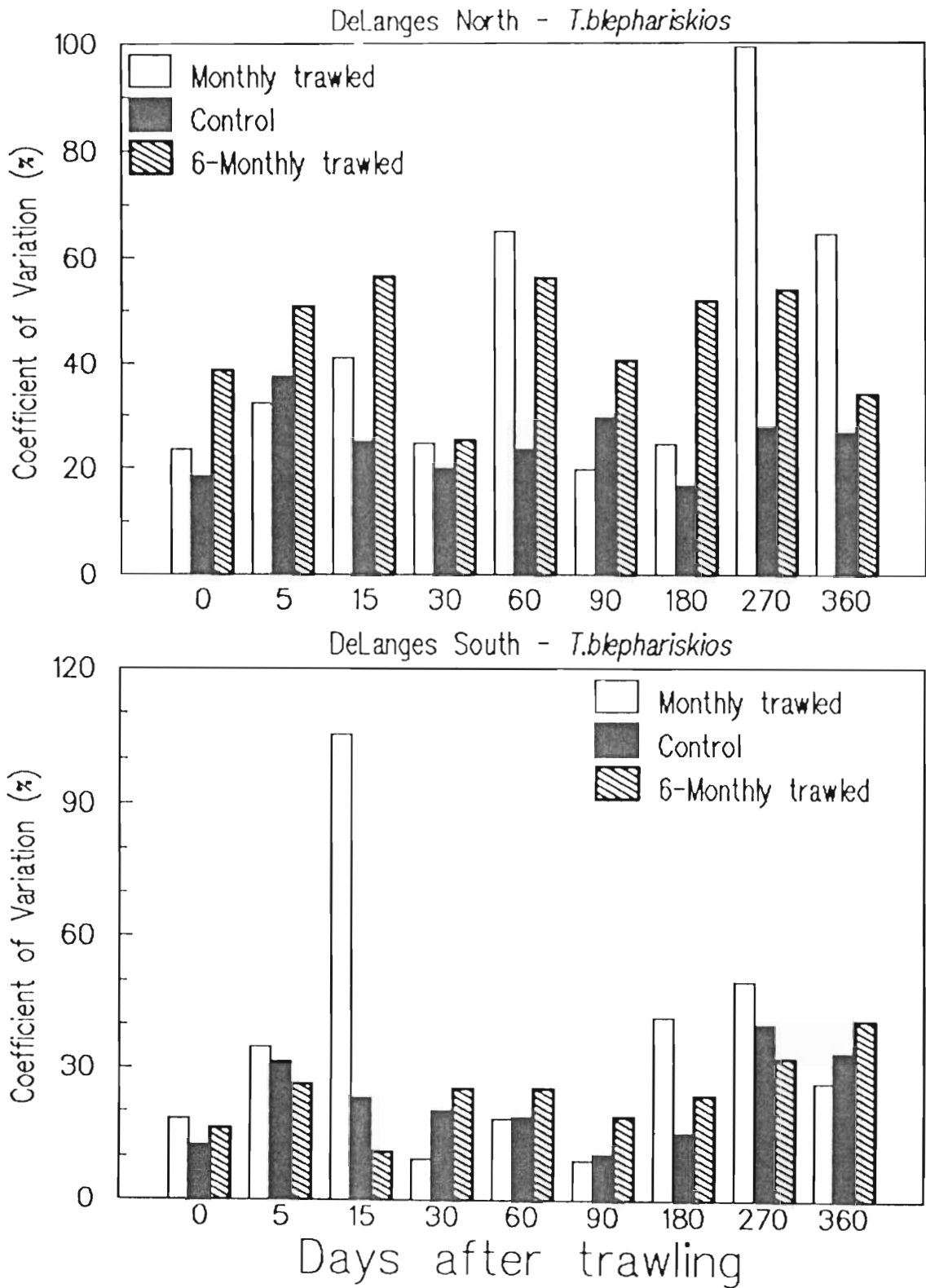


Fig. 6.13 Coefficients of variation of *T.blephariskios* in the DeLanges North and DeLanges South trowled and control quadrats between July 1989 and July 1990.

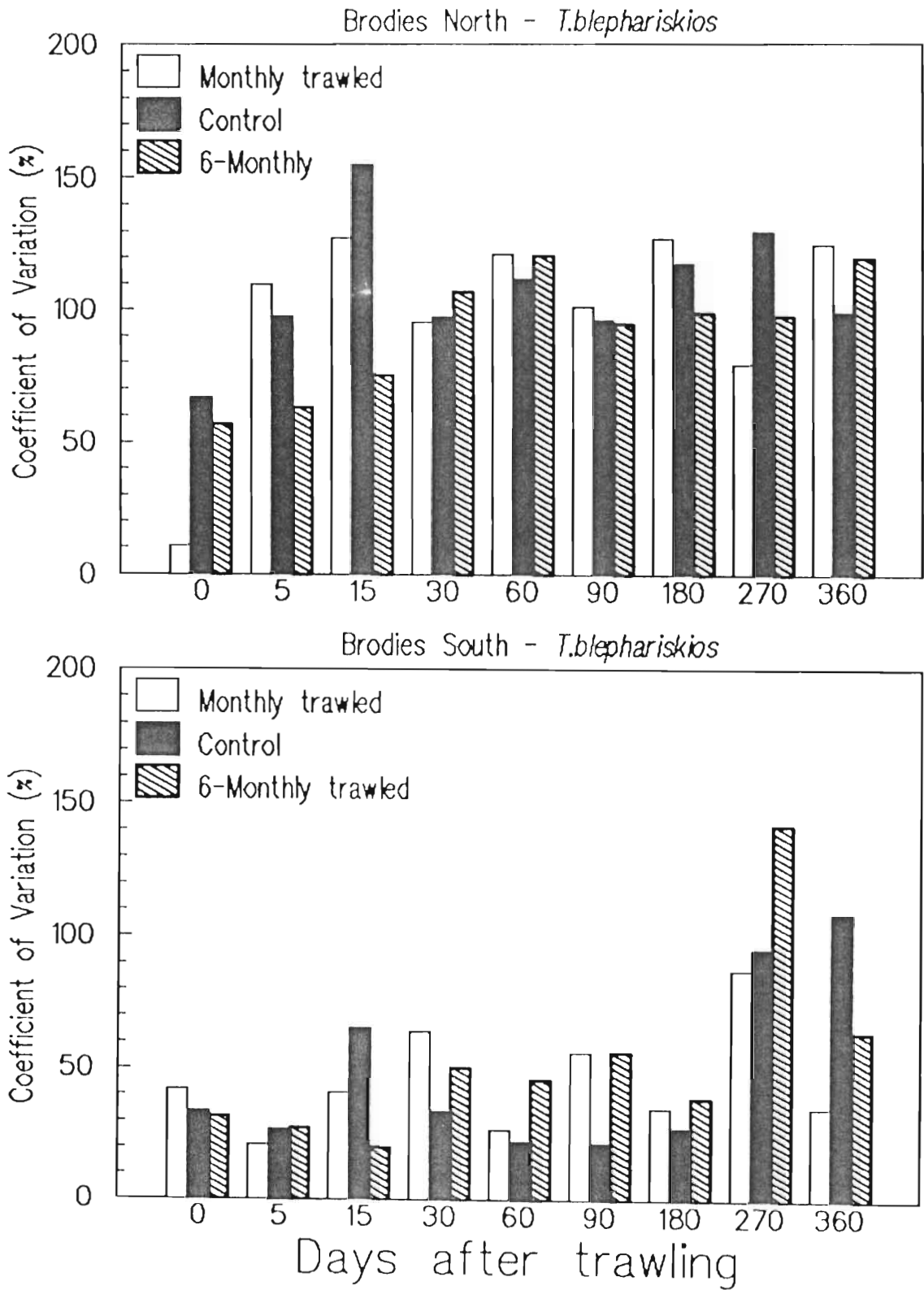


Fig. 6.14 Coefficients of variation of *T.blephariskios* in the Brodies North and Brodies South trawled and control quadrats between July 1989 and July 1990.

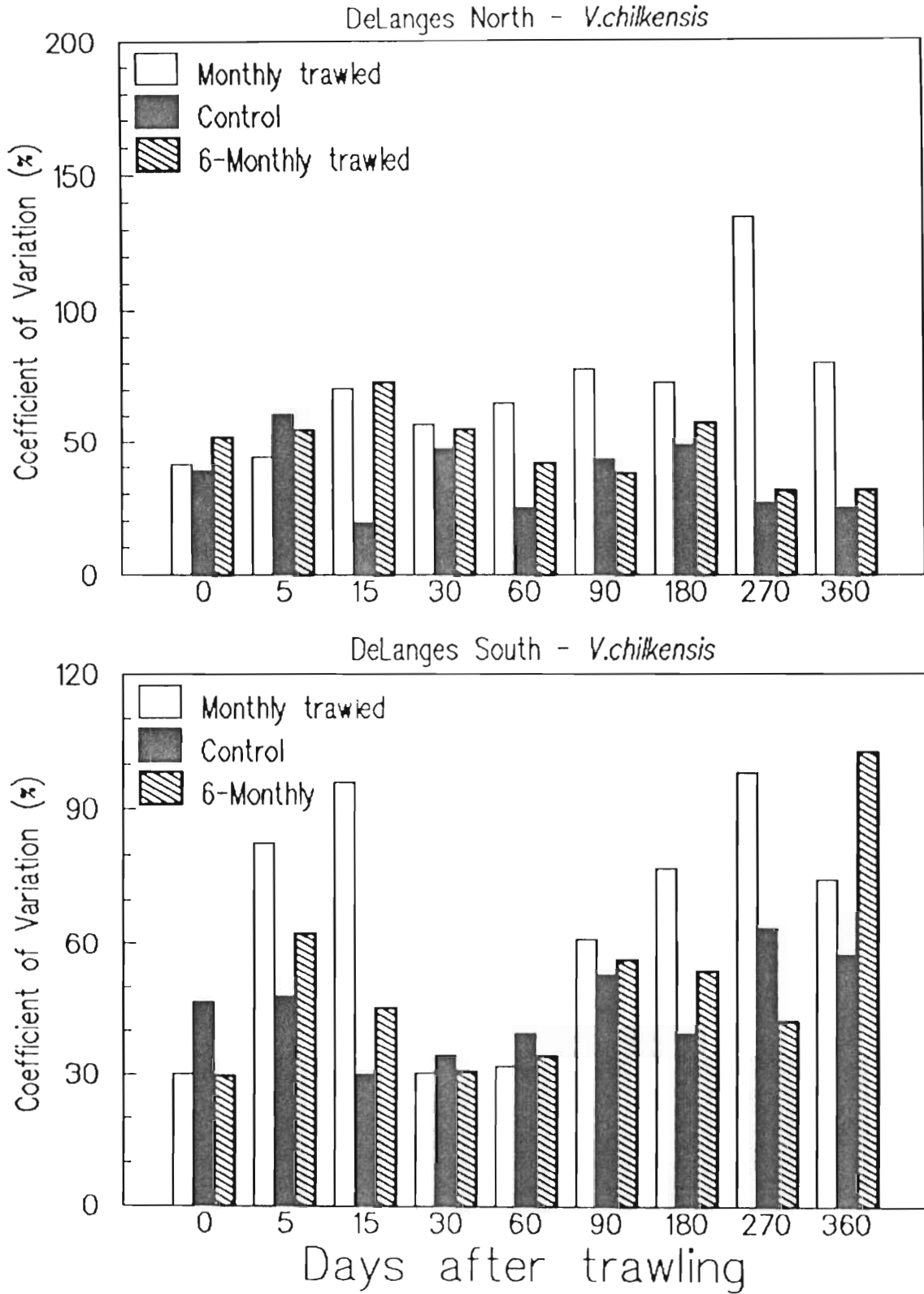


Fig. 6.15 Coefficients of variation of *V.chilkensis* in the DeLanges North and DeLanges South trawled and control quadrats between July 1989 and July 1990.

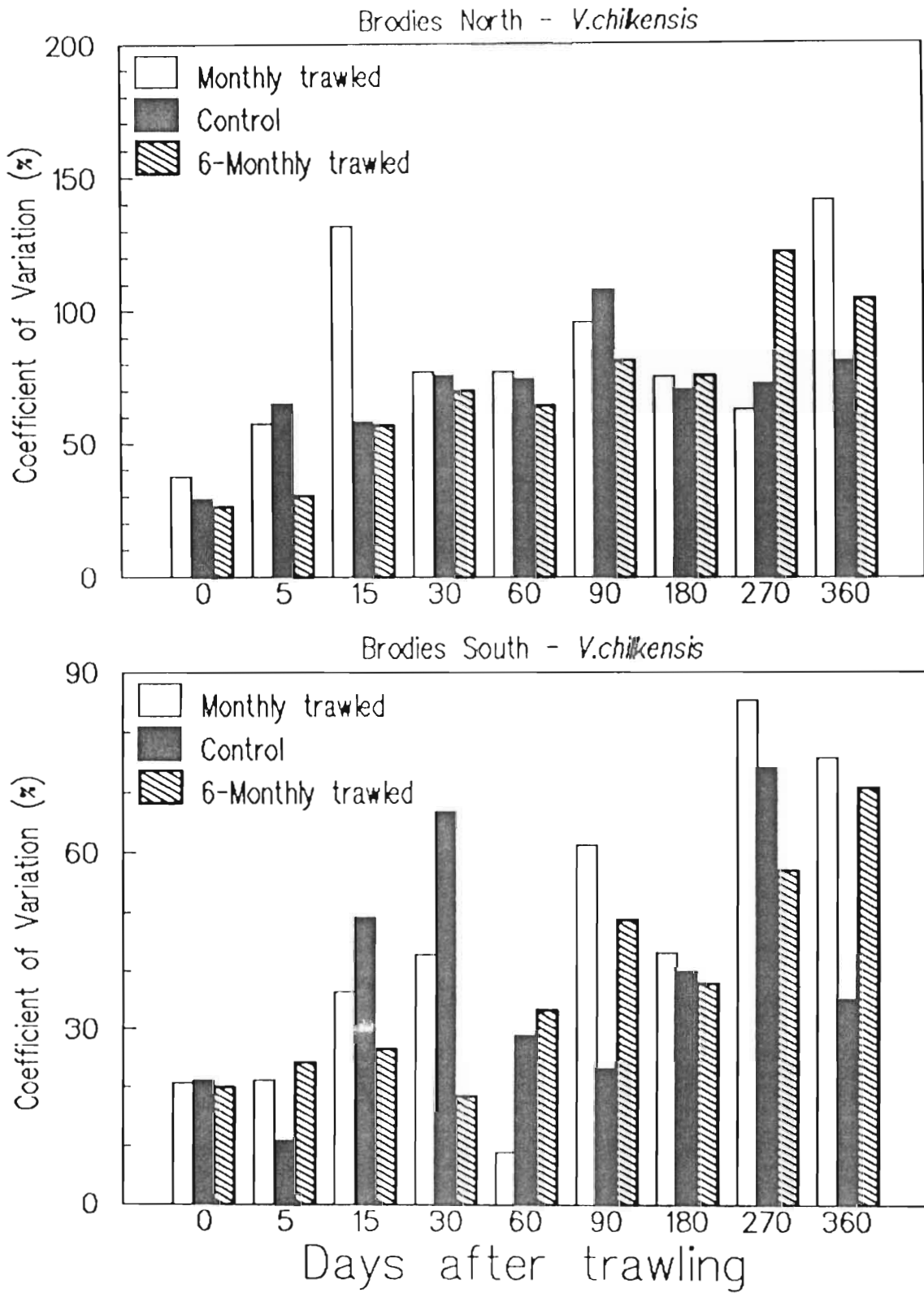


Fig. 6.16 Coefficients of variation of *V.chilkensis* in the Brodies North and Brodies South trawled and control quadrats between July 1989 and July 1990.

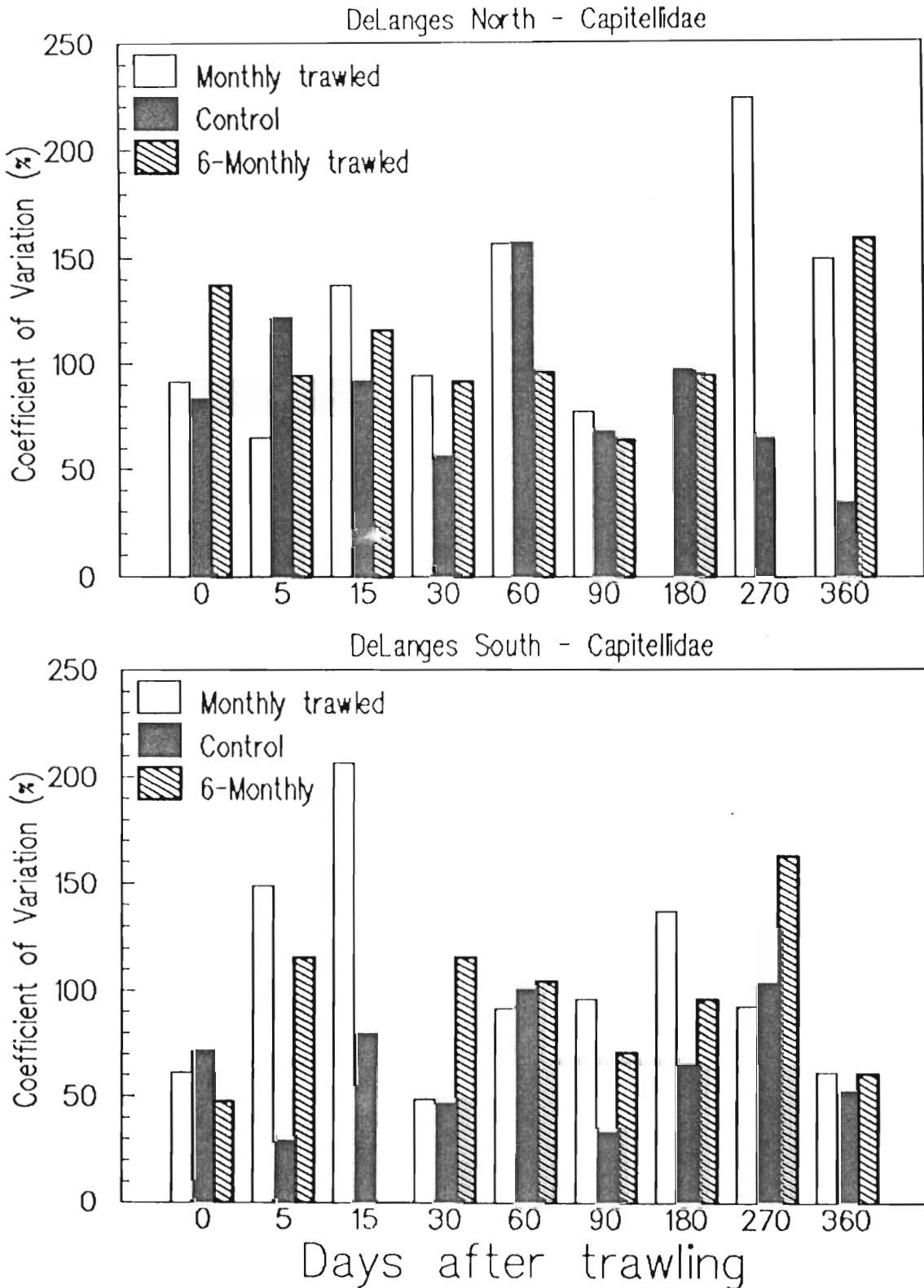


Fig. 6.17 Coefficients of variation of Capitellidae in the DeLanges North and DeLanges South trawled and control quadrats between July 1989 and July 1990.

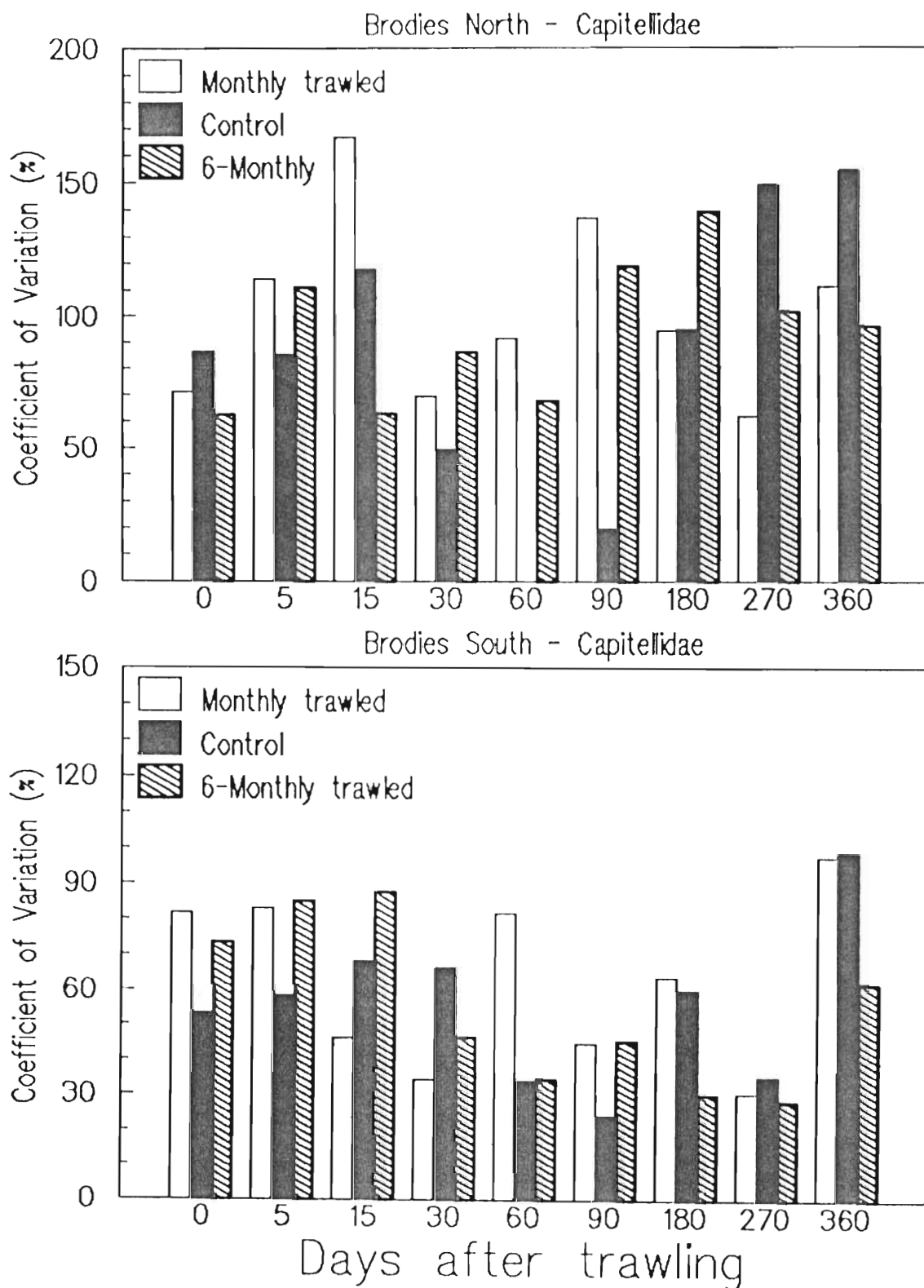


Fig. 6.18 Coefficients of variation of Capitellidae in the Brodiess North and Brodiess South trawled and control quadrats between July 1989 and July 1990.

Table 6.1 Mann-Whitney probabilities (p) of counts of *T.blephariskios*, *V.chilkensis* and Capitellidae between July 1989 and July 1990 equalling or exceeding the large test statistics for monthly (M) and 6-monthly (6-M) trawled quadrats compared with the adjacent control quadrats. Quadrats considered significantly different ($p < 0.05$) are marked *.

		<i>T.blephariskios</i>	<i>V.chilkensis</i>	Capitellidae
DeLanges North	M	0.29	0.01*	0.02*
	6-M	0.59	0.08	0.03*
DeLanges South	M	0.59	0.15	0.06
	6-M	0.36	0.43	0.08
Brodies North	M	0.99	0.45	0.96
	6-M	0.69	0.95	0.35
Brodies South	M	1.00	1.00	0.04*
	6-M	0.47	0.70	0.14

The numbers of *V.chilkensis* in the monthly trawled quadrat, and capitellids here and the 6-monthly trawled quadrat at DeLanges North were significantly lower than the adjacent control. The numbers of capitellids in the Brodies South monthly trawled quadrat were also significantly lower than the adjacent control. No significant differences between the numbers of *T.blephariskios* in trawled and control quadrats were apparent.

The linear and exponential regressions of the counts of *V.chilkensis* in the DeLanges North monthly trawled and control quadrats, capitellids in the DeLanges North monthly, 6-monthly and control quadrats, and capitellids in the

Brodies South monthly trawled and control quadrats are given in Figs. 6.19 - 6.21. Although these regressions generally indicate decreases in numbers with time after trawling, the ranges of the slopes of the regressions in the respective trawled and control quadrats overlap (Fig. 6.22), indicating that there was no significant decrease in the numbers of the species in the trawled quadrats compared with the adjacent controls.

6.3.4 Salinity and Temperature

Salinity and temperature data recorded at the DeLanges and Brodies quadrats are given in Fig. 6.23. Salinities at DeLanges were measured during high water, eliminating variation due to tidal fluctuations. An overall increase in salinity occurred at DeLanges and Brodies Shallows from July to October, followed by a marked decrease from January. This decrease corresponded to the net freshwater outflow from the Lakes after heavy rains in November 1989.

Temperatures at DeLanges and Brodies peaked in January, respectively nine and ten degrees higher than the minimum temperature of 15°C recorded at both areas in August.

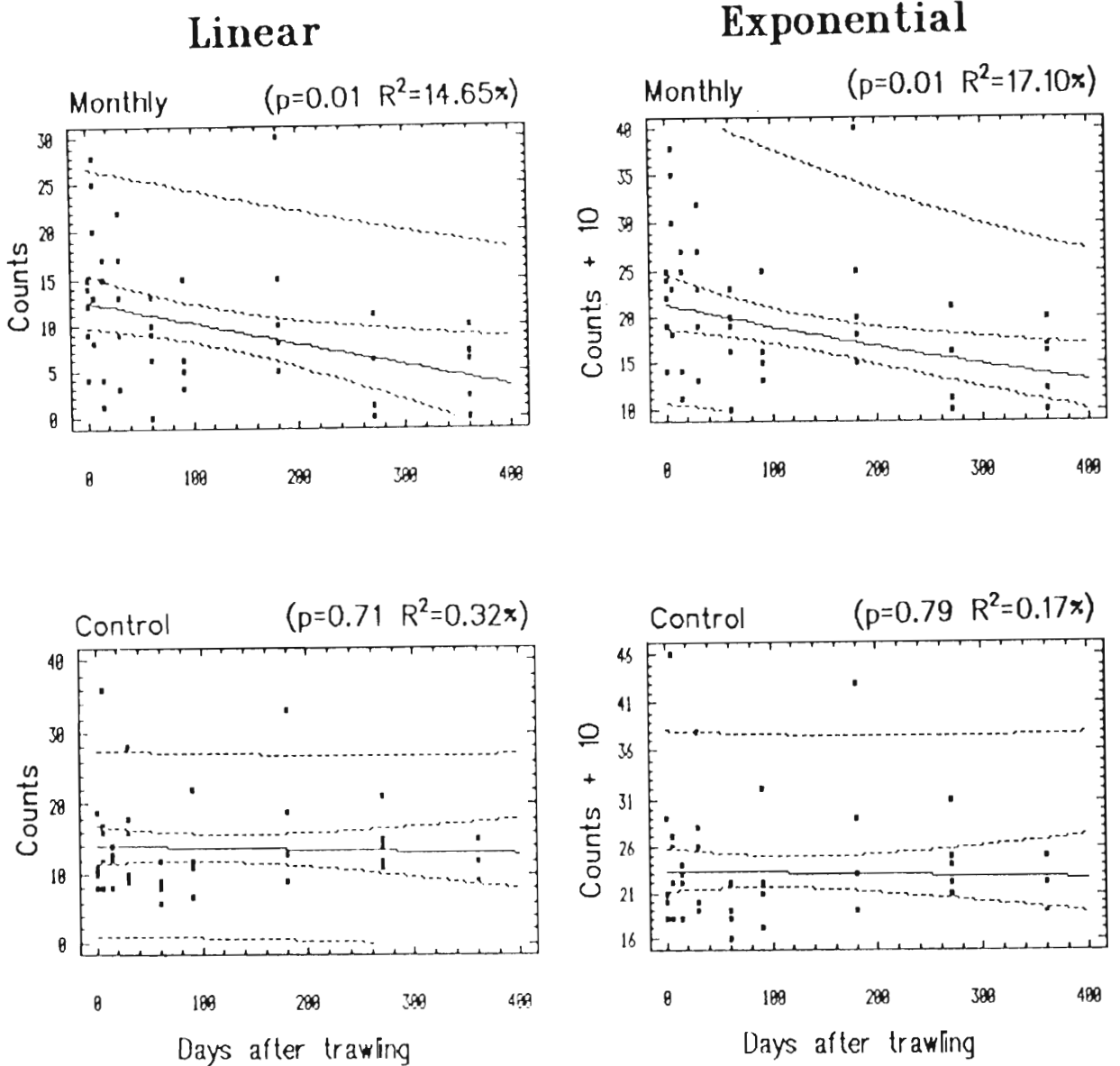


Fig. 6.19 Regression analysis of counts of *V. chilcensis* in the DeLanges North monthly trawled and control quadrats. [95% confidence limits are shown for the regression (inner) and the counts (outer)].

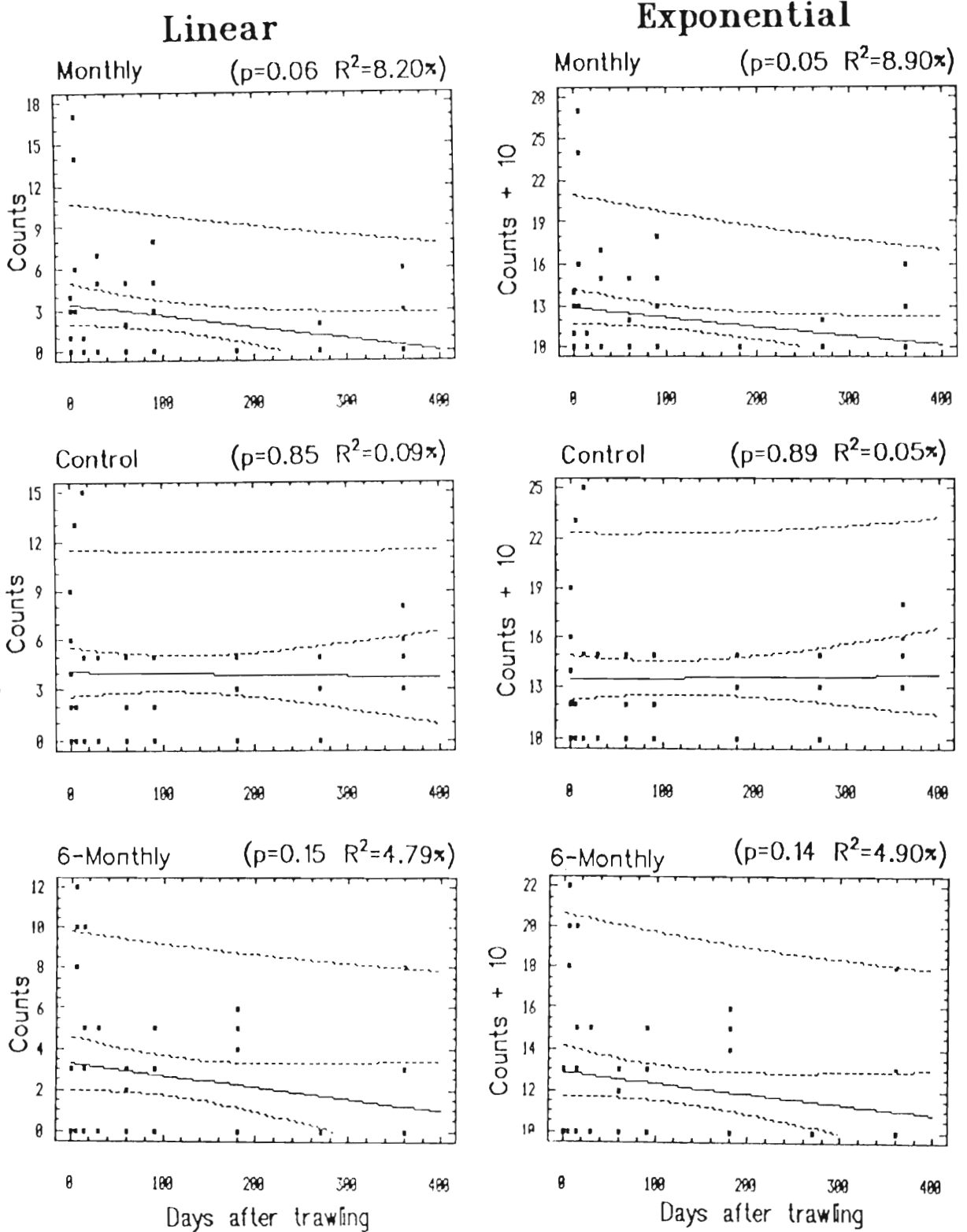


Fig. 6.20 Regression analysis of counts of Capitellidae in the DeLanges North monthly trawled, 6-monthly trawled and control quadrats. [95% confidence limits are shown for the regression (inner) and the counts (outer)].

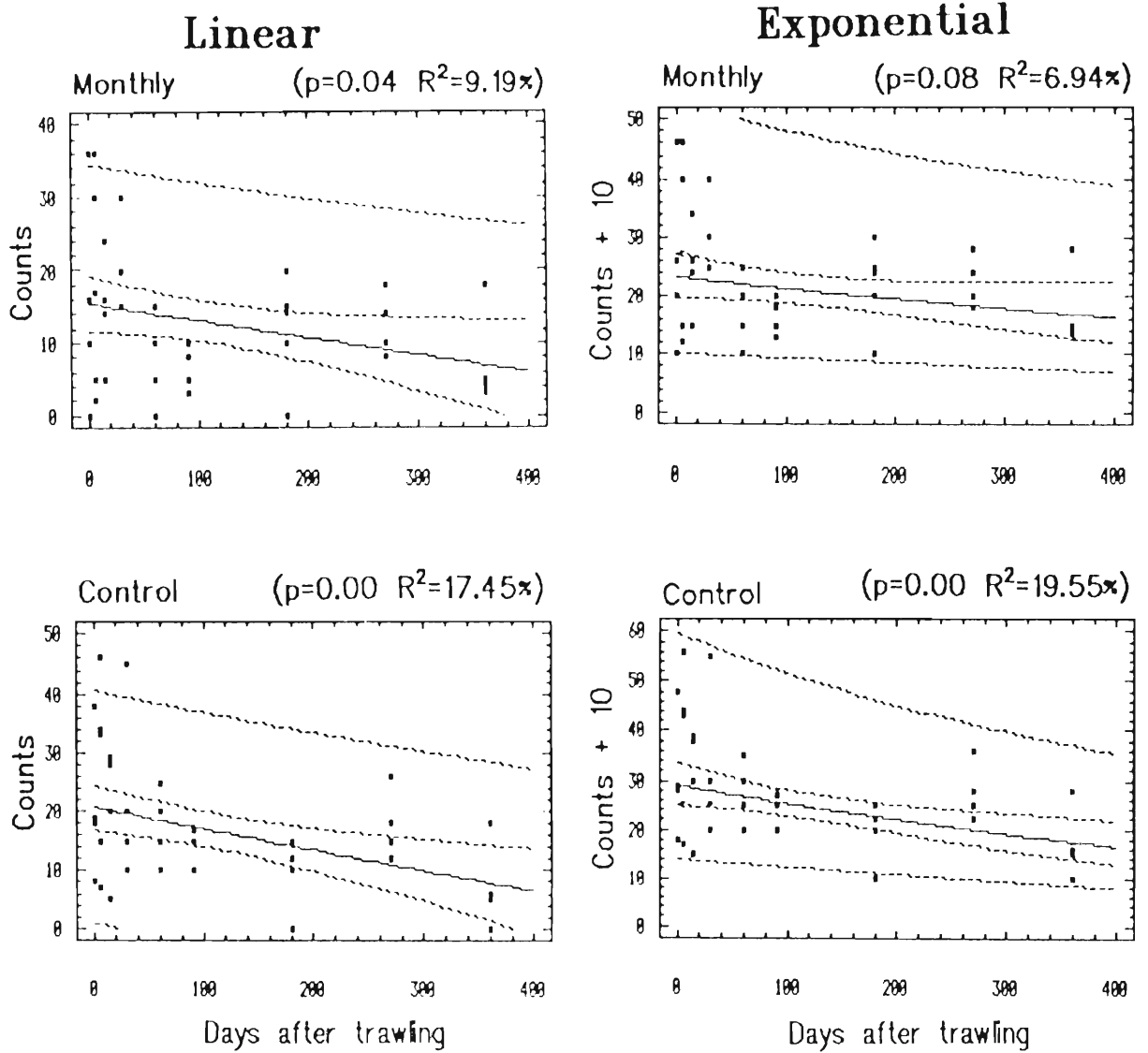


Fig. 6.21 Regression analysis of counts of Capitellidae in the Brodies South monthly trawled and control quadrats. [95% confidence limits are shown for the regression (inner) and the counts (outer)].

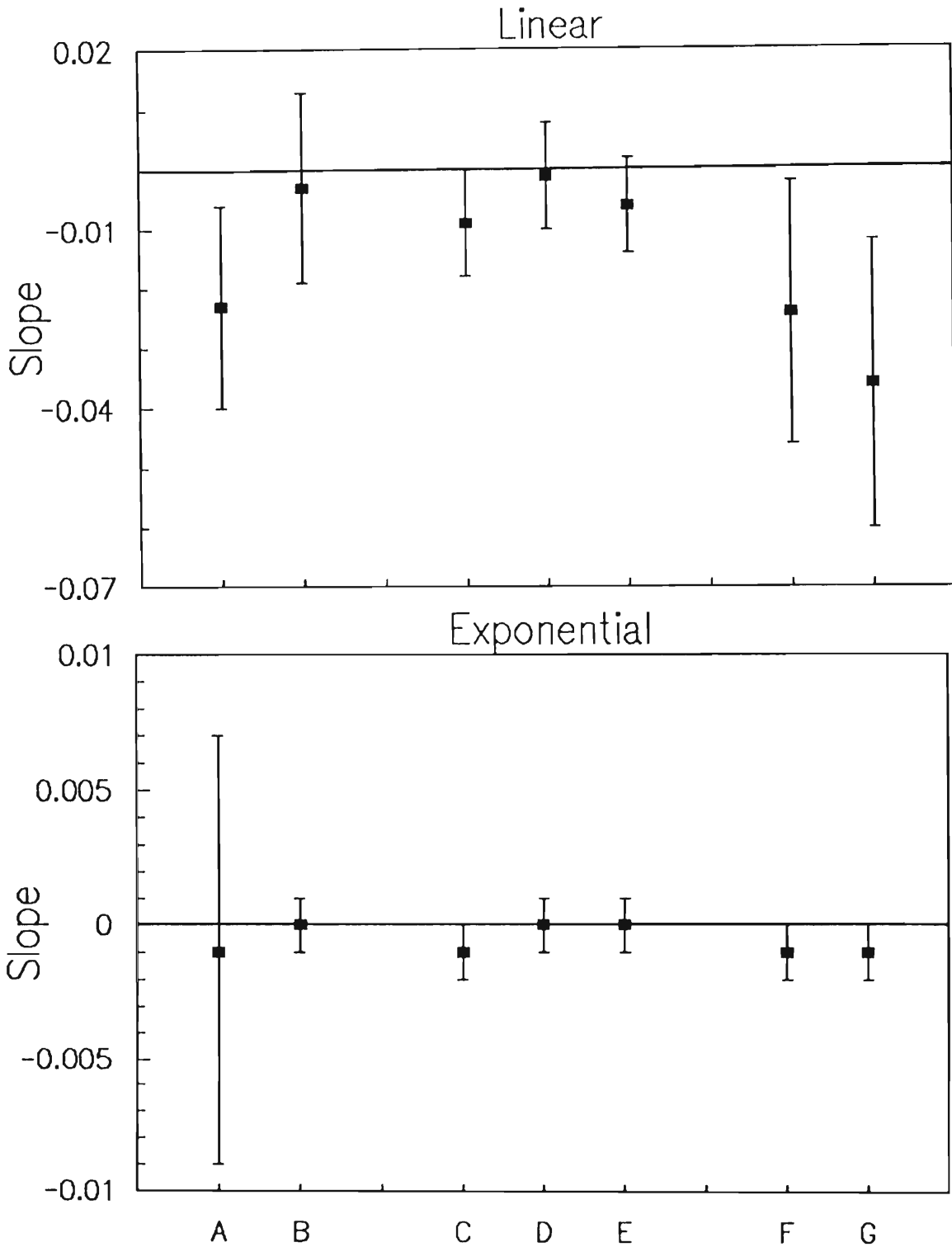


Fig. 6.22 Regression slope ranges for *V. chilensis* in the DeLanges North monthly trawled (A) and control (B) quadrats; Capitellidae in the DeLanges North monthly trawled (C), control (D) and 6-monthly (E) trawled quadrats; and Capitellidae in the Brodies South monthly trawled (F) and control (G) quadrats.

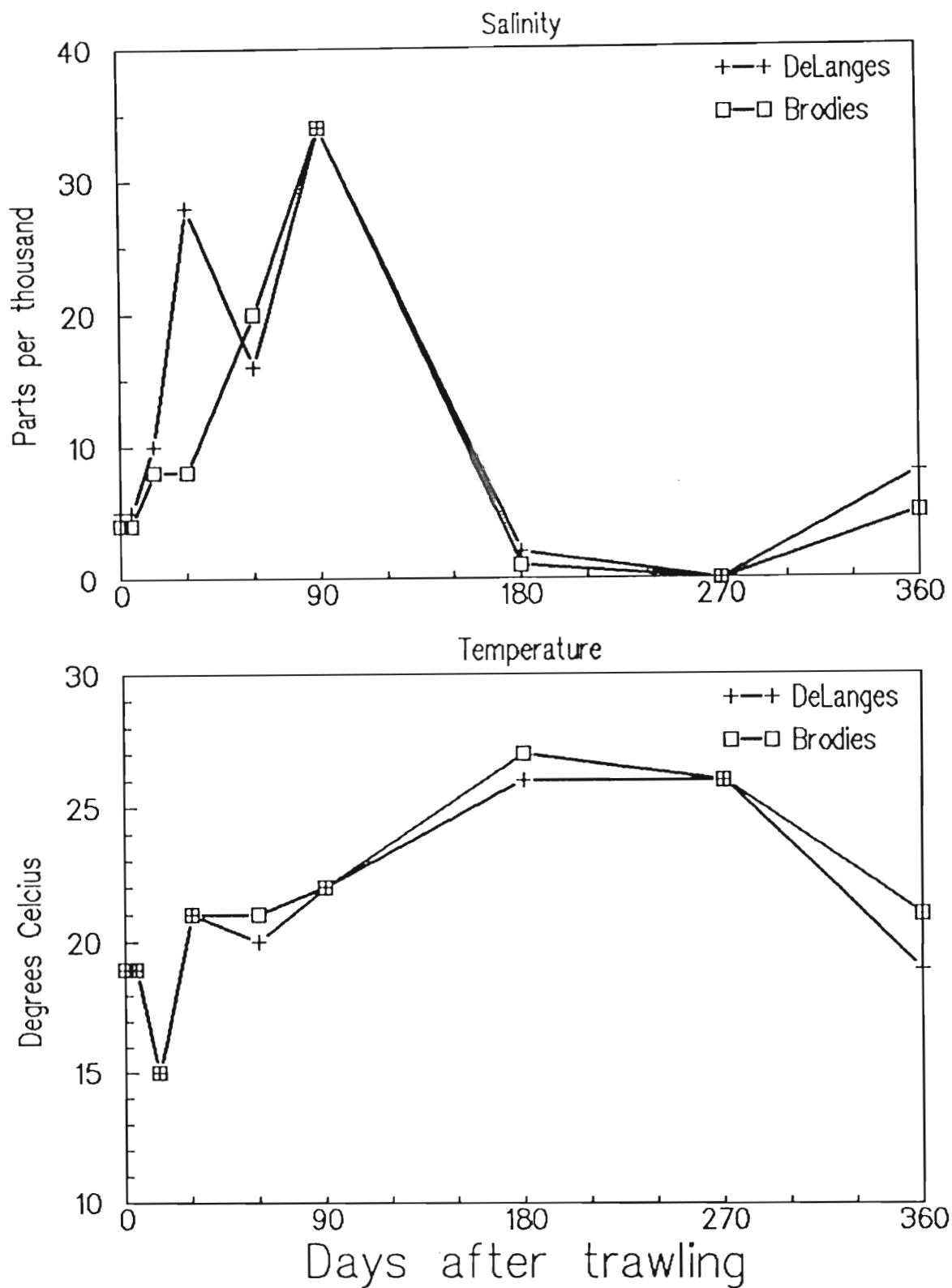


Fig. 6.23 Surface salinities and temperatures recorded at DeLanges and Brodies Shallows between July 1989 and July 1990.

6.3.5 Comparison of the Substratum in Trawled and Control Quadrats

The relative mud and sand fractions, and the organic contents of the substratum in the trawled and control quadrats over the study period are given in Figs. 6.24 and 6.25. An overall decrease in muddiness and organic content in all quadrats, except DeLanges North centre and south quadrats, after October was apparent. The mud fractions of the monthly trawled quadrats after October, apart from DeLanges South, were 20-35% lower than the October levels. The mud fractions of the six-monthly trawled and control quadrats were approximately 10% lower than the October levels. The mud fractions and organic content of the substrata in the DeLanges quadrats remained lower than the pre-October levels for the remainder of the study period. An increase in mud and organic fractions after the initial decrease was evident in the Brodies quadrats after April.

No trends showing increased sandiness or muddiness, or increased or decreased organic content were evident between the monthly and six-monthly trawled quadrats, and their controls. Although the sediment samples were collected from the approximate centre of each quadrat, the variation over the study period between the sand and mud fractions in each control quadrat was approximately 20%, indicating that the

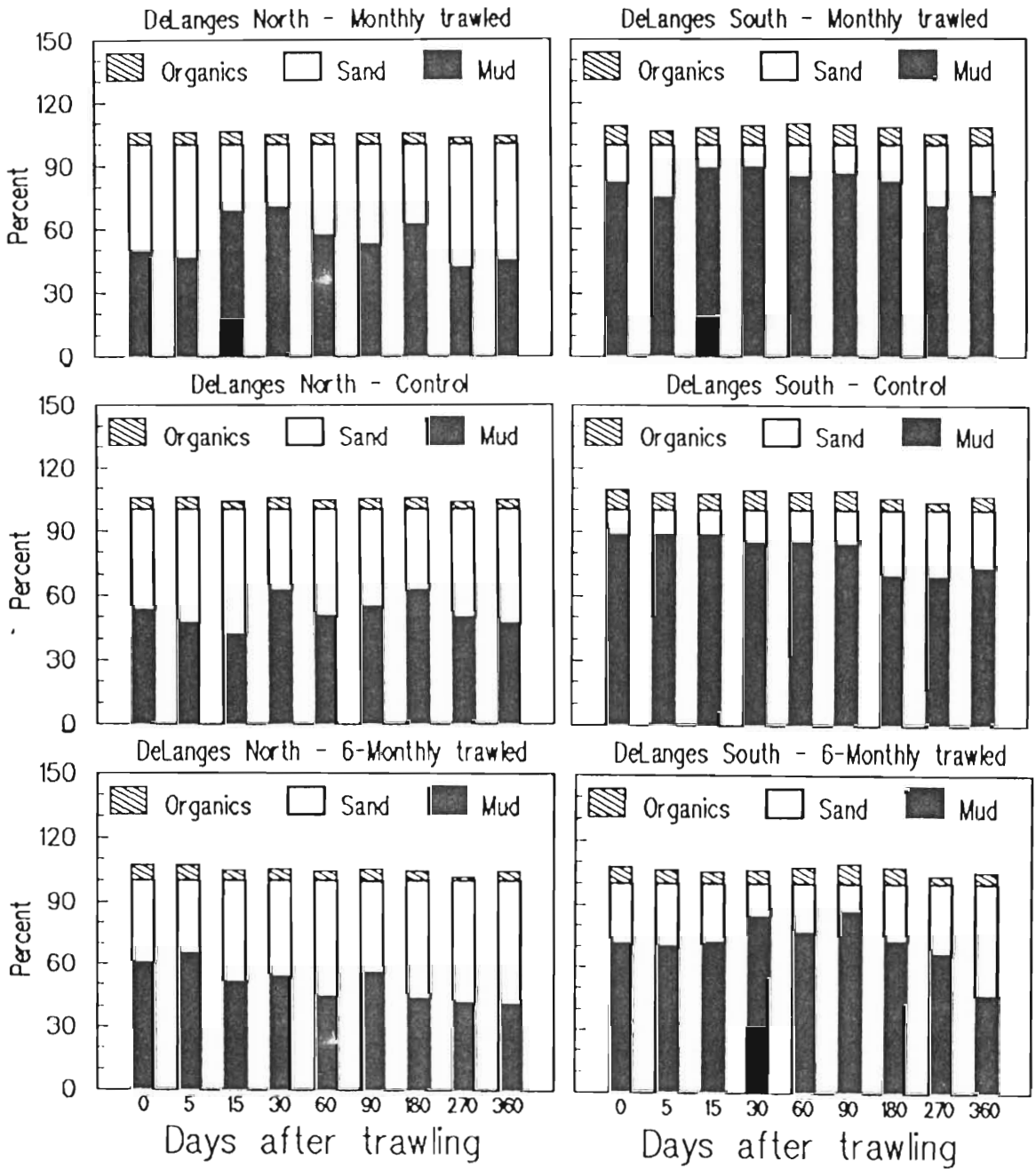


Fig. 6.24 Substratum composition in the DeLanges North and DeLanges South trawled and control quadrats between July 1989 and July 1990.

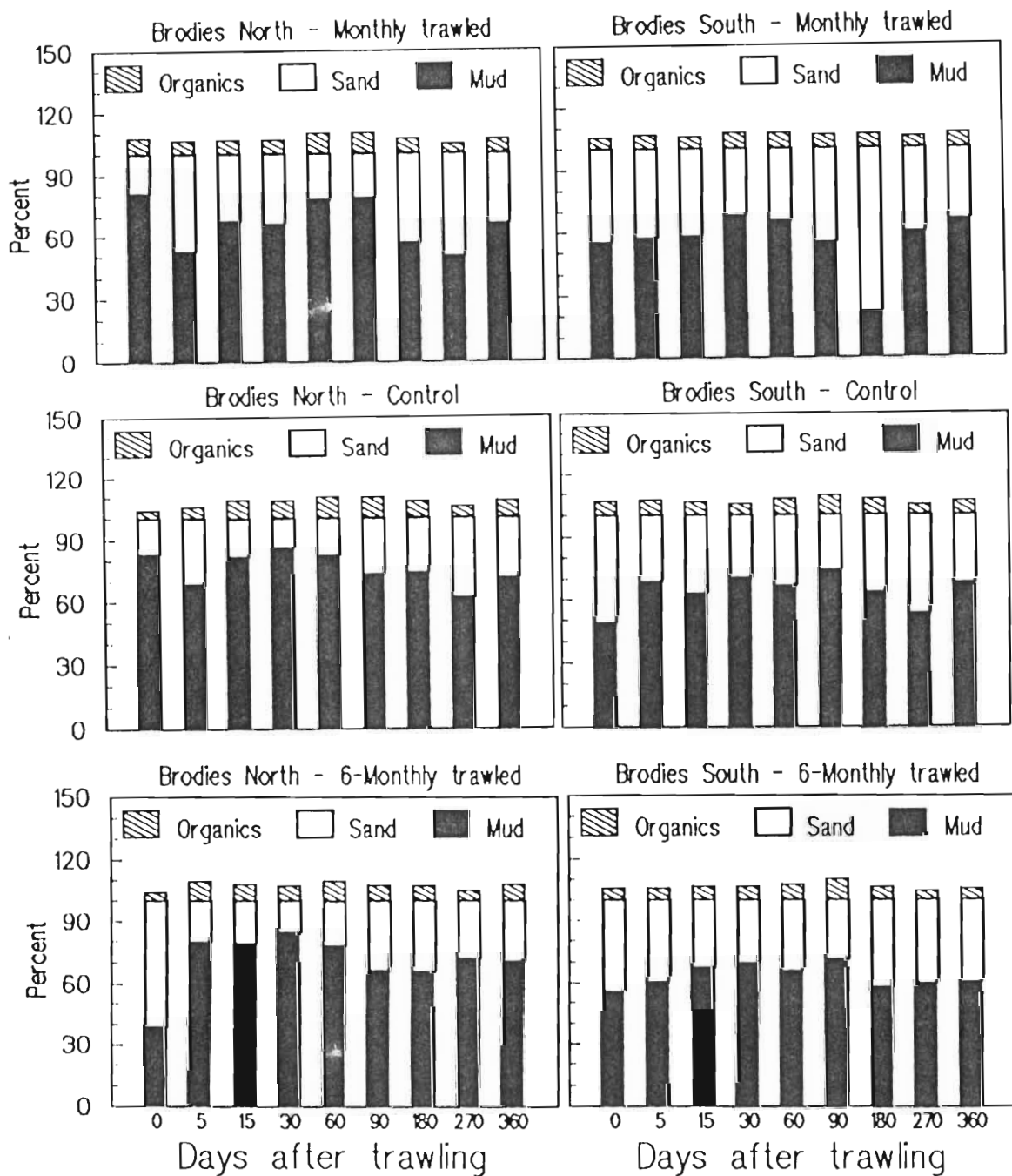


Fig. 6.25 Substratum composition in the Brodies North and Brodies South trawled and control quadrats between July 1989 and July 1990.

inherent patchiness of the substratum would obscure any possible changes due to disturbance by trawling.

6.3.6 Substratum Variation Within Quadrats

The relative mud and sand fractions, and the organic contents of sediment samples taken across each quadrat in July 1990 are given in Fig. 6.26. Although no trends across each quadrat were evident in relation to the bank and channel, each quadrat showed a marked variation in mud and sand fraction. The organic contents of the samples were proportional to their mud contents, and notably low in the sandier Brodies samples.

6.4 Discussion

6.4.1 Effects of Beam Trawling on the Benthos

No evidence was found to indicate that beam trawling had a negative effect on the benthos. The densities of *T.blephariskios*, *V.chilkensis* and capitellid polychaetes often showed wider fluctuations in the control quadrats than in the trawled quadrats which could tend to conceal more subtle changes.

The overall decrease in *T.blephariskios* and *V.chilkensis*

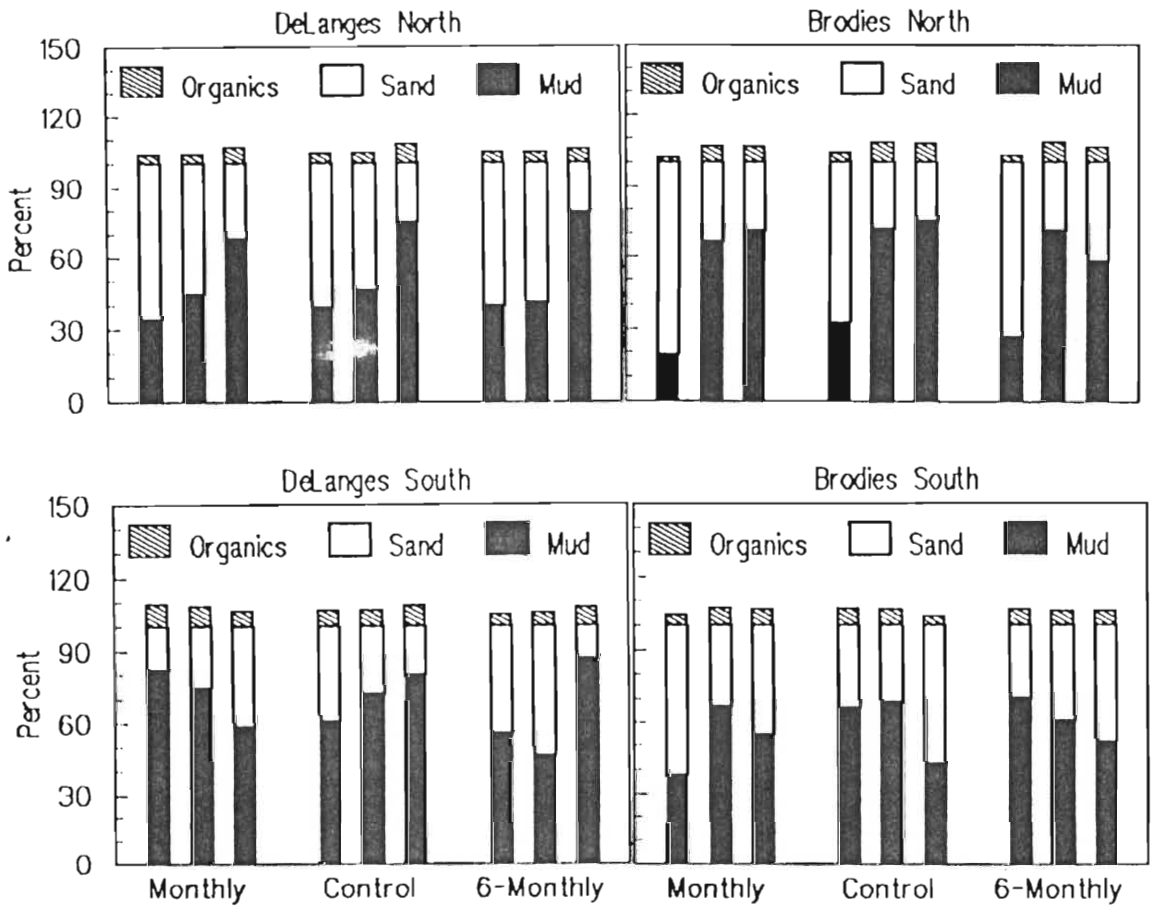


Fig. 6.26 Substratum composition across the trawled and control quadrats at DeLanges and Brodies in July 1990. DeLanges quadrats are shown (L-R) from east to west, and Brodies quadrats from north to south.

densities between October and January corresponded to the low salinities which prevailed in the Narrows after heavy rains in November. This indicated that such seasonal or episodic events could have a greater negative effect on the benthos than beam trawling, whether through reduced salinities, removal by currents or scouring of the substratum. No recovery was evident in these species by the end of the study period, suggesting that reduced densities are maintained as long as there is a net outflow of fresh water from the Lakes.

The high densities of *A.digitalis* recorded at the end of the study period in fresh conditions showed the reverse trend to the decreased densities of *T.blephariskios* and *V.chilkensis* at this time. *A.digitalis*, not recorded from the 1st Narrows and Brodies Shallows in pre-flood salinities of 33.5 ppt. to 35 ppt. in April 1983, were present at densities of 3500 m⁻² and 5000 m⁻² respectively at 1st Narrows and Brodies Shallows between February and March 1984 in post-flood fresh conditions (Hay, 1985). It is not known to what extent *A.digitalis* is transported into the Narrows from the Lakes during fresh conditions, or whether their high densities occurred because of reduced competitor densities.

A comparison between the trawling effort in this study and that of the bait boats was made to calculate the likelihood

of the bait boats affecting the benthos. Assuming a boat speed of 1.5 ms^{-1} , each point in the pilot study quadrat (area 3888 m^2) would have been disturbed with the 3.5 m wide trawl approximately 5.3 times in the 65 minute trawling period. Although the quadrats in the main study were trawled for only 30 minutes on each occasion, the average area of the quadrats (area 1832 m^2 , SD 392 m^2) was approximately half that of the pilot study quadrat. However, the use of the 1 m wide trawl in the main study reduced the coverage of each point to approximately 1.5 times per 30 minutes.

The bait boats trawl for an average of five hours per day to give an average of 450 boat days per year (Fielding, 1989). This effort translates to 7.5 hours of trawling per day for one boat. The time for each point in the Narrows to be covered (area 4 km^2) with a 4.9 m wide net, assuming the same boat speed of 1.5 ms^{-1} , would be 6.3 days. At a trawling effort of 7.5 hours per day, and assuming even coverage, every point in the Narrows would be disturbed once every 20.2 days. This is comparable to the coverage of 1.5 times per month calculated for the main trawling study, and suggests that, on the basis of these calculations, the bait fishery is not having a detrimental effect on the benthos.

6.4.2 Effects of Beam Trawling on the Substratum

No trends toward increased sandiness or muddiness were evident in the trawled quadrats compared with the controls. This indicated that beam trawling in this study did not measurably affect the composition of the substratum.

Observations in the North Sea revealed that the shoes of a 700kg beam trawl penetrated muddy substrata to a depth of up to 10 cm, while the use of as many as 15 tickler chains only disturbed the upper 3 cm of the substratum (Bergman et al., 1990). Video observations showed that the tracks left by these trawls had been eradicated by tidal currents after eight hours. The beam trawl used to trawl the quadrats in the Narrows was considerably lighter, weighing 8.5 kg, and implies that the substratum in the trawled quadrats would not have been significantly disturbed. However, the bait boats were seen to churn the substratum with their propellers which may have a longer lasting effect on the substratum than Bergman et al. (1990) showed.

The surface sediment layer, although disturbed, would resettle after the passage of the trawl. However, repeated trawling may prevent the surface layer of the substratum from consolidating and lead to its long term instability. Unconsolidated substrata would consequently be more

susceptible to erosion by tidal currents and floods. This accords with the decreased mud and organic contents of the substratum noted in most quadrats after the heavy rains in November 1989. It would thus appear that while beam trawling in the Narrows may not have an effect on the substratum, the effect could be more subtle in that some degree of substratum instability, possibly increasing turbidity levels, is being maintained.

6.4.3 Species Distribution and Substratum Variation

The distribution and densities of the gravimetrically important species in the Narrows appeared to be influenced by the nature of the substratum. This apparent relationship was supported by the lower species densities and richness on sandy compared with muddy substrata. The densities of *T.blephariskios* in generally sandier substrata at Brodies Shallows were less than half the densities at DeLanges, and were notably lower in very sandy samples. Notably higher densities of *D.arborifera* and *C.aestuaria* were evident in the sandier quadrats. The patchy distribution of the benthos in the quadrats was paralleled by the variation in mud and sand fractions across each quadrat. Furthermore, the general reduction in species densities recorded during the period of freshwater outflow from the Lakes coincided with an overall increase in the sand fraction of the substratum in all quadrats.

These trends suggest that beam trawling does not have sufficient impact on the nature of the substratum to have a significant effect on benthic species distributions or densities when compared with the inherent patchiness of the substratum or the effect of episodic or seasonal events such as floods. Sediment disturbance through prawn trawling and periodic cyclones was thought to be a factor negatively affecting the benthic biomass in trawled areas on the Great Barrier Reef continental shelf (Algoni, 1989). Even though the effects of beam trawling in the Narrows could not be related to changes in the nature of the substratum or species densities, the importance of the substratum as a determinant of benthic species distribution cannot be overlooked. Any process influencing the nature of the substratum will effect the distribution of the benthos.

7.0 GENERAL DISCUSSION

7.1 Community and Species Responses to the Nature and Scale of the Disturbance

It was evident from this study that the response of the benthos was related to the nature and scale of the disturbance. Decreased species densities and diversity were noted where the nature of the substratum was altered or where the benthos was exposed to currents in channels.

The creation of a channel in the St. Lucia Narrows appeared to have had a long term negative effect on the benthos, either through scouring of the substratum or exposure to increased current velocities, or through a combination of both. The scouring effect of the outflow from the Lakes decreased the mud fraction of the substratum on mudflats and in dredged channels, which was followed by a decrease in species densities and diversity in these habitats. Beam trawling however, did not appear to alter the substratum or have an effect on the benthos. The colonisation of the Link Canal indicated that the major benthic species are pioneering species capable of utilising a wide range of substratum types. Considering the history of sediment disturbance in the Narrows through dredging, beam trawling

and floods, these species appear to be resilient and form a persistent community.

The dominance of pioneering benthic species, comprising small, opportunistic tube building polychaetes, amphipods and tanaids, on the central Great Barrier Reef continental shelf was apparently maintained by physical disturbances such as beam trawling and cyclones (Algoni, 1989). The capitellid *Capitella capitata* has been described as an indicator of newly disturbed and polluted substrata on the north-eastern seaboard of the United States and off the Norwegian coast (Gray, 1981). It was noted that the numerical dominance of *C. capitata* in disturbed or polluted substrata was temporary, and that other polychaete species became dominant over time. The apparent persistence of capitellids as the numerically dominant polychaete in the Narrows suggests that a succession of polychaetes and possibly other benthic organisms is being prevented, whether by sediment disturbance or variations in salinity.

7.2 Benthic Adaptations to Sediment Disturbance

Estuaries are characterised by a naturally fluctuating physical environment. These disturbances include removal by floods, altered substratum characteristics through scouring and deposition, and changes in larval transport through

altered circulation patterns. Estuarine benthic habitats are consequently characterised by a low species diversity and tend to be dominated by stress tolerant, short lived opportunistic organisms (Schaffner, 1990).

Increased attention is being focused on the processes involved in enabling benthic organisms to colonise disturbed environments (Schaffner, 1990). Gray (1981) postulated that *C.capitata* is able to colonise disturbed substrata because it is a classical r-selected species. Its rapid reproduction rate and ability to reproduce by both benthic and planktonic larvae would increase the rate at which it could recolonise disturbed substrata (Gray, 1981). The little information available on polychaete larval transport mechanisms in estuaries suggests that their dispersal within an estuary is passive (Stancyk and Feller, 1986). Infaunal polychaetes in Mission Bay, California, were reported to brood their larvae, suggesting that localised increases in density are an important factor in colonising disturbed substrata (Levin, 1984, in Stancyk and Feller, 1986).

There is increasing evidence to suggest that biogenic stabilisation of disturbed substrata is an important factor in structuring benthic communities. Studies in Chesapeake Bay, USA, determined that polychaete tubes and burrows modified the substratum (Schaffner, 1990). An increased

diversity of smaller infaunal species was associated with the larger tube building polychaete *Chaetopterus variopedatus* in fine grained sediments. It was suggested that habitat availability was increased for species requiring a firmer substratum.

A positive relationship between the abundance of chironomid larvae and oligochaete worms, and the organic content of the substratum was noted in the Norfolk Broads, UK (Moss and Timms, 1989). Organic matter was thought to stabilise the substratum because of its fibrous nature and by facilitating tube building by infaunal species.

Laboratory experiments on two estuarine burrowing invertebrates, the amphipod *Corophium volutator* and the polychaete *Nereis diversicolor*, revealed that they stabilised sediments by producing secretions which bound the particles together (Meadows, Tait and Hussain, 1990). The secretions were found to comprise threads 1-2 microns long, which were used to construct burrows in the upper 15 cm of the sediment. These results imply that these species are able to increase the stability of sediments in the natural situation, increasing resistance to erosion by currents and stabilising disturbed substrata.

7.3 Conclusion

It would appear from this study that the macrobenthos of the Narrows is resilient and able to recover from disturbance provided that the benthic environment is not altered in the long term. While increased current velocities and changes in the nature of the substratum during floods reduced species richness and densities, the disturbance was not permanent, and complete recovery of the benthos would be probable. Beam trawling did not have any apparent impact on the benthos or any noticeable effect on the substratum however, and it would appear that the benthos is well adapted to small scale disturbances. The creation of channels through dredging appeared to have altered the benthic environment in the long term by providing a focus for currents and maintaining the dredged channels. The occurrence of the numerically dominant species in the dredged channels at a minimum of an order of magnitude less than the mudflats indicated that the channels are unfavourable habitats.

The apparent colonisation of the artificial Link Canal by the major mudflats species indicated the pioneering nature of the benthos in the Narrows and suggested that these organisms have some ability to stabilise disturbed substrata. Increasing evidence in the literature for the ability of benthic species to ameliorate disturbed substrata

suggests that the presence of a particular organism or organisms in disturbed areas is important, and that their presence will determine the rate and extent of recovery. It thus becomes important to investigate the tolerance and physiological reactions of the major species in the Narrows to disturbance, and to determine the role of each species in the recovery process, at both the species and community levels.

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