Report to:

Hornsby Council

Berowra Creek Estuary Process Study
Aquatic Ecological Investigations

FINAL

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SUMMARY

Investigations of aquatic biota were undertaken by The Ecology Lab Pty Ltd in November, 1997 as part of the Berowra Creek Estuary Process Study for Hornsby Council, under contract to Manly Hydraulics Laboratory. This report presents a broad overview of the distribution and abundance of sampled components of aquatic biota. The following components of the estuarine ecosystem were studied:

i) the biota of mangroves,
ii) the macrofauna of subtidal sediments and
iii) the fish and mobile invertebrates in seagrass beds and deep holes.

Quantitative, replicated sampling was done on a snapshot basis to allow a detailed analysis of a variety of habitats during a single period. Temporal sampling was not done as it would have limited the extent of sampling to one or two habitats in order to stay within the study budget. Data were analysed using multivariate and univariate techniques. Previous field investigations had mapped the locations of seagrass beds and noted variations in their distribution and abundance over the previous 20 years. Sampling sites ranged from near Crosslands in the upper section of the creek to Bar Island near the confluence with the Hawkesbury River, and extended into the lower reaches of Marramarra Creek.

Mangroves

Biota of intertidal mangroves were sampled for epifauna (plants and animals living on the surface of mangrove mud, trees and aerial roots (pneumatophores)) and infauna (animals living in the mangrove mud). In addition, important features of the mangrove habitat were recorded at each site.

The assemblage of epifaunal animals consisted of six species of snail, with only two common species (*Assiminea tasmanica* and *Salinator solida*). Statistical analyses showed that, while epifauna was variable from place to place, there was a tendency for more species, more individuals and more *S. solida* to occur in Big Bay, in the lower section of the creek. However, there was no relationship between the abundant species of snail and habitat characteristics such as the height of the mangrove trees, the proportion of sand in the muddy substratum or the other types of plants present.

Infauna from mangrove habitats were sampled by collecting a fixed area and depth of mud, and removing and identifying the animals present. Over 1,000 invertebrates were collected, mainly snails, bivalve molluscs and isopods (marine slaters). In contrast to epifaunal samples, there was no obvious trend in the abundance of animals or numbers of species present along the creek, with each site varying substantially.

Invertebrates in Muddy Subtidal Sediments

Muddy sediments in shallow (1-2 m) and deep (> 10 m) areas of Berowra Creek were sampled using a grab deployed from a small boat. A subset of the deep hole habitats present in the main channel of the creek were sampled: two were in the lower section of the creek and two were in the middle section near Calabash Bay. Over 1,800 invertebrates were collected, mainly polychaete worms, crustaceans (amphipods, isopods, crabs and shrimps), and molluscs. Statistical analyses showed that deep holes differed from shallow muddy habitats and that holes in the lower section were different from holes in the middle section

of the creek. One abundant polychaete worm collected is known to prefer muddy sediments in areas of the Hawkesbury River with similar levels of salinity to those measured in the lower section of Berowra Creek. Overall, the deep holes support a relatively diverse and abundant invertebrate fauna and may fulfil an important ecological function as a refuge for macroinvertebrates. Variations in the abundance of benthic invertebrates in deep holes may be related to variations in water quality, particularly to periodic low dissolved oxygen levels found at the bottom of the holes.

Invertebrates in Sandy Subtidal Sediments

Samples of invertebrates living in shallow (< 2m) sandy sediment were taken from near Calna Creek downstream onto Marramarra Creek. The most common groups found were molluscs (mainly a small pipi-like deposit-feeding bivalve *Sanguineolaria donacoides),* polychaete worms (mainly in the families Nephtyidae and Trichobranchidae) and crustacean amphipods. Assemblages of animals varied statistically at each site, but samples from the lower part of the creek were more similar to each other than to samples from further upstream. There tended to be more molluscs and crustaceans in middle and upper creek sediments and more polychaetes in the lower sections of the creek. The dominant invertebrate in sediments near Calabash Bay was the filter-feeding bivalve, *Sanguineolaria donacoides.* This species may be abundant here due to the generally high levels of phyto- and zooplankton in this part of the creek which may provide it with food in the form of detritus.

Fish and Mobile Invertebrates

Fish and mobile invertebrates (prawns and crabs) were sampled from seagrass beds using seine nets. A total of 18 samples were taken, from near Calna Creek, Calabash Creek and in Marramarra Creek.

A total of 17,854 animals were collected: 29 species of fish, 5 species of crustaceans and 1 species of mollusc. The assemblages at each site differed significantly, mainly due to the presence of flat-headed gudgeons (*Philypnodon grandiceps*) in the upper creek and large numbers of Tamar River gobies (*Favonogobius tamarensis*) in the lower creek. The former species occurs in fresh and brackish water and the latter prefers more saline habitats. The relative distribution of these two species may be a good indicator of short and long-term changes in the pattern of salinity in the Berowra Creek system. The large variations in the assemblages of fish in different seagrass beds found in this study are consistent with previous studies in other estuaries, where it has been hypothesised that the distance of the seagrass bed from the mouth of the estuary has a great influence on the assemblage of fish present.

Sampling was also done in deep holes using gill nets. Two holes were sampled in the lower creek and two in the middle section near Calabash Bay. For comparison gill nets were deployed in nearby shallow areas. A total of 63 animals comprising 14 species were collected, the most common fish being large-tooth flounder (*Pseudorhombus arsius*), flat-tail mullet (*Liza argentea*) and silver biddy (*Gerres subfasciatus*). Neither the assemblage of fish present or the average number present varied significantly between shallow and deep locations, indicating that at the time of sampling, deep holes were being used in much the same manner by fish as shallow areas. Anecdotal evidence suggests that fish are found in deep holes after rainfall, suggesting that they may be using deep holes as a refuge from physical changes associated with flooding. Fish may use deep holes during or after floods to remain in the higher salinity environment they prefer, or to avoid the fast surface water currents. The data on benthic invertebrates in deep holes suggests that in addition to providing a refuge from changes to their physical environment, fish would also have appropriate food to eat while in deep holes.

Overview

Berowra Creek is a dynamic aquatic system with large variations in physical factors such as salinity gradient, currents, sediment type and bottom topography, all factors that are known to influence the distribution of aquatic biota in estuaries.

The results presented here indicate that the species, assemblages and abundances of aquatic biota in Berowra Creek are similar to those from similar habitats in other estuaries in the region. Although the overall diversity recorded in various habitats was similar to that found in comparable estuaries, there was a tendency for assemblages to be dominated by a few taxa (eg two species of snail in mangrove epifauna, a snail and a bivalve in mangrove infauna, a bivalve and two species of polychaete worms in sandy benthos, two species of polychaetes in muddy benthos, two species of gobies in seagrass beds and three species of fish caught in gill nets). Future changes in the distribution and abundance of these species would be likely to reflect overall changes in the estuary, and therefore should be considered should any biotic monitoring program be undertaken. Currently there are only few indications that some species may be influenced by the poor water quality that have been common in some sections of the estuary.

Importantly, these results highlight the variable nature of the biota sampled. All of the variations recorded could be potentially explained in the context of the dynamic nature of this tidally influenced estuary. They form a valuable quantitative baseline against which the future condition of the estuarine biota can be measured.

There are very few data on the epifauna and infauna of mangrove habitats to which our results can be compared. Patterns in the distribution and abundance of epifauna may be explained by the nature and extent of their habitat, although this is not predictable from information on the physical features of the habitat. Mangrove areas in Big Bay have expanded over the past 50 years, support an abundant epifaunal community, and the area may represent a habitat of regional significance.

Results from other components of the biota were consistent with previously documented patterns in distribution and abundance. Although variable, some bottom-dwelling animals had distributions that could be related to factors considered important in estuaries such as salinity and type of sediment. The species of animals collected in the benthos had been recorded previously in the nearby Hawkesbury River. Assemblages of fish in seagrass beds were variable, as has been found previously in estuaries. Seagrass beds in Berowra Creek support juveniles of economically important species targeted by commercial and recreational fishers. Fish abundances and assemblages in seagrass beds resembled those from comparable habitats in other estuaries in the central part of New South Wales.

Some light has been shed on the potential role and function of the naturally-occurring deep holes in the creek. In contrast to initial impressions, the holes support a reasonably diverse and abundant assemblage of benthic fauna that was not significantly different to similar adjacent habitats. Although fish did not appear to be utilising deep holes differently from nearby shallow areas at the time of sampling, they have the potential to serve as an important refuge, providing both food and shelter during floods. Information from other specialist studies suggest that although the holes may undergo periods of anoxia a depth, these occurrences may not be common or long in duration. Hence, the deep holes are probably valuable habitats that have several important functions for the biota of the creek.

1.0 INTRODUCTION

1.1 What is an Estuary Process Study?

An Estuary Process Study is the third step of an 8 step Estuary Management Process developed by the NSW Government and implemented under the Estuary Management Program administrated by the Public Works and Services Department. It follows on from the assembly of all relevant available information on the estuary in question and is a precursor to defining management objectives, options and impacts which are compiled into an Estuary Management Plan (Estuary Management Manual, 1992). To prepare the management plan and oversee the process, Hornsby Council appointed the Berowra Creek Estuary Management Committee. They issued a brief for an Estuary Process Study for Berowra Creek which included the larger catchment area lying within their jurisdiction.

1.2 The Study Team

A team of environmental scientists with a variety of technical skills was commissioned by Hornsby Shire Council to undertake the Berowra Creek Estuary Process Study. The team was led by Manly Hydraulics Laboratory (NSW Department of Public Works and Services) in conjunction with The Ecology Lab Pty Ltd, Coastal and Marine Geosciences, Nelson Consulting, Water Research Laboratory and AWT Ensight. The Ecology Lab Pty Ltd sub contracted the services of Connell Wagner to compile and assess data on terrestrial flora and fauna and floral communities fringing the creek.

The plan of study for the Berowra Creek Estuary Process Study accepted by the Estuary Management Committee consisted of the following elements:

- The compilation, review and synthesis of available information;
- Conducting workshops to present findings of review and propose further work required;
- Undertaking separate technical investigations of the key estuarine processes of sedimentology, hydrology and aquatic ecology, to be presented as separate technical reports;
- Liaising with council, technical groups and other researchers to keep abreast of issues as they develop during the study period;
- Synthesise results of specialist reports and present a final summary report that includes recommendations for subsequent studies required to develop a management plan.

The role of The Ecology Lab Pty Ltd in the Berowra Creek Estuary Process Study was to develop an understanding of:

"Ecological and biological processes and characteristics, covering flora and fauna, species, composition and distribution, productivity and health of ecosystems, range and sensitivity of habitats, and rare and endangered species." (Berowra Creek Estuary Process Study Brief, page 3).

This report presents the findings of the specialist investigations of aquatic ecological components and processes in Berowra Creek. Interpretation of these results with respect to other concurrent technical studies will be presented the in final summary report referred to above. The roles of important estuarine processes identified in this technical report will be interpreted for the purposes of assisting management in the final report.

1.3 Stage 1: Review of Existing Information

Although some information on flora and fauna in Berowra Creek had been compiled by Hornsby Council (Johnson, 1996), a review and interpretation of relevant existing information was undertaken by the study team. This review was presented to Hornsby Council in a report titled "Berowra Creek Estuary Process Study – Review and Interpretation of Existing Data (Draft DPWS Report No. 97031, 30 March, 1998), referred hereafter as "the review document".

The Ecology Lab Pty Ltd in conjunction with Mitchell McCotter updated and reviewed existing information on flora and fauna and presented a summary of processes likely to be important to the aquatic ecology of the estuary based on that information. The review and interpretation of existing data identified many gaps in existing information. After consultation with the technical advisory panel set up to advise the study team, a specific study plan was presented to the Estuary Management Committee. The rationale for the agreed work schedule is summarised below.

1.4 Rationale for Study of Biology and Biological Processes

1.4.1 Terrestrial and Fringing Flora

As part of the data compilation and review, a review of floral communities in the catchment was undertaken. This presented a synthesised version of floral communities previously mapped in other studies. The overview concluded that weed species were widespread in a few areas (particularly those cleared for dairying) despite signs of native regeneration. Twenty-four significant plant species were identified in the catchment, with two species of particular significance due to the limited occurrence of their preferred habitats.

A foreshore vegetation map was created focussing on vegetation types present along the shore up to (approximately) the ridgeline above the main channel and up to 1 km up creeks and gullies. This map was updated by ground truthing in April 1997 and weed infestations were mapped.

It was concluded that the updated information formed an adequate base from which management decisions could be made. The Estuary Management Committee agreed with the recommendation of the study team that no further data gathering was required for terrestrial and fringing floral communities.

1.4.2 Aquatic Flora

Seagrasses, Saltmarshes and Mangroves

The existing information on the distribution of seagrass, saltmarsh and mangroves was compiled and updated using aerial photos and ground truthing. These were presented in the review document in GIS compatible map format. Long term (50 years) distribution data were available for mangroves and saltmarshes, based on interpretation of aerial photographs (Williams and Watford, 1997). Only relatively recent data (app. 20 years) were available for the distribution of seagrasses (West *et al.*, 1985). Distribution data for seagrasses and saltmarshes were ground truthed by The Ecology Lab Pty Ltd in April, 1997 and detailed results reported in the review document.

As a result of these investigations the study team recommended that no further information on the distribution of these aquatic floral communities was required at the present time. Based on documented changes in distributions of aquatic flora in the long term (e.g. the increase in the distribution and abundance of mangroves) and shorter term (e.g. reduction in abundance of seagrasses), recommendations were made to further investigate their roles in the estuary ecosystem (see Aquatic Fauna section below).

Macroalgae

The review document noted that information on the occurrence of rafting macroalgae was of anecdotal nature only. As it appears to occur in restricted areas of the estuary only during warmer months, it was recommended that council (possibly in conjunction with other parties such as Streamwatch) initiate record keeping procedures that would allow the sporadic occurrence of the algae to be correlated with other physico-chemical data already being routinely collected by Council. The study team proposed, and the Estuary Management Committee agreed that specific studies on rafting macroalgae would not be undertaken as part of the Estuary Process Study.

Phytoplankton and Zooplankton

These two groups are considered together here because they both consist of microscopic, floating organisms and the sampling techniques required to study their ecology and biology are generally similar.

The review document identified some recent information on phytoplankton dynamics in Berowra Creek (Senogles, 1996), but little information was available on zooplankton. Initially, it was decided not to undertake specific studies of phyto- and zooplankton dynamics in the estuary, due to limitations in funding. However, during the course of the project, additional funding was made available by DLWC and Hornsby Council to undertake a more detailed water quality monitoring study which included phyto- and zooplankton dynamics. This study was carried out by combined team comprising personnel from Manly Hydraulics Laboratory, DLWC and Hornsby Council. The results of this study will be presented in a separate technical report, and considered in the final, synthetic report.

1.4.3 Terrestrial Fauna

The available information on the distribution and abundance of terrestrial fauna within the Berowra Creek catchment was summarised in the review document. Briefly, Berowra catchment has relatively small populations of mammal but large populations of reptiles, birds and frogs compared to other bushland areas on Hawkesbury Sandstone. A review of the NPWS Wildlife Atlas identified nine threatened mammal species which are likely to occur in the catchment. The existing information related to threatened fauna species was considered adequate for the preparation of management plans. On that basis the study team recommended that no further specific information be collected on the terrestrial fauna of the Berowra Creek catchment.

1.4.4 Aquatic Fauna

Fauna of Catchment Creeks

The review document summarised the findings of several recent studies on the fauna of the freshwater section of the catchment. Long term surveys of macroinvertebrates showed considerable variability between sites, suggesting some influence of transient pollution. SIGNAL index values, a measure of chemical pollution, indicated that freshwater habitats high in the catchment were severely polluted and/or severely degraded. Fish assemblages in the upper freshwater sections consisted mainly of eels, gudgeons and mosquitofish, and were scarce in Calna Creek upstream of the Hornsby Heights STP. Because the long term study of macroinvertebrates in 19 streams was continuing, the study team recommended that no specific studies of the fauna of catchment creeks be undertaken as part of the Estuary Process Study.

Waterbirds

Consultation with NPWS indicated that Berowra Creek was not considered of local or regional significance as a key waterbird habitat, despite the popularity of the mudflats of Kimmerikong and Big Bay as feeding grounds for some protected species. Therefore, no specific studies on waterbirds were recommended to be undertaken as part of the Estuary Process Study.

Estuarine Fauna

Oysters

The review document reviewed and updated the map of oyster leases in the creek. Examination of the distribution of oyster leases in the creek (NSW Fisheries data) showed no overall pattern of change in use over the last 25 years, despite anecdotal reports that oysters were previously farmed further upstream than at present. NSW Fisheries data do not allow for comparison of production of oyster leases at different locations within the estuary.

Benthic Communities

No comprehensive surveys of the benthos in Berowra Creek were found, although some limited data were available from student studies and a limited survey done in 1995. No data were available for habitats such as deep holes and intertidal mangroves. The Estuary Management Committee accepted the recommendation that a broad scale, habitat-based quantitative survey of benthos be undertaken as part of the Estuary Process Study, and agreed that it should include the benthos of deep holes and mangroves.

The information available on the fauna of hard substrata in the creek confirm a general estuarine pattern of relatively few individuals and species present compared to open coastal hard substrata habitats. No further studies of the fauna of hard substrata was proposed for the present study.

Fish Communities
Information on the abundances of fish was available for selected habitats only. However, it was clear that the estuary provides habitat for a variety of species, many of which have importance in the recreational and commercial fishing industries. The Estuary Management Committee agreed with the recommendation that an estuary-wide quantitative survey should be undertaken as part of the Estuary Process Study and that economically important fish and crustacean species should be identified. In particular, the survey should include examining the fish fauna of the deep holes in the estuary.

The review document listed the incidences of fish kills in the estuary that have been recorded by NSW Fisheries. In the few cases where it was possible to do so, appropriate data on water quality were examined for the reported fish kills. Low levels of dissolved oxygen at the creek bottom were coincident with two documented fish kills, and in one incident elevated chlorophyll *a* levels were also recorded. Because fish kills occur infrequently and sporadically in the estuary, no specific studies were nominated as part of the Estuary Process Study. Rather it was thought that improved understanding of the distribution of fish, water quality processes and hydrological processes gained from other parts of the Estuary Process Study would be helpful in determining the causes of fish kills.

Recreational Fishing
Although Berowra Creek has been and continues to be a popular fishing location, no estimates are available of the magnitude of the fishing pressure in the estuary. The study team recommended that, due to other constraints of the Estuary Process Study, this issue would be best examined in a study to be undertaken separately from the Estuary Process Study.

Commercial Fishing
Commercial fishers target about a dozen species of fish, crabs and prawns in Berowra Creek at different times and locations in the creek. The review document concluded that inadequate information on commercial fishing was available. This is largely due to the method for recording commercial fish data, which does not distinguish commercial catches from Berowra Creek as separate from the greater Hawkesbury – Nepean catchment. The study team recommended that a survey of commercial fishing activities was needed, but that it should be undertaken as a separate study from the present Estuary Process Study.

1.5 Definition of Estuarine Processes

It is important to define what estuarine processes mean, as there is no specific definition given in the Estuary Management Manual of what a "process" is and what it encompasses. For the purposes of this study, The Ecology Lab Pty Ltd used an operational definition by describing the various estuary components and then assessing the linkages between them. Thus, both the estuary components themselves and the linkages between them were considered to form estuary processes. For instance, the release of nutrients from the sediment to the water column and the migration of fish between different habitats are considered processes that link estuary components together. Such an operational definition meets the requirements of an estuary process study as stated in the Estuary Management Manual to "define baseline conditions of the various estuary processes and the interactions between them".

Ecological estuarine processes important to the aquatic ecology of the Berowra Creek Estuary will largely be inferred from the information on estuary components nominated for study in the previous section. Although this is the only method available for the present study, it is important to point out that there are some limitations to this approach. For instance, the review of estuary components provided observations on patterns such as occurrence of phytoplankton blooms that are often confined to the middle section of estuary. There could be several alternative processes to explain such a pattern such as effect of tidal exchange in the middle section of the estuary on water circulation or, the poor quality of runoff water in that section of the estuary. Without direct tests of these alternate explanations or 'models' both remain valid as processes which could influence the development and distribution of phytoplankton blooms in Berowra Creek. The observation of a pattern may suggest that a particular process is occurring but it does not prove that this is so. Unfortunately, direct studies examining processes are few in Berowra Creek Estuary, and can be costly and time consuming to undertake. Therefore, estuarine processes or the linkages between estuary components are largely speculative and should be used as a guide to what ecological processes are important in the Berowra Creek Estuary and point to specific further studies which should be undertaken to understand the ecological system as a whole.

1.6 General Approach for This Study

In keeping with the objectives of an Estuary Process study, the focus of the present investigations into aquatic ecological processes was to provide an overview of the species, populations and assemblages of aquatic fauna in various habitats in Berowra Creek. We chose to sample in a rigorous, quantitative manner that would provide a robust baseline against which future changes in the creek could be compared. The habitat-based approach allowed us to collect data from a variety of habitats, some of which had not been sampled previously. Our sampling was conducted in late spring. It occurred after baseline information on the distribution of surface sediments had been collected, giving us a good overview of the distribution of sediment types on which to base our sampling design. Our work coincided with that of other specialists (water quality and hydrodynamics), allowing us to use a wider range of information to explore links between physical and biological components of the creek system. However, this focus precluded the inclusion of a study of temporal variation in aquatic fauna, as the study was necessarily restricted by both time and funds. While a more complete view of the dynamics of Berowra Creek would be gained from an understanding of how patterns of distribution and abundance change through time, this study provides the necessary first step by providing a quantitative overview of important biotic components.

2.0 STUDY METHODS

2.1 General Study Methods

The broad approach in this study was to compare the composition, distribution and abundance of various components of the fauna from a variety of habitats found in Berowra Creek. Generally, the null hypotheses being tested were of no difference among sampling places in Berowra Creek in:

iv) the biota of mangroves,
v) the macrofauna of subtidal sediments and
vi) the fish and mobile invertebrates in seagrass beds and deep holes.

The sampling design (the number and arrangement of samples taken along Berowra Creek) for each component of the fauna is given in Table 1 and the sampling methodology (the way the samples were collected) is described in subsequent sections.

The data collected were analysed using two main statistical procedures, multivariate and univariate analyses. These are outlined in Appendix 1, but are described briefly as follows. Multivariate procedures were used to examine differences among sampling locations, sites and depths (often termed treatments) using the rank abundance of taxa within the assemblage of all animals considered. We used the PRIMER statistical programme, with routines that allowed us to: 1) evaluate statistical differences among treatments (ANOSIM procedure); 2) view graphically the relationship among treatments (MDS); and 3) determine which taxa contributed most to observed differences among treatments (SIMPER). In all cases, an index of similarity (known as the Bray-Curtis Index) was used to ordinate the different treatments considered.

Univariate procedures were used to compare differences among sampling places using the number of taxa, the total abundance and the abundance of selected taxa. The statistical test used was analysis of variance (ANOVA), with supplementary tests used to evaluate the assumptions of ANOVA (Cochran's Test) and to compare treatment means for significant terms in the ANOVA (Student Newman Keuls Tests - SNK). See Appendix 1 for more details and refer to Underwood (1997) for a more detailed treatment of the topic.

For the purpose of examining spatial patterns along Berowra Creek, the waterway was divided up into 4 arbitrary sections, referred to in this report as Upper, Mid, Lower and Lower West. The boundaries of these sections are drawn on Figures 1, 2, 3.

2.2 Biota of Intertidal Mangroves

Five locations along Berowra Creek containing large stands of mangrove were selected to examine spatial patterns in the distribution and abundance of:

i) the epifauna living on the surface of the mud and
ii) the infauna living in the mud, within the mangrove forest.

The locations were Calna Creek (Upper section), Calabash Creek and Joe Crafts Bay (Middle section), Kimmerikong Bay (Lower section) and Big Bay (Lower West section) (Figure 1).

Within each location, 3 sites approximately 3 m x 3m in area and 20 m apart, within the mid-mangrove zone (*sensu* Warren, 1987 - under the forest canopy) were sampled.

At each site a GPS fix was taken to enable sites to be accurately re-located in the future if required. In addition, at each site the characteristics of the habitat including the dominant plant species, heights of the canopy, the presence of an understorey, description of the mud, topography and relative abundance of species of crabs were also recorded.

2.2.1 Epifauna of Mangroves

Within each site, six haphazardly placed 1 m^2 quadrats were sampled for the number of:
i) crab burrows greater than 5 mm in diameter,
ii) pneumatophores (peg roots of mangroves), and
iii) mangrove saplings and seeds.
In addition, the percentage cover of algae, leaf litter and refuse, was estimated from one hundred regular points within the quadrat using the point-intercept method. Within each of these 1 m^2 quadrats, a smaller area of 0.25 m^2 was sampled for the abundance of fauna such as snails, oysters and limpets.

Mangrove epifauna was sampled during low tides on 10 – 13 December, 1997.

2.2.2 Infauna of Mangroves

In 2 of the 6 large quadrats used to sample epifauna, a random 0.01 m^2 sample of mud and leaf litter was collected down to the nutritive root layer (approximately 2 cm depth) and preserved in 7 % formalin. In the laboratory, each sample was sieved through 0.5 mm mesh. Infauna were sorted and identified using a binocular microscope (x16 magnification). Animals were identified to the lowest practicable level, for example, to family for polychaetes and insect larvae, to morpho-species for crustaceans and species for molluscs. Infauna were then preserved in 70% alcohol for future reference if required.

Mangrove infauna was sampled during low tides on 10 – 13 November, 1997.

2.3 Macrofauna of Benthic Sediments

The size of sediment has been demonstrated in other estuarine studies to influence the composition, abundance and distribution of macrofauna (e.g. Whitlatch, 1981). For this reason, we proposed a stratified sampling design *i.e.* sampling muddy sediments and sandy sediments separately, to avoid confounding spatial patterns with the size of the sediment. The initial selection of potential sampling locations for macrofauna in benthic sediments in Berowra Creek was based on sedimentology maps provided by J. Hudson. This map was produced to display the results of particle size analysis of surface sediment samples taken in May, 1997 (see Figure 11 presented in Hudson, 1998). Inspection in the field by The Ecology

Lab, however, revealed minor discrepancies such as some shallow areas mapped as mud were more like muddy sand. The sampling design for macrofauna in muddy sediments was different to that of macrofauna in sandy sediments due to:
i) the limited number of sampling sites in muddy sediments in shallow water and
ii) the presence in deep holes of muddy sediments only.
In the field, every effort was made to ensure that the size of sediments were reasonably consistent among samples representing both mud and sand habitats.

Benthic samples were collected on 4 and 5 November, 1997. Samples were collected using a Van Veen grab operated from a small punt. Samples were initially emptied into plastic bags. After all samples had been collected, the samples were then sieved through a 1 mm mesh screen and preserved in 7% buffered formalin containing Rose Bengal crystals which stains the animals red, making them easier to sort from the remaining sediments. Samples were returned to the laboratory and animals were removed from the sediment and identified to the lowest practicable taxonomic level

2.3.1 Muddy Subtidal Sediments

Samples from muddy sediments were collected from deep holes (approximately 9 m and 16 m deep) and adjacent shallow areas (2 m deep) from 2 locations within Berowra Creek, Mid and Lower West (Figure 1). Within each location, 2 sites for each depth were sampled and four replicate grabs were taken at each sampling site, giving a total of 32 samples.

2.3.2 Sandy Subtidal Sediments

Four replicate grab samples from sandy sediments were collected from three sites within each of four locations within Berowra Creek; Upper, Mid, Lower and Lower West, giving a total of 48 samples (Figure 2).

2.4 Fish and Mobile Invertebrates

Two habitats were examined for their composition, distribution and abundance of fish and mobile invertebrates. Different methods and hence different sampling designs were used in each habitat. Seagrass beds were sampled using seine nets, which require nearby shoreline to haul out the net. To examine differences in fish and mobile invertebrate abundance and assemblages in deep holes compared to similar shallow areas, gill nets were set at the bottom of deep holes and over similar, nearby shallow areas characterised by muddy substrata.

2.4.1 In Seagrass Beds

A 10 m long seine net, approximately 1 m deep with 2 mm mesh, was used to sample fish and mobile invertebrates in dense *Zostera* beds from the Upper, Mid and Lower West locations along Berowra Creek (the Lower location did not have any *Zostera*). Three replicate seine hauls were done at each of two sites within each location, giving a total of 18 samples. The location of these sampling sites is given in Figure 3. All samples were preserved in dilute formalin (10%) and returned to the laboratory for identification to the lowest practicable taxonomic level. Species of economic importance were also measured to the fork in the caudal fin (LCF).

Seagrass beds samples were sampled on 6 and 7 November, 1997.

2.4.2 In Deep Holes

Two gill nets were set at each site within the Mid and Lower West locations of Berowra Creek. At each location, two sites were in shallow areas with muddy substratum near a deep holes, and two were deep holes, giving a total of 16 replicates (Figure 3). The gill nets were set at the bottom of the each hole. The gill nets were 60 m long, comprised of 30-m panels of 65 and 100 mm mesh and approximately 1.8 m deep. Nets were laid for about 4 hours, and the catch from each net were identified, recorded and released in the field. Species of economic importance were also measured to the fork in the caudal fin (LCF).

Gill net samples were collected on 6 November, 1997.

Table 1. Summary of sampling designs for each component of the fauna sampled in Berowra Creek.

Faunal Component	number of ...				
	locations	depths	sites	replicates	samples
Biota of intertidal Mangroves					
a) epifauna (snails, oysters)	5	na	3	6	90
b) infauna (worms, bivalves, amphipods)	5	na	3	2	30
Macrofauna Benthic Sediments					
a) muddy sediments (worms, bivalves, amphipods)	2	2	2	4	32
b) sandy sediments (worms, bivalves, amphipods)	4	na	3	4	48
Fish and Mobile Invertebrates					
a) in seagrass beds (gobies, gudgeons, prawns)	3	na	2	3	18
b) in deep holes (mullet, flounder, crabs)	2	2	2	2	16

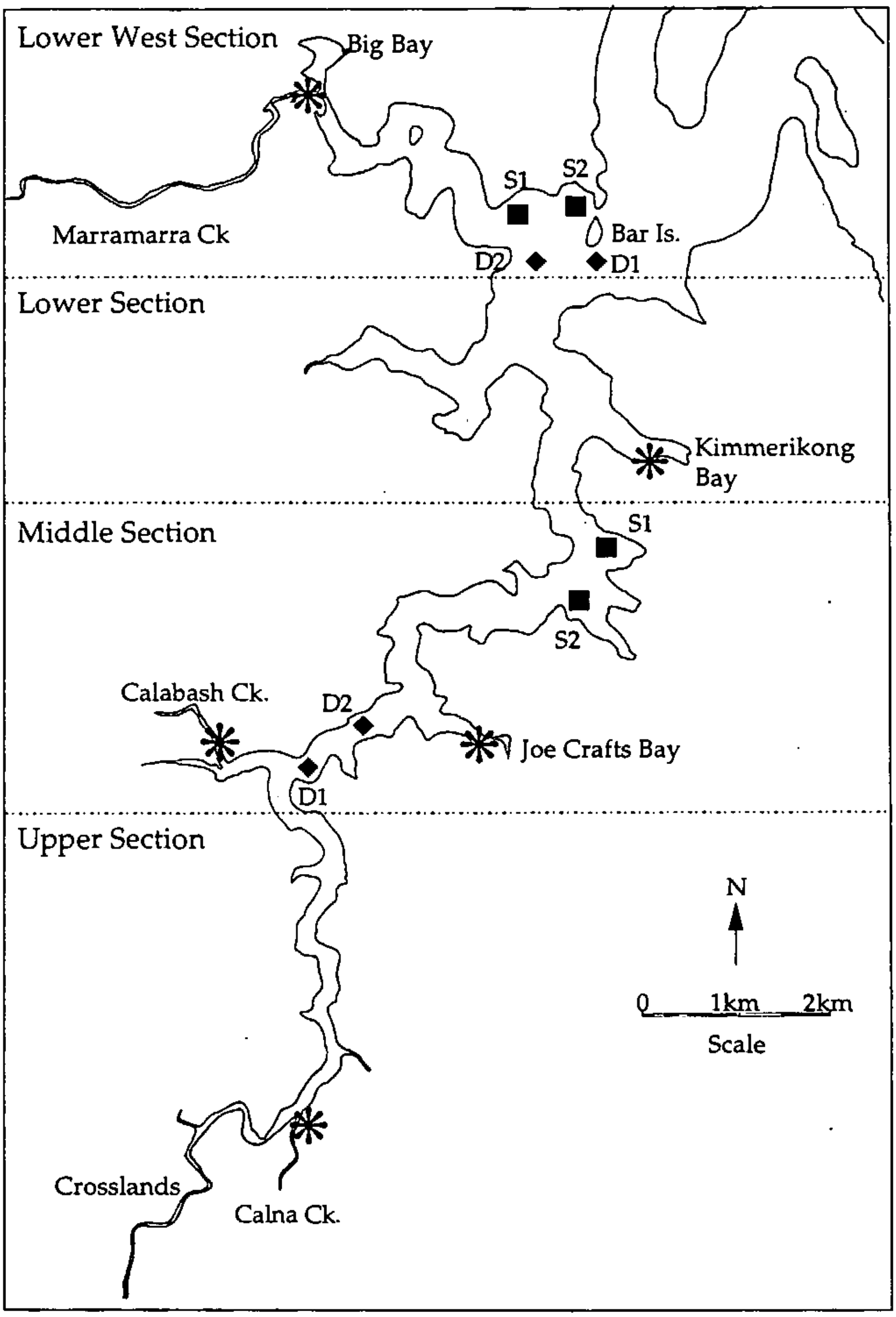


Figure 1. Mangrove sites (✻) and mud benthos sites (■ shallow, ◆ deep) located within Berowra Creek, November 1997.

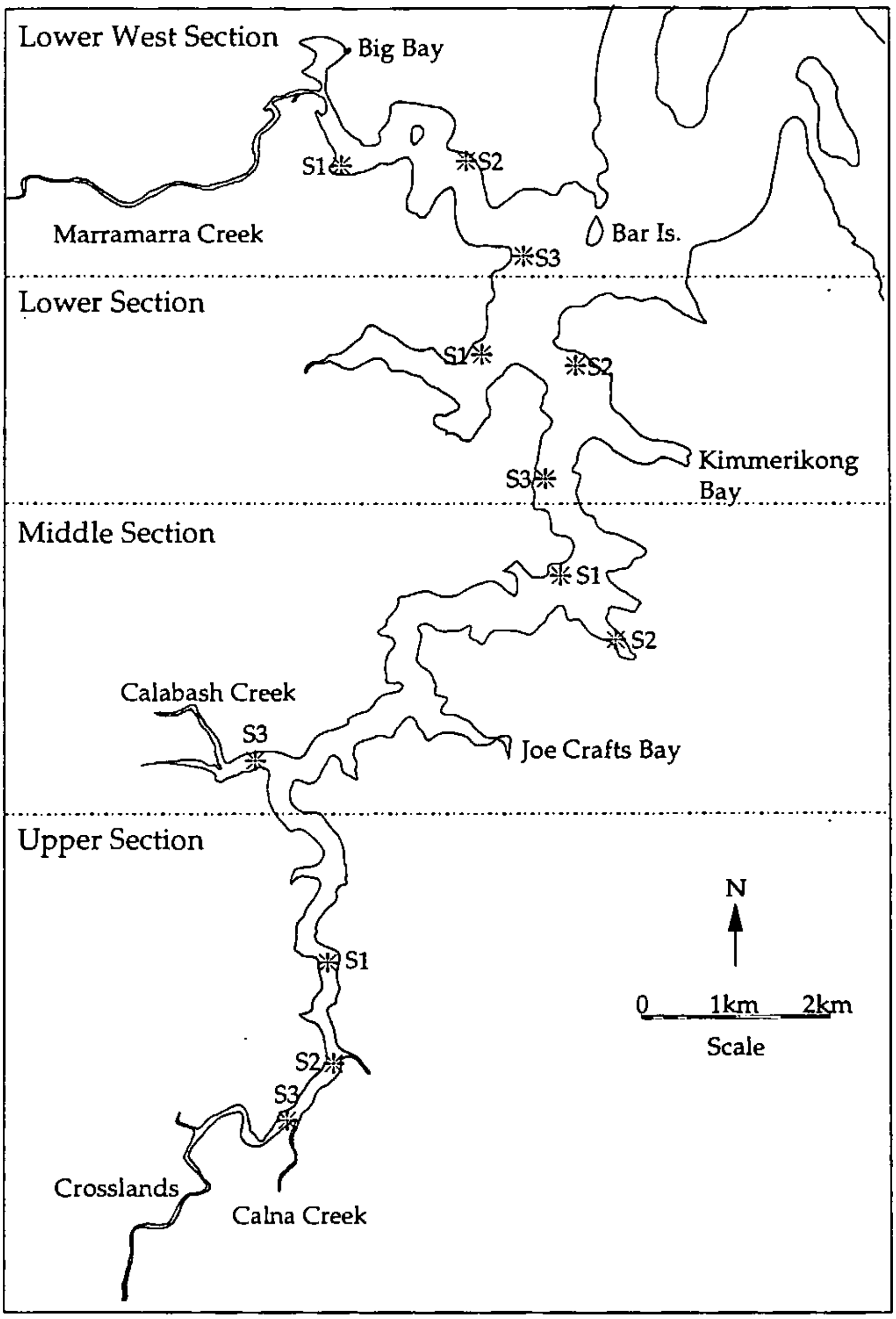


Figure 2. Sand benthos sites (⊛) located within Berowra Creek, November 1997.

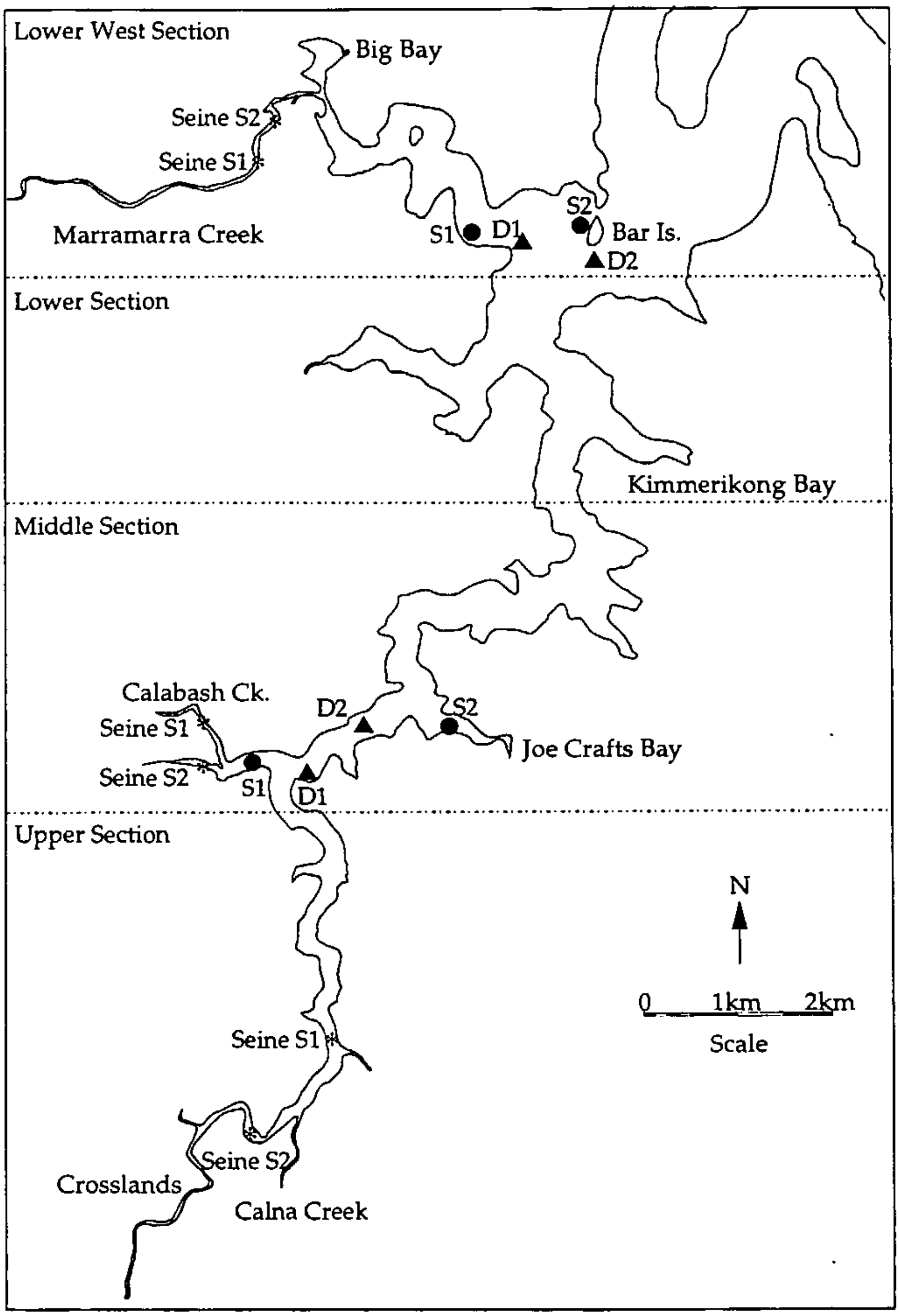


Figure 3. Gill net sites (● shallow, ▲ deep) and seagrass seining sites (*) within Berowra Creek, November 1997.

3.0 RESULTS

3.1 Biota of Intertidal Mangroves

Details of sites sampled are given in Appendix 2.

3.1.1 Epifauna

General Findings

The epifaunal assemblages of intertidal mangrove habitats in Berowra Creek consisted of 6 species of snail (Appendix 3). Of these, only 2 species, *Assiminea tasmanica* and *Salinator solida,* were found at all 5 sampling locations and they contributed 68% and 23% respectively to the total abundance. *Melosidula* sp. made up 7% of the total but only occurred in Big Bay. The remaining 3 species, *Bembicium nanum, Ophicardelus* sp. and *Tatea* sp., were uncommon, making up only 2% of the total abundance.

Analysis of Assemblages

Multivariate statistical analysis indicated that locations differed significantly in their assemblages of epifaunal snails, such that, the assemblage at Big Bay was different compared to all other locations which were, in turn, similar to each other (Table 2A). The 3 dimensional MDS plot demonstrates this by the clumping of samples from Big Bay which are separated from the clumping of samples from all other locations (Figure 4). The greater abundance of *Salinator solida* in Big Bay as well as the presence of *Melosidula* sp. only in Big Bay were the major contributors to the difference in assemblages between Big Bay and all other locations (Table 2B).

Analysis of Populations

The number of species of snail per quadrat and the total number of snails was greater at Big Bay compared to the other locations (Table 3, Figure 5 A,B,E). There was also significant variability at the smaller spatial scale of sites, for instance, the number of species varied among sites at Calabash Creek and Kimmerikong Bay and the total number of snails varied among sites at Calna Creek and Big Bay (Table 3, Figure 5A,B, E). Full details of the ANOVAs are given in Appendix 4. The most abundant snail, *Assiminea tasmanica,* varied greatly among sites within Calna Creek and Big Bay, overwhelming any differences at the larger spatial scale of locations (Table 3, Figure 5C). In contrast, the abundance of *Salinator solida* was fairly consistent among sites within each location, occurring in greater numbers in Big Bay compared to all other locations (Table 3, Figure 5D).

Relationship of Epifauna to Physical Characteristics

Characteristics of the habitat such as the cover of leaf litter and algae and the abundance of mangrove saplings, seeds, crab holes and pneumatophores varied significantly at both spatial scales of location and site (Table 3). Statistical analysis of the relationship between these characteristics and the abundance of *Assiminea tasmanica* and *Salinator solida* did not detect any significant correlations (Pearson Correlation Matrix, r ranged between -0.199 to 0.466, group-wide $\alpha > 0.05$).

3.1.2 Infauna

General Findings

A total of 1,117 infaunal animals representing 27 taxa were collected from mangrove habitats at 5 locations along Berowra Creek (Appendix 5). The most abundant taxa were 2 species of mollusc, *Tatea* sp. (snail) and *Arthritica helmsi* (bivalve) and the isopod crustacean, Isopod sp. A, representing 22%, 21.5% and 16% of the total abundance respectively.

Analysis of Assemblages

The assemblages of infauna in mangroves along Berowra Creek differed among locations but not at the smaller spatial scale of sites (Table 4A). Pair-wise comparisons between locations indicated that Big Bay differed from all other locations except Joe Crafts Bay and the assemblages at Calna Creek and Kimmerikong Bay differed (Table 4A). In the 3 dimensional MDS plot, however, these differences were not very clear, with the large stress value indicating the difficulty in representing the relationships among samples of infauna in 3 dimensions (Figure 6). Eleven taxa of infauna were ranked within the first 5 contributors to the dissimilarity between locations which was indicative of the complexity in spatial patterns of assemblages of infauna in mangroves (Table 4B). Furthermore, there were no consistent trends or obvious patterns in the contribution of taxa to the dissimilarity between the locations identified in the ANOSIM analysis (Table 4B).

Analysis of Populations

The number of taxa of infauna did not differ significantly among locations or sites, however, the number of taxa was highly variable, ranging between 2 and 9 per site on average (Appendix 6, Figure 7A, F). The total number of individual animals differed significantly among sites at Calna Creek (Appendix 6, Figure 7B, F). Again, total abundance was variable, ranging between 6 to 162 animals per site (Figure 7B, F).

The most abundant taxa, the snail *Tatea* sp., varied significantly among sites, due to the large difference among sites in Calna Bay with Site 3 having no *Tatea* sp. whereas Sites 1 and 2 had them in great abundance (Appendix 6, Figure 7C). Although *Tatea* sp. was the most abundant taxa, its distribution was limited primarily to Calna Creek (Figure 7C). The other 2 abundant taxa, the bivalve *Arthritica helmsi* and the crustacean Isopod sp. A, were more evenly distributed across the sampling locations (Figure 7D,E). The abundance of *Arthritica helmsi* did not differ among sites or locations whereas the abundance of Isopod sp. A was variable among sites at 3 locations: Calna Creek, Calabash Creek and Joe Crafts Bay. Note that for all 3 abundant taxa there was a trend of small abundance or absence from Kimmerikong Bay and Big Bay which largely explains the small total abundance at these locations (Figure 7).

Table 2. Results of multivariate analyses of assemblages of epifauna in mangroves at 5 locations along Berowra Creek.

A) ANOSIM test examining differences among locations. ns = not significant, * = significant at $p < 0.05$, ** = significant at $p < 0.005$ (adjusted alpha for multiple comparisons).

	Global R	Significance	Pairwise Tests R	Significance
Locations	0.486	*		
Calna Ck vs Calabash Ck			0.037	ns
Calna Ck vs Joe Crafts Bay			0.178	ns
Calna Ck vs Kimmerikong Bay			0.131	ns
Calna Ck vs Big Bay			0.724	**
Calabash Ck vs Joe Crafts Bay			0.232	ns
Calabash Ck vs Kimmerikong Bay			-0.063	ns
Calabash Ck vs Big Bay			0.637	**
Joe Crafts Bay vs Kimmerikong Bay			-0.016	ns
Joe Crafts Bay vs Big Bay			0.946	**
Kimmerikong Bay vs Big Bay			0.83	**

B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations. Location abbreviations are CN = Calna Ck, CB = Calabash Ck, JC = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

	Location									
Species	CN v CB	CN v JC	CN v KB	CN v BB	CB v JC	CB v KB	CB v BB	JC v KB	JC v BB	KB v BB
Bembicium nanum			3					2	5	5
Tatea rubiflaris	4	4	5	5						
Assiminea tasmanica	1	1	1	3	1	1	3	1	3	3
Ophicardelus sp.	3	3	4	4			4		4	4
Salinator solida	2	2	2	1	2	2	1	3	1	1
Melosidula sp.				2			2		2	2

Table 3. Summary of ANOVAs on the abundance of epifaunal snails and characteristics of the mangrove habitat at 3 sites at each of 5 locations along Berowra Creek. ns = not significant, * = significant at $p < 0.05$ and ** = significant at $p < 0.01$.

Variate Analysed	locations	sites
Epifaunal Snails:		
number of species	**	**
number of individuals	**	**
Assiminea tasmanica	ns	**
Salinator solida	**	ns
Characteristics of the Habitat:		
cover of leaf litter	**	ns
cover of algae	ns	**
number of mangrovesaplings	**	**
number of mangrove seeds	**	**
number of crab holes	**	**
number of pneumatophores	ns	**

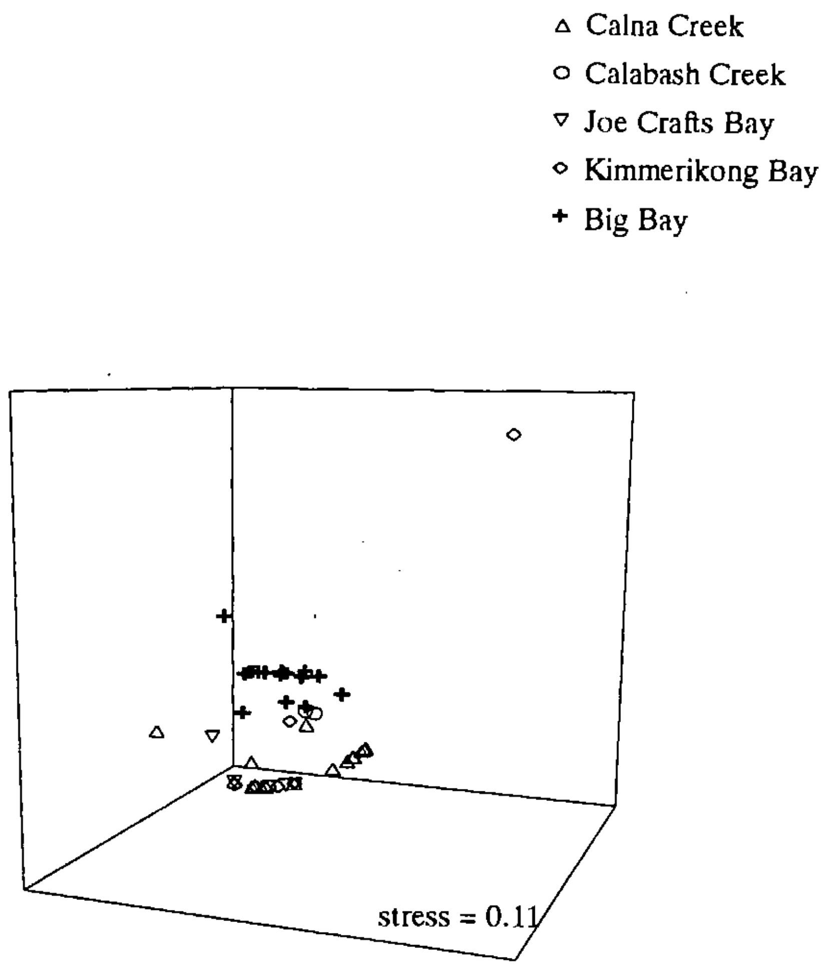


Figure 4. Three dimensional MDS of assemblages of epifauna associated with mangrove habitats from 5 locations along Berowra Creek.

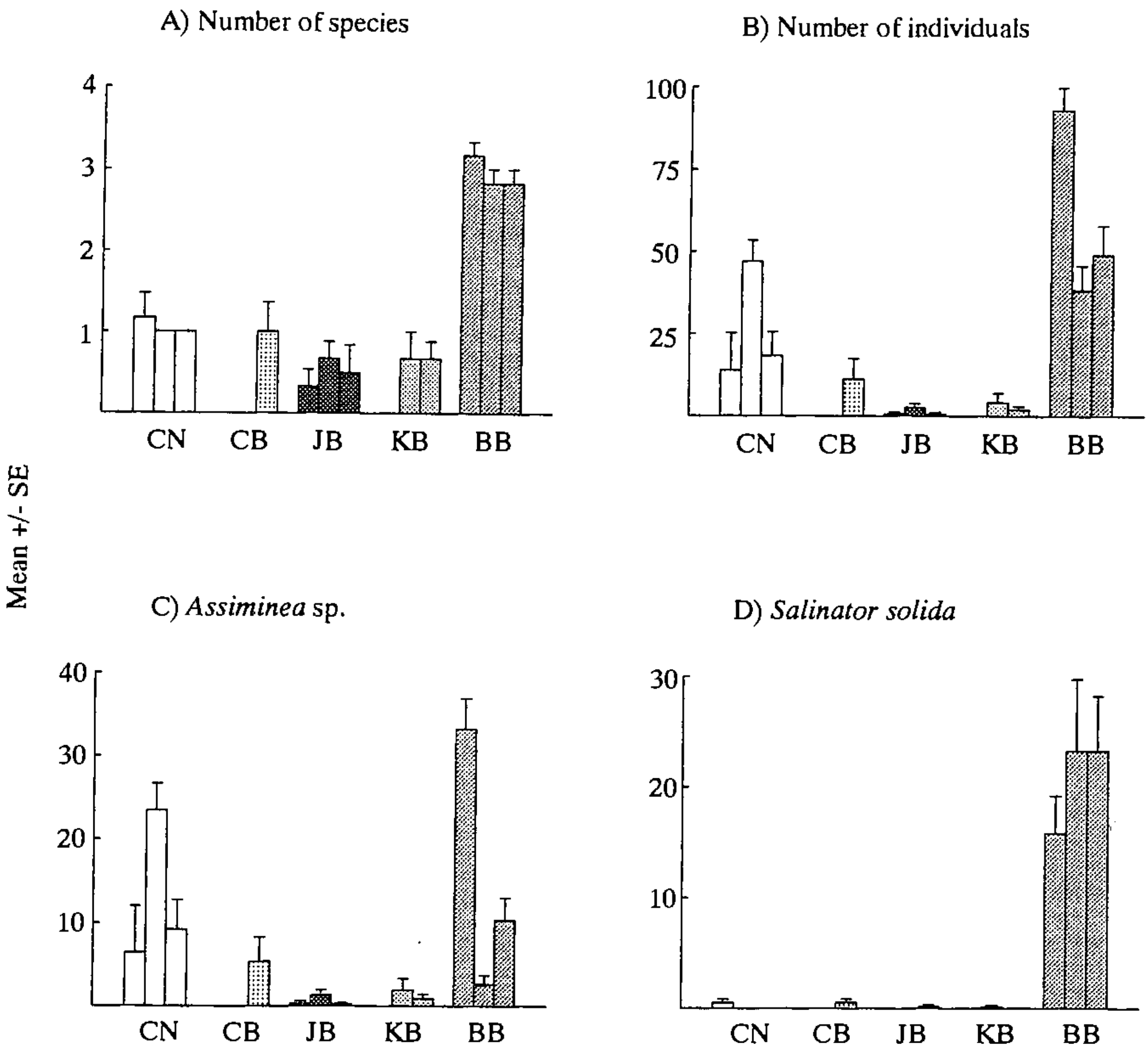


Figure 5. The mean (+SE) number of species and abundance of 2 species of epifaunal snails from 3 sites at each of 5 locations in mangrove habitats along Berowra Creek (n=6). CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

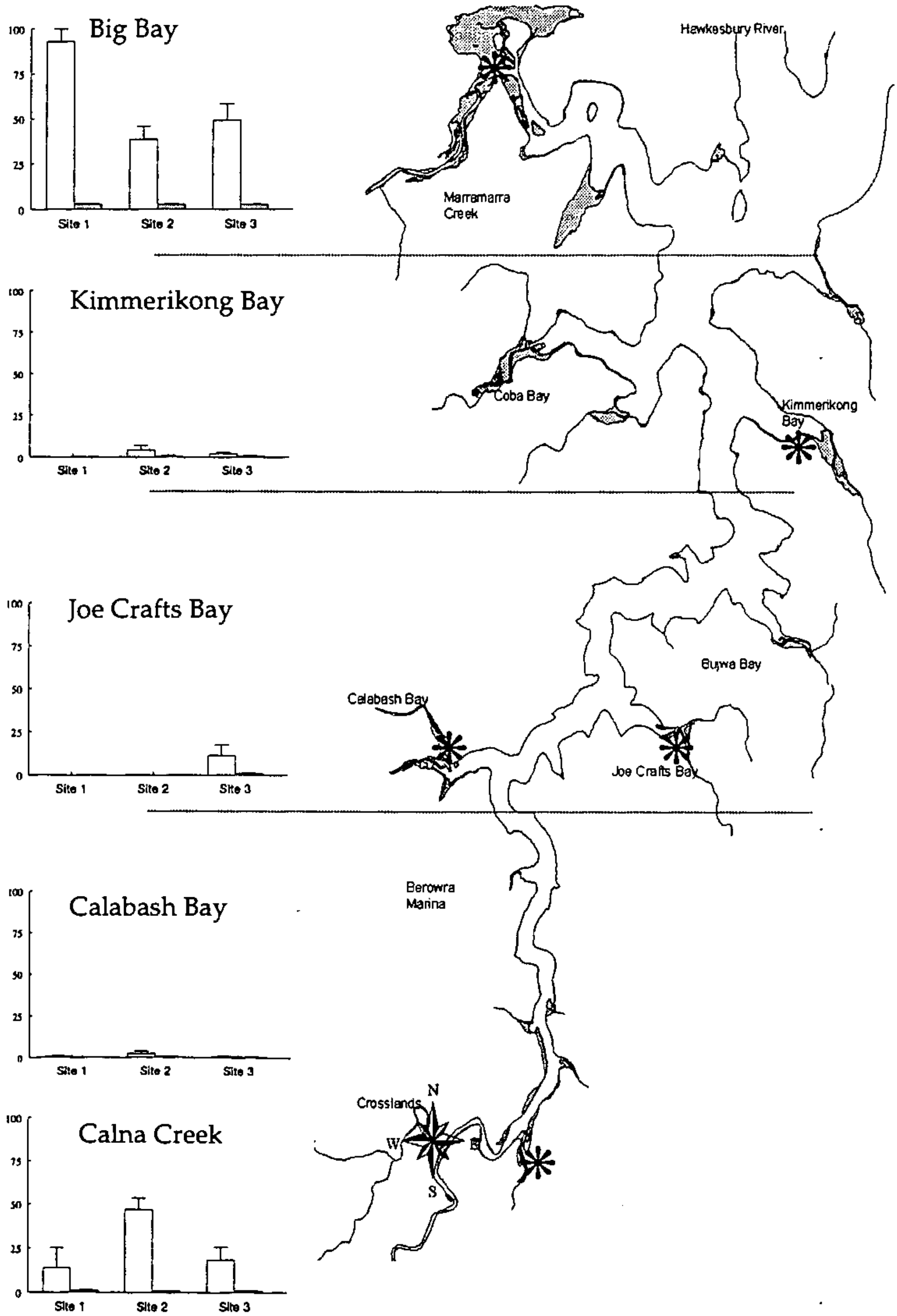


Figure 5 continued: E) Mean (+se) abundance (open bars) and mean (+se) number of species (shaded bars) of epifaunal snails in mangrove habitats in Berowra Creek.

Table 4. Results of multivariate analyses of assemblages of infauna in mangroves from 3 sites at 5 locations along Berowra Creek.

A) ANOSIM tests examining differences among sites and locations. ns = not significant, * = significant at $p < 0.05$,** = significant at $p < 0.005$ (adjusted alpha for multiple comparisons).

	Global R	Significance	Pairwise Tests R	Significance
Sites	0.028	ns		
Locations	0.34	*		
Calna Ck vs Calabash Ck			0.159	ns
Calna Ck vs Joe Crafts Bay			0.179	ns
Calna Ck vs Kimmerikong Bay			0.61	**
Calna Ck vs Big Bay			0.785	**
Calabash Ck vs Joe Crafts Bay			0.003	ns
Calabash Ck vs Kimmerikong Bay			0.239	ns
Calabash Ck vs Big Bay			0.413	**
Joe Crafts Bay vs Kimmerikong Bay			-0.02	ns
Joe Crafts Bay vs Big Bay			0.267	ns
Kimmerikong Bay vs Big Bay			0.352	**

B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations. Location abbreviations are CN = Calna Ck, CB = Calabash Ck, JC = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

	Location									
Species	CN v CB	CN v JC	CN v KB	CN v BB	CB v JC	CB v KB	CB v BB	JC v KB	JC v BB	KB v BB
Tatea sp.	1	2	2	2						
Arthritica helmsi	2	3	3	3	3	5		4		
Isopod sp. A	3	1	1	1	2	2	1			
Assiminea sp.	4	5	5				2		4	3
Oligochaete	5				1	1	3	5		4
Amphipod sp. B		4			5				1	1
Amphipod sp. D			4	4		3		1	3	
Salinator solida				5			5		2	2
Xenostrobus sp.					4	4	4	2		
Tipulidaea								3	5	
Helograpsus sp.										5

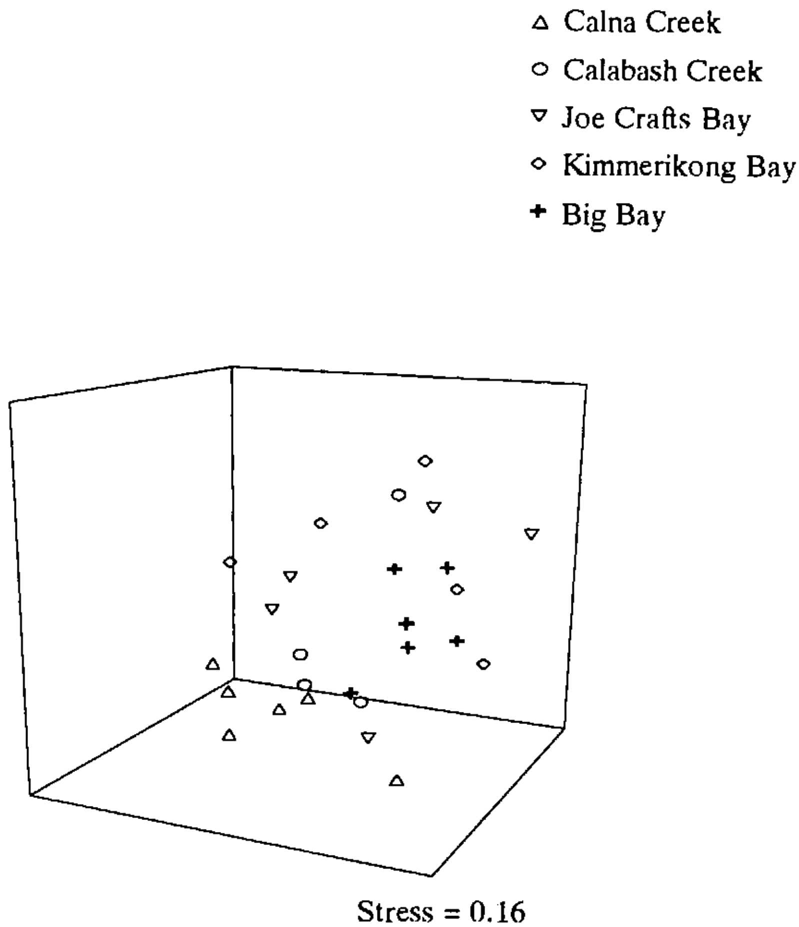


Figure 6. Three dimensional MDS of assemblages of infauna associated with mangrove habitats from 5 locations along Berowra Creek.

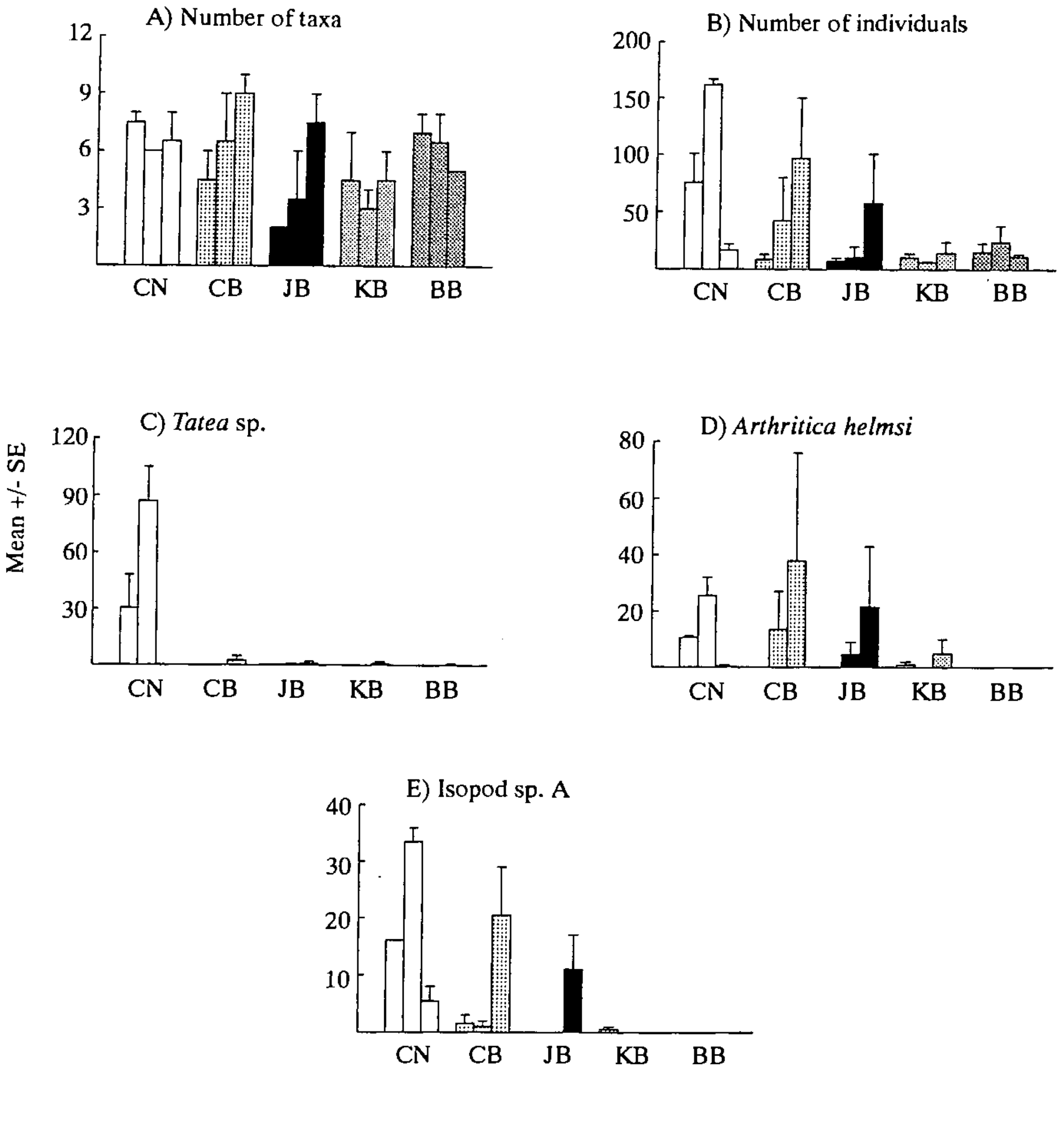


Figure 7. The mean (+SE) number of species, total abundance and abundance of 3 species of infauna from 3 sites at each of 5 locations in mangrove habitats along Berowra Creek (n=2). CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

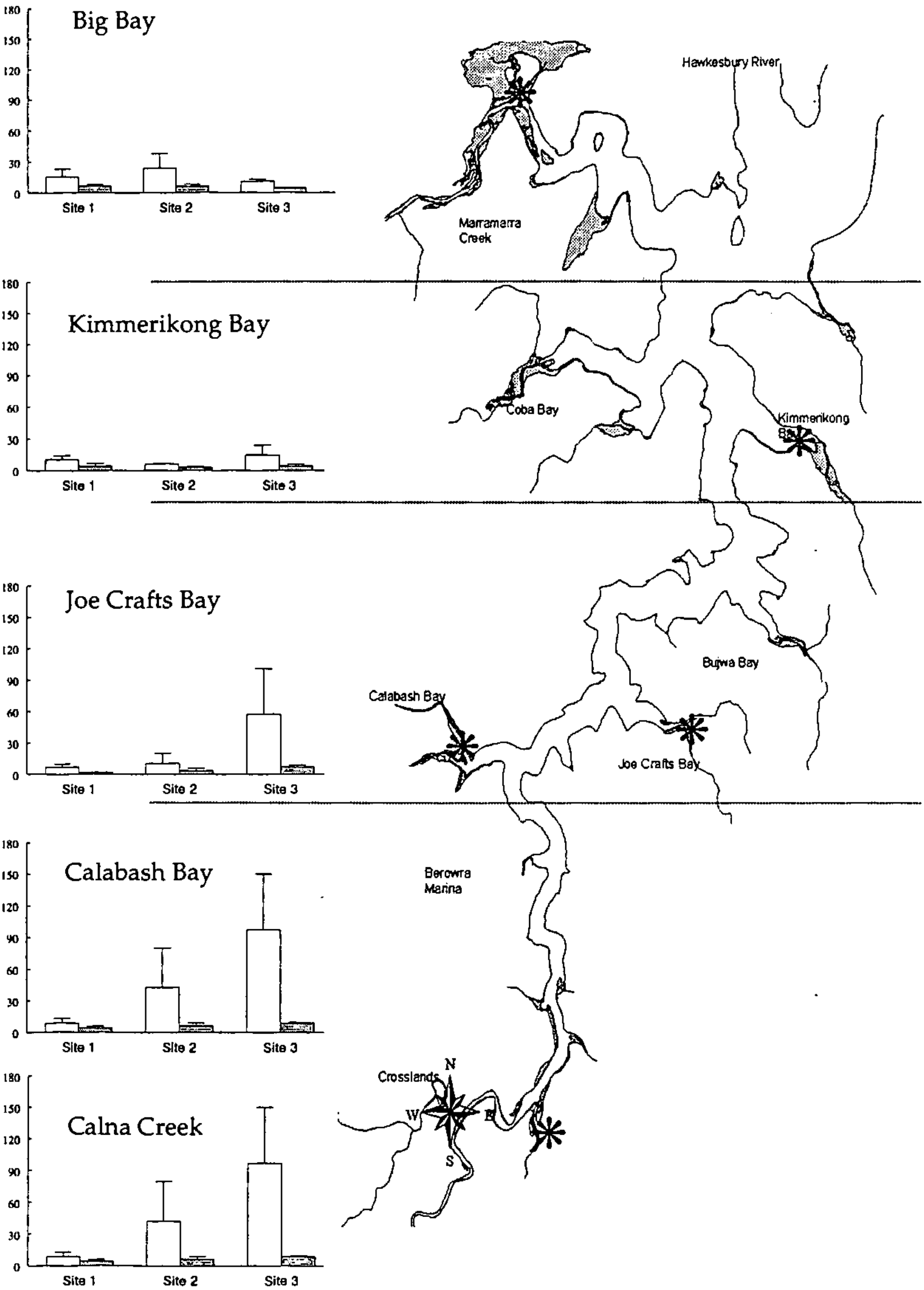


Figure 7 continued: F) Mean (+se) abundance (open bars) and mean (+se) number of species (shaded bars) of infauna from mangrove habitats in Berowra Creek.

3.2 Macrofauna of Benthic Sediments

3.2.1 Muddy Subtidal Sediments

General Findings

A total of 1, 837 individual animals representing 36 taxa were collected at 2 depths from 2 locations (Middle and Lower West) along Berowra Creek (Appendix 7). The most abundant taxonomic groups were polychaetes, crustaceans and molluscs comprising 80%, 18% and 2% of the total abundance respectively. Only 3 taxa, identified to the lowest practicable level, had abundances greater than 5% of the total. These were the polychaete families, Trichobranchidae (67.2%) and Nephtyidae (6.5%) and the crustacean, Amphipod type 4 (7.9%). Because the polychaete family Trichobranchidae dominated the fauna, we identified this family to the species level. All individuals collected were one species, *Terebellides stroemi,* a cosmopolitan species previously recorded from the Hawkesbury River (Jones, 1986).

Analysis of Assemblages

The assemblages of benthic macrofauna in muddy sediments along Berowra Creek differed significantly between locations and depths (Table 5A). There was insufficient replication, however, to examine smaller spatial scale differences among sites within each depth and location. The 3 dimensional MDS plot shows the clear separation of samples between locations, however, the separation between depths is not apparent (Figure 8). Nine taxa were ranked within the first 5 contributors to the dissimilarity between locations and depths (Table 5B). The relative abundance of the polychaete family, Trichobranchidae, and mysid crustaceans were primarily responsible for the differences between the location and depth groups (Table 5B).

Analysis of Populations

The number of taxa in muddy sediments did not differ significantly among locations or depths but varied at the smaller spatial scale of sites at Lower West creek in deep sediments (Appendix 8, Figure 9A, I). The range in the average number of taxa was 3.25 to 9.5 per site (Figure 9A). The total abundance of macrofauna also differed significantly among sites, such that, sites differed in abundance in shallow sediments in the Middle section of Berowra Creek and in deep sediments in Lower West section (Appendix 8, Figure 9B, I). The average abundance over all depths and locations ranged between 7.75 and 155.75 per site.

The 2 most abundant taxa identified to the lower level, the polychaete families, nephtyids and trichobranchids, varied significantly among sites (Appendix 8, Figure 9C,D). The abundance of both families differed between sites in the shallow sediments of Middle creek location and the trichobranchids also differed in abundance between sites in the deep sediments of Lower West creek location (Appendix 8, Figure 9C,D). The third most abundant taxon, the mysids, only occurred in shallow sediments at the Middle creek location and so were not formally analysed (Figure 9E).

Examination of taxa grouped into the broader categories of polychaetes, crustaceans and molluscs revealed, again, significant variability among sites in the shallow sediments at the Middle creek location and the deep sediments at Lower West creek location (Appendix 8, Figure 9F,G,H, I, J).

Table 5. Results of multivariate analyses of assemblages of benthic macrofauna in subtidal muddy sediments from 2 depths at 2 locations (Mid and Lower West) along Berowra Creek.

A) ANOSIM tests examining differences between locations and depths. ns = not significant, * = significant at $p < 0.05$.

	Global R	Significance
Locations	0.804	*
Depths	0.499	*

B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations and depths. Abbreviations are MS = Mid Creek Shallow, MD = Mid Creek Deep, LWS = Lower West Creek Shallow and LWD = Lower West Creek Deep.

	Location					
Species	MS v MD	MS v LWS	MS v LWD	MD v LWS	MD v LWD	LWS v LWD
Trichobranchidae	1	2	2	3	1	1
Amphipod Type 4	2			1	2	
Mysids	3	1	1			
Nephtyidae	4		5	4	4	3
Spionidae	5			2	3	
Amphipod Type 3		3	4	5	5	2
Opheliidae		4	3			
Notospisula trigonella		5				4
Sabellidae						5

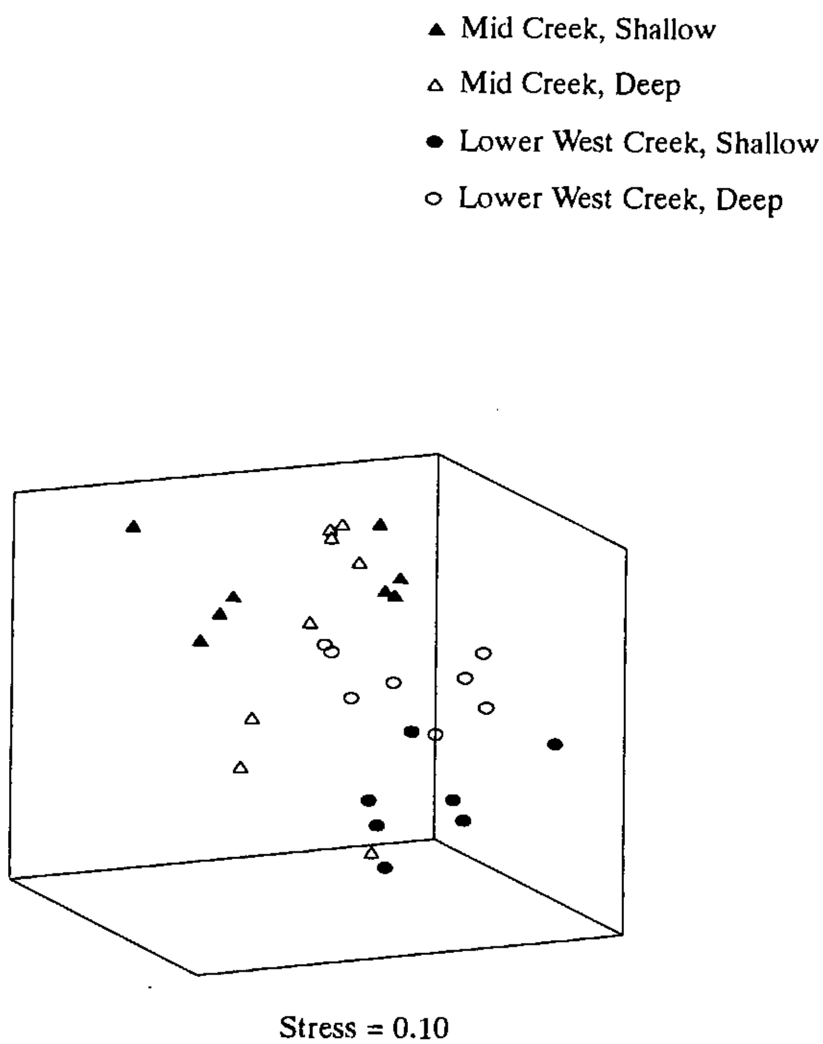


Figure 8. Three dimensional MDS of assemblages of benthos associated with subtidal muddy sediments from 2 locations and 2 depths along Berowra Creek.

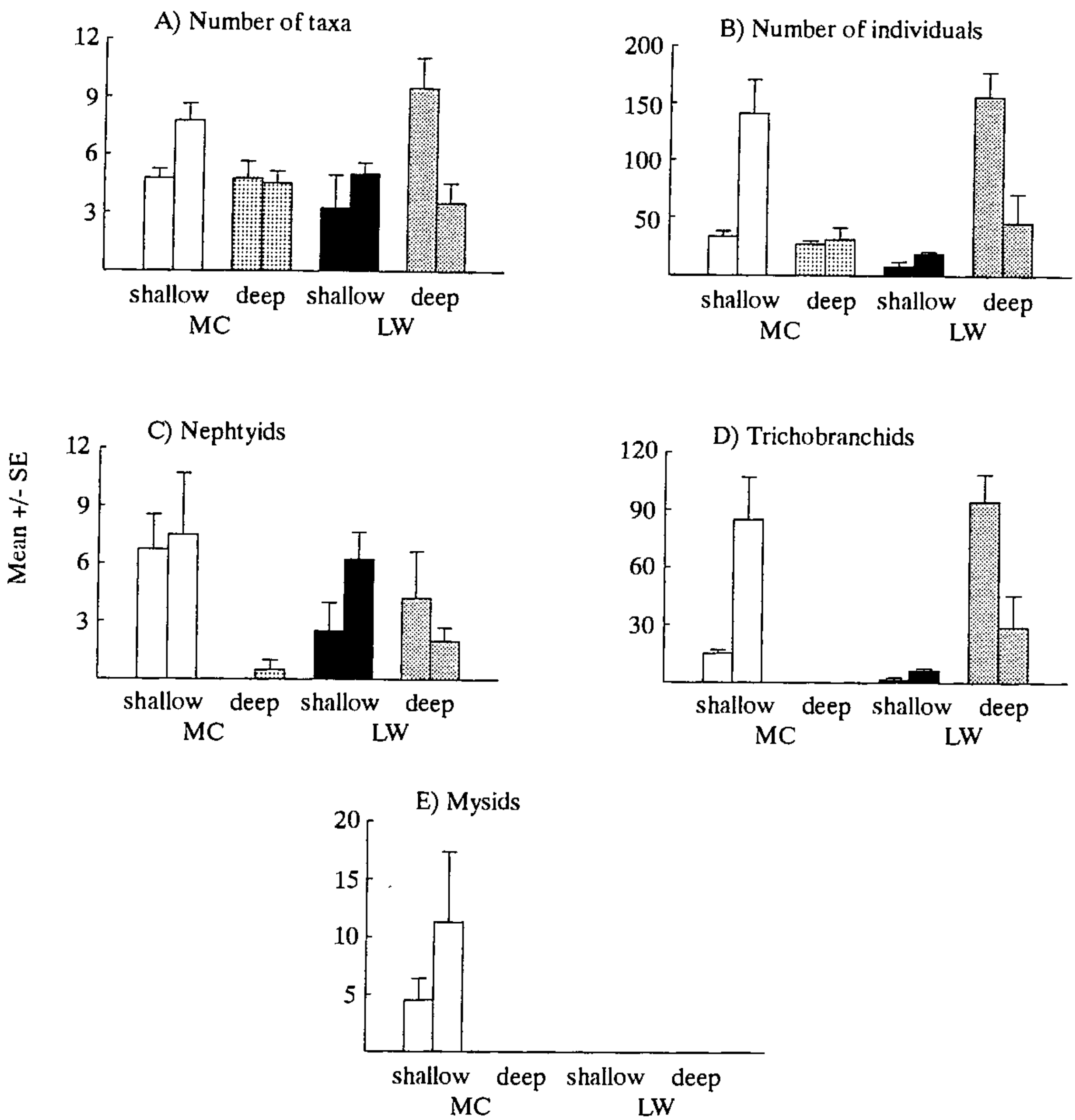


Figure 9. The mean (+SE) number of taxa, total abundance and abundance of taxonomic groups of benthic macrofauna from 2 depths at 2 sites at 2 locations in muddy sediments along Berowra Creek (n=4). MC = Mid creek and LW = Lower West creek.

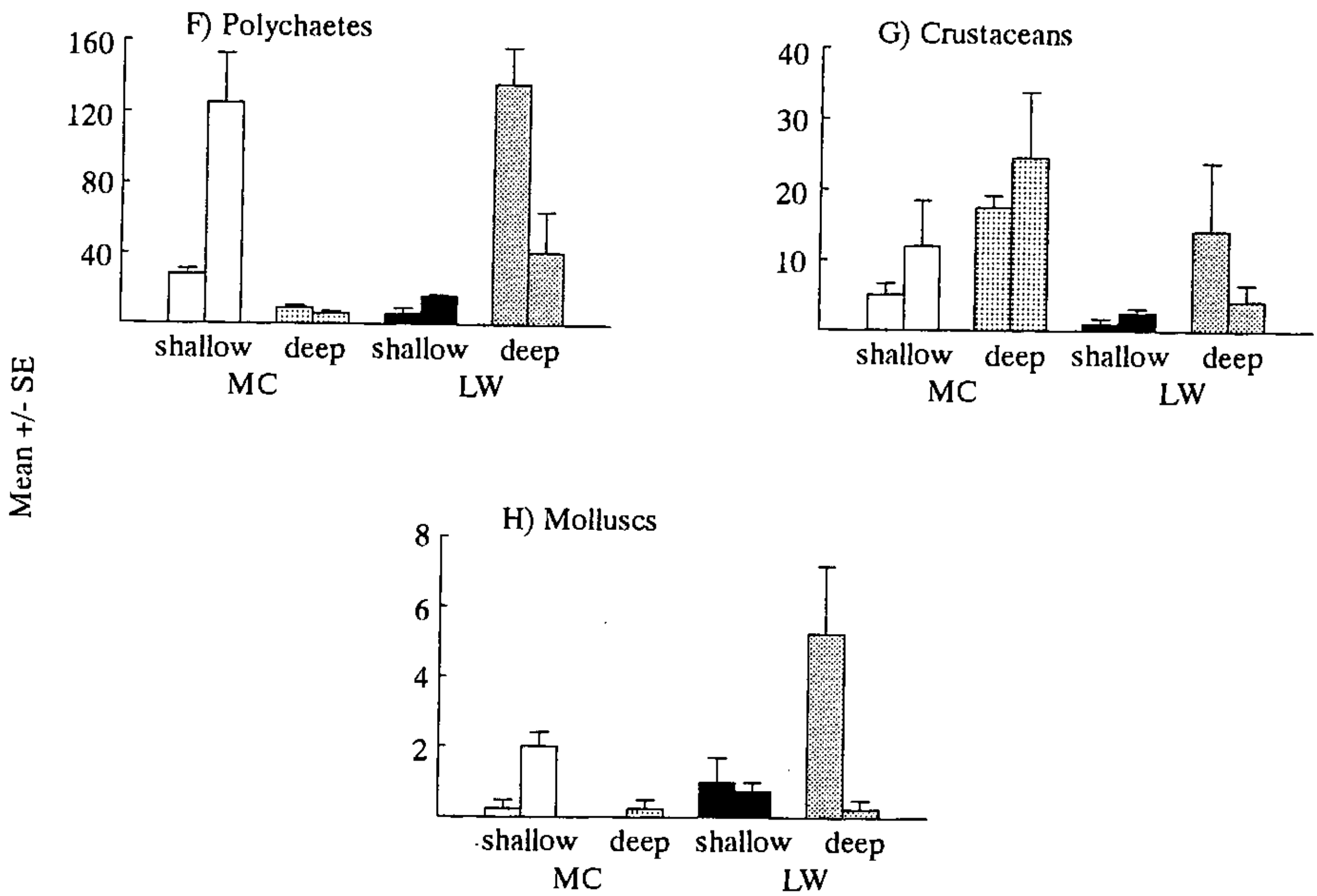


Figure 9. continued

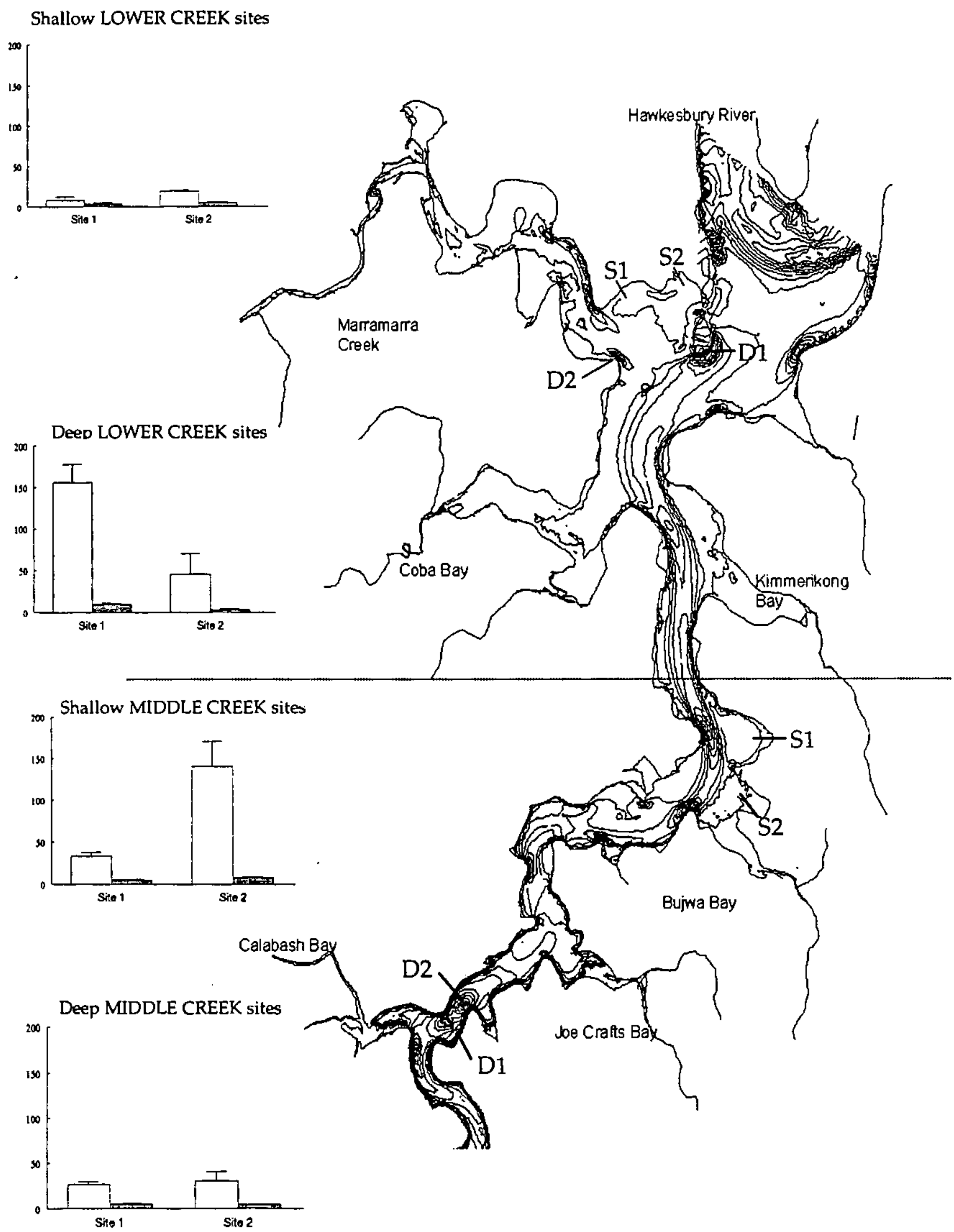


Figure 9 continued: I) Mean (+se) abundance (open bars) and mean (+se) number of species (shaded bars) of benthic fauna from muddy substrata in Berowra Creek.

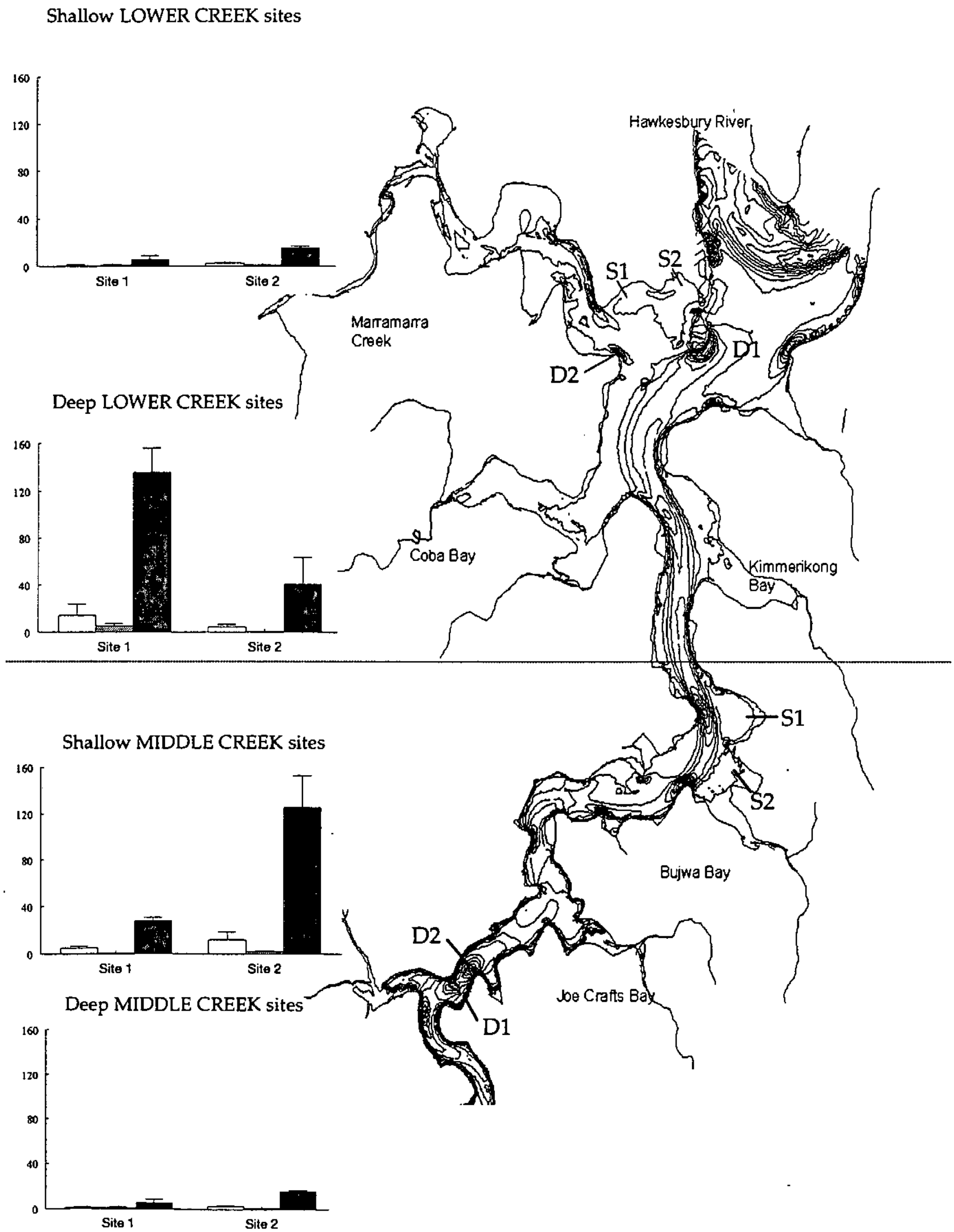


Figure 9 continued: J) Mean (+se) abundance of Crustaceans (open bars), Molluscs (striped bars) and Polychaetes (shaded bars) from muddy substrata in Berowra Creek.

3.2.2 Sandy Subtidal Sediments

General Findings

A total of 4, 051 individual animals were collected from 4 locations along Berowra Creek, representing 57 taxa (Appendix 8). The most abundant taxonomic groups were molluscs, polychaetes, and crustaceans comprising 46%, 34% and 18% of the total abundance respectively. Of these taxa identified to the lowest practicable level, few had abundances greater than 5% of the total. These were: the bivalve mollusc, *Sanguineolaria donacoides* (32.5%), the polychaete families, Nephtyidae (11.2%) and Trichobranchidae (10.7%), and the crustacean, Amphipod type 5 (7.7%).

Analysis of Assemblages

The assemblages of benthic macrofauna in sandy subtidal sediments along Berowra Creek differed among locations and sites indicating significant small scale (within location) variability (Table 6A). Pair-wise comparisons between locations (ignoring the smaller spatial scale differences) indicated that all locations differed from each other except the locations, Lower creek and Lower West creek, which had similar assemblages of macrofauna (Table 6A). The 3 dimensional MDS plot is an adequate representation of these spatial relationships because it shows the spread of samples from within each location (*i.e.* differences among sites within a location) and also shows the greater overlap of samples from the locations Lower Creek and Lower West creek (Figure 10). Eleven taxa were ranked within the first 5 contributors to the dissimilarity between locations which was indicative of the complexity in spatial patterns of assemblages of macrofauna in sandy sediments (Table 6B). *Sanguineolaria donacoides* and nephtyid polychaetes contributed most to the differences between all location pairs except for Lower creek and Lower West creek, which differed due to differences in the contribution of trichobranchid polychaetes and *Notospisula trigonella* (Table 6B).

Analysis of Populations

The number of taxa in sandy sediments did not differ significantly among locations or sites and averaged between 6.5 to 20.5 per site (Appendix 9, Figure 11A,J). The total abundance of macrofauna, however, differed significantly among sites in the locations, Upper and Middle creek (Appendix 9, Figure 11B, J). At these locations, the range in abundance per site is greater than the locations in the lower reaches of Berowra Creek, which tends to override any trends in abundance at the larger spatial scale of locations (Figure 11B, J). The average abundance over all locations ranged between 25.5 and 189.3 per site.

The most abundant taxa, the bivalve *Sanguineolaria donacoides*, varied significantly among sites in the Upper and Middle Creek locations (Appendix 9, Figure 11C,K). Although this species was largely absent from the 2 locations in the lower reaches of Berowra Creek, the great variation from site to site in both the Upper and Middle creek locations precludes the detection of significant differences in abundance along Berowra Creek. Data suggest, however, that there is a strong tendency for *Sanguineolaria donacoides* to occur in much greater numbers in the upper reaches of Berowra Creek (Figure 11C, K). A similar result was shown for the most abundant crustacean taxa, Amphipod type 5, as they were highly variable among sites within the upper creek locations yet obviously more abundant in the Upper and Middle Creek locations (Appendix 9, Figure 11D, K). In contrast, the abundance of the 2 dominant families of polychaetes, the nephtyids and trichobranchids, was highly

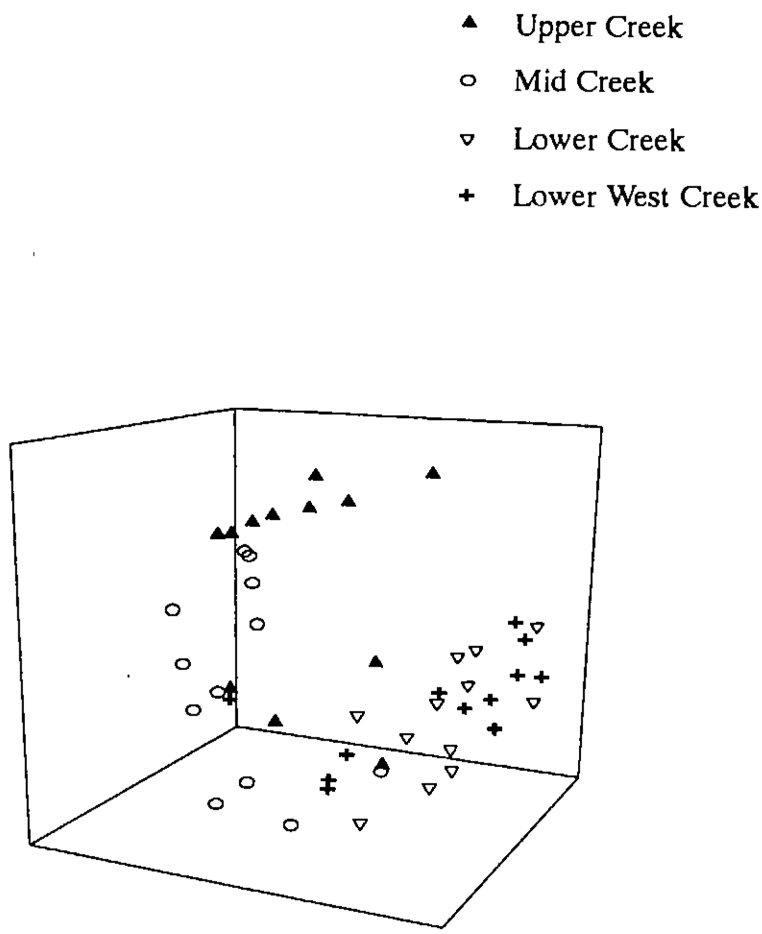
Table 6. Results of multivariate analyses of assemblages of benthic macrofauna in subtidal sandy sediments from 3 sites at 4 locations along Berowra Creek (n = 4).

A) ANOSIM tests examining differences among sites and locations. ns = not significant, * = significant at $p < 0.05$, ** = significant at $p < 0.0083$ (adjusted alpha for multiple comparisons).

	Global R	Significance	Pairwise Tests R	Significance
Sites	0.622	*		
Locations	0.531	*		
Upper vs Mid			0.246	**
Upper vs Lower			0.848	**
Upper vs Lower West			0.741	**
Mid vs Lower			0.727	**
Mid vs Lower West			0.621	**
Lower vs Lower West			0.126	ns

B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations. Location abbreviations are UC = Upper Ck, MC = Mid Ck, LC = Lower Ck and LW = Lower West Ck.

	Location					
Species	UC v MC	UC v LC	UC v LW	MC v LC	MC v LW	LC v LW
Sanguineolaria donacoides	1	2	2	1	1	
Nereididae	2	3	3			
Notospisula trigonella	3					2
Nassarius sp.	4			4		
Amphipod type 5	5	4	5	5	5	
Nephtyidae		1	1	2	2	
Trichobranchidae		5	4	3	4	1
Nemerteans					3	
Arthritica helmsi						3
Brachyura						4
Bivalve type d						5



Stress = 0.13

Figure 10. Three dimensional MDS of assemblages of benthos associated with subtidal sandy sediments from 4 locations along Berowra Creek.

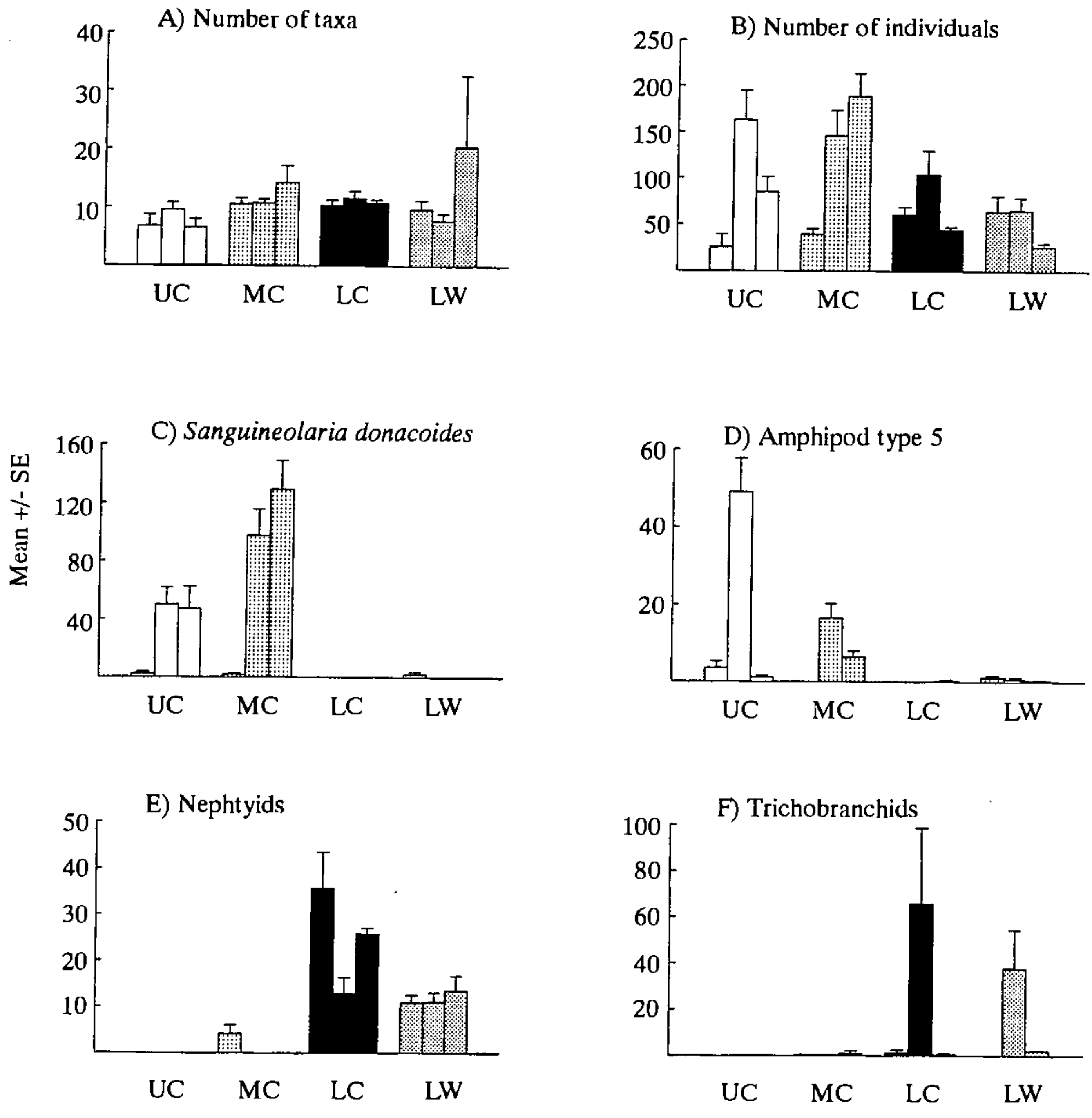


Figure 11. The mean (+SE) number of taxa, total abundance and abundance of taxonomic groups of benthic macrofauna from 3 sites at 4 locations in sandy sediments along Berowra Creek (n=4). UC = Upper Creek, MC = Mid Creek, LC = Lower Creek and LW = Lower West Creek.

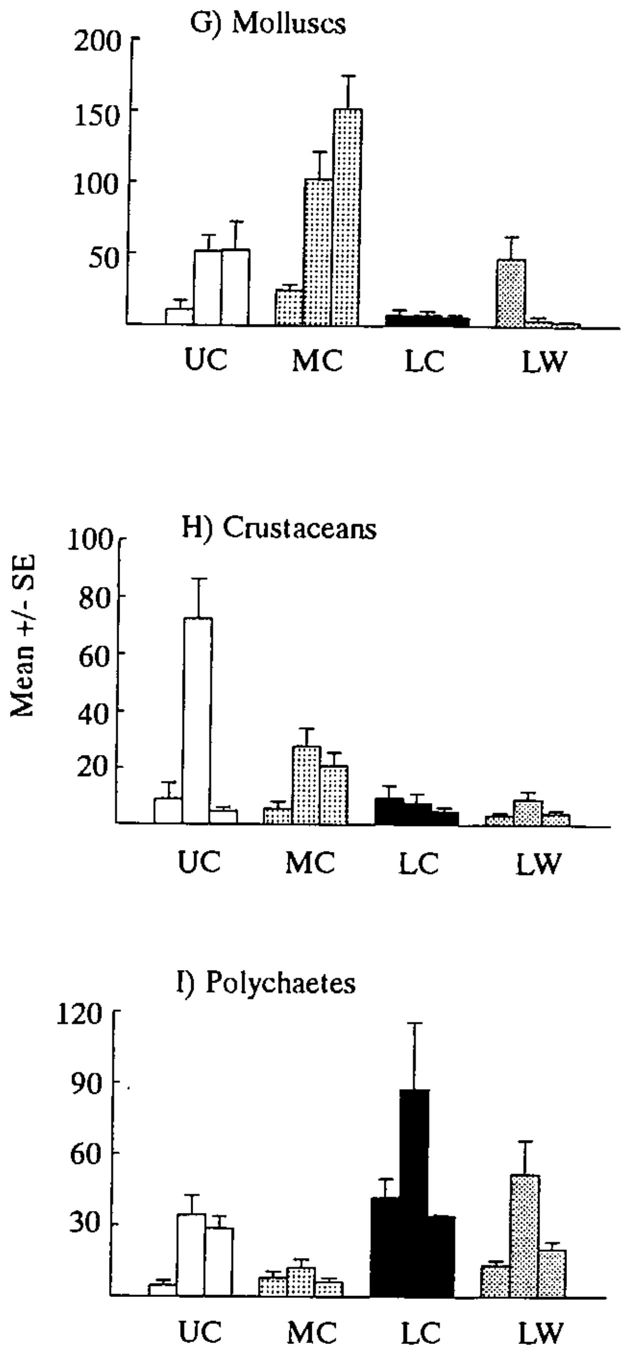


Figure 11. continued

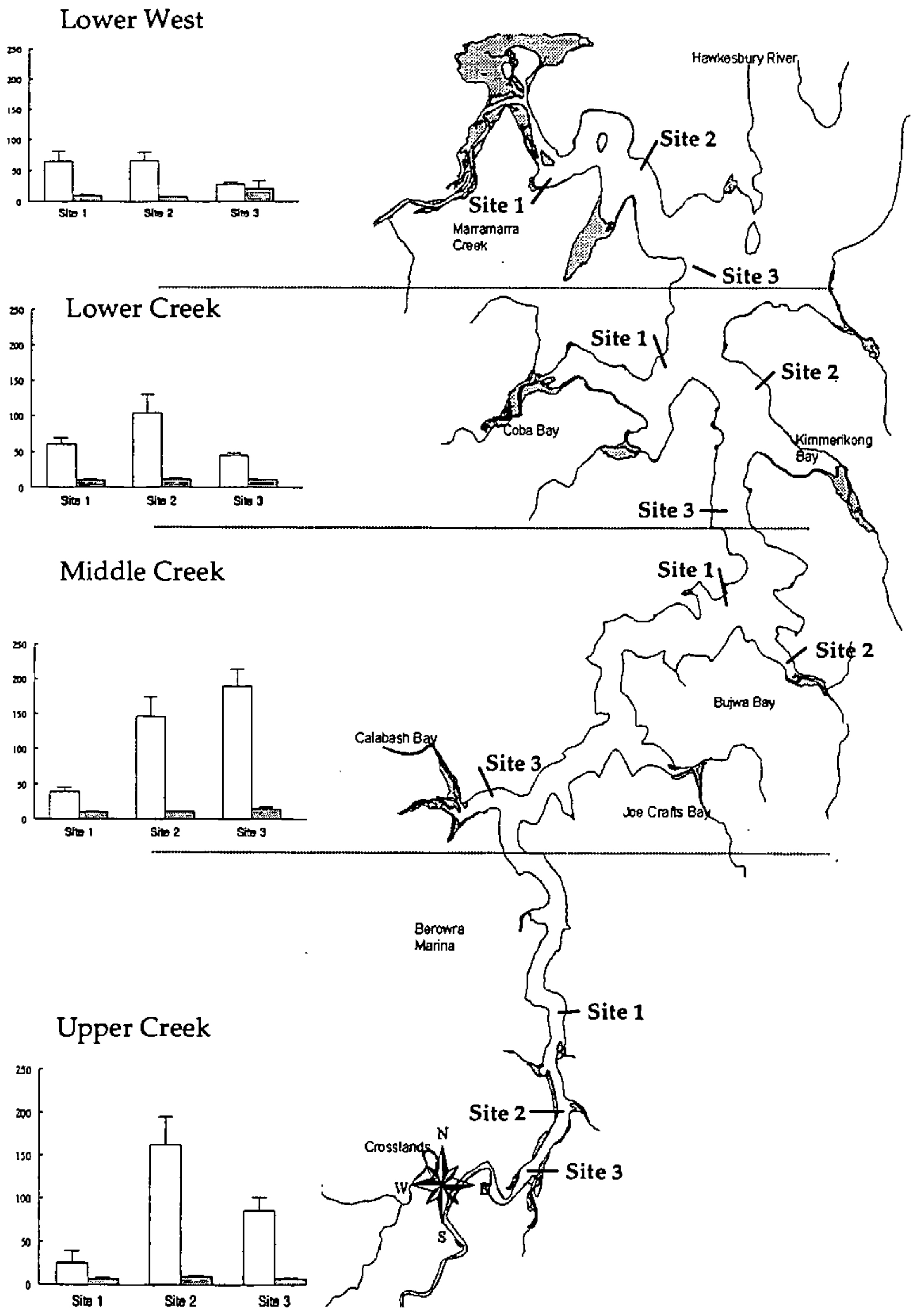


Figure 11 continued: J) Mean (+se) abundance (open bars) and mean (+se) number of species (shaded bars) of benthic fauna from sandy substrata in Berowra Creek.

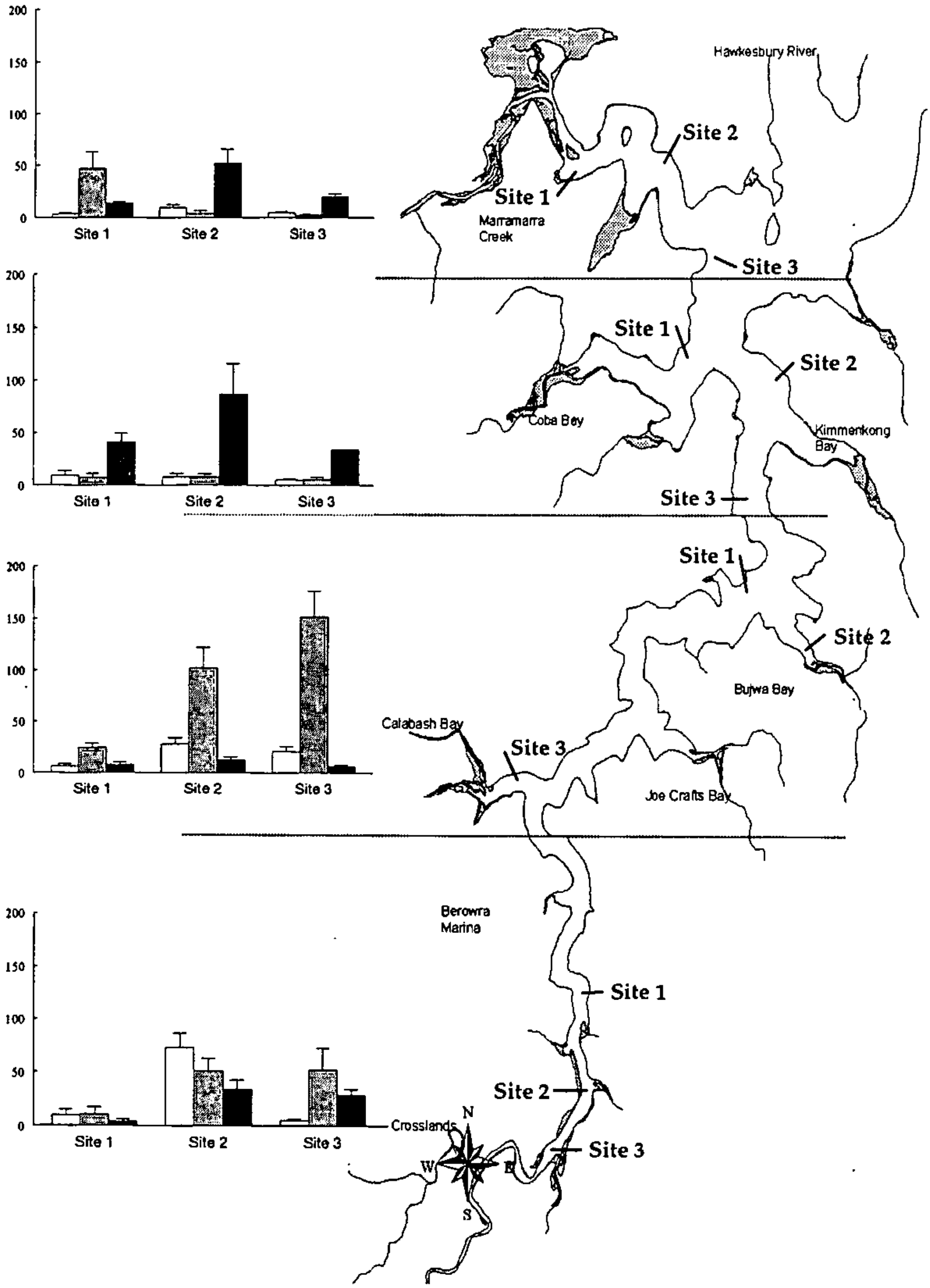


Figure 11 continued: K) Mean (+se) abundance of Crustaceans (open bars), Molluscs (striped bars) and Polychaetes (shaded bars) from sandy substrata in Berowra Creek.

variable among sites in the lower reaches of Berowra Creek masking the spatial trend among locations of them being more abundant in the lower reaches of Berowra Creek (Appendix 9, Figure 11E, F).

As shown above, abundant taxa identified at the lowest practicable level tended to be unevenly distributed across locations along Berowra Creek. Not surprisingly, examination of taxa grouped into broader categories such as molluscs, crustaceans and polychaetes revealed similar among location patterns *i.e.* large variability among sites within locations but with a tendency for more molluscs and crustaceans in the Upper and Middle creek locations and more polychaetes in the Lower and Lower West creek locations (Appendix 9, Figure 11G,H,I, K).

3.3 Fish and Mobile Invertebrates

3.3.1 Seagrass Beds

General Findings

A total of 17, 854 individual animals were collected from 2 sites at each of 3 locations along Berowra Creek, representing 29 species of fish, 5 species of crustaceans and 1 species of mollusc (Appendix 11). Although 14 species were of economic importance, they made up only 3.7% of the total abundance of animals. The most abundant species were the gobies, *Gobiopterus semivestita* and *Redigobious macrostoma*, and the pacific blue-eye, *Pseudomugil signifer*, comprising 35%, 20% and 12% of the total abundance respectively. Twenty-five species had abundances less than 1% of the total. Only one species of fish collected was an introduced species, the yellowfin goby (*Acanthogobius flavimanus*). A total of 5 individuals were caught, 1 –2 in each section of the creek sampled.

Analysis of Assemblages

The assemblages of fish and mobile invertebrates along Berowra Creek differed among locations and sites indicating significant small scale (within location) variability (Table 7A). Pair-wise comparisons between locations (ignoring the smaller spatial scale differences) indicated that all the locations sampled differed from each other (Table 7A). The 3 dimensional MDS plot shows the separation among locations as well as the spread of samples from within each location (*i.e.* differences among sites within a location) (Figure 12). Seven taxa were ranked within the first 5 contributors to the dissimilarity between locations, however, the relative abundance of 2 species primarily distinguished among the 3 locations (Table 7B). The Upper creek location differed from the other two locations largely due to the presence of the flat-headed gudgeon, *Philypnodon grandiceps* and the Lower West creek location had a greater abundance of the Tamar river goby, *Favonogobius tamarensis*.

Analysis of Populations

The number of species of fish and mobile invertebrates in seagrass beds did not differ significantly among locations or sites with an average of between 14 and 20 per site (Appendix 12, Figure 13A, J). The total abundance, however, differed significantly among sites at the Lower West location, on average, there being twice as many fish and mobile invertebrates there compared to other sites (Appendix 12, Figure 13B, K). The average

Table 7. Results of multivariate analyses of assemblages of fish in seagrass beds at 3 locations along Berowra Creek.

A) ANOSIM tests examining differences among locations and sites. ns = not significant, * = significant at $p < 0.05$, ** = significant at $p < 0.005$ (adjusted alpha for multiple comparisons).

	Global R	Significance	Pairwise Tests R	Significance
Sites	0.642	*		
Locations	0.486	*		
Upper Creek vs Mid Creek			0.424	**
Upper Creek vs Lower West Creek			0.641	**
Mid Creek vs Lower West Creek			0.459	**

B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations.

		Location	
Species	Upper Creek vs Mid Creek	Upper Creek vs Lower West Creek	Mid Creek vs Lower West Creek
Phylipnodon grandiceps	1	1	
Redigobious macrostoma	2		5
Ambassis sp.	3	4	2
Gobiopterus semivestita	4	5	
Macrobrachium sp.	5	2	3
Favonigobius tamarensis		3	1
Pseudomugil signifer			4

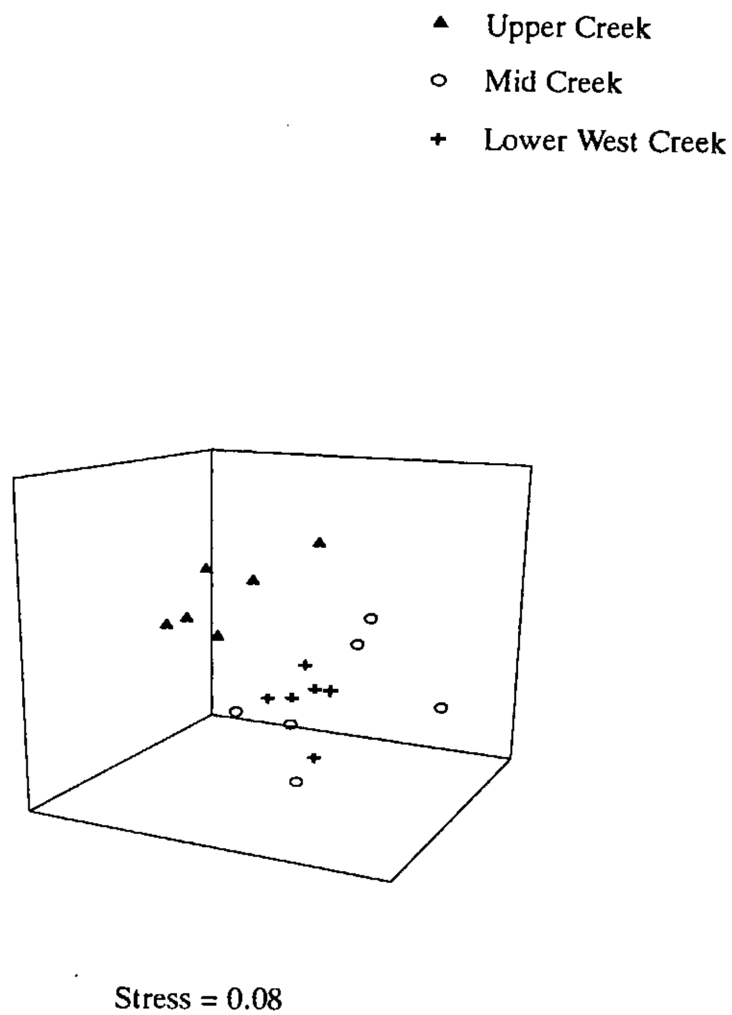


Figure 12. Three dimensional MDS of assemblages of fish associated with seagrass from 3 locations along Berowra Creek.

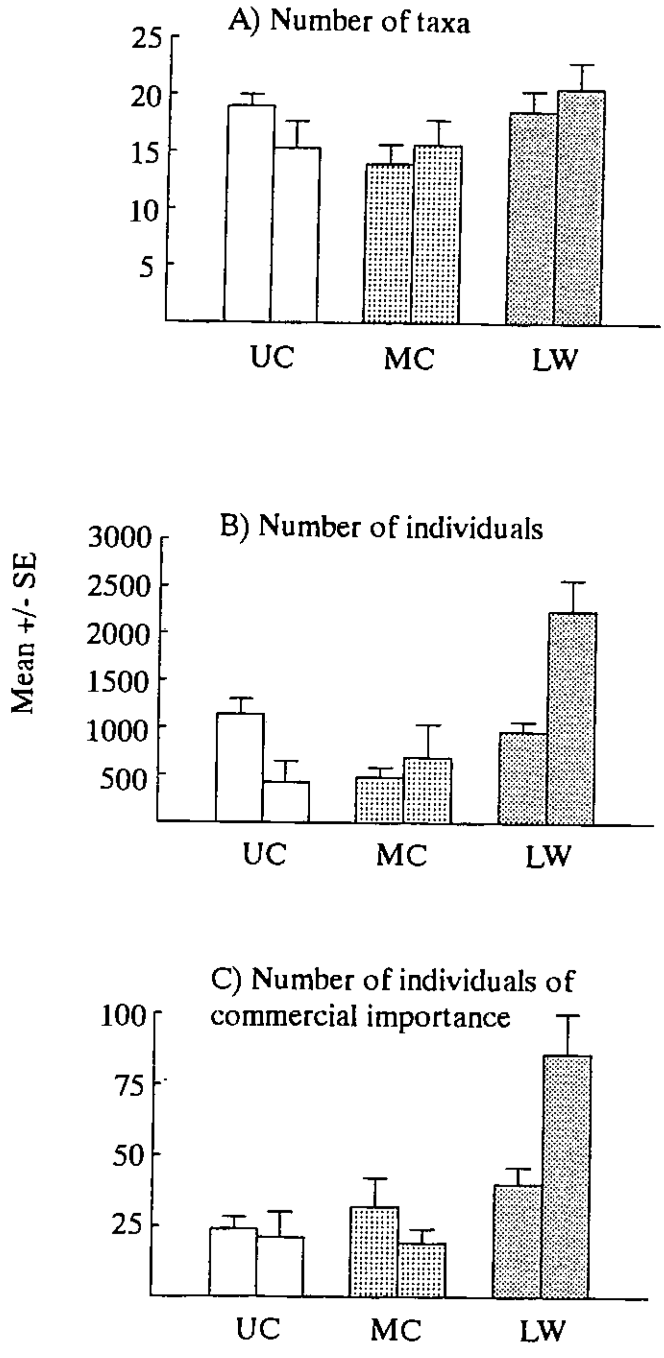


Figure 13. The mean (+SE) number of taxa, total abundance and abundance of commercially important species of fish and mobile invertebrates from 2 sites at 3 locations along Berowra Creek (n=3). UC = Upper creek, MC = Mid creek and LW = Lower West creek.

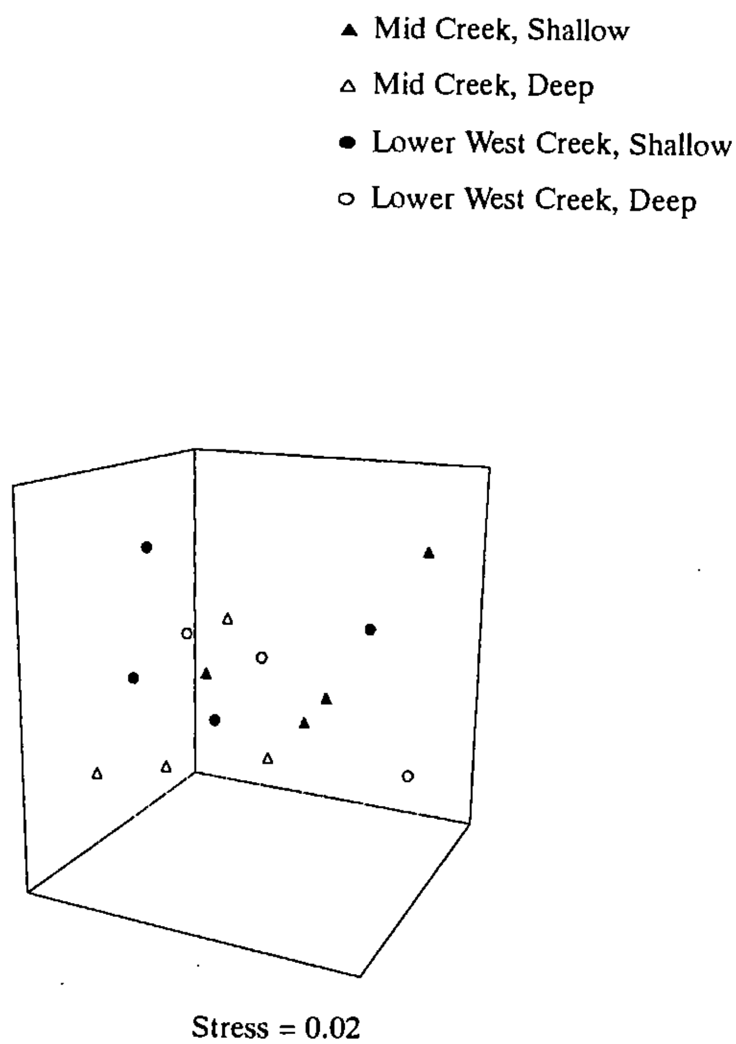


Figure 14. Three dimensional MDS of assemblages of fish and mobile invertebrates in shallow and deep water from 2 locations along Berowra Creek.

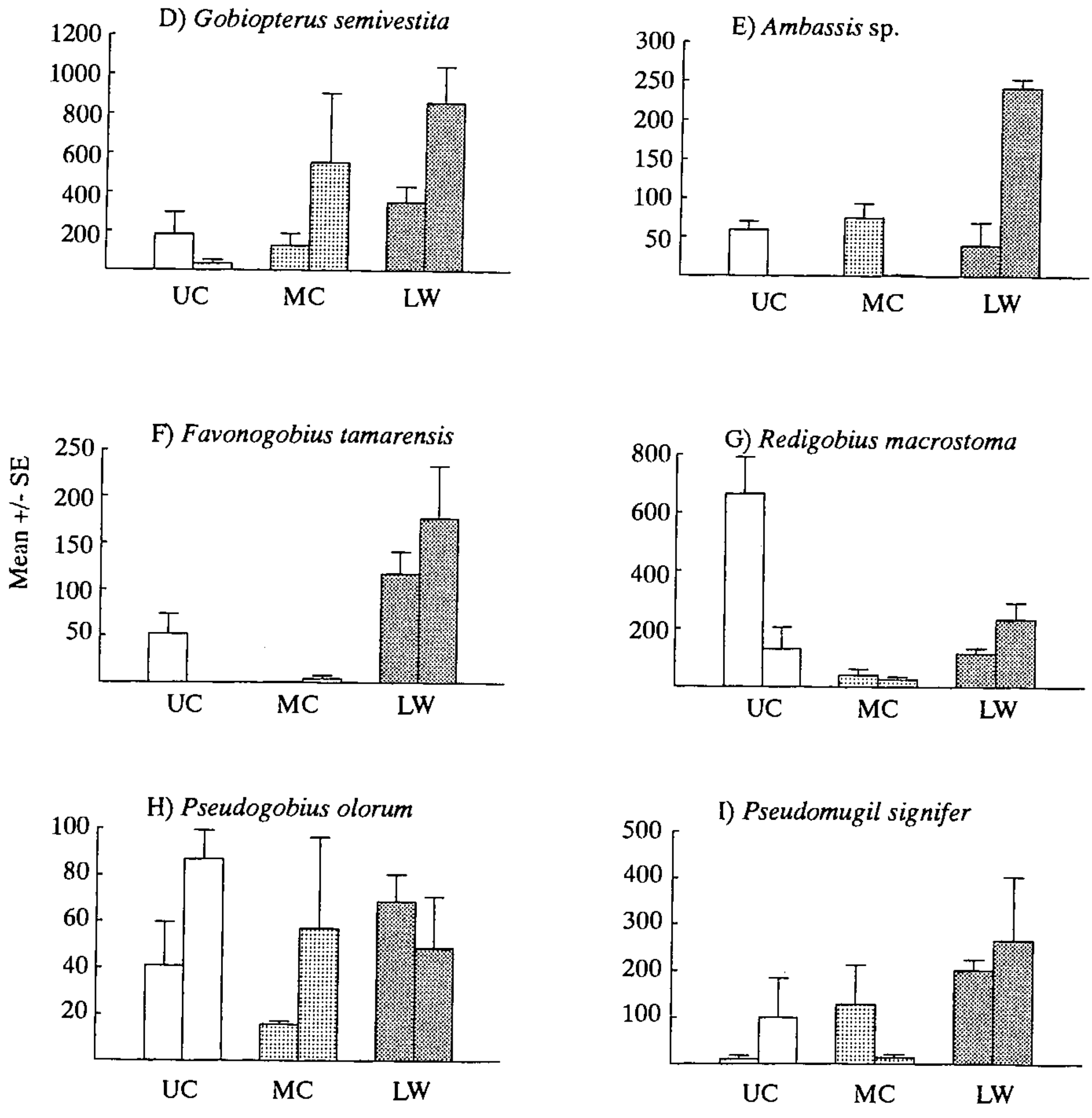


Figure 13. continued.

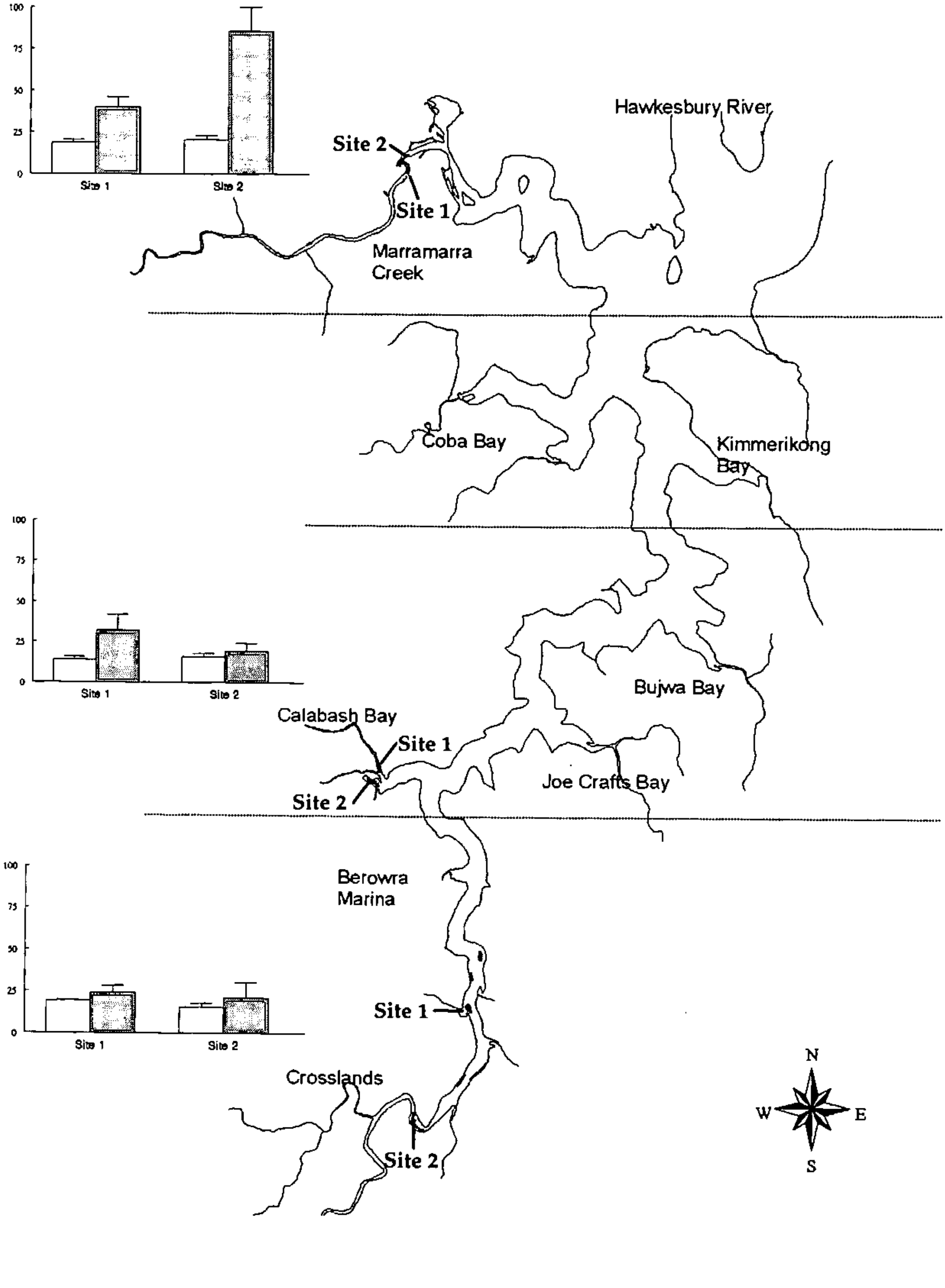


Figure 13 continued: J) Mean (+se) number of taxa and commercially important individuals (+se) of fish and mobile invertebrates caught in seine nets in seagrass beds in Berowra Creek.

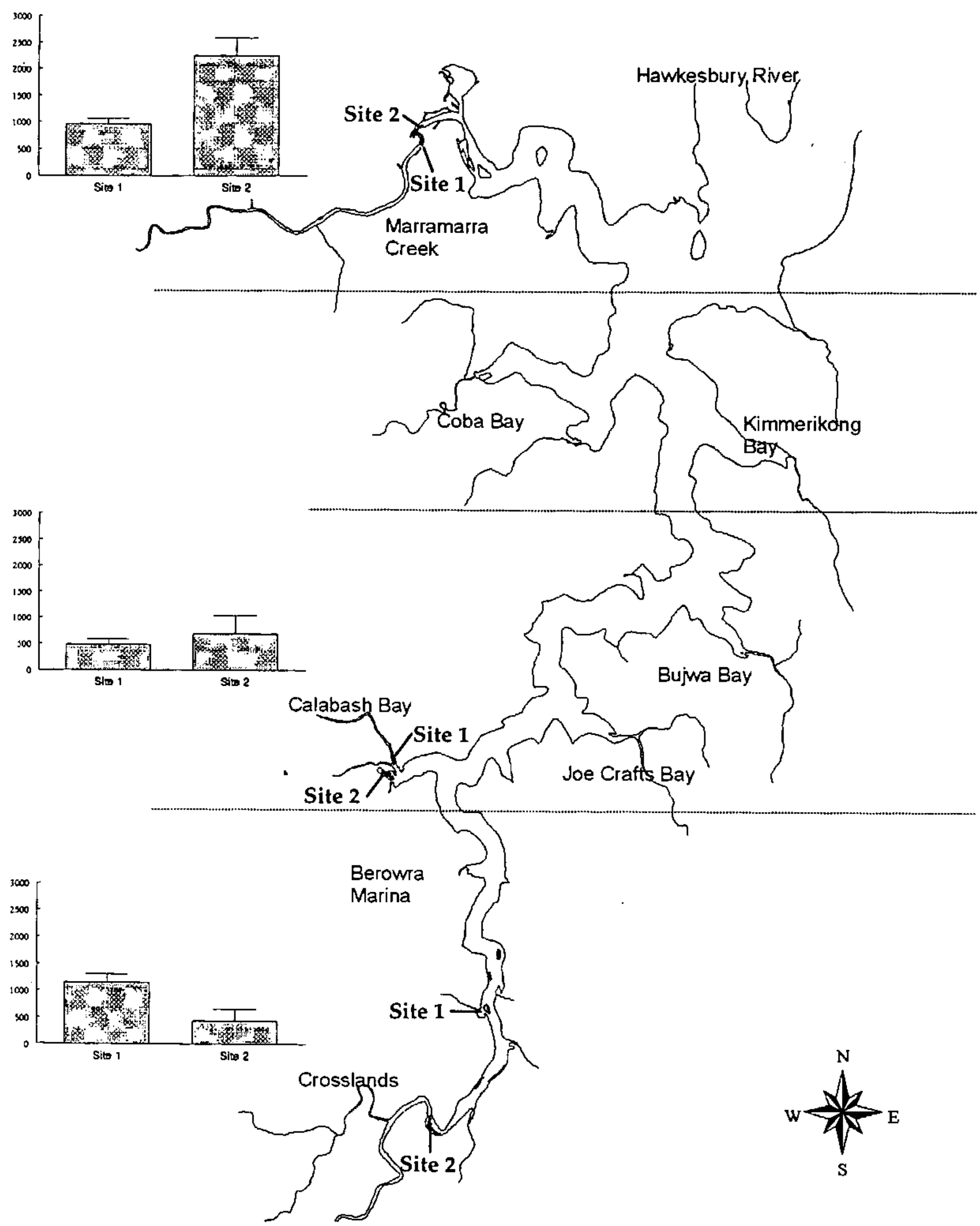


Figure 13 continued: K) Mean (+se) abundance of fish and mobile invertebrates caught in seine nets in seagrass beds in Berowra Creek.

abundance for all locations ranged between 426.7 and 2245.3 per site. A small proportion of these animals were of commercial significance and showed a similar result to that for total abundance (Appendix 12, Figure 13C, J).

For the most abundant species of fish, patterns in the distribution and abundance were variable, showing either no differences among locations along the creek or significant spatial differences at the scale of locations and sites (Appendix 12). The most abundant species, the goby *Gobiopterus semivestita*, varied significantly at the scale of locations along Berowra Creek, however, specific differences could not be resolved by the less powerful SNK test (Appendix 12, Figure 13D). In contrast, the abundance of perchlets, *Ambassis* sp., and the gobies *Favonogobius tamarensis* and *Redigobius macrostoma*, varied significantly at smaller spatial scales such that abundance in sites at the Upper creek location differed for the gobies and sites at the Lower West creek location differed for the perchlets (Appendix 12, Figure 13E,F,G). The abundance of the goby, *Pseudogobius olorum* and the pacific blue-eye *Pseudomugil signifer* did not vary significantly along Berowra Creek (Appendix 12, Figure 13H,I).

3.3.2 Deep Holes

General Findings

Fourteen species of fish and mobile invertebrates were captured by gill nets in the deep holes and shallow areas from 2 locations along Berowra Creek (Appendix 13). The majority of the 63 individuals caught were fish and the remainder were crabs: 7 individuals of the blue-swimmer crab, *Portunus pelagicus* and 1 mud crab, *Scylla serata*. The most abundant species of fish were the large-tooth flounder (*Pseudorhombus arsius* - 16), flat-tail mullet (*Liza argentea* – 12) and silver biddy (*Gerres subfasciatus* – 10).

Analysis of Assemblages

The assemblages of fish and crabs did not significantly differ between depths (Global $R = 0.038$, $p > 0.05$) nor locations (Global $R = 0.051$, $p > 0.05$). The three dimensional MDS plot clearly illustrates the overlap in distribution of samples from different depths and locations (Figure 14).

Analysis of Populations

The mean number of species of fish and mobile invertebrates did not vary significantly between the deep holes and the shallow areas along Berowra Creek (Appendix 14, Figure 15A, C). The total abundance of fauna did vary at the spatial scale of sites, with the sites in the deep hole at the Lower West creek location differing significantly from each other (Appendix 14, Figure 15B. C). Overall, there were no consistent differences between deep holes and adjacent shallow areas nor between locations along Berowra Creek (Figure 15B, C).

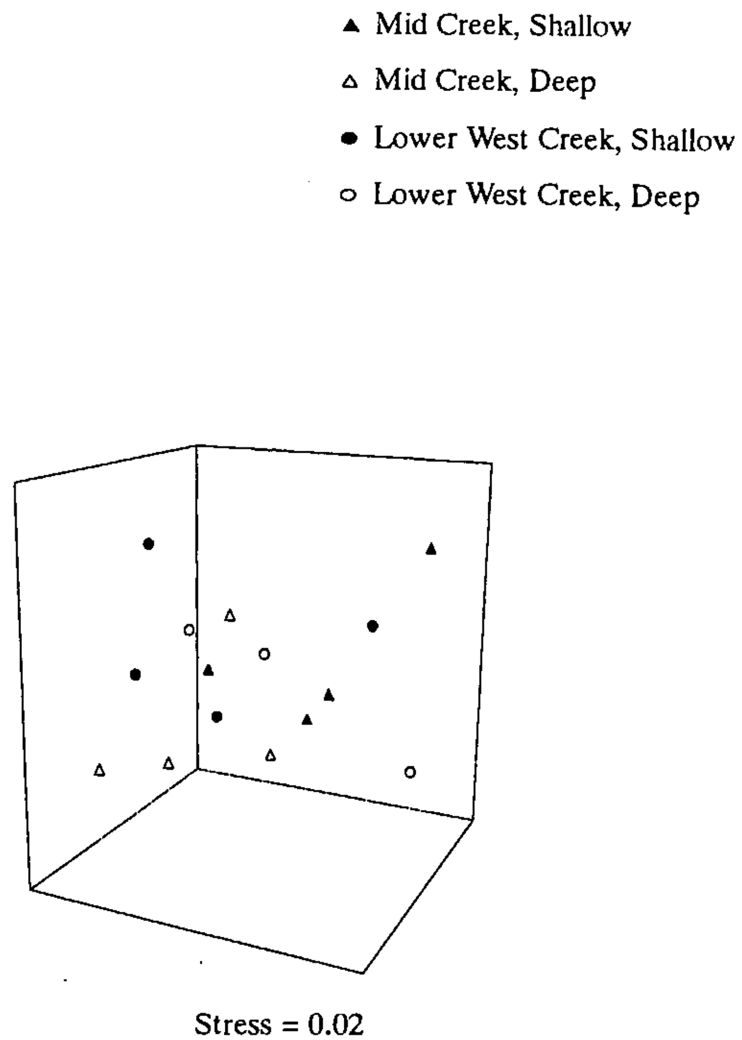


Figure 14. Three dimensional MDS of assemblages of fish and mobile invertebrates in shallow and deep water from 2 locations along Berowra Creek.

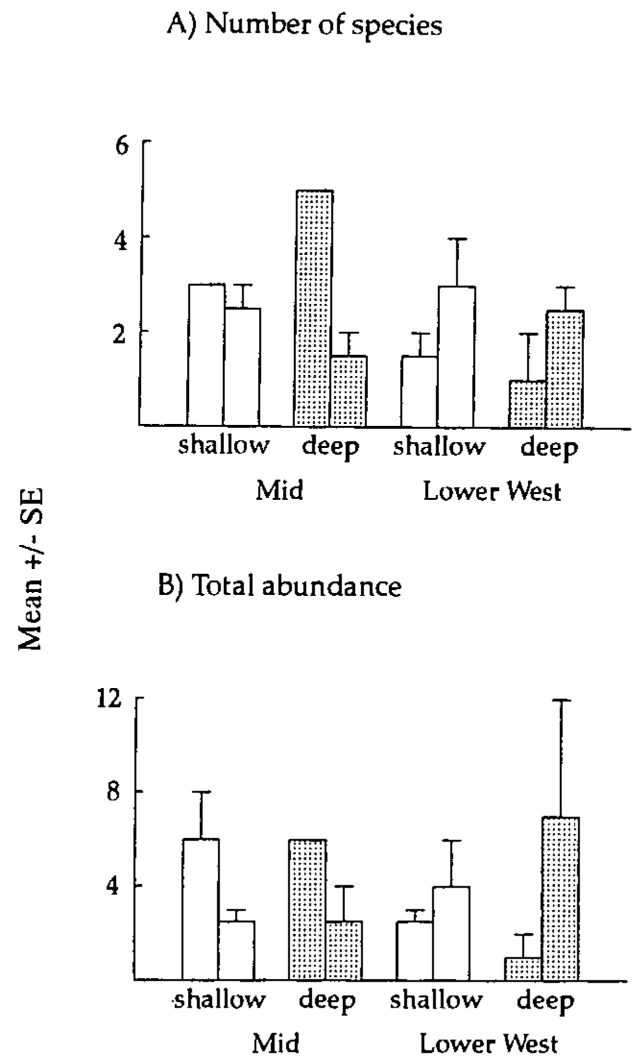


Figure 15. The mean (+SE) number of species and total abundance of fish and mobile invertebrates captured by gill netting at 2 sites in deep holes and shallow areas in each of 2 locations along Berowra Creek (n=2).

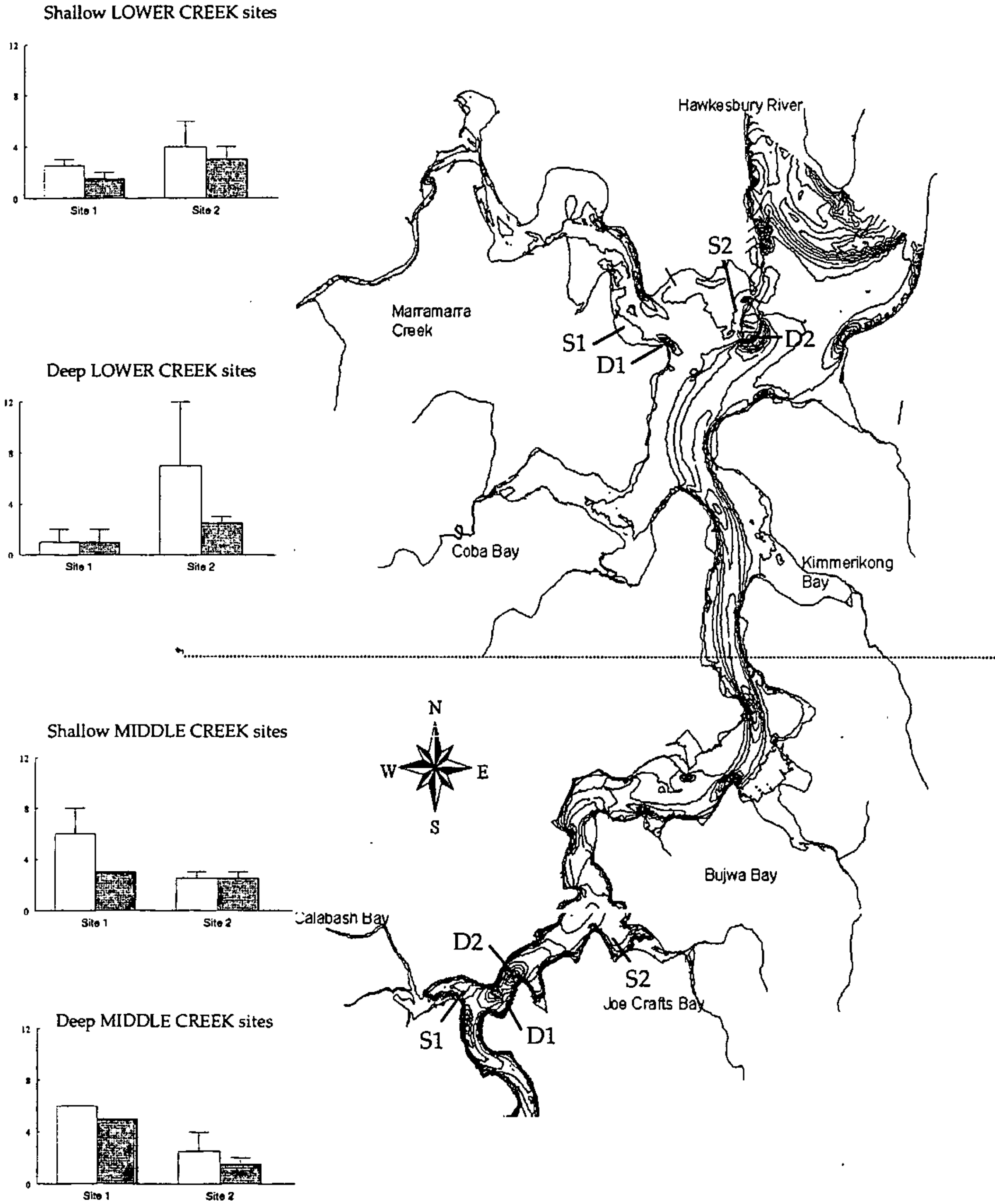


Figure 15 continued: C) Mean (+se) abundance (open bars) and mean (+se) number of species (shaded bars) of fish and mobile invertebrates caught using gill nets in deep holes and shallow areas in Berowra Creek.

3.3.3 Commercially Important Fish and Mobile Invertebrates

General Findings

A total of 698 individuals of commercially important fish and crustacean species were collected using either seine or gill nets. Five hundred and thirty three (533) of these were fish and 158 were crustaceans, the latter dominated by prawns (150 individuals) (Appendix 15). With the exception of mulloway (*Argyrosomus hololepidotus*), our samples contained representatives of all the species of fish reported as targeted by recreational species in Berowra Creek (B. Harrison, NSW Fisheries, pers. comm.). Mulloway have been previously recorded from Berowra Creek (Gray and McDonall, 1993; The Ecology Lab Pty Ltd, 1993).

The sizes and life stages of fish caught using the two methods of netting differed because each net targets a different size of fish: seines tend to catch smaller fish than gill nets. As expected, all fish caught in seine nets were small juveniles, except for yellowfinned leatherjackets (*Meuschenia trachiensis*), which were made up of approximately half small juveniles and half large juveniles. Although three common fish species (luderick, sea mullet and flat-tailed mullet) were caught in both seine and gill nets, all individuals from seine samples were small juveniles, and those caught in gill nets were a combination of adults and large juveniles (Appendix 15). Three other fish species caught in gill nets (silverbiddy, black sole and dusky flathead) were all in the adult life stage and one species (large tooth flounder) consisted of half large juveniles and half adults (Appendix 15).

Blue swimmer crabs caught in gill nets were juveniles, and the single mud crab caught in a gill net was an adult. Prawns were caught only in seine nets, and due to damage caused to the rostrums during capture were not measured. However, observations made during sorting and counting of the catch indicated that, in general, Eastern King prawns (*Penaeus plebjus*) were juveniles and Greasyback (*Metapenaeus bennetae*) and School prawns (*Metapenaeus macleayi*) were a combination of juvenile and adult life stages.

Commercially important fish and crustacean species were collected from all regions of the creek sampled, including Marramarra Creek. (Note: no fish samples were collected in the Lower Section, see Figure 3). Because the sampling methodology was habitat-based and not designed to identify overall differences in the distribution of commercial species in the creek, only limited information can be derived about their distributions from these data. The main observation is that the abundance of commercial species in each section varied with the sampling method. A greater proportion (57.8%) of the total number of commercially important species caught in seines were from the Lower West section (Marramarra Creek) compared to the Middle (22.9%) and Upper Section (19.3%). However, commercially important species caught in gill nets were fairly evenly divided between the middle section (54.8%) and the Lower West section (45.2%) of the creek. While these data demonstrate that seagrass beds, shallow areas and deep holes in Berowra Creek all provide habitat for both juveniles and adult life stages of commercially important species, a more detailed examination of the abundance and distribution of commercially important species requires a sampling design that specifically targets such species.

4.0 CONCLUSIONS

4.1 Biota of Intertidal Mangroves

Consistent trends in the composition, abundance and distribution of epifaunal animals of mangrove forests along Berowra Creek were evident. Although the assemblages of epifaunal animals were variable from place to place, there was a tendency for there to be more species, more individuals, more *Salinator solida* and *Melosidula* sp. in Big Bay, in the lower section of Berowra Creek, than other sections. In part, this trend may be explained by variations in the sediment type found at each site sampled. Mud was the more common substrata in the Lower and Lower West sections of the creek (Kimmerikong and Big Bay), compared to the more sandy sediments in the Upper and Middle sections. However, mud was the dominant sediment type in at least one of the three sites sampled in the Upper and Middle sections (Calna Creek and Calabash Creek). This suggests that although small scale (within-bay) distribution of sediment type varies, the general trend in sediment distribution may be one factor driving the distribution of mangrove epifauna. Additionally, large-scale physical/structural differences were apparent between sites at Big Bay and the other sampling locations. In summary, mangrove stands in Big Bay had an open understorey, were contiguous and the mangrove zone was wider than at other sampling sites, even in comparison to mangroves in other embayments such as Calabash and Kimmerikong Bays.

If the abundance of epifaunal biota can be considered an indicator of the level of productivity of the mangrove habitat, then Big Bay is a productive mangrove habitat. Furthermore, increases in mangrove area in Big Bay would represent greater contributions to overall productivity in the system compared to increases in other mangrove areas in Berowra Creek. These findings indicate that the mangroves at Big Bay may be a significant natural resource at a local (and perhaps regional) scale.

While it is not clear what processes have produced these patterns, two related factors bear further examination: the characteristics of hydrology in Big Bay and the nature of the recently documented increase in the extent of mangroves. The expansion of mangroves in Big Bay has been primarily upslope and downslope into deeper water from existing mangrove stands into channels and bays)(Williams and Watford, 1997). This has resulted in the expansive, wide mangrove zone we observed. The more common method of mangrove expansion seen in the middle and upper sections of the creek involves the expansion, initially by single trees, along the channel shoreline from existing stands into areas not previously colonised (Williams and Watford, 1997).

The observed method of mangrove expansion in Big Bay is consistent with the nature of tidal currents observed there. Big Bay is essentially a backwater, separated from the main channel current, and is subject to considerably slower tidal velocities than those experienced in the main channel. These slower currents create a physical environment more conducive to sediment accumulation and subsequent stabilisation of sediments by mangrove encroachment. Because new mangrove habitats in Big Bay are surrounded by epifauna in established habitat, stabile sediments can be quickly colonised by epifauna, resulting in a productive mangrove community. Ecological theory alone (e.g. the species – area hypothesis, MacArthur and Wilson, 1967) would predict greater numbers of species in large, contiguous areas of mangroves compared to the narrow strips of habitat common in the middle and upper creek. The observation of greater abundance of epifauna in Big Bay, and the pattern of one common species of snail occurring only in Big Bay, lend support to the idea that the different physical environment in Big Bay has led to differences in the abundance and assemblage of epifaunal animals found there. In support of this, we observed that there was no relationship between the abundance of the numerically dominant species and the characteristics of the habitat that were measured (e.g. abundance of pneumatophores, crab burrows, mangrove seeds and saplings) that may provide habitat for epifauna. This indicates that the availability of small-scale habitat is not likely to be a factor in determining the abundance of epifauna in this estuary.

In contrast, mangroves expanding linearly along the shoreline may be subject to higher rates of sediment erosion due to the more rapid current velocities found there. Additionally, potential colonisers to newly accumulated sediments along the main channel are likely to arrive from a smaller source of habitats (often other, single mangrove trees) immediately up- and/or downstream of the new habitat. The combined effects of greater tidal current velocities and a more restricted source of potential colonising organisms is likely to result in less stable "fringing" mangrove stands that support fewer numbers of animals and fewer species. The data collected for this study support such proposed mechanisms, and the high levels of variation recorded further lend credence to the importance of these factors in structuring the epifaunal mangrove community. Despite the relative paucity of epifauna they contain, mangroves in the middle and upper sections of the creek may nevertheless play an important role in providing shelter and resting spots for fish and mobile epifauna as they move to forage between habitats.

In contrast to epifaunal animals, the infaunal animals of the mangrove forests, showed no consistent spatial trends in their composition, abundance and distribution along Berowra Creek. There was a suggestion of greater total abundance and abundance of numerically dominant species in the upper and mid sections of Berowra Creek, however, this pattern was overwhelmed by the greater variability within each section, at the smaller spatial scale of sites, indicating patchy distributions across relatively small spatial scales.

With the exception of epifauna recorded in Big Bay, the abundance and diversity of mangrove biota as a whole within Berowra Creek appears to be at the lower range of those encountered in similar studies done elsewhere in NSW. As indicated above, these differences may be due to the nature and effect of environmental factors and further speculation is beyond the scope of the current study. Furthermore, epifaunal abundance and diversity at Calabash Creek, Joe Crafts Bay and Kimmerikong Bay was very low, with no epifauna encountered at two sites within Calabash Creek and one site in Kimmerikong Bay. These trends were not apparent among infauna associated with mangrove sediments or the physical/structural attributes of mangrove trees or communities, suggesting that the mangrove communities within Berowra Creek are relatively unique in comparison with those studied elsewhere.

Dieback and Mangrove Expansion within Berowra Creek

Mangrove dieback has been reported in Berowra Creek upstream of the Woolwash since the second half of 1997. This dieback was investigated by The Ecology Lab (1998) on behalf of Hornsby Shire Council during November 1997. Dieback resulted in defoliation and/or death of individual *A. corniculatum* and *A. marina* trees among fringing mangroves. Dieback affected individual trees, rather than areas of trees, and was usually apparent only on the side of the river along which the deeper channel flowed. The loss of mangroves due to dieback was not considered significant in terms of overall mangrove abundance within

Berowra Creek, but did lead to noticeable losses in small areas e.g. immediately downstream of Crosslands Youth Camp. As indicated in the discussion above, it is likely that the observed losses may have relatively little effect on the overall productivity of mangrove habitats in Berowra Creek. The levels of dieback recently observed in Berowra Creek are not sufficient to question the documentation of a greater than 30 % increase in mangrove cover over a 50 year period (Williams and Watford, 1997), and it is likely that there have been both increases and decreases in mangrove cover in various areas through this time. Mangroves appear to be increasing at the expense of seagrass in the Woolwash area (TEL data, review document Section 9.6) and saltmarshes in others (Williams and Watford, 1997).

4.2 Macrofauna of Benthic Sediments

Assemblages and populations of macrofauna in sandy sediments varied along Berowra Creek. Assemblages from the lower reaches of Berowra Creek (Lower and Lower West) were similar to each other but differed from the locations in the upper reaches of Berowra Creek. Despite large variation within locations, there was an overall trend toward more molluscs and crustaceans in the Upper and Middle creek locations and more polychaetes in the Lower and Lower West creek locations. This overall pattern of abundance and composition of fauna at different distances along the creek may reflect the varying tolerances of different taxa to the range in salinity along the creek. Previous studies on macroinvertebrates in the Hawkesbury River (Jones *et al*, 1986, Jones *et al.*, 1988, Jones, 1987) have confirmed the importance of salinity as a factor influencing the distribution and composition of assemblages, and have also emphasised the roles of floods and droughts on the high variability of zoobenthos in the estuary.

The effect of algal blooms on benthic macroinvertebrates may be evident in the abundance and distribution of one species, the bivalve *Sanguineolaria donacoides* (Family Psammobiidae), which has no common name. Other specialists studies have indicated that, probably due largely to flushing patterns in the estuary, algal blooms can persist in the Middle section of the estuary for longer periods than further upstream or downstream. *Sanguineolaria donacoides* is a deposit-feeding bivalve, and was abundant in this section of the estuary. It is likely that this species is able to feed on the detritus produced by algae and zooplankton that are abundant during a bloom. The abundance of this species may serve as a short-term indicator of the impact of blooms, however more details on its biology would be required. There are no studies on the ecology of this endemic species, and important information such as its life span (presumed to be 2 years or more) and method of larval dispersal (presumed to be planktonic) are currently extrapolated from the ecology of similar species overseas (Willan, 1998).

Fewer individuals and taxa of macrofauna were collected in muddy sediments compared to sandy sediments. This may, however, be a reflection of the bias in sampling effort , which was greater in sandy sediment. Regardless of sampling effort, it would appear that the assemblages of macrofauna do differ between sandy and muddy sediments as reflected in the different proportions of contributing taxa. For instance, muddy sediments were dominated by polychaetes whereas sandy sediments were dominated first by molluscs then polychaetes. This indirectly supports the frequently verified hypothesis that the size of sediment (or another related factor) is a contributing factor in structuring assemblages and populations of macrofauna. Thus, the processes affecting the distribution of macrobenthos in Berowra Creek may be very similar to those in other estuaries.

The composition and abundance of macrofauna of muddy sediments in deep holes and adjacent shallow areas were highly variable at the smaller spatial scale of sites, which in turn, influenced the detection of trends at the larger spatial scales of between 2 sections of Berowra Creek and between depths. Importantly, abundances of taxa were inconsistent among locations and depths, such that macrofauna were comparatively depauperate in the deep holes in the Mid creek location compared to adjacent shallow areas, but were greater in abundance in the deep holes of the Lower West location compared to adjacent shallow areas. Thus, the influence of the deep holes on the composition and abundance of macrofauna would appear to vary according to location along Berowra Creek. This pattern may reflect the combined effects of the fauna's varying response to salinity and to different sediment composition. The abundant polychaete worm collected in the deep hole at the Lower West location, *Terebellides stroemi* was found to be distributed in muddy areas of the Hawkesbury River that had mean salinities of 28.2 ppt (Jones *et al.*, 1986). Salinity profiles taken just prior to sampling benthos indicate salinity levels of 27 to 29 ppt in the vicinity of deep hole in the Lower West section, while salinity was 25 to 26 ppt in the vicinity of the deep hole in the middle section of the creek (Figure B3 in van Senden, 1998). Thus, the greater abundance of this species in holes in the Lower West section of the creek may be explained by their salinity preference. Deep holes may also provide a refuge from great changes in salinity, particularly during flood events.

Additionally, polychaete species in a family closely related to *Terebellides* have in their blood a pigment capable of storing oxygen for release when ambient oxygen tension is low. *Terebellides* is likely to have a similar adaptation to estuarine conditions, making it possible to survive in habitats with periodically low oxygen tension such as those at the bottom of the deep holes in Berowra Creek.

The relatively greater abundance of macrofauna in deep holes in the Lower West Section of Berowra Creek is consistent with another indication of high levels of productivity in that area: greater abundance of mangrove epifauna. Together these observations suggest that the larger populations of commercially important species of fish and crustaceans caught in seine nets in that region may prefer the Lower West section of the creek because local habitats supply adequate food, and probably, shelter for their survival.

4.3 Fish and Mobile Invertebrates in Seagrass Beds

The assemblages and populations of fish and mobile invertebrates in seagrass beds varied significantly within and between locations along Berowra Creek. Overall, there was no difference in the average number of taxa along Berowra Creek, but there were differences in the assemblages and abundance of the dominant species. At the level of assemblages, locations along Berowra Creek were primarily distinguished by the presence or absence of particular species rather than by the relative abundances of widespread species. For instance, *Philypnodon grandiceps* was found in the upper reaches of Berowra Creek only, which is not surprising as it is mainly a fresh and brackish water species. For those numerically dominant species that occurred at most sampling sites, some were more abundant in the lower reaches of Berowra Creek and others were more abundant in the upper reaches, that is, there were no consistent trends.

The composition of the assemblages of fish and mobile invertebrates in seagrass beds along Berowra Creek would appear to be fairly site-specific. In the scientific literature, there have been many factors suggested to explain the variability among fish and mobile invertebrate assemblages of seagrass beds, including microhabitat preferences, influence of adjacent habitats, distance from mouth of estuary, predation pressure, larval settlement patterns, fish behaviour to mention a few (summarised in Bell and Pollard, 1989). Without experimental studies, it is not possible to assess further the contribution of these factors to the spatial pattern of fish and invertebrate assemblages along Berowra Creek. It is likely, however, that there is an effect due to the position of the seagrass bed within the creek. Such an effect has been demonstrated by Bell *et al.* (1988) when they examined differences in abundance and species composition of juvenile fish and decapods (crabs and prawns) in *Zostera* beds at different distances along Cowan Creek and Pittwater, N.S.W. They concluded that the location of a seagrass bed within an estuary has a significant effect on the abundances of juvenile fish and decapods rather than the size, shape, leaf height or density of the beds. They further concluded that the most likely cause of these effects was variation in the distribution and availability of competent larvae. In the case of Berowra Creek, the distribution and availability of competent larvae may be even more variable than in estuaries that open directly into the ocean or into fully saline habitats. All larvae entering the lower end of the estuary would have already survived transport in the Hawkesbury River, probably enhancing the already variable supply of larval fish and mobile invertebrates.

Seagrass Beds

Because of their importance in the life cycles of fish and mobile invertebrates, concern has been expressed over the condition and extent of seagrass beds in Berowra Creek. As reported in the review document, the current distribution of seagrasses has changed slightly since the last comprehensive survey (West *et al.*, 1985, based on aerial photographs and ground-truthing in 1981). Several small, patchy seagrass beds were observed that were not recorded in West *et al.* (1985), and several large beds recorded in the vicinity of the Woolwash were absent or had been replaced by mangroves. Small and patchy seagrass beds not recorded in West *et al.* (1985) were present, and the previously recorded beds in Joe Crafts Bay were absent. These changes are consistent with the findings of other studies which examined aerial photographs of a number of estuaries in central New South Wales. They showed large year-to-year variations in the areal extent of *Zostera* beds (West *et al.*, 1985; Fisheries Research Institute, 1987; Larkum and West, 1983; 1990), but the specific mechanisms of decline and recolonisation were not, in general, determined. Potential mechanisms for change in the extent of seagrass beds include natural seasonal variation (Larkum *et al.*, 1984), fragmentation of beds (Fisheries Research Institute, 1987; Larkum & West, 1990), natural blowouts due to storm events (West & Larkum, 1979; Larkum & West, 1990) and damage by human activities including boat moorings and anchors (Walker *et al*, 1989). Furthermore, our casual observations while mapping and seining in seagrass beds suggested that, while they could be considered to be sparse compared to elsewhere, their general condition seemed reasonable. That is, they had a normal epiphyte load on their blades, and we not visibly in a state of decay. Taken in this context, the changes observed in seagrass beds during this study are not sufficient to cause concern at the present time, but should be monitored for further decreases in extent and to assess their condition.

The abundances and assemblages of fish and mobile invertebrates found in seagrass beds in this study support the premise that seagrass beds in Berowra Creek, although changeable through time, support similar biota to those in other estuaries. We examined published data on fish and mobile invertebrates from three other estuaries sampled using similar methods to this study. In samples from comparable habitats, fish abundances and assemblages from seagrass beds in Wallis Lake and nearby Cowan and Pittwater estuaries contained similar mean numbers of and species of fish and mobile invertebrates (The Ecology Lab Pty Ltd, 1998; Bell *et al.*, 1988). The fish assemblage reported in this study was also similar to the assemblage reported from shallow, muddy bottom sites in Botany Bay (SPCC, 1981), dominated by non-commercial species, particularly gobies.

4.4 Fish and Mobile Invertebrates in Deep Holes and Adjacent Shallow Areas

The fish and mobile invertebrate assemblage collected from deep holes did not differ significantly from that found in the adjacent shallow areas, indicating that the deep holes in Berowra Creek were not being utilised as unique habitats by fish and mobile invertebrates at the time of sampling. The presence of populations of zoobenthos in deep holes suggests that these habitats can it least supply the basic necessity of food, although the amount present in each hole varies considerably. However, the greater value of the deep hole habitat to fish and mobile invertebrates may lie in their provision of shelter, particularly as a refuge from high current velocities in the main channel after significant rain events, or when tidal flux is high. In such circumstances the quality of water at depth in the deep holes may have a direct effect on fish. Although fish are mobile and would tend to move away from stressful environmental conditions, upwelling of oxygen-poor water from the bottom of deep holes can occur rapidly, causing fish kills in potentially large numbers. To date there are no records, anecdotal or otherwise, that link fish kills with the poor quality of water upwelled from deep holes. Such evidence would be difficult to acquire, as fish kills are infrequent events, and the provenance of dead fish is difficult to determine.

4.5 Commercially Important Fish and Mobile Invertebrates

The results from this study indicate that habitats in all sections of the creek sampled contained commercially important fish and crustacean species. Juveniles life stages of fish tended to be captured in seine nets, and adults in gill net samples. Commercially important species of prawns were caught in seine nets and tended to be more abundant in the Lower West section of the creek. However, these data were collected using a habitat-specific design and hence were not appropriate to determine in detail the distributions of this group. A specifically designed sampling study is required to examine the distribution and abundance of commercially important species and to estimate the potential effect of commercial and recreational fishing on this resource.

5.0 ACKNOWLEDGEMENTS

This report was written by Libby Howitt and Peggy O'Donnell. Marcel Green, Karen Astles, Tim Cooper, Robert Cawley and Ben Cater completed field investigations. Robert Cawley, Marcel Green, Alice Zeitseff, Ben Carter, Peter Collins, Jane Harris and Shannon McCune completed laboratory analyses. Libby Howitt and Tim Cooper prepared the figures and Libby Howitt undertook the statistical analyses. Marcus Lincoln Smith reviewed the report.

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TABLES

Table 1: Summary of sampling designs for each component of the fauna sampled in Berowra Creek.

Table 2: Results of multivariate analyses of assemblages of epifauna in mangroves at 5 locations along Berowra Creek. A) ANOSIM test examining differences among locations. B) SIMPER analysis indicating the rank contribution of each species to the pair-wise comparisons between locations.

Table 3: Summary of ANVOAs on the abundance of epifaunal snails and characteristics of the mangrove habitat at 3 sites at each of 5 locations along Berowra Creek.

Table 4: Results of multivariate analyses of assemblages of infauna in mangroves from 3 sites at 5 locations along Berowra Creek.

Table 5: Results of multivariate analyses of benthic macrofauna in subtidal muddy sediments from 2 depths at 2 locations (Mid and Lower West) along Berowra Creek.

Table 6: Results of multivariate analyses of assemblages of benthic macrofauna in subtidal sandy sediments from 3 sites at 4 locations along Berowra Creek.

Table 7: Results of multivariate analyses of assemblages of fish in seagrass beds at 3 locations along Berowra Creek.

FIGURES

APPENDICES

APPENDIX 1. SUMMARY OF STATISTICAL PROCEDURES

Data were analysed statistically using two broad procedures, multivariate and univariate analyses. Multivariate analyses allow us to examine differences among sites, locations and depths for all species or taxa present (commonly called "the assemblage"). Univariate analyses allow us to examine variation in the number of taxa or species, the total abundance and abundance of individual species or taxa.

Multivariate Analyses

Variation in the assemblages of biota among all locations and sites (and, where appropriate, depths) was examined using multivariate procedures described by Clarke (1993). These analyses use a measure of similarity between samples to map their relationships in an ordination using non-parametric Multi-dimensional Scaling (MDS). They produce a graphical representation of the similarity (and dissimilarity) of the samples from all locations/sites/times sampled.

The data matrix (species by samples) was double square root transformed to reduce weighting given to abundant taxa and increase the weighting given to rarer taxa. Similarities among samples were calculated using the Bray-Curtis Similarity measure and used to construct three dimensional MDS plots. The adequacy of the three dimensional representations of the similarities among samples is assessed by examining the stress value. Stress values of < 0.1 indicate a good representation which may be easily interpreted and plots with < 0.2 indicate reasonable representation of the data. Plots where stress values exceed 0.2 indicate a poor representation of the relationship among samples in three dimensions and are of little value.

The significance of any apparent differences among locations and sites (and, where appropriate, depths) was determined using the ANOSIM randomisation test (Clarke, 1993). The null hypothesis tested was one of no differences among sites, depths and locations. The significance levels in pair-wise tests were adjusted to allow for multiple comparisons using the Bonferroni Correction formula (Winer, 1971). A limitation of ANOSIM is that a maximum of two factors can be examined. Thus, in some cases, it was necessary to use several ANOSIM tests to examine all the factors of interest.

Similarity analyses (SIMPER) were used to determine the relative contribution that particular taxa make to the dissimilarity of groupings and are based on the Bray-Curtis similarity measures among all samples (Clarke, 1993). SIMPER identifies which taxa are good discriminators between locations or times. All taxa can potentially contribute to the dissimilarity among locations but for reasons of brevity, only those that were ranked amongst the top 5 are presented and discussed.

Univariate Analyses

Statistical analysis of data on the number and abundance of biota was done using analyses of variance (ANOVA). Separate ANOVA's were done for each taxa that had sufficient abundances to warrant analysis, generally contributing greter than 5% to the total abundance. Cochran's test was used to test for homogeniety of variances. Data were transformed where necessary to stabilise variances either by log transform for abundance data. If this did not result in homogeneity of variance, analyses were done on the untransformed data and significance accepted at an adjusted α of < 0.01 (Winer *et al.*, 1991; Underwood, 1981). Otherwise, statistical significance in the ANOVA's was determined with $\alpha < 0.05$ for 1-tailed F-tests. Post-hoc pooling procedures involving elimination of terms from the mean square estimates were used if a term was non-significant at $\alpha > 0.25$, as recommended by Underwood (1981). Post-hoc comparisons among means for significant factors in the ANOVA were done using SNK tests. In some cases, a factor detected as significant in the ANOVA will not be detected by the SNK tests due to less power. Graphical interpretation was used in these cases.

In all analyses, locations and sites were considered random factors, with sites nested within locations and depths was considered a fixed factor, orthogonal to locations.

Appendix 2. Details of sampling sites for intertidal mangroves.

Location	Area Sampled	Site	GPS	*Avicennia*	*Aegiceras*	Canopy Height	Fixed Point Cover	Substratum	Notes
Calna Creek	Entrance to Calna creek	1	33° 37' 43S : 151° 07' 06E	dominant	mature	10 m	95%	Sandy	Casuarina present, saltmarsh behind.
		2	33° 37' 43S : 151° 07' 06E	dominant	understorey	9 m	95%	sandy	Casuarina present, saltmarsh behind.
		3	33° 37' 42S : 151° 07' 11E	dominant	understorey	7 m	95%	muddy	Bank steeper than S1 and S2, saltmarsh behind.
Calabash Creek	Entrance to Creek (both banks)	1	33° 35' 14S : 151° 06' 33E	dominant	absent	6 m	85%	muddy	*Xenostrobus* very abundant.
		2	33° 35' 03S : 151° 06' 26E	dominant	very dense understory	7 m	90%	Sandy	Black rafting algae
		3	33° 35' 19S : 151° 06' 32E	dominant	very dense understory	7 m	90%	Sandy	Black rafting algae
Joe Crafts Bay	Southern shore midway into bay	1	33° 35' 14S : 151° 08' 25E	dominant	front + rear	7-8 m	85%	muddy	
		2	33° 35' 11S : 151° 08' 25E	dominant	understorey	9 m	80%	very muddy	algae abundant
		3	33° 35' 08S : 151° 08' 27E	dominant	understorey	7 m	70%	less muddy	

Appendix 2. Details of sampling sites for intertidal mangroves.

Location	Area Sampled	Site	GPS	*Avicennia*	*Aegiceras*	Canopy Height	Fixed Point Cover	Substratum	Notes
Kimmerikong Bay	Southern shore midway into bay	1	33° 33' 13S : 151° 09' 26E	dominant	understorey	7 m	95%	very muddy	Casuarinas behind
		2	33° 33' 13S : 151° 09' 27E	dominant	understorey	8 m	95%	muddy, sandy to rear	Casuarinas behind
		3	33° 33' 15S : 151° 09' 26E	dominant	front	7 m	90%	muddy, sandy to rear	Casuarinas behind
Big Bay	At entrance to Big Bay on	1	33° 30' 46S : 151° 07' 09E	dominant	rear	5 m	55%	muddy	algae abundant, steep drop to creek
	north bank of Marramarra Creek	2	33° 30' 47S : 151° 06' 09E	dominant	front + rear	5 m	55%	muddy	algae abundant, steep drop to creek
		3	33° 35' 14S : 151° 06' 33E	dominant	front + rear	8 m	60%	very muddy	steep drop to creek

Appendix 3. The mean and standard error (SE) of the abundance of epifauna and characteristics of the mangrove habitat at 3 sites from each of 5 locations along Berowra Creek (n = 6).

Location	Calna Creek						Calabash Creek						Joe Crafts Bay						Kimmerikong Bay						Big Bay					
Site	1		2		3		1		2		3		1		2		3		1		2		3		1		2		3	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Epifaunal Animals																														
Bembicium nanum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.17	0.17	0.00	0.00	0.00	0.00
Tatea sp.	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Assiminea tasmancia	12.83	11.29	47.00	6.46	18.33	7.26	0.00	0.00	0.00	0.00	10.67	5.87	0.67	0.49	2.50	1.28	0.50	0.34	0.00	0.00	3.83	2.71	1.67	1.12	66.50	7.49	5.17	2.09	20.67	5.45
Ophicardelus sp.	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.33	4.33	2.00	1.48	0.00	0.00
Salinator solida	0.50	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.34	0.00	0.00	0.00	0.00	0.17	0.17	0.00	0.00	0.17	0.17	0.00	0.00	15.83	3.38	23.33	6.46	23.33	4.92
Melosidula sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.17	2.26	7.83	5.32	5.00	1.86
number of species	1.17	0.31	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.37	0.33	0.21	0.67	0.21	0.50	0.34	0.00	0.00	0.67	0.33	0.67	0.21	3.17	0.17	2.83	0.17	2.83	0.17
total abundance	13.83	11.28	47.00	6.46	18.33	7.26	0.00	0.00	0.00	0.00	11.17	6.17	0.67	0.49	2.50	1.28	0.67	0.49	0.00	0.00	4.00	2.88	1.83	1.08	93.00	8.66	38.33	7.33	49.00	9.06
Habitat Characteristics:																														
% cover of leaf litter	5.33	1.38	5.00	0.58	12.33	2.76	0.00	0.00	2.00	0.73	3.83	1.92	3.33	0.71	7.50	1.20	2.17	0.48	11.67	3.95	10.33	2.23	19.17	13.09	2.67	0.56	2.17	1.01	2.67	0.67
% cover of algae	61.83	19.56	38.00	14.53	18.67	11.15	0.00	0.00	71.50	10.95	59.17	12.83	3.83	1.01	45.83	16.90	48.50	15.45	0.00	0.00	8.67	4.67	12.83	6.98	51.50	12.46	74.00	12.63	81.50	4.79
% cover of rubbish	0.00	0.00	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% cover of *Xenostrobus*	0.00	0.00	0.00	0.00	0.00	0.00	5.67	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
no. mangrove saplings	7.17	2.33	0.50	0.34	2.83	1.01	0.50	0.34	0.17	0.17	1.17	0.65	0.00	0.00	0.50	0.34	0.00	0.00	3.17	0.95	0.50	0.34	1.33	0.42	6.83	2.48	6.83	2.91	33.17	8.01
no. mangrove seeds	3.67	1.23	4.83	2.47	3.33	0.80	4.50	1.38	4.33	1.31	2.00	0.68	4.33	0.95	10.83	1.22	1.33	0.42	30.00	9.58	28.00	11.09	25.67	10.84	7.33	2.55	12.83	1.78	42.00	7.81
no. crab holes	9.67	1.26	0.67	0.42	11.50	1.73	42.00	8.16	30.17	5.29	24.83	3.72	81.33	6.21	48.33	7.52	47.33	4.36	69.00	8.68	55.00	15.85	48.33	11.84	62.50	4.78	49.17	6.64	58.17	11.44
no. of pneumatophores	61.83	18.25	36.83	5.51	68.33	13.34	94.50	16.03	28.50	8.87	41.50	4.09	71.83	10.07	103.50	7.56	43.67	3.68	39.83	5.76	37.50	3.55	60.00	7.45	46.33	4.61	42.83	8.90	41.67	2.60

Appendix 4. Summary of ANOVAs on the abundance of epifauna and characteristics of the habitat in mangrove along Berowra Creek (n = 6). Due to post-hoc pooling, mean square has been tested over [a] = Residual.

Location abbreviations: CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

leaf litter % — untransformed, C = 0.8601 **

Source of Variation	df	MS	F	p	SNK tests:
locations	4	420.8722 [a]	5.01	**0.00**	CB = BB = JB = CN < KB
sites	10	61.7333	0.73	0.69	
residual	75	84.0289			
total	89				

algae % — untransformed, C = 0.1976 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	8873.5833	2.60	0.10	
sites	10	3411.2222	4.40	**0.00**	at CN, KB, BB all sites equal, at CB: 1 < 3 = 2
residual	75	774.4911			and at JB: 1 < 2 = 3.
total	89				

number of saplings — loge(x+1) transformed, C = 0.1816 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	13.3612	6.36	**0.01**	JB = CB = KB = CN < BB
sites	10	2.1001	5.78	**0.00**	at CB, JB, KB all sites equal, at CN: 2 < 3 = 1
residual	75	0.3633			and at BB: 2 = 1 < 3.
total	89				

number of seeds — loge(x+1) transformed, C = 0.1420 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	11.865	6.18	**0.01**	CB = CN = JB < BB = KB
sites	10	1.9198	4.35	**0.00**	at CN, CB, KB all sites equal, at JB: 3 < 1 < 2
residual	75	0.4418			and at BB: 1 = 2 < 3.
total	89				

Appendix 4. Summary of ANOVAs on the abundance of epifauna and characteristics of the habitat in mangrove along Berowra Creek (n = 6). Due to post-hoc pooling, mean square has been tested over [a] = Residual.

Location abbreviations: CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

number of crab holes — loge(x+1) transformed, C = 0.1692 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	17.1931	8.89	0.00	CN < CB = KB = BB = JB
sites	10	1.934	8.13	0.00	all sites equal except at CN: 2 < 1 = 3
residual	75	0.2379			and at BB: 1 = 2 < 3.
total	89				

number of pneumatophores — untransformed, C = 0.2614 **

Source of Variation	df	MS	F	p	SNK tests:
locations	4	2422.5167	0.79	0.56	
sites	10	3064.6889	6.01	0.00	at CN, KB, BB all sites equal, at CB: 2 = 3 < 1
residual	75	509.6667			and at JB: 3 < 1 < 2
total	89				

Assiminea tasmanica — untransformed, C = 0.3568 **

Source of Variation	df	MS	F	p	SNK tests:
locations	4	3773.7944	2.25	0.14	
sites	10	1675.8444	11.73	0.00	at CB, JB, KB all sites equal, at CN: 1 = 3 < 2
residual	75	142.8489			and at BB: 2 < 3 < 1
total	89				

Salinator solida — untransformed, C = 0.5379 **

Source of Variation	df	MS	F	p	SNK tests:
locations	4	1545.9333 [a]	49.76	0.00	JB = KB = CN = CB < BB
sites	10	22.7222	0.73	0.69	
residual	75	31.0689			
total	89				

Appendix 4. Summary of ANOVAs on the abundance of epifauna and characteristics of the habitat in mangrove along Berowra Creek (n = 6). Due to post-hoc pooling, mean square has been tested over [a] = Residual.

Location abbreviations: CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

number of species/quadrat untransformed, C = 0.1983 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	21.4722	32.21	0.00	CB = KB = JB = CN < BB
sites	10	0.6667	2.48	0.01	at CN, JB, BB all sites equal, at CB: 1 = 2 < 3
residual	75	0.2689			and at KB: 1 < 2 = 3
total	89				

number of individual snails untransformed, C = 0.2640 **

Source of Variation	df	MS	F	p	SNK tests:
locations	4	11621.7667	8.00	0.00	JB = KB = CB = CN < BB
sites	10	1452.0889	7.53	0.00	at CB, JB, KB all sites equal, at CN: 1 = 3 < 2
residual	75	192.8444			and at BB: 2 = 3 < 1
total	89				

Appendix 5. The mean and standard error (SE) of the abundance of infauna at 3 sites from each of 5 locations along Berowra Creek (n=2).

Location	Calna Creek						Calabash Creek					
Site	1		2		3		1		2		3	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Amphipod B	11.5	10.5	0.5	0.5	1	0	0	0	1	0	10.5	1.5
Amphipod D	0	0	0	0	0	0	0.5	0.5	0	0	1	0
Isopod A	16	0	33.5	2.5	5.5	2.5	1.5	1.5	1	1	20.5	8.5
Isopod E	0	0	0.5	0.5	0	0	0	0	0	0	0	0
Anthurid	0	0	0	0	0	0	0	0	1	0	0	0
Sulinator solida	0	0	0	0	0	0	0	0	0	0	1	1
Tatea sp.	30.5	17.5	87	18	0	0	0	0	0	0	2.5	2.5
Assiminea sp.	1.5	1.5	12.5	3.5	1.5	1.5	0	0	0	0	2.5	2.5
Littorina scabra	0	0	0	0	0	0	0	0	0.5	0.5	0	0
Arthritica helmsi	10.5	0.5	25.5	6.5	0.5	0.5	0	0	13.5	13.5	38	38
Xenostrobus sp.	0.5	0.5	2.5	0.5	2	2	0.5	0.5	3	3	7.5	1.5
Tipulidae	0.5	0.5	0	0	2.5	0.5	2	2	0.5	0.5	0.5	0.5
Chironomidae	2	2	0	0	1.5	1.5	0.5	0.5	1	1	2	2
Psycodididae	1.5	1.5	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	0.5	0.5	0	0	0	0	0	0	0	0	0	0
Tabanidae	0	0	0	0	0	0	0	0	0	0	0.5	0.5
Colembolla	0	0	0	0	0	0	1.5	1.5	0	0	0	0
Mite	0.5	0.5	0	0	0.5	0.5	0.5	0.5	0	0	0	0
Helograpsus sp.	0	0	0	0	0.5	0.5	0	0	0.5	0.5	0	0
Oligochaete	0	0	0	0	1	1	1	1	8	8	7.5	2.5
Nematode	0	0	0	0	0	0	0.5	0.5	0	0	0	0
Spionidae	0	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	0	0	0	0	0	0	0	0	0	0
Nephtyid	0	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0	0
Ascidian	0	0	0	0	0	0	0	0	0	0	0	0
Fish embryo	0	0	0	0	0	0	0	0	12.5	12.5	3	3
total abundance	75.5	25.5	162	5	16.5	5.5	8.5	4.5	42.5	37.5	97	53
number of taxa	7.5	0.5	6	0	6.5	1.5	4.5	1.5	6.5	2.5	9	1

Location	Joe Crafts Bay						Kimmerikong Bay					
Site	1		2		3		1		2		3	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Amphipod B	0	0	0	0	2.5	2.5	0	0	0	0	0.5	0.5
Amphipod D	5.5	3.5	0	0	0.5	0.5	1.5	1.5	3	1	3	0
Isopod A	0	0	0	0	11	6	0.5	0.5	0	0	0	0
Isopod E	0	0	0	0	0	0	0	0	0	0	0	0
Anthurid	0	0	0	0	0	0	0	0	0	0	0	0
Sulinator solida	0	0	0	0	4.5	3.5	0	0	0	0	0	0
Tatea sp.	0	0	0.5	0.5	1	1	0	0	0	0	1	1
Assiminea sp.	0	0	0	0	1	0	0.5	0.5	0	0	0.5	0.5
Littorina scabra	0	0	0	0	0	0	0	0	0	0	0	0
Arthritica helmsi	0	0	4.5	4.5	21.5	21.5	1	1	0	0	5	5
Xenostrobus sp.	0.5	0.5	0.5	0.5	10	10	1.5	1.5	0.5	0.5	0	0
Tipulidae	0	0	0	0	0.5	0.5	0	0	2	1	0.5	0.5
Chironomidae	0	0	2.5	2.5	0.5	0.5	0	0	0	0	0	0
Psycodididae	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	0	0	0	0	1.5	1.5	0	0	0	0	0	0
Tabanidae	0	0	0	0	0	0	0	0	0	0	0	0
Colembolla	0	0	0	0	0	0	0	0	0	0	0	0
Mite	0	0	0	0	0	0	0	0	0	0	0	0
Helograpsus sp.	1	1	0	0	0	0	0	0	0	0	0	0
Oligochaete	0	0	0	0	3	3	2	2	0	0	2.5	2.5
Nematode	0	0	0	0	0	0	0	0	0	0	0	0
Spionidae	0	0	1	1	0	0	2	2	0	0	0	0
Nereidae	0	0	0.5	0.5	0	0	0.5	0.5	0.5	0.5	1.5	1.5
Nephtyid	0	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	1	1	0	0	1	1	0	0	0	0
Ascidian	0	0	0	0	0	0	0	0	0	0	0	0
Fish embryo	0	0	0	0	0	0	0	0	0	0	0	0
total abundance	7	3	10.5	9.5	57.5	43.5	10.5	3.5	6	1	14.5	9.5
number of taxa	2	0	3.5	2.5	7.5	1.5	4.5	2.5	3	1	4.5	1.5

Location	Big Bay					
Site	1		2		3	
	mean	se	mean	se	mean	se
Amphipod B	1.5	0.5	8	4	0.5	0.5
Amphipod D	3	0	2	1	3.5	3.5
Isopod A	0	0	0	0	0	0
Isopod E	0	0	0	0	0	0
Anthurid	0	0	0	0	0	0
Sulinator solida	1.5	1.5	2	2	3	0
Tatea sp.	0	0	0	0	0.5	0.5
Assiminea sp.	2.5	1.5	1	1	1	0
Littorina scabra	0	0	0	0	0	0
Arthritica helmsi	0	0	0	0	0	0
Xenostrobus sp.	0	0	0	0	0	0
Tipulidae	0.5	0.5	2	1	1	1
Chironomidae	0	0	0	0	0	0
Psycodididae	0	0	5.5	5.5	1	1
Ceratopogonidae	0	0	0	0	0	0
Tabanidae	0	0	0.5	0.5	0	0
Colembolla	0	0	0	0	0	0
Mite	0	0	0	0	0	0
Helograpsus sp.	2	1	1.5	0.5	0	0
Oligochaete	3	3	1.5	1.5	0.5	0.5
Nematode	0	0	0	0	0	0
Spionidae	0	0	0	0	0	0
Nereidae	0.5	0.5	0	0	0	0
Nephtyid	0.5	0.5	0	0	0	0
Capitellidae	0	0	0	0	0	0
Ascidian	0.5	0.5	0	0	0	0
Fish embryo	0	0	0	0	0	0
total abundance	15.5	7.5	24	14	11	2
number of taxa	7	1	6.5	1.5	5	0

Appendix 6. Summary of ANOVAs on the abundance of infauna in mangrove habitats along Berowra Creek (n = 6). Location abbreviations are CN = Calna Creek, CB = Calabash Creek, JB = Joe Crafts Bay, KB = Kimmerikong Bay and BB = Big Bay.

number of individuals — untransformed, C = 0.3852 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	5528.6333	1.68	0.23	
sites	10	3282.2333	3.38	0.02	all sites equal except at CN: 3 = 1 < 2
residual	15	972.3			
total	29				

number of taxa — untransformed, C = 0.1880 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	10.1333	1.63	0.24	
sites	10	6.2333	1.41	0.27	
residual	15	4.4333			
total	29				

***Tatea* sp.** — loge(x+1) transformed, C = 0.3856 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	6.6629	2.87	0.08	
sites	10	2.3232	8.37	0.00	all sites equal except at CN: 3 < 2 < 1
residual	15	0.2776			
total	29				

Arthritica helmsi — loge(x+1) transformed, C = 0.3294 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	3.409	1.78	0.21	
sites	10	1.9205	1.01	0.48	
residual	15	1.9097			
total	29				

Isopod sp. A — loge(x+1) transformed, C = 0.3103 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	4	7.4392	4.13	0.03	differences could not be resolved
sites	10	1.8014	8.72	0.00	sites different at CN: 3 < 1 = 2; CB: 2 = 1 <3; JB: 1 = 2 < 3
residual	15	0.2065			
total	29				

Appendix 7. The mean and standard error (SE) for infauna collected in muddy sediments at 2 sites from 2 depths at 2 locations along Berowra Creek (n=4).

Location	Mid Creek								Lower West Creek							
Depth	Shallow				Deep				Shallow				Deep			
Site	1		2		1		2		1		2		1		2	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Nematodes: Round worms	0	0	1.25	0.75	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Capitellidae	0	0	1	0.408	0	0	0	0	0.5	0.5	0.5	0.5	0.75	0.25	0	0
Cirratulidae	0	0	0	0	0.25	0.25	0.25	0.25	0	0	0	0	0	0	0	0
Hesionidae	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0
Lumbrineridae	0	0	0.25	0.25	0	0	0	0	0	0	0.25	0.25	1.25	0.25	0.25	0.25
Nephtyidae	6.75	1.887	7.5	3.175	0	0	0.5	0.5	2.5	1.5	6.25	1.436	4.25	2.358	2	0.707
Opheliidae	0.75	0.25	2.75	0.75	0.25	0.25	0	0	0.25	0.25	0.25	0.25	0	0	0	0
Orbiniidae	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Pilargiidae	0	0	0	0	0.25	0.25	0.75	0.25	0	0	0	0	0	0	0	0
Polynoidae	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Sabellidae	0	0	0	0	0	0	0	0	0.25	0.25	0	0	3.75	1.652	0	0
Spionidae	0	0	0.25	0.25	8	1.225	4.25	1.031	0	0	0	0	0	0	0	0
Terebellidae	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchidae	20.25	2.626	113.3	29.49	0	0	0	0	2.25	1.315	8.5	1.658	125.8	19.39	38.5	22.41
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	1.25	1.25	0	0
Opistobranchs	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Laternulidae: Laternula spp	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0.75	0	0
Mactricidae:																
Notospisula trigonella	0	0	1.25	0.629	0	0	0	0	0.5	0.289	0.5	0.289	2.5	1.848	0.25	0.25
Type a	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Type b	0.25	0.25	0.25	0.25	0	0	0.25	0.25	0.5	0.5	0	0	0.25	0.25	0	0
Type c	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0
Type d	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
Mysidacea: Mysids	4.5	1.893	11.25	6.088	0	0	0	0	0	0	0	0	0	0	0	0
AmpType 1	0	0	0	0	0	0	0	0	0	0	0	0	4.25	4.25	0	0
AmpType 2	0	0	0	0	0	0	0	0	0	0	0	0	3.75	2.78	0	0
AmpType 3	0	0	0.5	0.5	0	0	0	0	0.75	0.479	1.75	0.479	5.75	2.175	3.5	2.363
AmpType 4	0	0	0	0	15.5	1.936	20.75	7.087	0	0	0	0	0	0	0	0
AmpType 5	0	0	0	0	0.75	0.479	1	0.577	0	0	0	0	0	0	0	0
AmpType 6	0	0	0	0	0.5	0.289	2.75	2.75	0	0	0	0	0	0	0.25	0.25
AmpType 7	0	0	0	0	0.75	0.479	0	0	0	0	0	0	0	0	0	0
isoType 1	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0.5	0.289
Thalassinidea: Burrowing Shrimps	0.25	0.25	0.25	0.25	0	0	0	0	0.25	0.25	0.25	0.25	0.25	0.25	0	0
Brachyura: Crabs	0.25	0.25	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0
Phylum Cordata: Fish	0	0	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0
Others: Eel	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0
number of taxa	4.75	0.479	7.75	0.854	4.75	0.854	4.5	0.645	3.25	1.702	5	0.577	9.5	1.555	3.5	1.041
total abundance	33.25	4.589	140.5	29.8	26.75	3.01	30.75	10.13	7.75	4.171	19	1.633	155.8	21.83	45.5	24.98
total polychaetes	28	3.24	125.3	27.61	9	1.472	5.75	1.377	5.75	3.065	15.75	1.109	136	20.5	41	23.04
total amphipods	0	0	0.5	0.5	17.5	1.708	24.5	9.314	0.75	0.479	1.75	0.479	13.75	9.105	3.75	2.394
total crustaceans	5	1.683	12	6.494	17.5	1.708	24.5	9.314	1	0.707	2.5	0.645	14.25	9.604	4.25	2.323
total molluscs	0.25	0.25	2	0.408	0	0	0.25	0.25	1	0.707	0.75	0.25	5.25	1.931	0.25	0.25

Appendix 8. Summary of ANOVAs on the abundance of benthic macrofauna in muddy sediments along Berowra Creek (n = 4). a = Post-hoc pooling, mean square tested over Residual.
Location abbreviations are MC = Mid Creek and LW = Lower West Creek and depth abbreviations are S = shallow and D = deep.

Nephtyids — untransformed, C = 0.4155 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	0.0313 [a]	0.00	0.96	
depths	1	132.0313	2.09	0.39	
locations x depths	1	63.2813 [a]	5.21	**0.03**	S: LW = MC, D: MC = LW; MC: D < S, LW: D = S
sites (loc x depth)	4	9.9688	0.82	0.52	
residual	24	12.1354			
total	31				

Trichobranchids — untransformed, C = 0.4944 *

Source of Variation	df	MS	F	p	SNK tests:
locations	1	861.125	0.11	0.76	
depths	1	200	0.00	0.96	
locations x depths	1	41184.5	5.05	0.09	
sites (loc x depth)	4	8150.3125	9.27	**0.00**	Sites differ at MCS and LWD only
residual	24	879.625			
total	31				

Number of taxa — untransformed, C = 0.3278 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	0.125	0.01	0.95	
depths	1	1.125	0.04	0.88	
locations x depths	1	32	1.33	0.31	
sites (loc x depth)	4	24.0625	5.45	**0.00**	Sites differ at LWD only
residual	24	4.4167			
total	31				

Total individuals — untransformed, C = 0.4146 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	5.2813	0.00	0.98	
depths	1	1696.5313	0.04	0.87	
locations x depths	1	42267.7813	3.55	0.13	
sites (loc x depth)	4	11900.0938	11.12	**0.00**	Sites differ at MCS and LWD only
residual	24	1070.5729			
total	31				

Appendix 8. Summary of ANOVAs on the abundance of benthic macrofauna in muddy sediments along Berowra Creek (n = 4). a = Post-hoc pooling, mean square tested over Residual.
Location abbreviations are MC = Mid Creek and LW = Lower West Creek and depth abbreviations are S = shallow and D = deep.

Polychaetes — untransformed, C = 0.4385 **

Source of Variation	df	MS	F	p	SNK tests:
locations	1	465.125	0.05	0.83	
depths	1	144.5	0.00	0.96	
locations x depths	1	43218	4.65	0.10	
sites (loc x depth)	4	9296.5625	10.69	**0.00**	Sites differ at MCS and LWD only
residual	24	869.5417			
total	31				

Crustaceans — untransformed, C = 0.3955 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	684.5 [a]	5.87	**0.02**	no difference between locations detected
depths	1	800	16.00	0.16	
locations x depths	1	50	0.50	0.52	
sites (loc x depth)	4	100.125	0.86	0.50	
residual	24	116.6042			
total	31				

Molluscs — loge(x+1) transformed, C = 0.3626 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	1.0398	0.69	0.45	
depths	1	0.0423	0.02	0.90	
locations x depths	1	1.7067	1.14	0.35	
sites (loc x depth)	4	1.499	7.63	**0.00**	Sites differ at MCS and LWD only
residual	24	0.1965			
total	31				

Appendix 9. The mean and standard error (SE) for benthic macrofauna collected in sandy sediments from 3 sites at 4 locations along Berowra Creek (n=4).

Location	Upper						Mid						Lower						Lower West					
Site	1		2		3		1		2		3		1		2		3		1		2		3	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Anemones	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flatworms	0.00	0.00	4.25	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nemerteans: Ribbon Worms	0.25	0.25	0.50	0.29	0.00	0.00	0.75	0.25	3.50	1.26	9.00	2.94	0.75	0.75	1.25	0.48	0.50	0.29	0.00	0.00	0.25	0.25	0.00	0.00
Ampharetidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Capitellidae	0.50	0.29	0.00	0.00	0.00	0.00	0.75	0.75	0.25	0.25	0.25	0.25	1.50	1.19	4.50	2.02	3.75	0.95	0.50	0.29	2.00	0.91	3.25	0.63
Hesionidae	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Lumbrineridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.50	0.29	0.50	0.29	0.00	0.00	0.00	0.00
Magelonidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.29	1.00	0.58	1.75	0.85	0.00	0.00	0.25	0.25	0.75	0.75
Nephtyidae	0.00	0.00	0.00	0.00	0.00	0.00	4.25	1.75	0.00	0.00	0.00	0.00	35.50	7.80	12.75	3.47	25.75	1.31	10.75	1.70	11.00	1.96	13.50	3.07
Nereididae	0.00	0.00	15.25	2.72	1.75	1.44	0.00	0.00	8.25	3.54	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.75	0.75	0.25	0.00	0.00	0.50	0.50	0.50	0.29	0.00	0.00	0.50	0.29	0.00	0.00
Orbiniidae	0.00	0.00	13.25	3.79	26.75	6.60	0.00	0.00	0.50	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oweniidae	1.00	0.58	0.00	0.00	0.00	0.00	2.50	1.19	0.00	0.00	3.75	2.17	1.00	1.00	0.50	0.50	0.25	0.25	1.00	0.41	0.00	0.00	0.00	0.00
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
Sabellidae	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	2.75	1.31	5.50	3.01	0.00	0.00	0.00	0.00	2.25	1.25	0.25	0.25	1.00	0.58	1.50	0.96	0.25	0.25	0.50	0.50	0.25	0.25	0.25	0.25
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	1.00	1.00	1.50	0.96	65.75	32.82	0.50	0.50	0.00	0.00	37.50	16.96	2.00	0.71
Oligochaeta	0.75	0.48	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.75	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barnacles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassaridae: *Nassarius* spp	1.00	0.71	0.00	0.00	0.00	0.00	1.50	0.65	2.50	1.66	18.25	4.84	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.41	0.25	0.25	0.50	0.29
Salinator fragilis	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.85	0.00	0.00	0.25	0.25	2.25	1.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudoliotia micans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Erycinidae: *Arthritica helmsi*	0.75	0.75	1.00	0.41	0.75	0.48	0.75	0.48	1.00	0.41	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	31.25	13.39	0.00	0.00	0.00	0.00
Laternulidae: *Laternula spp*	0.00	0.00	0.00	0.00	0.00	0.00	2.25	1.44	0.00	0.00	0.00	0.00	1.25	0.95	0.75	0.48	0.00	0.00	1.00	0.71	0.00	0.00	0.00	0.00
Mactricidae: *Notospisula trigonella*	1.00	0.41	0.00	0.00	0.00	0.00	15.75	2.59	1.25	0.95	2.75	1.11	1.75	0.85	2.25	1.93	2.50	0.65	9.00	3.58	2.50	1.89	0.50	0.50
Mytilidae: *Xenostrobius securis*	0.00	0.00	0.00	0.00	4.50	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae: *Sanguineolaria donacoides*	2.00	1.68	50.00	11.36	46.75	15.50	1.75	0.85	97.50	18.12	129.50	19.73	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.35	0.00	0.00	0.00	0.00
Bivalve Type a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bivalve Type c	1.50	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bivalve Type d	4.50	3.86	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.25	0.25	0.75	0.75	4.25	2.17	2.75	1.80	1.75	0.85	1.25	0.63	1.25	0.63

Appendix 9. The mean and standard error (SE) for benthic macrofauna collected in sandy sediments from 3 sites at 4 locations along Berowra Creek (n=4).

Location	Upper						Mid						Lower						Lower West					
Site	1		2		3		1		2		3		1		2		3		1		2		3	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Mysidacea: Mysids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	1.00	0.71	0.75	0.48	2.25	0.75	0.25	0.25	6.00	2.16	1.75	0.25
Amp Type 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.25	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AmpType 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.29	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	1.25	0.63	2.50	2.18	0.25	0.25	0.00	0.00	2.25	0.75	1.75	1.11
Amp Type 4	2.00	1.22	0.50	0.50	0.75	0.48	0.00	0.00	0.00	0.00	0.50	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 5	3.50	1.85	49.00	8.78	1.00	0.41	0.00	0.00	16.50	3.69	6.25	1.70	0.00	0.00	0.00	0.00	0.25	0.25	1.00	0.58	0.50	0.50	0.25	0.25
Amp Type 5a	0.50	0.50	9.75	3.04	0.00	0.00	0.00	0.00	6.25	1.93	1.75	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Amp Type 6	0.00	0.00	0.25	0.25	2.00	0.71	0.00	0.00	1.50	1.19	0.25	0.25	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 7	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	3.00	2.12	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Amp Type 8	0.50	0.29	0.00	0.00	0.00	0.00	0.50	0.29	1.00	1.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 9	0.00	0.00	1.25	0.95	0.00	0.00	0.00	0.00	0.00	0.00	5.25	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amp Type 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Halicarcinus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anthuridae	1.50	1.50	11.25	2.95	1.00	1.00	0.25	0.25	1.00	0.71	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.48	0.25	0.25	0.00	0.00
Iso Type 1	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
IsoType 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumacea: Cumaceans	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penaeidea: Penaeid Prawns	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
King Prawn	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caridea: Carid shrimps	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	1.25	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25
Thalassinidea: Burrowing Shrimps	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	1.60	0.25	0.25	0.00	0.00	0.00	0.00	0.25	0.25
Brachyura: Crabs	0.50	0.50	0.00	0.00	0.00	0.00	5.00	2.38	0.00	0.00	1.50	1.19	5.75	3.47	0.50	0.50	0.75	0.48	0.50	0.29	0.00	0.00	0.00	0.00
Insect Larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.48	1.75	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sipunculids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00
Phylum Cordata: Fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
number of taxa	6.75	1.97	9.50	1.32	6.50	1.50	10.50	1.04	10.75	0.63	14.25	2.87	10.25	1.03	11.50	1.32	10.75	0.63	9.75	1.38	7.75	1.18	20.50	12.18
total abundance	25.50	13.80	162.50	32.27	85.25	16.12	39.25	6.13	145.75	27.90	189.25	24.67	60.50	8.76	104.25	25.73	44.50	3.23	64.25	17.05	65.25	14.24	26.50	3.80
total number of polychaetes	4.50	2.33	34.25	8.08	28.50	5.24	7.75	2.69	12.25	3.33	6.00	1.87	41.50	8.30	87.25	28.52	33.75	0.48	13.25	1.80	51.75	14.27	20.00	2.92
total number of amphipods	6.50	3.30	61.25	11.15	3.75	0.63	0.50	0.29	26.25	6.22	18.00	4.95	2.50	0.96	3.00	2.04	1.25	0.63	1.50	0.96	2.75	1.03	2.00	1.08
total number of crustaceans	9.25	5.47	72.50	13.85	4.75	1.49	5.75	2.43	27.75	6.54	20.75	4.94	9.50	4.27	7.75	3.40	4.75	1.44	3.50	0.87	9.25	2.72	4.25	1.11
total number of molluscs	10.75	6.16	51.00	11.28	52.00	19.91	24.75	3.57	102.25	19.38	151.75	24.14	7.00	3.89	7.50	2.87	5.50	2.06	47.00	16.05	4.00	2.48	2.25	0.85

Appendix 10. Summary of ANOVAs on the abundance of benthic macrofauna in sandy sediments along Berowra Creek (n = 4).

Location abbreviations are UC = Upper Creek, MC = Mid Creek, LC = Lower Creek and LW = Lower West Creek.

Sanguineolaria donacoides — loge(x+1) transformed, C = 0.3138 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	3	35.5181	4.27	0.04	unresolved differences
sites	8	8.3207	32.60	0.00	sites at LC and LW similar, sites different at
residual	36	0.2552			UC: 1 < 3 = 2 and MC: 1 < 2 = 3.
total	47				

Nephytids — untransformed, C = 0.6486 **

Source of Variation	df	MS	F	p	SNK tests:
locations	3	1562.6944	11.27	0.003	UC = MC = LW < LC
sites	8	138.6042	4.43	0.001	all sites similar except at LC: 2 < 3 < 1
residual	36	31.3056			
total	47				

Trichobranchids — untransformed, C = 0.7877 **

Source of Variation	df	MS	F	p	SNK tests:
locations	3	1420.4097	0.77	0.542	
sites	8	1843.0417	4.04	0.002	sites at UC and MC similar, sites different at
residual	36	455.8681			LC: 3 = 1 < 2 and LW: 1 = 2 < 3.
total	47				

Amphipod type 5 — untransformed, C = 0.7879 **

Source of Variation	df	MS	F	p	SNK tests:
locations	3	823.1875	1.03	0.430	
sites	8	799.6458	24.49	0.000	sites at LC and LW similar, sites different at
residual	36	32.6458			UC: 3 = 1 < 2 and MC: 1 = 2 < 3.
total	47				

Polychaetes — loge(x+1) transformed, C = 0.2993 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	3	6.9311	3.17	0.085	
sites	8	2.1876	6.09	0.000	sites at MC, LC and LW similar, sites different a
residual	36	0.359			UC: 1 < 3 = 2
total	47				

Appendix 10. Summary of ANOVAs on the abundance of benthic macrofauna in sandy sediments along Berowra Creek (n = 4).

Location abbreviations are UC = Upper Creek, MC = Mid Creek, LC = Lower Creek and LW = Lower West Creek.

Crustaceans — loge(x+1) transformed, C = 0.5671 **

Source of Variation	df	MS	F	p	SNK tests:
locations	3	1387.0208	0.88	0.491	
sites	8	1577.0208	13.99	0.000	sites at MC, LC and LW similar, sites different at
residual	36	112.7153			UC: 3 = 1 < 2
total	47				

Molluscs — untransformed, C = 0.3193 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	3	17620.1875	3.33	0.077	
sites	8	5294.875	8.71	0.000	sites at LC similar, sites different at UC: 1<2=3
residual	36	608.1042			MC: 1 < 2 < 3; LW: 3 = 2 < 1
total	47				

total individuals — untransformed, C = 0.2495 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	3	11748.6875	0.97	0.453	
sites	8	12118.1458	8.71	0.000	sites at LC and LW similar, sites different at
residual	36	1391.0625			UC: 1 < 3 < 2; MC: 1 < 2 = 3
total	47				

total taxa — untransformed, C = 0.4245 **

Source of Variation	df	MS	F	p	SNK tests:
locations	3	59.5208	1.09	0.407	
sites	8	54.5833	0.95	0.489	
residual	36	57.4514			
total	47				

Appendix 11. The mean and standard error (SE) of fish and mobile invertebrates caught in seine nets in seagrass beds at 2 sites from 3 locations along Berowra Creek (n = 3). * = Species of commercial importance, ** = Introduced species.

			Upper			
			1		2	
Family name	Common name	Scientific name	mean	se	mean	se
FISH						
Hemiramphidae	Garfish*	*Hyporhamphus spp.*	0	0	0.67	0.33
Syngnathidae	Hairy pipefish	*Urocampus carinorostris*	6	1.73	1	1
Pseudomugilidae	Pacific blue-eye	*Pseudomugil signifer*	10.3	7.13	100	83.9
Scorpaenidae	Fortescue	*Centropogon australis*	6	4.58	1	0.58
Ambassidae	Perchlets	*Ambassis spp.*	59.3	40.9	0	0
Percichthyidae	Australian bass*	*Macquaria novemaculeata*	0.33	0.33	1	1
Terapontidae	Eastern striped trumpeter	*Pelates sexlineatus*	1	0.58	0.33	0.33
Sparidae	Tarwhine*	*Rhabdosargus sarba*	3	1.73	1	0.58
	Yellow-finned bream*	*Acanthopagrus australis*	0.33	0.33	2.33	1.2
Monodactylidae	Diamond fish	*Monodactylus argenteus*	1.67	1.67	2	2
Girellidae	Luderick*	*Girella tricuspidata*	1.33	0.33	4	3.51
Mugilidae	Sea mullet*	*Mugil cephalus*	0	0	2.67	2.19
	Flat-tail mullet*	*Liza argentea*	0.67	0.67	0.33	0.33
Gobidae	Swan River goby	*Pseudogobius olorum*	41	18.5	86.7	12.5
	Large-mouth goby	*Redigobius macrostoma*	666	126	130	76.1
	Glass goby	*Gobiopterus semivestita*	185	114	32.7	16.9
	Tamar R. goby	*Favonigobius tamarensis*	52	21.5	0	0
	Exquisite goby	*F. exquisitus*	23.7	17.5	0	0
	Long-finned goby	*F. lateralis*	0	0	0	0
	Bridled goby	*Arenigobius bifrenatus*	0.33	0.33	0	0
	Mangrove goby	*Mugilogobius stigmaticus*	0	0	0	0
	Yellowfin goby**	*Acanthogobius flavimanus*	0.67	0.67	0	0
Eleotridae	Flatheaded gudgeon	*Philypnodon grandiceps*	60	10.2	46	24.9
	Dwarf flatheaded gudgeon	*Philypnodon sp.*	0.33	0.33	0.33	0.33
	Empire gudgeon	*Hypseleotris compressa*	0	0	0.33	0.33
Monacanthidae	Yellowfin leatherjacket*	*Meuschenia trachylepis*	9.33	4.91	5.33	3.38
	Six-spined leatherjacket*	*Meuschenia freycineti*	1.33	0.33	0.67	0.67
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	5	1.15	4.33	2.03
Diodontidae	Three-bar porcupinefish	*Dicotylichthys punctulatus*	0.33	0.33	0	0
CRUSTACEANS						
Penaeidae	Eastern king prawn*	*Penaeus plebejus*	7	3.61	2.33	0.88
	Greasyback prawn*	*Metapenaeus bennettae*	0	0	0	0
	School prawn*	*Metapenaeus macleayi*	0.67	0.67	0.67	0.67
Palaeomonidae	Carid shrimp sp. A	*Macrobrachium sp.*	0.67	0.33	0.33	0.33
	Mysid shrimp		0	0	0	0
MOLLUSCS						
Loliginidae	Squid*		0	0	0	0
		Number of taxa	19	1	15.3	2.4
		Total abundance	1143	161	427	222
		Fish abundance	1135	164	423	221
		Crustacean abundance	8.33	3.28	3.33	1.86
		Mollusc abundance	0	0	0	0
		Commercial fish abundance	16.3	6.89	18	7.51

Appendix 11. The mean and standard error (SE) of fish and mobile invertebrates caught in seine nets in seagrass beds at 2 sites from 3 locations along Berowra Creek (n = 3). * = Species of commercial importance, ** = Introduced species.

			Mid			
			1		2	
Family name	Common name	Scientific name	mean	se	mean	se
FISH						
Hemiramphidae	Garfish*	*Hyporhamphus spp.*	0	0	0	0
Syngnathidae	Hairy pipefish	*Urocampus carinorostris*	4.67	4.18	1	1
Pseudomugilidae	Pacific blue-eye	*Pseudomugil signifer*	128	83.6	13.7	6.36
Scorpaenidae	Fortescue	*Centropogon australis*	0.67	0.67	1.33	0.88
Ambassidae	Perchlets	*Ambassis spp.*	75	18.3	1	1
Percichthyidae	Australian bass*	*Macquaria novemaculeata*	0	0	0	0
Terapontidae	Eastern striped trumpeter	*Pelates sexlineatus*	0	0	0	0
Sparidae	Tarwhine*	*Rhabdosargus sarba*	1	1	2.33	0.88
	Yellow-finned bream*	*Acanthopagrus australis*	0.67	0.67	3.67	1.86
Monodactylidae	Diamond fish	*Monodactylus argenteus*	0	0	0	0
Girellidae	Luderick*	*Girella tricuspidata*	4.67	0.67	1.67	0.67
Mugilidae	Sea mullet*	*Mugil cephalus*	15.7	4.81	4	1.53
	Flat-tail mullet*	*Liza argentea*	0	0	0.33	0.33
Gobidae	Swan River goby	*Pseudogobius olorum*	15.7	1.2	56.7	39.2
	Large-mouth goby	*Redigobius macrostoma*	39.3	22.5	25.7	8.29
	Glass goby	*Gobiopterus semivestita*	125	64.1	554	352
	Tamar R. goby	*Favonigobius tamarensis*	0.33	0.33	3.67	3.67
	Exquisite goby	*F. exquisitus*	0.33	0.33	6.67	2.4
	Long-finned goby	*F. lateralis*	0.67	0.67	0	0
	Bridled goby	*Arenigobius bifrenatus*	0	0	0	0
	Mangrove goby	*Mugilogobius stigmaticus*	0	0	0	0
	Yellowfin goby**	*Acanthogobius flavimanus*	0	0	0.67	0.33
Eleotridae	Flatheaded gudgeon	*Philypnodon grandiceps*	3.33	2.03	0	0
	Dwarf flatheaded gudgeon	*Philypnodon sp.*	0	0	1.67	0.33
	Empire gudgeon	*Hypseleotris compressa*	0	0	0	0
Monacanthidae	Yellowfin leatherjacket*	*Meuschenia trachylepis*	0	0	1	1
	Six-spined leatherjacket*	*Meuschenia freycineti*	0	0	0	0
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	4	1	2	1.53
Diodontidae	Three-bar porcupinefish	*Dicotylichthys punctulatus*	0.67	0.33	0	0
CRUSTACEANS						
Penaeidae	Eastern king prawn*	*Penaeus plebejus*	4.33	1.2	4.33	2.85
	Greasyback prawn*	*Metapenaeus bennettae*	0	0	0	0
	School prawn*	*Metapenaeus macleayi*	5.67	5.67	1.67	1.2
Palaeomonidae	Carid shrimp sp. A	*Macrobrachium sp.*	50	18.6	1	0.58
	Mysid shrimp		0	0	0	0
MOLLUSCS						
Loliginidae	Squid*		0	0	0	0
		Number of taxa	14	1.73	15.7	2.19
		Total abundance	480	103	688	352
		Fish abundance	420	114	681	351
		Crustacean abundance	60	12.7	7	2.65
		Mollusc abundance	0	0	0	0
		Commercial fish abundance	22	3.61	13	4

Appendix 11. The mean and standard error (SE) of fish and mobile invertebrates caught in seine nets in seagrass beds at 2 sites from 3 locations along Berowra Creek (n = 3). * = Species of commercial importance, ** = Introduced species.

			Lower West			
			1		2	
Family name	Common name	Scientific name	mean	se	mean	se
FISH						
Hemiramphidae	Garfish*	*Hyporhamphus spp.*	0	0	0	0
Syngnathidae	Hairy pipefish	*Urocampus carinorostris*	0.67	0.33	4.67	2.19
Pseudomugilidae	Pacific blue-eye	*Pseudomugil signifer*	201	22.5	266	138
Scorpaenidae	Fortescue	*Centropogon australis*	2.67	2.19	13.7	8.29
Ambassidae	Perchlets	*Ambassis spp.*	39.7	29.4	243	11.3
Percichthyidae	Australian bass*	*Macquaria novemaculeata*	0	0	0	0
Terapontidae	Eastern striped trumpeter	*Pelates sexlineatus*	0.33	0.33	0	0
Sparidae	Tarwhine*	*Rhabdosargus sarba*	2	0.58	9.67	2.85
	Yellow-finned bream*	*Acanthopagrus australis*	8.33	4.33	6.67	2.85
Monodactylidae	Diamond fish	*Monodactylus argenteus*	0	0	0	0
Girellidae	Luderick*	*Girella tricuspidata*	9.67	3.48	17	5.13
Mugilidae	Sea mullet*	*Mugil cephalus*	4.67	3.18	25.7	9.26
	Flat-tail mullet*	*Liza argentea*	0.33	0.33	6.33	3.18
Gobidae	Swan River goby	*Pseudogobius olorum*	68.3	11.9	48.3	22.1
	Large-mouth goby	*Redigobius macrostoma*	115	18.8	234	58.4
	Glass goby	*Gobiopterus semivestita*	351	80.6	859	184
	Tamar R. goby	*Favonigobius tamarensis*	117	24	177	56.2
	Exquisite goby	*F. exquisitus*	3.67	3.67	3.33	3.33
	Long-finned goby	*F. lateralis*	0	0	0.33	0.33
	Bridled goby	*Arenigobius bifrenatus*	2	1.15	3.67	0.67
	Mangrove goby	*Mugilogobius stigmaticus*	1.67	0.88	0.33	0.33
	Yellowfin goby**	*Acanthogobius flavimanus*	0.33	0.33	0	0
Eleotridae	Flatheaded gudgeon	*Philypnodon grandiceps*	0	0	0	0
	Dwarf flatheaded gudgeon	*Philypnodon sp.*	0	0	0	0
	Empire gudgeon	*Hypseleotris compressa*	0	0	0	0
Monacanthidae	Yellowfin leatherjacket*	*Meuschenia trachylepis*	0.33	0.33	12.7	2.91
	Six-spined leatherjacket*	*Meuschenia freycineti*	0	0	0	0
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	5	2	8	1.53
Diodontidae	Three-bar porcupinefish	*Dicotylichthys punctulatus*	0.67	0.67	2.67	1.45
CRUSTACEANS						
Penaeidae	Eastern king prawn*	*Penaeus plebejus*	13	7.09	5	2.89
	Greasyback prawn*	*Metapenaeus bennettae*	0	0	5.67	5.67
	School prawn*	*Metapenaeus macleayi*	0.67	0.67	1.33	1.33
Palaeomonidae	Carid shrimp sp. A	*Macrobrachium sp.*	18	10.4	289	135
	Mysid shrimp		0.33	0.33	0.33	0.33
MOLLUSCS						
Loliginidae	Squid*		1	0.58	1.33	0.88
		Number of taxa	18.7	1.76	20.7	2.33
		Total abundance	967	103	2245	331
		Fish abundance	934	119	1942	249
		Crustacean abundance	32	17.6	302	136
		Mollusc abundance	1	0.58	1.33	0.88
		Commercial fish abundance	25.3	2.33	78	16.7

Appendix 12. Summary of ANOVAs on the abundance of fish and mobile invertebrates from seagrass beds along Berowra Creek (n = 4). [a] = Post-hoc pooling, mean square tested over Residual.

Location abbreviations are UC = Upper Creek, MC = Mid Creek and LW = Lower West Creek.

number of taxa — untransformed, C = 0.2500 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	35.0556 [a]	3.03	0.09	
sites	3	10.1111	0.87	0.48	
residual	12	11.5556			
total	17				

total abundance — untransformed, C = 0.3759 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	1759339.556	1.61	0.34	
sites	3	1095079.556	6.63	0.01	UC: 2=1, MC: 1=2, LW: 1<2
residual	12	165084.1667			
total	17				

abundance of commercial species — untransformed, C =0.4439 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	3029.5556	2.68	0.22	
sites	3	1131.7222	4.83	0.02	UC: 2=1, MC: 2=1, LW: 1<2
residual	12	234.3889			
total	17				

***Ambassis* sp.** — untransformed, C = 0.5577 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	23145.0556	0.92	0.49	
sites	3	25102.7222	16.73	0.00	UC: 2=1, MC: 2=1, LW: 1<2
residual	12	1500.8333			
total	17				

Appendix 12. Summary of ANOVAs on the abundance of fish and mobile invertebrates from seagrass beds along Berowra Creek (n = 4). [a] = Post-hoc pooling, mean square tested over Residual.

Location abbreviations are UC = Upper Creek, MC = Mid Creek and LW = Lower West Creek.

Favonogobius tamarensis sq. root transformed, C = 0.5087 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	177.1677	8.47	0.06	
sites	3	20.9217	5.25	**0.02**	UC: 2<1, MC: 1=2, LW: 1=2
residual	12	3.9858			
total	17				

Gobiopterus semivestita loge(x+1) transformed, C = 0.4346 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	8.0238 a	6.65	**0.01**	unresolved differences
sites	3	1.8388	1.52	0.26	
residual	12	1.2067			
total	17				

Pseudogobius olorom untransformed, C = 0.5764 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	1287.0556 [a]	0.97	0.41	
sites	3	2083.2222	1.56	0.25	
residual	12	1332.6111			
total	17				

Pseudomugil signifer untransformed, C = 0.5642 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	58395.0556 [a]	3.48	0.06	
sites	3	12736.7222	0.76	0.54	
residual	12	16773.3889			
total	17				

Redigobius macrostoma untransformed, C = 0.6117 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	2	204099.3889	1.35	0.38	
sites(location)	3	150901.4444	11.57	**0.00**	UC: 2<1, MC: 2=1, LW: 1=2
RESIDUAL	12	13044.5			
TOTAL	17				

Appendix 13. The abundance of fish and mobile invertebrates caught in gill nets at 2 sites in 2 depths from 2 locations along Berowra Creek (n=2). * = Species of economic importance.

			Mid								Lower West							
			shallow				deep				shallow				deep			
			site 1		site 2		site 3		site 4		site 5		site 6		site 7		site 8	
Family Name	Common Name	Scientific Name	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
FISH																		
Clupeidae	Southern herring*	*Herklotsichthys castelnaui*	0	0	0	0	1	0	1	1	0	0	1	0	0	0	0	0
Platycephalidae	Dusky flathead*	*Platycephalus fuscus*	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0
Sillaginidae	Sand whiting*	*Sillago ciliata*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Gerreidae	Silverbiddy*	*Gerres subfasciatus*	1	5	1	0	0	1	0	0	0	0	0	0	0	0	2	0
Monodactylidae	Diamond fish	*Monodactylus argenteus*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Girellidae	Luderick*	*Girella tricuspidata*	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Mugilidae	Flat-tail mullet*	*Liza argentea*	0	2	0	0	2	2	0	0	3	0	3	0	0	0	0	0
Mugilidae	Sea mullet*	*Mugil cephalus*	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0
Bothidae	Large-tooth flounder*	*Pseudorhombus arsius*	2	0	1	0	1	1	3	0	0	0	0	1	0	0	6	1
Soleidae	Black sole*	*Synaptura nigra*	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Monacanthidae	Yellowfin leatherjacket*	*Meuschenia trachylepis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEANS																		
Portunidae	Blue swimmer crab*	*Portunus pelagicus*	0	0	0	0	0	1	0	0	0	0	1	0	0	0	4	1
Portunidae	Mud crab*	*Scylla serata*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		total abundance	4	8	3	2	6	6	4	1	3	2	6	2	2	0	12	2
		total taxa	3	3	3	2	5	5	2	1	1	2	4	2	2	0	3	2

Appendix 14. Summary of ANOVAs on the number of species and total abundance of fish and mobile invertebrates from 2 depths at 2 locations along Berowra Creek (n = 2).

Location abbreviations: MC = Mid Creek, LW = Lower Creek. Depth abbreviations: S= shallow, D = deep.

total abundance — untransformed, C = 0.3963 NS

Source of Variation	df	MS	F	p	SNK tests:
locations	1	0.301	0.43	0.55	
depths	1	0.0467	0.07	0.81	
locations x depths	1	0.0281	0.04	0.85	
sites (loc x depth)	4	0.6978	2.06	0.18	
residual	8	0.3391			
total	15				

number of taxa — untransformed, C = 0.4944 *

Source of Variation	df	MS	F	p	SNK tests:
locations	1	4	0.94	0.39	
depths	1	0	0.00	1.00	
locations x depths	1	1	0.24	0.65	
sites (loc x depth)	4	4.25	5.67	**0.02**	all sites equal except at MCD: 2 < 1
residual	8	0.75			
total	15				

Appendix 15. Lengths of fish, (LCF, mm) and crustaceans (CL, mm) of commercial significance collected by gillnetting (gn) and seining (sn). Life history definition based on SPCC (1981) and Kailola (1993), SJ=small juvenile, LJ=large juvenile, AD=adult; n=number of fish measured; [a] = not measured.

Species	Common name	Life History Definition (mm)			n	Sampling	Range	Mean	Percentage of total measured		
		SJ	LJ	AD		method	(mm)	(se)	SJ	LJ	AD
Fish											
Rhabdosargus sarba	Tarwhine	<170			55	sn	13-39	22.8 (1.1)	100		
Acanthopagrus australis	Yellow-finned bream	<105	105-204	>204	65	sn	14-57	24.4 (1.0)	100		
Girella tricuspidata	Luderick	<144	144-284	>284	115	sn	13-41	23.5 (0.6)	100		
Mugil cephalus	Bully mullet	<84	84-300	>300	130	sn	23-43	31.6 (0.4)	100		
Liza argentea	Flat-tail mullet	<164	164-204	>204	24	sn	24-85	47.0 (3.3)	100		
Meuschenia trachiensis	Yellowfinned leatherjacket	<44	44-224	>224	85	sn	16-70	43.2 (1.3)	59	41	
M. freycineti	Six spined leatherjacket	<154			4	sn	55-69	61.3 (3.0)	100		
Hyperhamphus australis	Garfish				1	sn	26	26			
Macquaria novemaculeata	Australian bass				4	sn	24-29	26.8 (1.0)			
Gerres subfasciatus	Silverbiddy	<64	65-124	>125	10	gn	144-185	161 (3.7)			100
Girella tricuspidata	Luderick	<144	144-284	>284	2	gn	260-299	279.5 (19.5)		50	50
Mugil cephalus	Sea mullet	<84	84-300	>300	4	gn				50	50
Liza argentea	Flat-tail mullet	<164	164-204	>204	12	gn	155-314	259.0 (14.0)		17	83
Pseudorhombus arsius	Large-tooth flounder	<104	104-204	>204	16	gn	144-245	196.0 (9.0)		50	50
Sillago ciliata	Sand whiting	<144	144-244	>244	1	gn	170	170		100	
Synaptura nigra	Black sole			>170	2	gn	201-230	216.0 (14.5)			100
Platycephalus fuscus	Dusky flathead	<125	125-324	>325	3	gn	356-372	366.0 (5.0)			100

Appendix 15. Lengths of fish, (LCF, mm) and crustaceans (CL, mm) of commercial significance collected by gillnetting (gn) and seining (sn).
Life history definition based on SPCC (1981) and Kailola (1993), SJ=small juvenile, LJ=large juvenile, AD=adult; n=number of fish measured; [a] = not measured.

Species	Common name	Life History Definition (mm)			n	Sampling	Range	Mean	Percentage of total measured		
		SJ	LJ	AD		method	(mm)	(se)	SJ	LJ	AD
Crustaceans											
Portunus pelagicus	Blue swimmer crab			82 (♀), 95 (♂)	7	gn	54-83	64.9 (3.6)			
Scylla serrata	Mud crab			>85	1	gn	150	150			
Penaeus plebjus	Eastern King Prawn [a]			40 (♀), 40 (♂)	108	sn	[a]			See text	
Metapenaeus bennettae	Greasyback Prawn [a]			16 (♀), 20 (♂)	17	sn	[a]			See text	
Metapenaeus macleayi	School Prawn [a]			23 (♀), 25 (♂)	32	sn	[a]			See text	